REPORT

ANALYSIS OF THE MARCH 1995 BRIGHT ANGEL CREEK FLOOD EVENT

GRAND CANYON NATIONAL PARK

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Introduction

This report is intended to provide management with an accurate interpretation of the March 5, 1995 flood event in Bright Angel Creek. This report includes an analysis of: 1) the peak discharge of the event, 2) frequency of the event, 3) comparisons in terms of magnitude with other events, 4) and a discussion of the implications of such event's for resource management. It is important to note that this report is focused on the Phantom Ranch area of Bright Angel Creek, where flood discharge was at its highest stage, and concerns for health and safety is greatest.

During the storm event that occurred March 4 - 6 of 1995, The North Rim of the Grand canyon received 5 inches of precipitation on snowpack over a 48 hour period, compared to the average total for March of 2.5 inches. The South Rim received roughly half that (2.3 in.) in the same amount of time, compared to the average total for March of 1.4 inches. The flood/debris flow event in Prospect Canyon was, hydrologically speaking, the largest event in the Park. Clearly, because of pipeline and trail damage, the flood in Bright Angel Creek was far more significant in terms of damage. Interestingly, in terms of river management, the flood in Nankoweap Creek may be the most significant owing to the blockage of the trout spawning run (at least until the next flood in Nankoweap Creek carves a new channel). The bald eagles will be unhappy next winter. Bob Webb of the USGS provided an eyewitness account of the event at Prospect Canyon and should be of interest to River Rangers (Appendix 1).

The most notable changes in Bright Angel Creek morphology is the delta area (Plate 1). Here the stream reoccupied and modified a wide, shallow storm channel that was also active in the 1966 flood event. A battered one meter section of pipeline was recovered in this channel just a few meters from the Colorado River. A similar process occurred above "the box" which caused extensive trail and pipeline damage. Hillslope geomorphic processes were responsible for extensive damages to trail and pipeline structures in the Supai Formation of Roaring Spring Canyon. Most debris flows in the canyon originate in the Supai Formation. There is one colluvial deposit which is resting in the channel of this canyon. This deposit probably predates this storm event but may have grown in size. During the storm this feature, composed of rock in a fine grained matrix, became saturated to the point that it came close to forming a large debris flow. This was evident from a small lobe of supersaturated debris that did begin to flow from the colluvial deposit. There is no doubt that in a larger storm event, a substantial debris flow will be generated from this point.

Indirect Measurement of Peak Discharge

Method

High water marks left by the flood were readily identifiable. These were marked every 15 meters along the straight reach of stream from just above the Silver Bridge to the end of the gabion structure lining both sides of the channel (approximately at the end of the campground). All geomorphic features associated with the flooding were photo documented (for Phantom Ranch area see Appendix 2.). It was noted that fencing placed around the base of Cottonwood trees as protection against beaver damage, acted as debris traps when submerged. The resulting obstruction to flow resulted in an artificial rise in flood stage of one to two feet. Where the trees ended, stage dropped accordingly.

A credible study Cross-section was located downstream of the tree influence (such obstructions make indirect discharge estimates difficult due to problems encountered in estimating the Manning's "n" (roughness coefficient) factor. It was also vital to place the cross-section at a point where flow energy is equally distributed across the channel. With the assistance of John Rote of the USGS, the cross-section was then surveyed using Rod and Level techniques. In addition, the slope of the high water mark and the slope of the channel bed were determined by surveying both for a distance of about 75 meters upstream of the cross-section. Due to high flow velocities, it was necessary to assume that channel bed slope was approximately equal to the water surface slope of the discharge stage present at the time. This assumption is reasonable because a direct discharge measurement taken along the cross-section indicated that 73 cfs was flowing in the channel which is close to the base flow value. Survey data was then entered into EXCEL computer program that I wrote to generate elevation values and plots of both the cross-section (Figure 1.) and longitudinal profiles of both slopes (Appendix 3). Channel bed slope was estimated at 1.9% and the high water mark slope was estimated at 3.1%.

Along with taking a direct discharge measurement along the cross-section (Appendix 3), a Wolman pebble count was performed along the same transect. This produces a D84 estimate (when analyzed with a EXCEL program). The D84 value is a number representing the 84th percentile size class in the bed material (Appendix 3).

Cross-section data was then entered into a program written by Dr. Gordon Grant for the BLM/FS called "XSPRO." This program was specifically developed to handle channel geometry and hydraulic conditions for single transects in steep (gradient > 0.01) streams. Analysis options include developing stage-to-discharge relationships (necessary for hydraulic reconstructions) and evaluating changes in channel cross-sectional area (the latter may be useful after the next event). One more note on this program; it can and should be implemented in designing effective channel and riparian structures.

Results

Results are dependent on choosing reasonable roughness coefficients (often such choices fall into the grey boundary between art and science). Basically, the cross-section was subdivided into three sections (active channel, right high water bank, and left high water bank). A range (one for High stage and one for low stage) of Manning's "n" values were then assigned to each section. The program was run

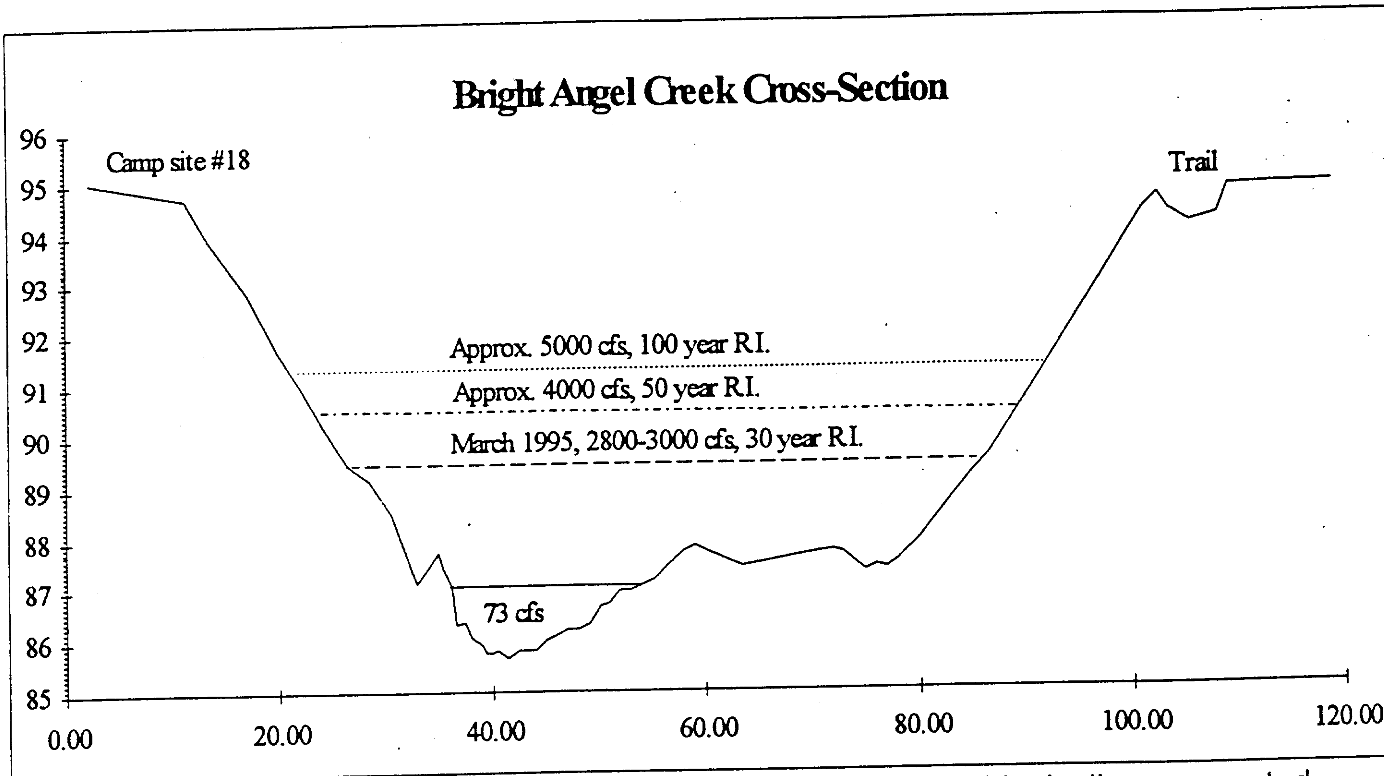

Figure 1. Stage to discharge with associated recurrence intervals. Vertically exaggerated.

numerous times varying the "n" values within parameters that seemed reasonable for what was observed in the field and represented in the pebble count data. Output is in the form of a table with predicted discharges (Q) for a given stage increment. Results for the high water stage (3.85 ft.) of march the 5th ranged from 2,802 cfs to 3,020 cfs. The most reasonable number was from the 4th run which gave a value of 2931.37 cfs with an average velocity of 21.8 ft/sec (Appendix 4). This value was judged to be most reliable because the average velocity and discharge at the stage where we took a direct measurement were closest. It must be noted that this result is still an estimate, and not an absolute. Although no rigorous statistical analysis of the % error has been made, for management purposes we can say that 3000 cfs (a nice round number) is within an order of magnitude correct, and agrees exactly with original eyeball estimates.

Relative Magnitude and Frequency of the Event

Flood frequency analysis on ungaged streams is based on geomorphic indicators of past events. Such methods are difficult and often useless for streams in the southwest due to the "flashy" nature of the system and frequent debris flow character. Fortunately, Bright Angel Creek is a perennial stream and was at one time gaged by the USGS for a sufficient period of time that is statistically significant.

Using annual peak discharge data obtained from the USGS (period of record from 1924 to 1973), the following magnitude and probability figures have been calculated:

Recurrence Interval in Years	2	5	10	25	50	100
Exceedance Probability in %	50%	20%	10%	4%	2%	1%
Discharge in CFS	435	1,010	1,600	2,640	3,670	4,970

Further analysis of the data indicates that the 3000 cfs event of March 1995 has a return period of nearly 30 years (31 to be precise). The 25 year event is of virtually the same magnitude as the 30 year event. The 1966 event (4000 cfs) was between 50 and 100 year event. The 100 year event has not been witnessed yet.

Water Resource Management Concerns

In the March 1995 event, flood waters did reach the level of the sewer pipe that crosses the stream at the Silver Bridge. The cross-section in Figure 1. does not indicate that the water reached that high of a stage because the stream contracts upstream at the bridge. The above cross-section was chosen because it had fewer obstructions (trees and/or trees with fences) to flow that artificially increase stage. In a higher flood, say the same as in 1966, we will probably lose the pipeline and possibly the bridge as well. Prior to channelizing the straight reach of stream at Phantom Ranch, the natural channel was wider and velocities were lower. Consequently, flood stage's of the same magnitude would not have been so high and perhaps velocities would not have been so damaging. Although placing gabions along the stream bank prevents minor erosion with events of similar magnitude to the one in March of 1995, it may be causing other problems in addition to the one described above. Increased velocities caused by channelizing this reach may have contributed to the downstream destruction at the bend (undermining that segment of sewer pipe). This is speculative, but it has been my experience that if you engineer one reach of stream, you eventually end up channelizing or armoring all or most of it. However, it is obvious that Phantom Ranch requires protection from flood waters, and given the existing technology of the sixties, they did very well.

Unfortunately, constructing a gabion to protect the sewer line is necessary. However, this will mean increased stress to the left bank (looking downstream) foundation of the first bridge (the Rock House bridge). This bridge constricts flow to such an extent that it is only a matter of time before it is washed out. The constrictive nature of this bridge may have also contributed to the erosion problem on the upstream right bank (and associated sewer line). The left bank foundation should be removed and placed 10-20 feet further back from the channel. This will of course mean installing a longer bridge. The ideal time to perform this task is now, while the peoplepower and materials are down there.

The pipeline break near the mouth of the box was instigated by rockfall (classic wedge failure). Due to the joint and fracture trend of the rock outcrop and overall steepness of the terrain such processes can be considered common. One large overhanging section with fractures parallel with the cliff face threatens to remove the trail and pipeline in the exact same spot. Minimizing this hazard to life and property is possible only by moving structures to the other side of the stream (not practical) or physically removing the most threatening features of this outcrop. Dan Blackwell points out that the later scenario is probably a "catch-22" in that removal operations will in all likelihood take the pipeline out to.

Techniques in flood control and floodplain management have been, and still are experiencing a revolution. This has come about because the science of hydrology and geomorphology have grown, broadened and coalesced. Not all of the new methods are applicable to fixing the problems associated with the trails, pipeline and protecting Phantom Ranch, but the options need to be explored.

One positive outcome of this flood event could be that it initiates installation of a flood early warning system. If installed, perhaps near Bruce Aiken's residence, it would give Ranger's at Cottonwood campground and Phantom Ranch time to implement emergency evacuation procedures and shut down the sewer line at Phantom Ranch. The problem with such systems is that they are often left neglected over a period of uneventful years and may not operate at the critical moment. Such a system would require annual upkeep. Annual flood awareness seminars given to NPS and Fred Harvey Employees stationed at the affected locations should also be implemented. Heightening flood awareness should make upkeep of the early warning system easier.

APPENDIX 1

NEW DEBRIS FLOW AT LAVA FALLS RAPID

Lava Falls Rapid is, at all water levels, the most severe rapid in Grand Canyon. Its severity increased markedly in the early morning hours of March 6, 1995, when a debris flow from Prospect Creek constricted the Colorado River by approximately 50 percent. For Prospect Creek, the debris flow is the first since 1963 and the largest debris flow since 1955. The changes in Lava Falls Rapid are the most significant in Grand Canyon since the 1966 debris flow in Crystal Creek. There may be an increase in the number of boating accidents at Lava Falls.

The debris flow was witnessed by members of a Glen Canyon Environmental Studies (GCES) research trip who ironically were monitoring past debris flows in Grand Canyon. The GCES trip arrived at Lava Falls during the morning of March 4 and camped at the sand bar about a quarter mile above the rapid on river left. Work began immediately on repeat photography of historic photographs of the rapid. Although it had been cloudy with sporadic rain for nearly a week, March 4 was clear by noon.. Rainfall began at midnight March 5. Light rainfall continued steadily the following day, but scientists matched photographs and collected data on the rapid and the source areas of historic debris flows. The storm culminated in steady hard rainfall that began about 6 PM and continued until after midnight. No thunder was heard during the storm, and no estimates were made of the total rainfall.

At midnight, March 6, several gusts of wind blew down the kitchen tarps and turned over tables. Several trip members got up to pick up items that could get wet and to stabilize the kitchen gear. After returning to bed, at approximately 12:30 AM, at least three members of the trip were startled by a roaring sound that came from the direction of Lava Falls Rapid. The exact time of the beginning of the sound is unknown but probably was between 1:00 and 1:30 AM. Part of the noise was identified as distinct rockfalls. Most of those that heard the roaring sound, including boatman Bob Grusy, were concerned that the river was rising with storm runoff and that boats or the camp would be threatened. Bob Webb remembers that the noise lasted 3-5 minutes and then subsided, but others thought the sound lasted much longer.

At about 2:30 AM, Grusy got up to find rising water and put extra lines on his boat. At about 4:00 AM, Mimi Murov rose to take down the wash table that was threatened by the rising Colorado River. The rainfall had stopped by this time. Murov thought the eddy was pooled up and calm; she thought at the time that the high water was not from a Colorado River flood but instead resulted from an increased constriction downstream.

Trip members rose at 6:00 AM on March 6 to clear skies and a river that was 3 to 4 feet higher than the previous night. The discharge in the river was about 18,000 cubic feet per second (Table 1). The river appeared ponded with little movement. After cleaning up the wind-strewn equipment in the kitchen area, trip members hiked to the left scout of Lava Falls to view what we thought would be high water flowing through the rapid. Instead, at 7:00 AM, we saw the new debris fan and recessional flood waters in Prospect Creek. Despite the passage of about 6 hours, the new debris fan was still changing from reworking by the Colorado River and recessional flow in Prospect Creek.

A 1,000-foot dark brown waterfall at the upper end of Prospect Canyon was jetting about 500-1,000 cubic feet per second of water into the creek channel. The waterfall sent a fine brown mist into the canyon. Flow in the creek was a dark chocolate brown, and boulders and cobbles could be distinctly heard rolling along the bed. The creek channel was too high to cross until about 3:00 PM, and flow in Prospect Creek stopped after dark on March 6. Storm runoff lasted 18-20 hours.

When we first saw it, the new debris fan extended into the river to about the left edge of the Ledge Hole. The new fan extended about 100-150 feet into the river over a distance of 600 feet. The fan sloped continuously into the river with no sign of a cutbank on its edge. Photographic monitoring of the debris fan began immediately because floodwaters prevented us from getting on the new debris fan. As the morning progressed, the edge of the debris flow was cut away by about 20-24 feet, leaving an 8-foot high cutbank on the left side of the rapid. Photographers on the left side of the rapid saw large sections of the new fan fall into the rapid. Recessional flow in Prospect Creek cut two channels through the debris fan, further reducing its size. The floodwater entering on the left side contributed to the failures.

The rapid appeared markedly different on the morning of March 6. The entry water was extremely fast. Some well-known hydraulic features, such as the Ledge Hole and the V Waves, were still present but greatly increased in size. The right lateral of the V waves became much stronger than the left wave. The Ledge Hole had a different shape, a sharper drop, and a stronger hydraulic than before. The slot run was not apparent. Marker rocks, such as the Domer Rock (also known as Big Bertha) and the Meteor Rock, and their identifying waves and holes were not visible. The large waves that used to form between the V Waves and the Black Rock initially were very large but disappeared by the end of the day. A large, continuously breaking wave formed off of the Black Rock, and large whirlpools formed to the right of and behind the Black Rock. Floodwaters entering on the left eliminated any possibility of running left of the Ledge Hole. Boulders were heard rolling along the bottom above the sound of the rapid. Kenton Grua and Grusey both thought that initially the rapid was unrunnable.

Downstream, the former eddies on river left and right were replaced by fast-moving water. A secondary rapid formed at the Warm Springs, but its waves subsided to riffle size as the day progressed. We interpreted the secondary riffle as water flowing around and over a new island where the pool used to be; the size of the riffle probably changed as a gravel/cobble bar migrated downstream into Lower Lava Rapid. By the afternoon on March 6, a run developed just to the left of the Ledge Hole.

On March 7, trip members had full access to both sides of the rapid and Prospect Canyon. We had a peak of 16,300 cubic feet per second in the rapid, but the rapid looked much larger. The debris fan did not change during the day. Most of the familiar features of the rapid, such as the slot run and the marker rocks, reappeared. The Ledge Hole remained slightly different and stronger than before. The breaking wave off the Black Rock was still present, and the secondary riffle remained small. The left run continued to develop and remained in a condition judged runable. The rapid appeared much more energized than before; the former right run appeared more than likely to flip oar boats, and the wave off the Black Rock was strong enough to potentially flip motor rigs.

On March 8 and 9, normal fluctuating flows were observed in the rapid. We still could not determine the discharge from the stage in the vicinity of the rapid. The entire rapid had a much higher velocity. Both Grua and Grusy felt that the right side appeared as if the discharge were 6,000 cubic feet per second higher than it actually was. The entry to the right run is much faster, and the right side of the V Waves is much larger. Several large waves that previously formed between the V Waves and the Black Rock are no longer present, but the continuously breaking wave off the Black Rock persists. On March 9, we ran the rapid on 11,000 cubic feet per second (Table 1). Grusy ran his 37-foot motorboat through the right run and stated the rapid was faster but may be easier because the Big Wave no longer exists. The left run consists of passing close to the left side of the Ledge Hole and then running a haystack wave and left of the Domer Rock and hole. Grua made the run easily in a 22-foot motor snout, although the speed of the water entering the run was measured to be 15 feet per second. Both boats came close to the Black Rock but easily missed it.

The debris-flow project had previously identified Lava Falls Rapid as the most unstable in Grand Canyon and was finalizing work on a paper on historic changes in the rapid. Because of the previously collected information, the new debris flow was easily interpreted in terms of size and recurrence interval. The most recent debris flow at Lava Falls was in 1963; the 1995 debris fan exceeded the depositional area of the 1963 flow, and the 1995 debris flow eroded all the terraces deposited in 1963. The 1955 debris flow was larger; the 1995 debris flow did not exceed the stage of 1955 and created a smaller constriction. Therefore, the 1995 debris flow in Prospect Creek is the largest debris flow in 40 years and the first in 32 years.

The 1995 debris flow in Prospect Creek set several benchmarks in Grand Canyon history. The storm that spawned it was only the second winter storm since 1872 that is known to have created a debris flow (after December 1966). The debris flow is the second largest in Grand Canyon since closure of Glen Canyon Dam (after the Crystal Creek debris flow of 1966). Changes to Lava Falls Rapid are less than changes to Crystal Rapid in 1966 but are comparable with other recent debris flows, such as House Rock Rapid in 1966-1971 and Specter, 24-Mile, and Bedrock Rapids in 1989.

One other potentially significant change we observed was at 209-Mile Rapid. Granite Park Canyon had a flash flood that closed off the left channel around the island. The left lateral on the entry to 209-Mile Rapid is now stronger, which makes missing the hole on the right more difficult.

WITNESSES

John Elliott	Steve Eudaley	Bruce Finley	Peter Griffiths
Diane Grua	Kenton Grua	Bob Grusy	Mia Hanson
Marker Marshall	Ted Melis	Mimi Murov	Dominic Oldershaw
Steve Tharnstrom	Meg Viera	Robert Webb	Tom Wise

TABLE 1. Preliminary discharges in the Colorado River during the observations following the debris flow of March 6, 1995, at Lava Falls Rapid.

	DISCHARGE, IN CUBIC FEET PER SECOND					
	LEES FERRY GAGE		BRIGHT ANGEL GAGE		DIAMOND CREEK GAGE	
Date	Low	High	Low	High	Low	High
Mar 5	7,630	11,000	11,400	13,400	9,800	12,200
Mar 6	8,110	12,100	13,600	17,200	12,600	17,800
Mar 7	8,280	11,300	13,700	16,800	11,400	16,300
Mar 8	8,320	11,300	13,300	15,100	11,300	13,400
Mar 9	7,730	11,200	14,200	*18,700	10,700	11,500

*may be an error due to change in stage-rating curve at gaging station. Deposits from the Bright Angel Creek flood may have affected the gaging station.