**Utah Department of Transportation**

# BRIDGE SCOUR ANALYSIS REPORT

**for**

## Structure 053030F

**Washington County, Utah**
**North Creek**

**June 2013**

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## *Section 1 - Executive Summary*

Constructed in 1981, Structure 053030F over North Creek is located three miles northeast of Virgin, Utah. The bridge is approximately 54 feet long and 29 feet wide and constructed on a spread footing foundation. According to bridge plans, the foundation depth is approximately 15.5 feet below the top of the bridge deck. Loosely placed riprap is located immediately upstream and downstream of the bridge along the right bank of the channel; however, targeted countermeasures for erosion and scour are not currently in place around the bridge abutments.

This scour analysis accounts for long-term, contraction, and local scour potential for the 100-year and 500-year storm events. Pertinent information regarding the bridge site was gathered during a site visit and an initial review of applicable bridge records on file at the Utah Department of Transportation (UDOT), Structures Division. This information was used to model the bridge hydraulics and calculate total scour using U.S. Department of Transportation (USDOT) and Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 18 (HEC-18) (USDOT, 2012a). Finally, recommendations for scour mitigation and future bridge inspections were based on USDOT and FHWA Hydraulic Engineering Circular No. 23 (HEC-23) guidelines (USDOT, 2009).

Estimates of the flow rates at Structure 053030F were based on the U.S. Geological Survey (USGS) StreamStats application using regional regression equations (USGS, 2013a). The 100-year and 500-year storm events used for this report were 3,430 cubic feet per second (cfs) and 5,790 cfs, respectively. The modeling of the bridge used a topographic survey from January 2013 and observed stream conditions.

Using HEC-18 methodologies, contraction and local scour were estimated to potentially exceed over 15 feet during the 100-year storm event, and 23 feet during the 500-year storm event, as shown in Table 1. The abutment scour for the 100-year and 500-year events warrants countermeasures. Channel flow immediately at Structure 053030F should be kept to the center of the channel as much as possible. Flows directed toward the abutments can cause excess scour. HEC-23 specifies reinforced concrete apron as a suitable countermeasure for abutment and contraction scour. The estimated cost for this countermeasure is $21,000.

In addition to scour countermeasures, future inspections of the bridge should consider any geomorphic changes that would affect the scour potential at the bridge. The channel around the bridge is downcutting and exposing the footings. Some of the banks are eroding back and the associated undercutting is allowing the channel to migrate laterally. This could alter the angle of approach of the flow of the creek to the bridge. Future inspections should focus on the alignment and approach of the channel. Additional stream cross sections are strongly recommended so a larger data set can be used to determine the trends of bed elevation and lateral movement at the bridge. Inspections should occur promptly after large storm events exceeding a discharge of 2,630 cfs, or the 50-year flow at this bridge.

**Table 1 – Scour Analysis Results Summary**

| | 100-Year | | | 500-Year | | |
|---|---|---|---|---|---|---|
| | **Left Abutment** | **Channel** | **Right Abutment** | **Left Abutment** | **Channel** | **Right Abutment** |
| **Contraction Scour** | NA | 0.9 ft | NA | NA | 3.5 ft | NA |
| **Local Scour** | 15.5 ft | NA | 10.3 | 23.1 ft | NA | 16.5 ft |
| **Total Scour** | **15.5 ft** | **0.9 ft** | **10.3 ft** | **23.1 ft** | **3.5 ft** | **16.5 ft** |

ft - feet
NA - Not Applicable

## *Section 2 - Introduction and Objectives*

Flowing water can affect bridges by eroding streambed or bank material. This scour can expose bridge elements, compromising bridge stability and safety. Total scour is a combination of contraction scour, local scour, and long-term channel bed elevation changes. Contraction scour results from a contraction of the flow area at the bridge. Local scour is the removal of material around piers, abutments, spurs, and embankments. Long-term bed elevation changes consist of stream aggradation or degradation due to modification of the stream and/or watershed.

UDOT currently regulates the National Bridge Inspection (NBI) rating system for all bridges in the State of Utah. In order to comply with FHWA, UDOT compiled a list of approximately 450 bridges in the State that had an NBI item 113 scour code U listed in the PONTIS bridge database (UDOT, 2012). Each of the 450 bridges were evaluated to update the NBI item 113 scour code and produce a Plan of Action (POA) complying with FHWA directives. UDOT, assisted by URS Corporation (URS), contacted bridge owners for available bridge plans, flood history, and maintenance records. A screening process, based on the best available data, was used to analyze each bridge's scour criticality. Of the approximate 450 initial bridges, 30 required further in-depth analysis using USDOT and FHWA HEC-18 methodology (USDOT, 2012a). Structure 053030F is one of these 30 bridges and requires an in-depth scour analysis documented in this report.

Constructed in 1981, Structure 053030F is located three miles northeast of Virgin, Utah. Figure 1 shows the downstream side of the structure. The bridge is approximately 54 feet long and 29 feet wide and consists of reinforced concrete decking, vertical concrete cantilever abutments, wing walls, and a spread footing foundation. Loosely placed riprap is located immediately upstream and downstream of the bridge along the right bank of the channel; however, targeted countermeasures for erosion and scour are not currently in place around the bridge abutments.

**Figure 1 – Structure 053030F**

This study performed a scour analysis that accounts for long-term, contraction, and local scour potential for the 100-year and 500-year storm events. Contraction and local scour values were calculated, while the long-term component was analyzed through available cross section data and a qualitative geomorphic assessment.

Initially, URS conducted a review of all information pertaining to the bridge; including bridge plans and inspection reports, soils information, and hydrologic, hydraulic, and historical flood data. In addition, URS used geographic information systems (GIS) technology to compile information about the structure's location and contributing watershed. This was completed using USGS's StreamStats and ESRI ArcGIS® (USGS, 2013a; ESRI, 2010). The data collection included detailed topography, aerial photography, watershed extents, elevation distributions, and stream flow gage locations. Data collection also includes a site visit (see appendix H) to validate assumptions, collect channel and floodplain data, and make observations pertinent to the scour analysis.

Using this data, a hydraulic model was created using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) (USACE, 2010a). This hydraulic model provided the information necessary to calculate the total scour for the bridge. This final report includes a description of analysis, supporting documentation, and recommendations for future inspection or scour mitigation measures.

## *Section 3 - Location and Bridge Conditions*

As shown in Figure 2, Structure 053030F is located three miles northeast of Virgin, Utah. The bridge is approximately 54 feet long and 29 feet wide and constructed with a spread footing foundation. The bridge carries Kolob Road over North Creek, providing one travel lane in each direction and is classified as a rural minor collector road according to the Highway Reference Manual. Bridge plans are available for this structure. However, the bridge plans do not indicate that scour calculations were performed prior to construction. The bridge plans show that the spread footing foundations were originally buried 5.5 feet below the channel bed. The existing channel bed at Structure 053030F is approximately 1.5 feet below the bottom of spread footing. This change in channel bed elevations indicates that the channel has degraded and estimated 7 feet since the bridge was constructed.

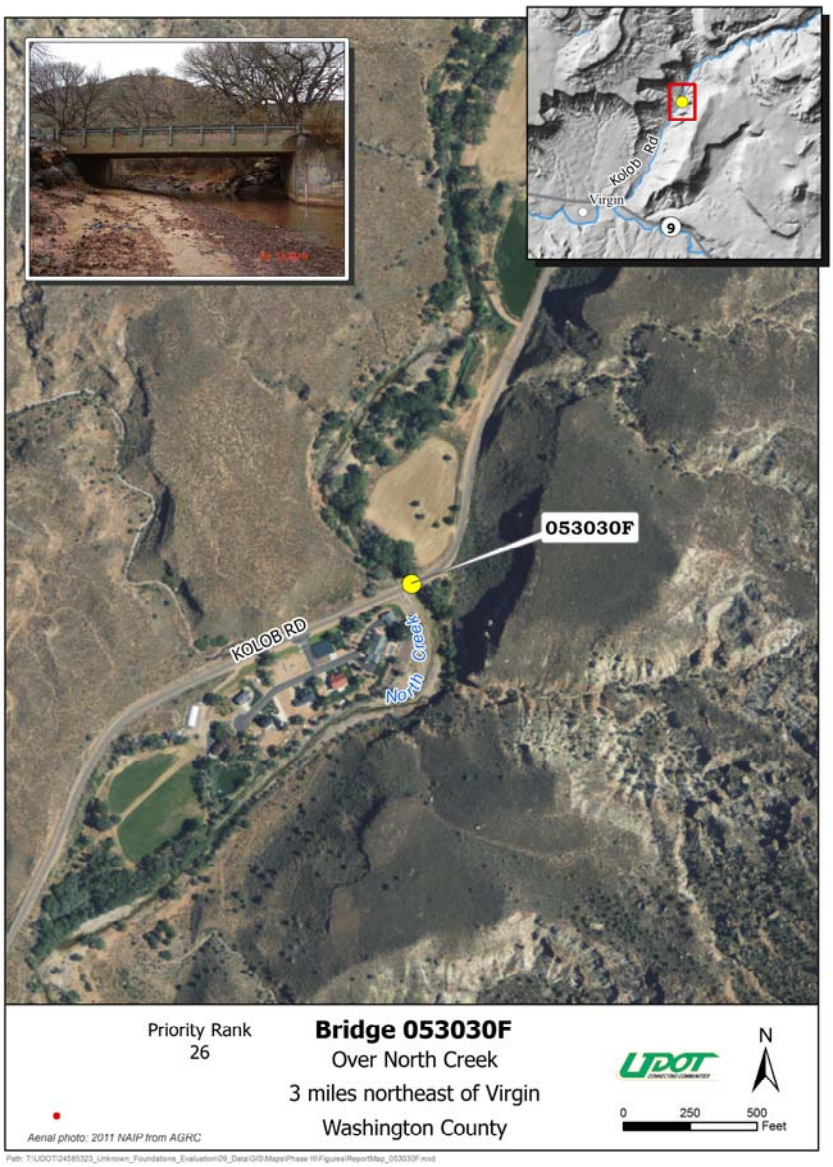


**Figure 2 – Bridge Location Map**

Table 2 summarizes the bridge dimensions and conditions. Additional pictures of the structure and surrounding environment are included in Appendix A.

**Table 2 – Bridge Dimensions**

| | |
|---|---|
| **Number of Spans** | 1 |
| **Length of Span** | 50 ft |
| **Deck Width** | 29 ft |
| **Deck Type** | Reinforced Concrete |
| **Beam Type** | Concrete Double-T Beam |
| **Abutment Type** | Vertical Concrete Cantilever |
| **Wing Walls** | Angled 45 degrees Concrete |
| **Number of Piers** | 0 |
| **Foundation*** | Spread Footings 15.5 ft below top of bridge deck |

* determined from bridge plans
ft - feet

The FHWA requires each state to structurally evaluate and rate key bridge elements. These NBI ratings are summarized in the Structural Inventory and Appraisal Sheets that are updated when a bridge is inspected (USDOT, 2006). The ratings indicate of the bridge's ability to stay in service based on a range from 0 to 9, with 0 denoting a failure condition and 9 indicating an excellent condition. Table 3 presents the most current ratings for Structure 053030F.

**Table 3 – Summary for Structure 053030F**

| Year Built | Sufficiency Rating | Deck | Superstructure | Substructure | Channel & Protection | Scour | ADT |
|---|---|---|---|---|---|---|---|
| 1981 | 85 | 6 – Satisfactory | 6 – Satisfactory | 5 – Fair | 6 – Bank Slump | 3 – Scour Critical | 151 |

ADT - Average Daily Traffic

Structure 053030F was last inspected on February 9, 2010. During this inspection, the bridge's superstructure and deck both received ratings of 6; suggesting they are in "satisfactory" condition. The bridge's substructure, with a rating of 5, is in "fair" condition. Figure 3 shows the condition of the bridge during a previous inspection. The condition of the channel and its protection measures are rated 6, indicating "Bank Slump". The scour rating of 3 denotes that the bridge is in a "scour critical" condition. Observations from previous inspections include erosion occurring along the north abutment causing the footings on the northeast side of the bridge to become exposed, an erosion hole developing near the southwest corner of the bridge and minor cracking in the abutments. Currently, there are no protective measures along the abutments where scour is most likely to occur. In addition, a large boulder has been displaced creating a scour hole that is consequently undermining the foundation of the north abutment.

**Figure 3 – Deck and Superstructure**

## *Section 4 - Geomorphic Conditions*

North Creek at Structure 053030F is a small flashy perennial stream with bed material ranging widely in size from sands to boulders. This location of the creek is set in a narrow valley with high relief on either side. There are little or no floodplains, with no sign of natural levee development. The channel is incised at the bridge but fluctuates upstream and downstream of the bridge. The channel boundaries are semi-alluvial. About 50-90 percent of the banklines are tree-covered. The channel has a sinuous pattern with no braiding or anabranching. Its width varies randomly and has frequent and irregular bar development.

Lateral migration of the channel has been restricted along some parts by artificial encroachments including roads, bridges, and riprap armored revetments along residential development. Upstream of the bridge about a quarter mile there is a diversion structure that acts as a grade control. There are also several natural controls including bedrock and large boulders. Despite these controls the channel has several visible failures along its banks and appears to be fairly active in some locations. This channel is susceptible to large flash floods which can cause severe scour and erosion in unprotected areas. Signs of recent flash floods along this channel include debris deposits in the guard rails on top of the bridge deck.

Some bank protection exists along this channel. The channel around the bridge is downcutting and exposing the footings. A large boulder deposited under the bridge is causing local scour around the abutments and footings. Some of the banks are eroding back and undercutting allowing the channel to migrate laterally. This could alter the angle of approach of the flow of the creek to the bridge.

**Figure 4 – Structure 053030F, Looking Upstream**

**Figure 5 – Channel Approach at Structure 053030F**

**Figure 6 – Structure 053030F, Looking Downstream**

The results of a cross section analysis of data collected in 2002, 2004, and 2010, where the elevation of the stream bed was measured along the upstream bridge face at 5 foot intervals, are shown in Figure 7. Continued monitoring of cross section profiles of the channel at the bridge for degradation/aggradation as well as lateral channel movement is recommended.

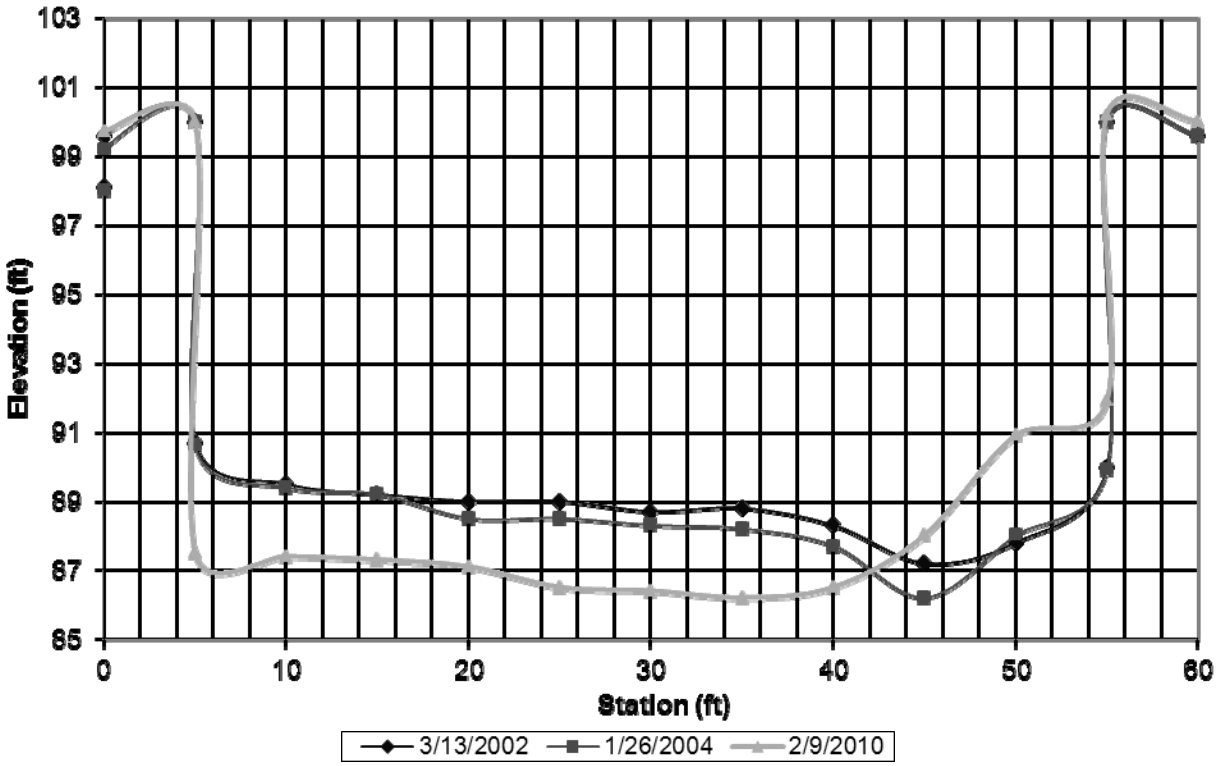


**Figure 7 – Channel Cross Section at Structure 053030F**

Geomorphic factors that affect stream stability, as shown in Figure 8, are useful in characterizing a stream in the field (USDOT, 2012b). For the channel at Structure 053030F, the applicable characterizations are circled.

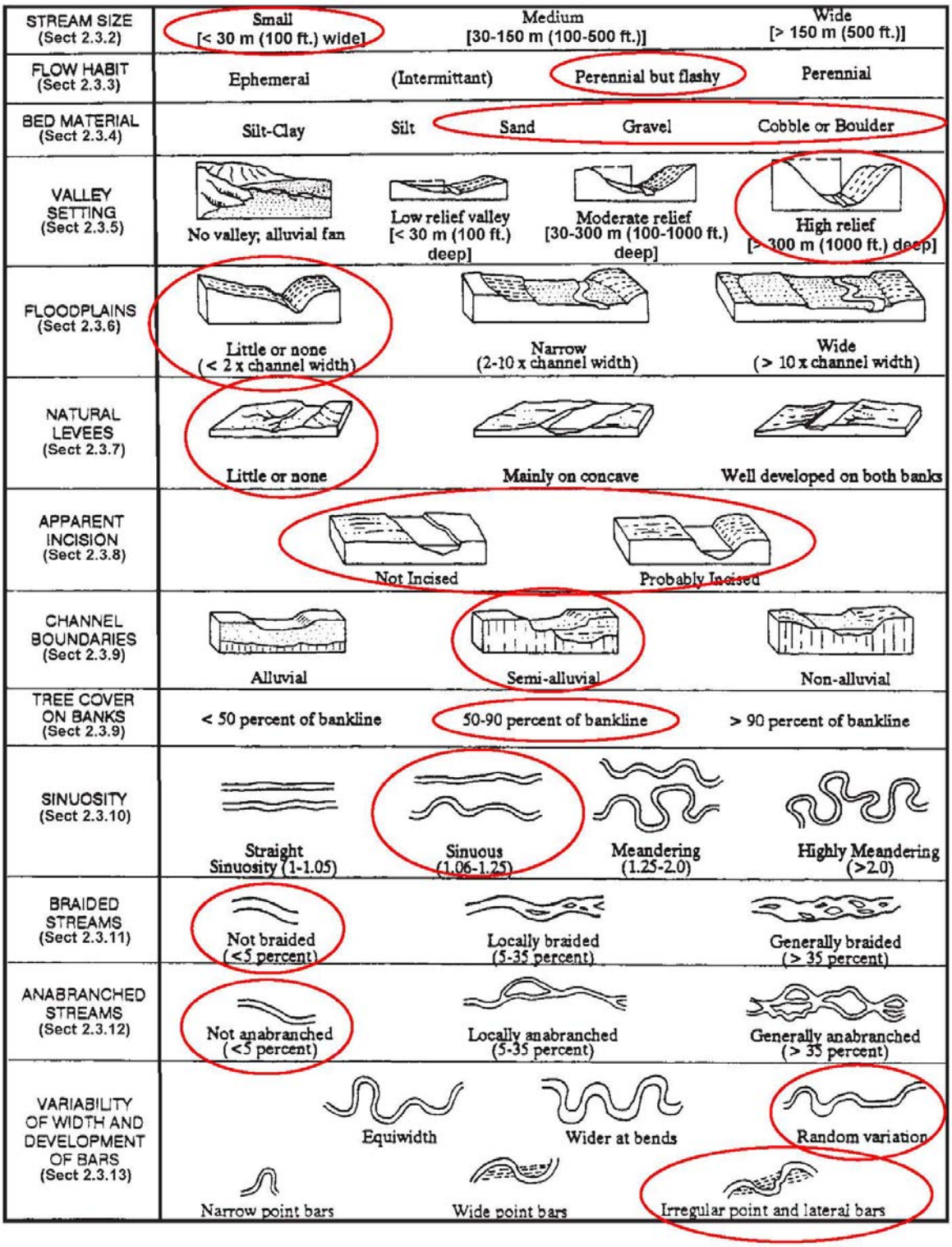


**Figure 8 – Geomorphic Factors That Affect Stream Stability**

## *Section 5 - Watershed and Hydrology*

Structure 053030F is located on North Creek near Virgin, Utah, downstream of the confluence of the right and left forks of North Creek. The headwaters are in Washington County near the Horse Pasture Plateau. The drainage area upstream of the bridge is 94 square miles with elevations ranging from about 3,670 feet above mean sea level (ft amsl) at the bridge site to about 8,500 ft amsl in the upper reaches of the watershed. The average elevation is about 5,900 ft amsl. Precipitation averages 10.5 inches annually at the bridge site, as determined from the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) (NOAA, 2013). The watershed for the structure was delineated using USGS StreamStats and displayed with ArcGIS® software, as shown in Figure 9 (USGS, 2013a; ESRI, 2010).

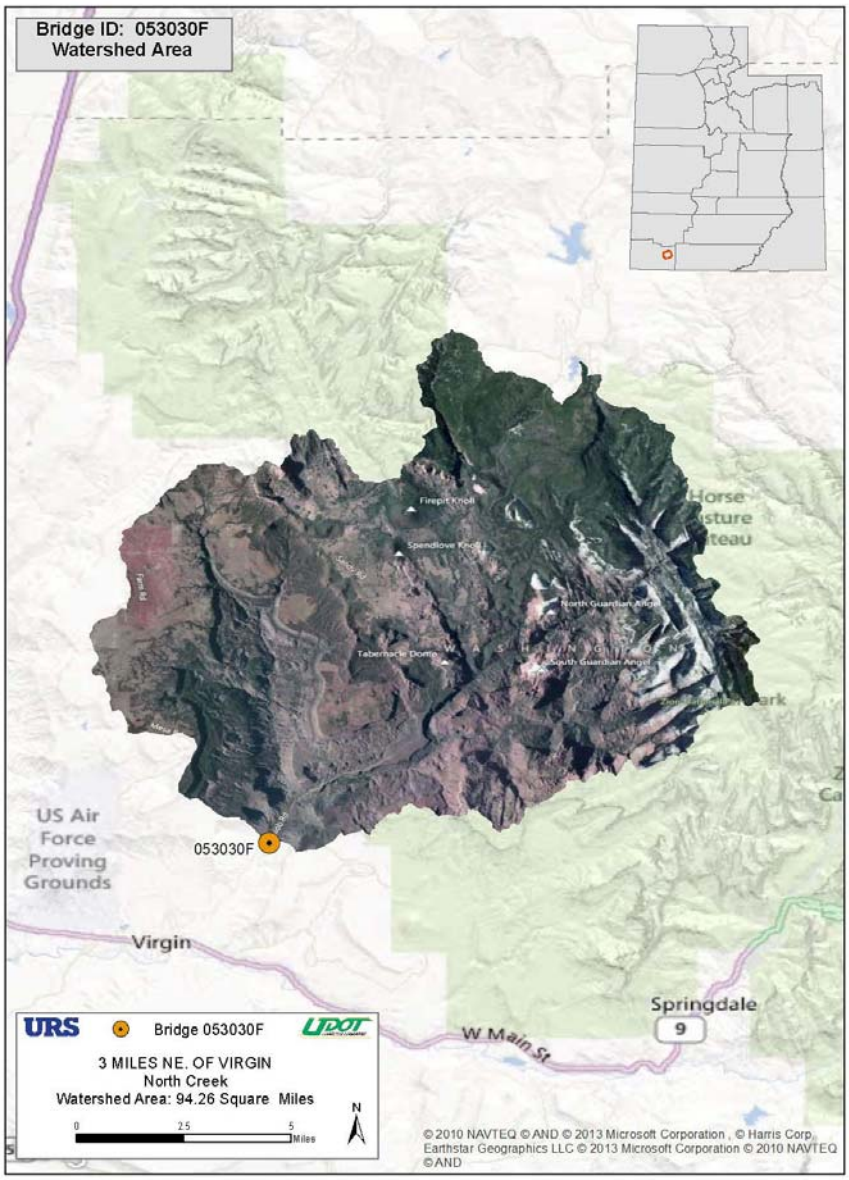


**Figure 9 – Structure 053030F Watershed**

StreamStats is a web-based GIS product from the USGS that automatically delineates the stream's watershed boundary, measures basin characteristics, and provides streamflow statistics using regional regression equations (USGS, 2013a). StreamStats flow rate estimates for North Creek at Structure 053030F for the 100-year and 500-year are 3,430 cfs and 5,790 cfs, respectively.

Flood frequencies for the hydraulic and scour modeling were obtained using the USGS Stream Gage 09405900 located north of Virgin, Utah within a mile of Structure 053030F (USGS, 2013b). The USGS software PKFQWin 5.2.0 was used to analyze the gage data (USGS, 2007). The gage data contains 11 years of peak flow records with one year (2007) being a data anomaly (13,500 cfs). The discharge data for 2007 were excluded for this analysis resulting in a 100-year and 500-year peak flow of 4,727 cfs and 7,431 cfs, respectively.

The Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Washington County was updated in 2009, but a hydrologic analysis of North Creek was not performed as part of the FIS (FEMA, 2009).

This study used 3,430 cfs for the 100-year flood and 5,790 cfs for the 500-year flood obtained from StreamStats regional regression equations, as shown in Figure 10.

USGS Utah StreamStats

# Streamstats Ungaged Site Report

Date: Wed Apr 27 2011 07:08:19 Mountain Daylight Time
Site Location: Utah
NAD27 Latitude: 37.2371 (37 14 13)
NAD27 Longitude: -113.1498 (-113 08 59)
NAD83 Latitude: 37.2370 (37 14 13)
NAD83 Longitude: -113.1506 (-113 09 02)
Drainage Area: 94.3 mi2

| Peak Flows Basin Characteristics | | | |
|---|---|---|---|
| 100% Region 7 (94.3 mi2) | | | |
| Parameter | Value | Regression Equation Valid Range | |
| | | Min | Max |
| Drainage Area (square miles) | 94.3 | 5.43 | 1670 |

| Peak Flows Streamflow Statistics | | | | | |
|---|---|---|---|---|---|
| Statistic | Flow ($ft^3/s$) | Prediction Error (percent) | Equivalent years of record | 90-Percent Prediction Interval | |
| | | | | Minimum | Maximum |
| PK2 | 323 | 76 | 2.7 | | |
| PK5 | 781 | 95 | 2.5 | | |
| PK10 | 1230 | 110 | 2.6 | | |
| PK25 | 1950 | 130 | 2.8 | | |
| PK50 | 2630 | 150 | 3 | | |
| PK100 | 3430 | 170 | 3.1 | | |
| PK200 | 4350 | 190 | 3.2 | | |
| PK500 | 5790 | 210 | 3.4 | | |

**Figure 10 – Flood Frequencies for North Creek at Structure 053030F**

# Section 6 - Hydraulics

## Section 6.1 - Modeling Approach

The hydraulic analysis of Structure 053030F was performed using HEC-RAS (USACE, 2010a), a one-dimensional standard step solver for backwater calculations. During a site visit to the bridge and the surrounding area, URS collected the following information relevant for hydraulic and scour analyses: valley setting/general geomorphology, channel/floodplain vegetation, bed/bank material ($D_{50}$), signs of existing scour related issues, and the general condition of the structural components of each bridge. The values for the variables used in HEC-RAS to model are shown in the Table 4.

**Table 4 – Variables Estimated for Hydraulic Model**

| Variable | Value |
|---|---|
| **$Q_{100}$** | 3,430 cfs |
| **$Q_{500}$** | 5,790 cfs |
| **Flow Regime** | Subcritical |
| **Downstream Normal Depth Slope** | 0.01107 ft/ft |
| **$D_{50}$** | 5 mm |
| **Manning's "n" Channel** | 0.04 |
| **Manning's "n" Banks** | 0.04 – 0.076 |

cfs - cubic feet per second
ft/ft - feet per feet
mm - millimeter

### Section 6.1.1 - HEC-RAS Model

A topographic survey of the area collected during the field visit was used to generate the channel location and layout in HEC-RAS. From this topographic survey, cross sections, generated using HEC-GeoRAS, were transferred to HEC-RAS (USACE, 2010a and 2010b). Cross sections were placed approximately every 100 feet, except near the bridge crossing where two cross sections were placed upstream and downstream from the bridge to account for expansion and contraction at the bridge site. The geometric configuration of the model in HEC-RAS is shown in Figure 11.

The way water interacts with the bridge at the upstream face is represented by the input of bridge geometry in relation to the channel geometry. Figure 12 shows the bridge crossing in HEC-RAS. The bridge is denoted as river station "617" because it falls between the cross sections labeled as "644.6396" and "590.2868."

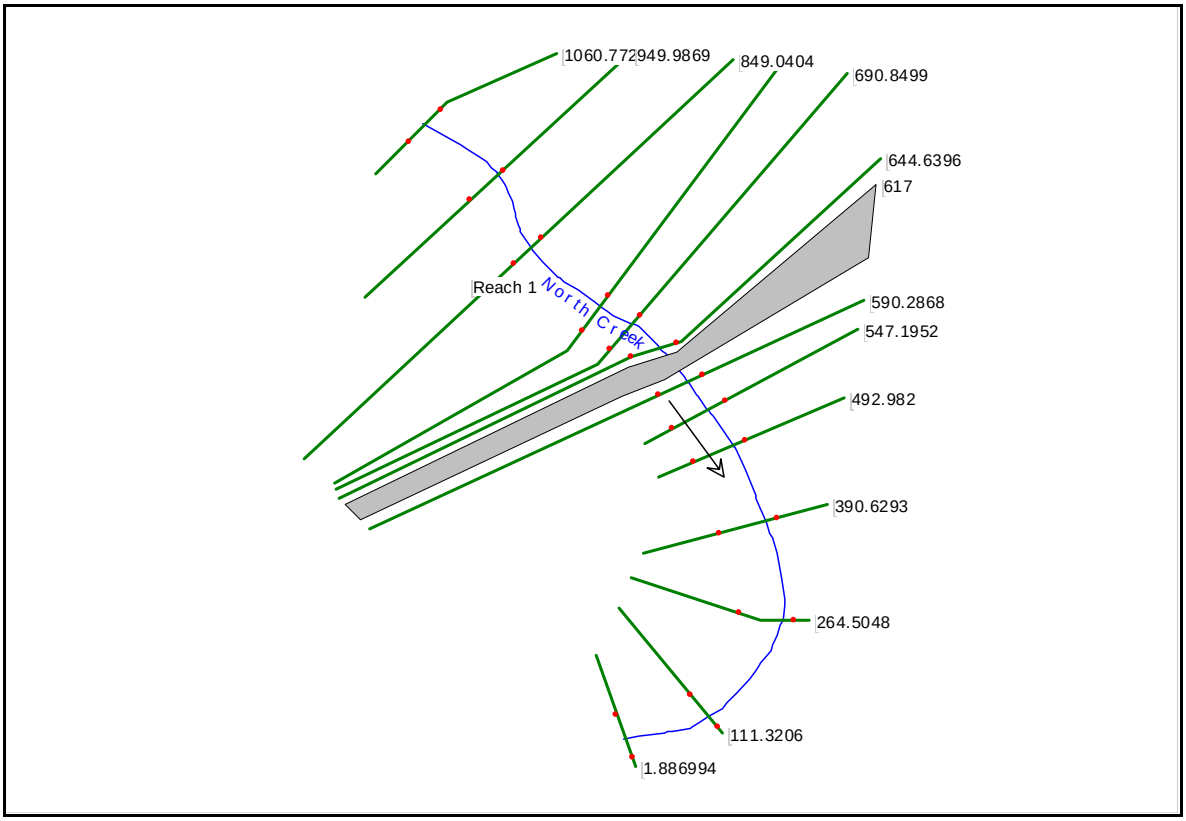


**Figure 11 – Geometric Data in HEC-RAS**

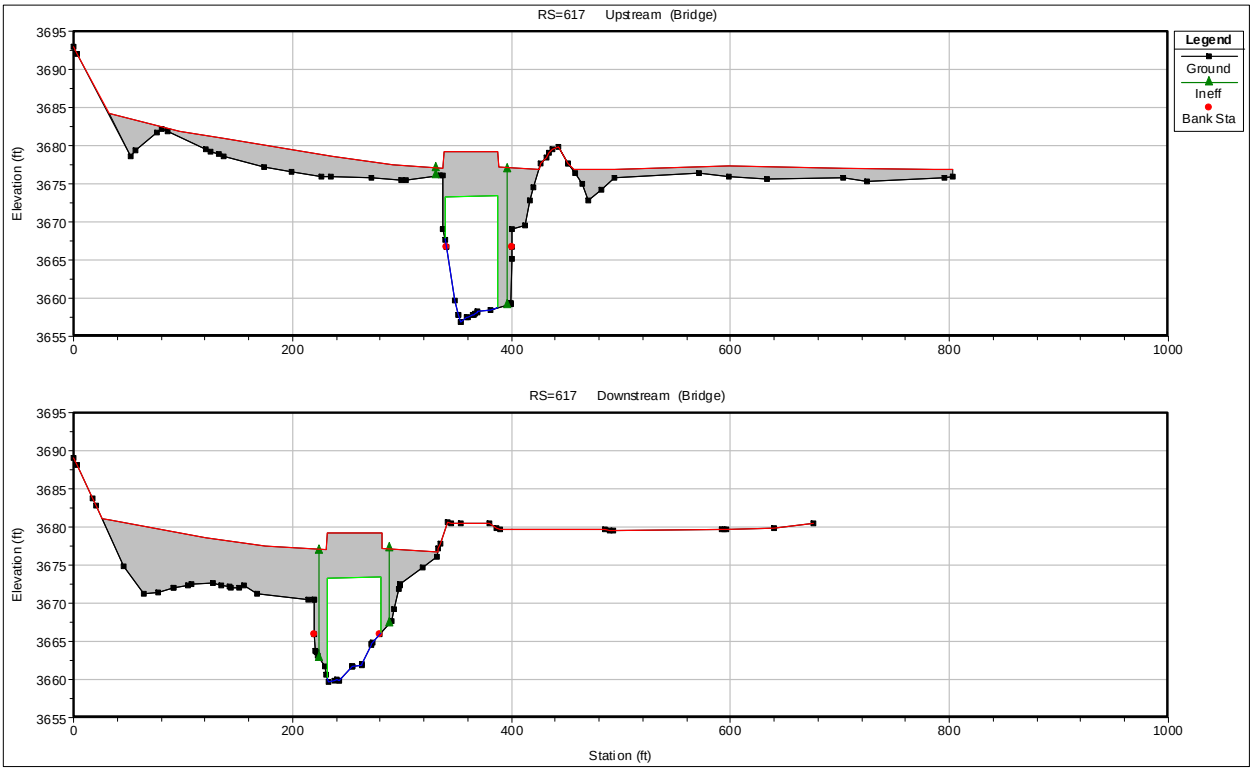


**Figure 12 – Bridge Crossing in HEC-RAS**

Modeling included a steady state flow analysis for the 100-year and 500-year storm events. Figure 13 shows the water surface profile of the stream for both 100-year and 500-year storm events.

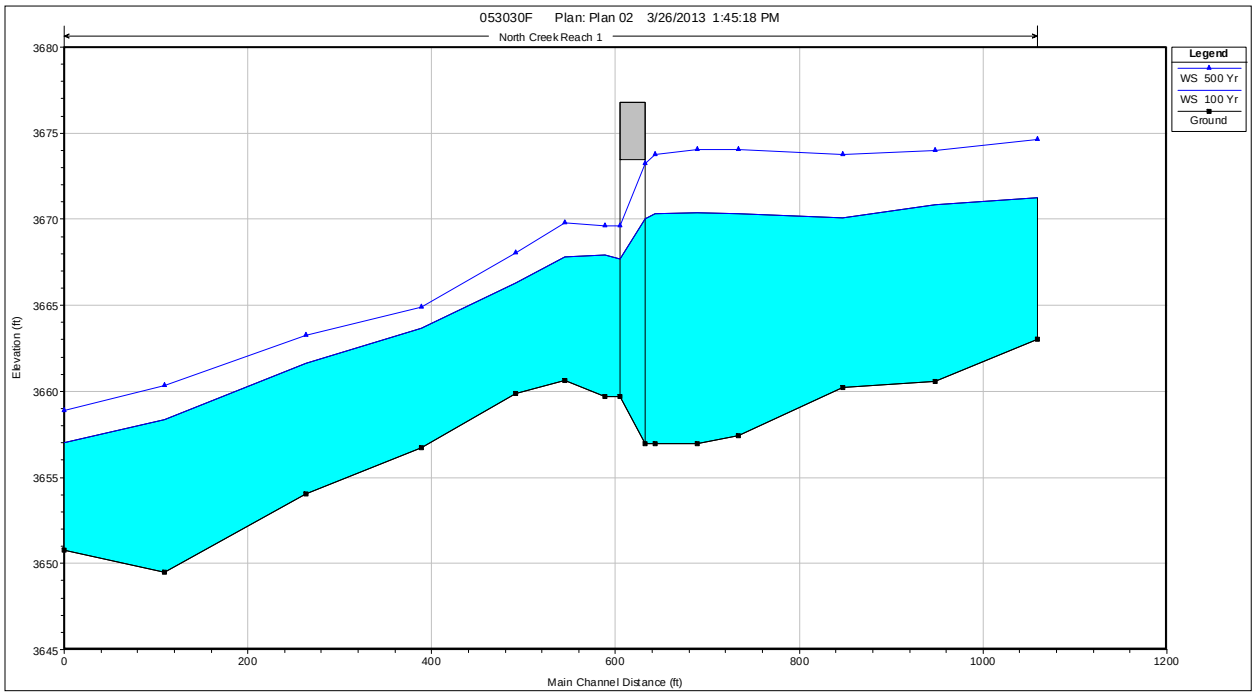


**Figure 13 – Water Surface Profile**

### *Section 6.2 - Contraction and Local Scour Analysis*

Using the information gathered during the site visit and output from HEC-RAS, scour calculations were performed for the 100-year and 500-year events using the HEC-18 methodologies (USDOT, 2012a). Contraction scour results from the reduction in flow area at the bridge, while local scour is the removal of material from around piers, and abutments. The complete scour calculations are in Appendix D. Analysis results are shown in Table 5.

**Table 5 – Scour Calculations Results**

| | 100-Year | | | 500-Year | | |
|---|---|---|---|---|---|---|
| | **Left Abutment** | **Channel** | **Right Abutment** | **Left Abutment** | **Channel** | **Right Abutment** |
| **Contraction Scour** | NA | 0.9 ft | NA | NA | 3.5 ft | NA |
| **Local Scour** | 15.5 ft | NA | 10.3 ft | 23.1 ft | NA | 16.5 ft |
| **Total Scour** | **15.5 ft** | **0.9 ft** | **10.3 ft** | **23.1 ft** | **3.5 ft** | **16.5 ft** |

ft - feet
NA - Not Applicable

The contraction scour values indicate that there would be only a minor amount of contraction scour occurring at the bridge site because the flow area prior to crossing underneath the bridge does not change significantly at the bridge opening . For the 100-year storm event, the left and right abutment scour is estimated to be 15.5 feet and 10.3 feet, respectively. For the 500-year storm event, the left and right abutment scour is 23.1 feet and 16.5 feet, respectively. The local abutment scour is based on the National Cooperative Highway Research Program 24-20 live-bed scour calculation which accounts for local and contraction scour (NCHRP, 2010). Results from the scour calculations are provided in Appendix D.

## *Section 7 - Countermeasures and Recommendations*

While the overall condition of Structure 053030F does not warrant immediate bridge replacement, countermeasures are needed to stabilize bridge conditions. URS recommends countermeasures due to the local abutment scour and the approach angle that is skewed with relation to the bridge abutments. The evaluation of risk and cost is critical in determining the appropriate action for this bridge. The installation of these countermeasures will reduce the risk of scour and extend the life of the bridge. It is likely the most practical and cost effective solution.

Currently, there is large diameter riprap placed immediately upstream and downstream of the bridge along the right bank of the channel. This riprap has been installed as a countermeasure to protect the right bank from eroding. However, it is evident that the much of the riprap has become dislodged and displaced downstream over time due to a single high flow event or the cumulative action of multiple high flow events. Scour holes have developed along the right upstream and left downstream sides of the bridge along the abutments due to the skewed approach angle of the channel with respect to the bridge abutments. In addition, a large boulder has been deposited near the left abutment which has created a local scour hole that is consequently undermining the foundation of the left abutment.

North Creek is susceptible to large flash floods resulting in high channel velocities and shear stresses at Structure 053030F. Given the channel's high velocities and shear stresses during large storm events along with evidence that much of the existing large diameter riprap along the right bank has washed downstream, riprap would not be a suitable countermeasure for abutment scour at this location. Instead, the recommended system must be able to withstand the shear stresses in the channel. HEC-23 recommends the use of reinforced concrete as a viable option to protect against abutment scour (USDOT, 2009). Research has determined that a reinforced concrete apron is a suitable system able to withstand the high velocities and shear stresses in the channel. It is imperative during installation of the reinforced concrete apron that the upstream and downstream ends of the apron be keyed into the channel at least five feet to protect the system from undermining. It is also essential that the apron be installed on stable material to prevent the deterioration of the apron due to ground settlement. If properly installed, a concrete apron would be a suitable system that can be used to protect Structure 053030F. Figure 1 of Appendix F shows a preliminary layout of the reinforced concrete apron within the extents of the bridge abutments. The estimated cost for the reinforced concrete apron presented in Figure 1 is $21,000.

In addition to scour countermeasures, future inspections of the bridge should consider any geomorphic changes that would affect the scour potential at the bridge. The channel around the bridge is downcutting and exposing the footings. Some of the banks are eroding back and the associated undercutting is allowing the channel to migrate laterally. This could alter the angle of approach of the flow of the creek to the bridge. Inspections should focus on alignment and approach changes of the channel. Additional stream cross sections to be taken during bridge inspections are strongly recommended to provide a larger data set that can be used to determine the trends of the bed elevation and lateral movement at the bridge.

Additional inspections should be made promptly after storm events exceeding a discharge of 2,630 cfs, which is the 50-year flow at this bridge. Special attention should be given to the reinforced concrete apron put in place along the bridge abutments after these large storm events.

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