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United States Department of the Interior

NATIONAL PARK SERVICE

Water Resources Division
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November 4, 2013

Memorandum

To: Jeff Bradybaugh, Superintendent, Bryce Canyon National Park (BRCA)

Through: Dr. Ed Harvey, Chief, Water Resources Division (WRD)
Gary Rosenlieb, Chief, ASB (WRD)

From: Mike Martin, Hydrologist (WRD),

Subject: Trip report detailing assessment of a hydraulic drop structure at the confluence of the Paria River and Water Canyon

Purpose and Summary of Findings

The purpose of this site visit was to evaluate the overall stability, associated geomorphic conditions, and possible repair/replacement options of a large, hydraulic drop structure constructed at the confluence of the Paria River and Water Canyon in Bryce Canyon National Park (Figure 1). Downstream channel incision of the Paria River has undermined the lower portion of the structure and it appears that it could be completely lost in the future if no action is taken. This report summarizes our field observations, describes the immediate geomorphic setting, and presents an evaluation of the structure's condition. Although we conclude that undertaking some type of repair is essential to maintain the structure and protect the nearby infrastructure, developing a specific engineering treatment was beyond the scope of this visit. We suggest that local engineers, which have expertise with this type of hydraulic structure and these river conditions, be consulted for specific treatment strategies. However, WRD will be available to interact with any design engineers or other interested parties in order to follow NPS objectives.

Setting/Background

Early exploration of the Paria River valley occurred in 1866 when a U.S. military contingent passed through the area, and by 1871, settlement of the valley had begun. Within a decade there were a number of communities in the Paria Valley including Cannonville (8 mi downstream) and Rockhouse, farther downstream. The town of Tropic (about 3.5 mi downstream) was founded around 1900 when water was diverted from the Sevier River. This diversion passes across the Paunsaugunt Plateau, through Bryce Canyon National Park via a ditch and then into Water Canyon, where it is diverted by a headgate just above the confluence of Water Canyon and the Paria River, into a buried pipe. This

conveyance continues in one form or another, downstream to the town of Tropic where the associated water rights are used for irrigation (Figure 1).

It is at this precise location, the confluence of Water Canyon and the Paria River where the drop structure in question was constructed. About half of the structure is above the confluence and about half is below (Figure 1). The buried conveyance pipe passes under the upper portion of the drop structure. Also located at this site is a bridge crossing and road grade for State Highway 12. The highway bridge, which crosses Water Canyon is a standard two-lane span about 70 feet long with two sets of piers. The piers and abutments are protected with gabion structures and grouted rip-rap. Some of the bridge protection has undergone erosion and some has been recently replaced.



Figure 1 - Google Earth image of the site at the confluence of the Paria River and Water Canyon. The Paria River channel runs north-south and Water Canyon enters from the west. Note the drop structure adjacent to the bridge crossing, all of the visible water is being diverted into an underground pipe, but on a regular basis, the system is “flushed” of sediment by diverting the imported water directly into the Paria River.

Based on historic photos, the dam and headgate were constructed sometime around 1900 and it was likely around that time that the drop structure was also constructed. The purpose of the structure was likely to provide grade control for the upper Paria River following construction of the Tropic Ditch. Given the varying types of materials used, it appears that there have been multiple “generations” of treatment, the latest of which was likely within the last 50 years or so. The structure is a mixture of large, dry-stacked rip-rap at the base,

grouted rip-rap overlying the base, and several layers of re-enforced concrete drapes overlying most of the structure. The overall vertical drop is about 35 feet and it appears that the complete structure provided a stable transition from the upper Paria River channel to the lower, until recently. Currently, the lower end of the drop structure has been undercut by downstream channel incision and the entire structure could be on the brink of failure (Figure 2).

Most of the remaining, re-enforced concrete drape, which probably capped the entire structure, is still in good condition, both above and immediately below the confluence, and the portion of the structure that is still intact shows no obvious sign of structural failure. However, an unknown length, maybe as much as 40 feet, of the lower end of the structure has been completely lost. This loss includes the large rip-rap base material and the overlying re-enforced concrete drape. Additionally 3 – 4 feet of the river alluvium that was underneath the structure has also been eroded. At the point of failure of the structure there is about an 8-10 feet scarp of exposed river alluvium, base material, and overlying rip-rap and concrete (Figure 2).

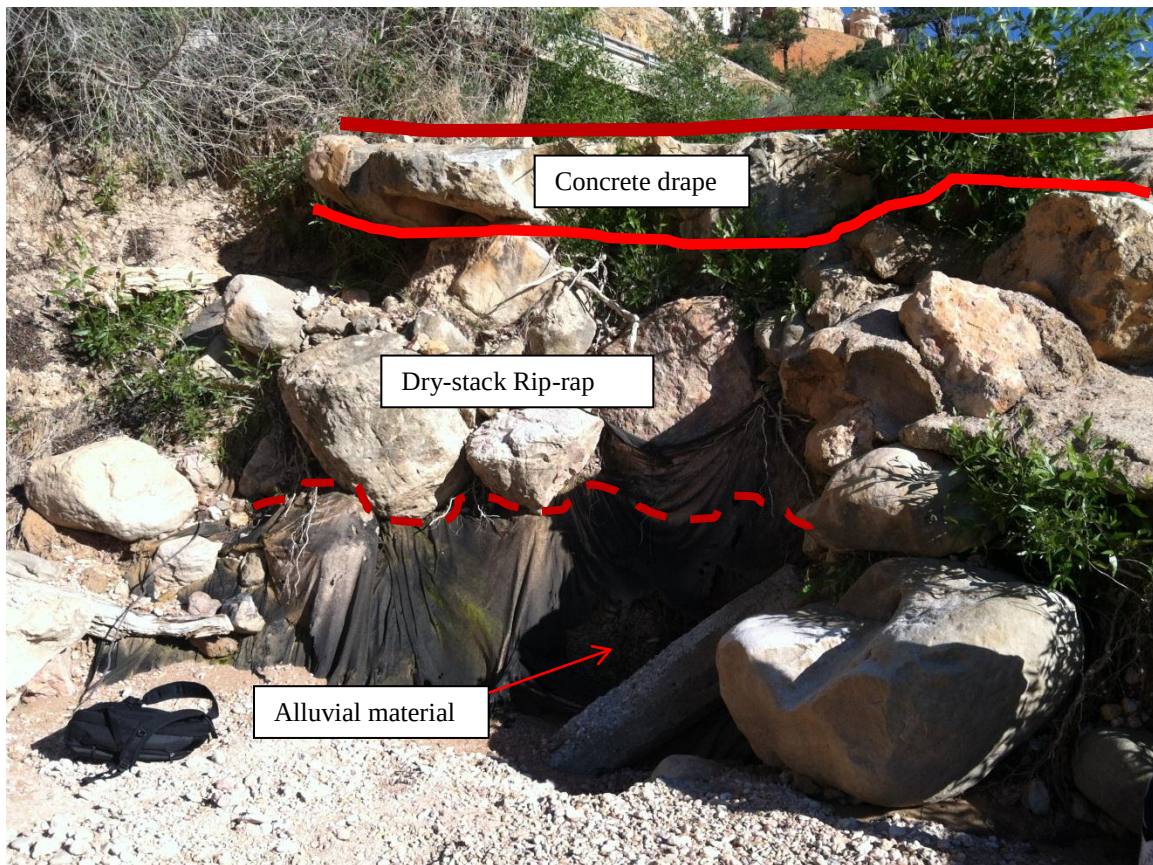


Figure 2 - Area where the structure has failed. Note the exposed geo-fabric marking the elevation of the channel bottom at the time of emplacement, directly below the large boulders (dashed red line). Also note the “upper bench” bracketed by a solid red line marking the level of the concrete drape. NPS-2013.

Hydrology of the Paria River

This site on the Paria River, elevation of 6823 feet above mean sea level, is near the headwater area of the watershed. Above Water Canyon, the main channel splits into two tributary streams; Tropic Canyon and Little Henderson Canyon, both second order drainages. The total watershed area above the drop structure is about three to five square miles.

From the site, the river channel extends predominantly south and south-southeast until forming a confluence with the Colorado River at Lees Ferry, Arizona, far downstream. There are two active USGS gages located on the Paria River, Kanab Utah (09381800) and Lees Ferry (04382000), with about 25 and 89 years record, respectively. However, neither of these gages are near the site so measured flows are probably not representative of conditions in the reach of interest.

The flow in this reach of the Paria River can be both seasonal in response to snowmelt, and intermittent due to summer rainstorms. Additionally, imported water from the Sevier River and Tropic Reservoir is sometimes flushed through the channel augmenting natural flows in this watershed. The largest flow events usually occur in the late summer or early fall and can be the result of dissipating tropical cyclones (Topping, 1997). Park staff reports that substantial floods occur about every three years or so, and that a “major” flood took place in 2003.

Regional regression equations developed by the USGS used to estimate flood magnitudes in ungaged watersheds, indicate that a watershed of this size and elevation, in this hydroclimatic zone is capable of producing sizable flows. Calculations for a four square mile watershed above the Water Canyon confluence estimate annual peaks to range from about 75 cubic feet per second (cfs) for a 2-year flood to 1260 cfs for a 100-year flood. The Maximum Estimated Flood is 5180 cfs. Given the steep slopes and sparse vegetation in the headwaters, and the excessive amount of sediment from the highly erosive geology that will add bulk to the floods, these amounts probably underestimate the magnitude. Consequently, the more frequent flow events like the 2-year flood, are probably very capable of re-working the alluvial channel.

Geomorphic Assessment of the Paria River Channel

The Paria River has undergone substantial geomorphic changes over the last several thousand years, as well as observed periods of incision and aggradation since the area was settled in the late 1800's. In fact, rivers throughout the southwest are characterized by a period of deep incision from about 1862 to 1909, and more specifically, arroyo cutting was documented on the Paria River from 1884 to 1909 (Webb and Hereford, 2001).

A significant flood took place on March 13, 1884, which resulted in a headcut forming in the channel and moving upstream near Rockhouse. By 1886 the headcut had reached Cannonville, about 8 miles downstream of the site. Within about 25 years, (September 1909) a massive regional storm caused the largest historical flood on the Paria (Webb 1985). This resulted in loss of bridges on the upper river and some degree of downcutting throughout the drainage. Leopold (1994) is among several authors that have identified

cycles of channel deposition and filling followed by channel incision in alluvial channels on the Colorado Plateau. These cycles flip on a time-frame of hundreds to a few thousand years and indicate an inherent instability in channel morphology.



Figure 3 - Bedrock out crop about 100 yards upstream from drop structure. NPS 2013.

The channel in the reach of interest is primarily alluvial, although, there are some bedrock outcrops both up and downstream of the structure. The bedrock outcrop about 100 yards upstream of the structure is a well indurated sandstone on the left bank (Figure 3). If this bedrock outcrop extends under the river bed at a reasonably shallow depth, it could provide very good grade control for the upstream reach. However, we were unable to locate any other outcrops here in the channel or the opposite bank

and found no signs of shallow bedrock control in this reach. The downstream exposed bedrock is a layer of fine grained mud or siltstone that appears to offer only slight resistance to erosion. Consequently, we have to conclude that there is no obvious vertical control along this reach of the river, both up and downstream of the structure. There is nothing downstream that will completely stop further channel incision and if the headcut protected by the drop structure migrates upstream, substantial incision of the upper channel will likely take place.

Currently, the upstream channel is mostly on-grade with active floodplains and no signs of incision. The downstream reach, however has obvious signs of multiple episodes of incision with two distinct terrace levels as well as an inner, active channel (Figure 4).



Figure 4 - View of the channel downstream of the drop structure taken from the highway. Note the terrace levels (red lines) and the inner channel (blue line). NPS - 2013.

Park staff reports that these two terrace levels are remnants of river bed elevations from the last few decades. The medium terrace level is from about 50 years ago and the low terrace level from about 10 years ago. So, the inner channel, which is currently about 3 to 4 feet below the lower terrace, likely began downcutting about 10 years ago, and it was sometime after this period of recent incision began that the failure of the structure base occurred.

Careful inspection of the river channel and both the failed and intact portions of the drop structure indicate that it was channel incision and the formation of the inner channel that led to the structural failure. Apparently, a headcut migrated upstream and undermined the alluvium that supported the lower structure. This led to failure of the large, dry-stacked rip-rap and the overlying grouted rip-rap and re-enforced concrete blanket. The former level of the stream channel is well defined by the remaining geofabric that was underneath the structure (Figure 5).

As mentioned, the compromised drop structure is currently protecting a substantial nickpoint, a vertical drop in the streambed, at this location on the Paria River. If the structure is lost, there will be headward migration of the nickpoint and downcutting of the upper reach of the Paria River. Additionally, Water Canyon will probably incise threatening both the highway bridge and the headgate on Water Canyon.

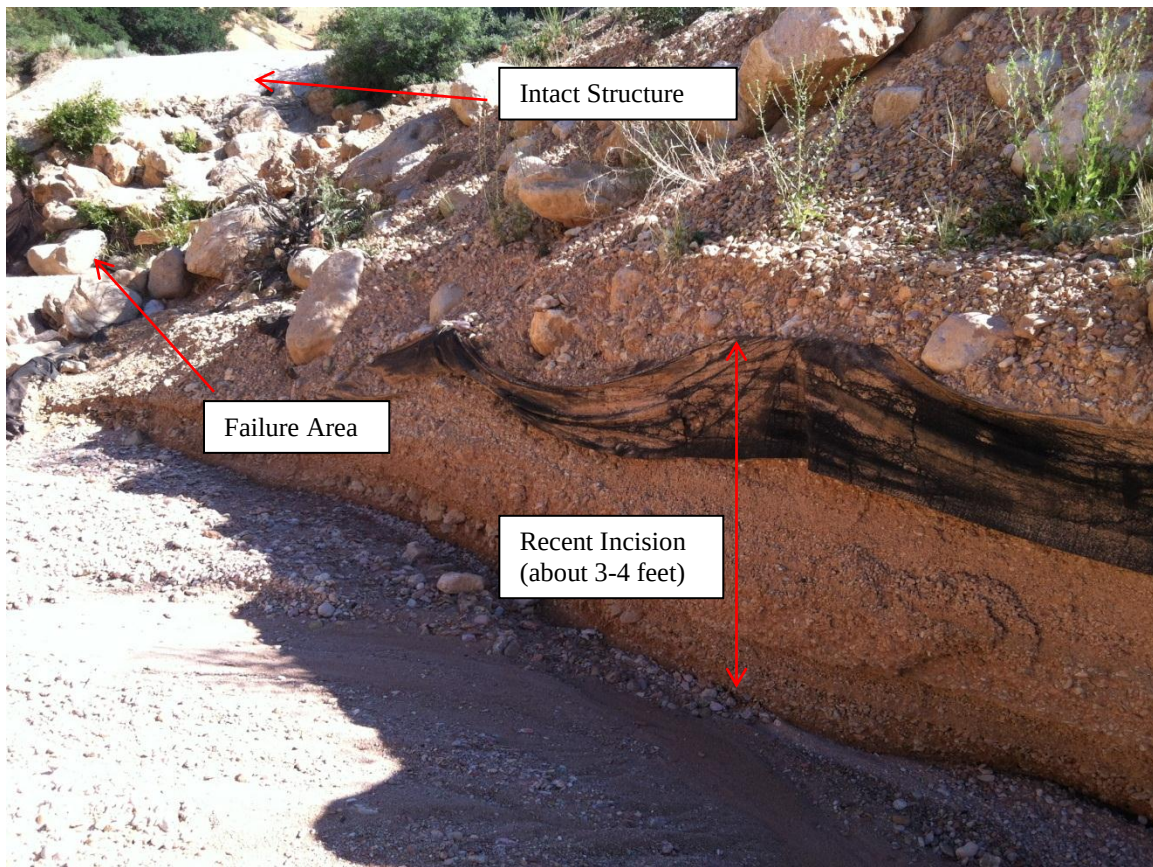


Figure 5 - Left bank of channel about 50 yards downstream of structure. Geo-fabric marks the streambed elevation prior to the recent incision. Note the structure visible in the upper left corner. NPS - 2013.

The reason that the current headcut formed is not known but any number of downstream, in-channel activities could have initiated or exacerbated the process. During the site visit, we identified a substantial constriction a few hundred yards downstream and there are reports of gravel removal operations just downstream of the Park boundary. Furthermore, recent floods, possibly augmented with imported floodwater from the irrigation system in Water Canyon could also have led to channel instability. Likely, it is a combination of factors, and not a condition that is readily treatable.

Regardless of the cause of downcutting, the relatively recent evolution, and the current state of the channel, severely threatens the future of the drop structure. At the very base of the structure, where erosive energy is the greatest, there is about three to four feet of exposed alluvium (Figure 6). While this alluvium appears well compacted, it is not at all cemented and therefore, will probably erode somewhat during all sizable flow events. During a large, sustained flow event, there could be substantial loss of this material, which will further undermine the base of the structure.



Figure 6 -- About 3.5 feet of alluvial material at the base of the headcut. The dry-stack rip-rap that serves as the base for the concrete drop structure is visible in the upper portion of the picture. Also note the remaining geo fabric that was at the base of the structure. NPS – 2013.

Summary and Conclusions

The failure at the base of the drop structure is indicative of what will eventually happen to the entire structure if no corrective action is taken. This failure occurred due to channel incision that began downstream of the drop structure, migrated upstream, and was able to undermine the base of the structure. Currently, there is about three feet of river alluvium exposed at the base of the structure. This alluvium is erodible and this headcut will continue to migrate upstream when flow conditions reach a high enough level. So, even if no additional channel incision takes place, headward migration of the nickpoint will undermine the structure.

Ultimately, the water conveyance pipe will likely be destroyed and continued headward channel incision will also threaten the road grade of Highway 12, which is adjacent to Paria River for several miles. The Water Canyon channel will probably also incise to match the new grade of the Paria River and this process will likely threaten the bridge crossing and undermine the headgate.

The failure could be incremental, as has already occurred, but it could also be catastrophic. The rate of failure is entirely flow/flood dependent and therefore not predictable. One certainty, the more damage that occurs to the drop structure through time, the harder it will be to repair, and, at some point, all opportunity to maintain this

configuration will be lost. Consequently, protective action(s) should be evaluated and implemented in the immediate future to arrest further headward erosion and forestall the loss of the infrastructure.

Since most of the upper part of the drop structure appears to be functioning well, treatment and repair of the lower section, where the structure has failed, may be the most cost effective measure. As mentioned, development of specific engineering designs for treatment was beyond the scope of this field reconnaissance, however, after our assessment, we have noted a number of important design elements that need to be considered.

One crucial design element would be to make sure the repaired drop structure extends beyond any reasonably possible level of future incision, i.e. keyed fairly deep into the bed of the river. The depth of potential incision is not predictable, so the keyed depth of the structure should be at a low enough level to forestall any future incision. A geotechnical study might provide the depth of the bedrock, which would be a desirable feature to key into, however, its depth may make it cost prohibitive. Additionally, solid keys into the banks will need to be re-established.

Both upstream and downstream reaches of the channel are wide, shallow, and braided at lower flows indicating that they transport a large amount of sediment as bed load. The gravel, cobble and boulder sized material bounding and rolling down the channel will be very abrasive to structures built in the channel. Consequently, any hydraulic structures will require routine maintenance and periodic replacement, in part or complete.

In addition to repair of the drop structure, we would recommend including additional downstream protection such as one or more loose rock check dams, or similar structures, to provide both early warning of channel incision and add to overall grade control. Well-constructed, downstream protection could not only help to maintain the current grade but could possibly trap sediment and restore the channel elevation to some degree.

In evaluating the overall geomorphic evolution of the Paria River, maintenance of the headcut and drop structure is an attempt to hold this fluvial system in an “out of equilibrium” condition. In a totally natural setting, our recommendation to the Park would be to allow the natural channel evolution to occur, ultimately, establishing a constant grade with no nickpoints. However, to protect the public and privately owned infrastructure present in the area, repair of the drop structure and stabilization of the nickpoint is necessary.

Action Items:

WRD will be available for ongoing consultation and support regarding and of these technical issues

cc: (by e-mail only)

2380 - Rosenlieb, Smillie, Enck (file);

BRCA – Cloud, Haas, Johnson, Pollock, Sharrow

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