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Development and Implementation of a Scour Monitoring Program for Selected Bridges Crossing the Truckee River

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16. Abstract

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Based on the results of a bridge scour evaluation program conducted by NDOT in 1993, the accepted methods used to predict bridge scour (e.g., HEC-18) are likely to substantially overestimate the potential for scouring around bridge piers in the Truckee River. Typically, these accepted methods are more appropriate for sediments exhibiting more cohesive properties and, thus, may not be suitable for the coarse-grained, noncohesive sediments in the Truckee River.

In order to more accurately monitor the amount of scour occurring at bridge piers in the Truckee River, a preliminary field-monitoring program was developed during this project. The potential for pier scour to occur was evaluated using the revised scour depth equations in the fourth edition of HEC-18 (Richardson and Davis, 2001) and the suitability of bridges for routine scour monitoring were assessed as part of this program.

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DEVELOPMENT AND IMPLEMENTATION OF A SCOUR MONITORING PROGRAM FOR SELECTED BRIDGES CROSSING THE TRUCKEE RIVER

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Problem Statement

The vulnerability of a bridge to scour around piers may be estimated using a variety of methods. These include routine monitoring of scour by taking field measurements, conducting laboratory studies, using mathematical equations developed from laboratory experiments, and using hydraulic analysis software (e.g., HEC-RAS and HEC-18).

Based on the results of a bridge scour evaluation program conducted by NDOT in 1993, the accepted methods used to predict bridge scour (e.g., HEC-18) are likely to substantially overestimate the potential for scouring around bridge piers in the Truckee River. Typically, these accepted methods are more appropriate for sediments exhibiting more cohesive properties and, thus, may not be suitable for the coarse-grained, noncohesive sediments in the Truckee River.

In order to more accurately monitor the amount of scour occurring at bridge piers in the Truckee River, a preliminary field-monitoring program was developed during this project. The potential for pier scour to occur was evaluated using the revised scour depth equations in the fourth edition of HEC-18 (Richardson and Davis, 2001) and the suitability of bridges for routine scour monitoring were assessed as part of this program.

Background Summary

A bridge scour evaluation program was developed and implemented by NDOT in November 1993 in order to comply with recommendations from the Federal Highway Administration (FHWA) (Soltani *et al.*, 1993). Under this evaluation program, all of the bridges owned by NDOT were evaluated and the vulnerability of these bridges to scour was estimated.

Bridges are classified as either "stable" or "scour critical" according to their vulnerability to scour using a rating system developed by the FHWA (FHWA, 1995). A "scour critical" bridge is one that has abutment or pier foundations that are considered unstable due to: (1) observed scour at the bridge site; or (2) the potential for scour as determined from a scour evaluation study (FHWA, 1995).

A scour evaluation study may consist of three parts identified as Level 1, Level 2, and Level 3 (Williams *et al.*, 1997). A Level 1 study is a qualitative evaluation of the stability of a streambed at a bridge crossing and an examination of the bridge structure for evidence of scour. A Level 1 study is often used to identify bridges that require more detailed study. A Level 2 study involves the collection of field data, hydraulic modeling, and prediction of the estimated maximum depth of scour for a selected design flood. A Level 3 study typically involves sediment transport modeling.

The development of realistic models for sediment transport is presently limited by the ability to identify, formalize, and parameterize the individual transport and reaction processes that occur (Van Cappellen and Wang, 1995). The rate of erosion or resuspension depends on the erosive forces exerted by the flowing water at the sediment-water interface and the resistance of the sediment to erosion or resuspension (Lagasse *et at.*, 1995).

Determining an expression for the rate of erosion or resuspension remains one of the most challenging aspects of modeling the bed exchange process (Bedford, 1992). The currently accepted expressions for predicting the amount of sediment transport and potential for scour around bridge piers (e.g., HEC-18) have been successfully applied in many locations (Richardson and Davis, 1995 and 2001). However, when these expressions are applied to channel reaches along the Truckee River, they seldom provide results that are consistent with observed field measurements of sediment transport and potential for scour. This may be due to a combination of geomorphic, hydrologic, and hydraulic conditions in the Truckee River.

This research project extended earlier studies completed by NDOT. The results of the earlier work resulted in a number of bridges being classified as scour critical. However, subsequent field inspections conducted by NDOT personnel suggested that there was no evidence of excessive scouring at a number of these locations.

Original Scope of Work

This project examined the suitability of bridges crossing the Truckee River between Verdi and Lockwood for routine field-scale scour monitoring as well as the installation of fixed devices to monitor bridge scour. Available historical information including soil boring logs and field measurements of scour during periodic bridge inspections was gathered and summarized. Specific tasks that were included in the original scope of work for this project are described below.

Task 1: Preliminary selection of bridge sites and scour monitoring devices.

The specific bridge sites to be studied in this research will be selected after conducting a literature review and identifying the locations of flow gauging stations operated by the USGS. The literature review will summarize historical information contained in bridge construction reports, periodic bridge inspection reports, and any available reports on field monitoring of scour. Bridge sites that have been classified as "scour critical" based on previous Level 1 and/or Level 2 scour analyses will receive primary consideration. Boring logs will also be examined in order to define the geologic strata at each bridge site. Any historical records showing channel cross sections will be examined in order to determine how the channel cross section may have changed over time. It is anticipated that the majority of this information will be collected from NDOT.

Various types of scour monitoring devices (e.g., fixed and portable) for potential bridge sites were evaluated. All monitoring devices and instrumentation to be used in the scour-monitoring program are to be acquired by NDOT.

Task 2: Select three bridge sites for the scour-monitoring program.

Based on the information collected during Task 1, specific bridge sites were to be selected for a long-term scour-monitoring program. All fixed monitoring devices and instrumentation to be used in the scour-monitoring program were to be acquired by NDOT and installed by NDOT personnel at the selected bridge sites.

Task 3: Measure flow, depth of scour, and channel cross sections over time and characterize sediment samples.

The flow in the Truckee River can be monitored using the USGS gauging stations that are already in place at various sites along the Truckee River. Fixed scour monitoring devices installed at the selected bridge sites can be monitored to determine changes in scour depth over time.

Detailed measurements of the channel cross sections at the selected bridge sites were to be collected. These channel cross sections were to be compared to any available historical records of channel cross sections at the same site. Channel cross sections at each of the selected bridge sites were to be measured approximately every four months or immediately following significant flow events in order to monitor changes in overall channel geometry with time.

Samples of streambed material immediately upstream and downstream from the selected bridge sites would potentially provide important information about how the size of the bed material varies with depth. This would provide a qualitative evaluation of the significance of bed armoring in preventing scour at bridge piers in the Truckee River.

Task 4: Calibrate existing scour equations for conditions in the Truckee River.

The experimental data collected during this study was to be used in an effort to calibrate the existing scour models described in *Hydraulic Engineering Circular No. 18* (Richardson and Davis, 2001) for the conditions that are observed in the Truckee River. Current methods tend to substantially overestimate the depth of scour around bridge piers in the Truckee River. For example, appropriate values for parameters such as the correction factor K_4 used to account for armoring by bed material were to be determined using the data collected during this study.

Anticipated Benefits

The intent of this research project was to help NDOT identify how to improve the existing methods for predicting scour depth at bridge crossings along the Truckee River. Further, the results of this project were intended to provide experimental data that could be incorporated into models used to predict the scour of coarse-grained bed material in the Truckee River and other rivers having similar characteristics. The scour of coarse-grained bed material around bridge piers and abutments is important to the fields of hydraulic, geotechnical, and bridge engineering. Improved prediction is needed to ensure the stability of these structures.

Project Duration and Schedule

This duration of this project was 36 months. It was hoped that adequate flows to initiate measurable scour around bridge piers in the Truckee River would occur during this period so that real time data could be collected. Since drought conditions existed throughout this period, no real time data related to scour depths were collected. The original schedule for this project is shown in Figure 1.1.

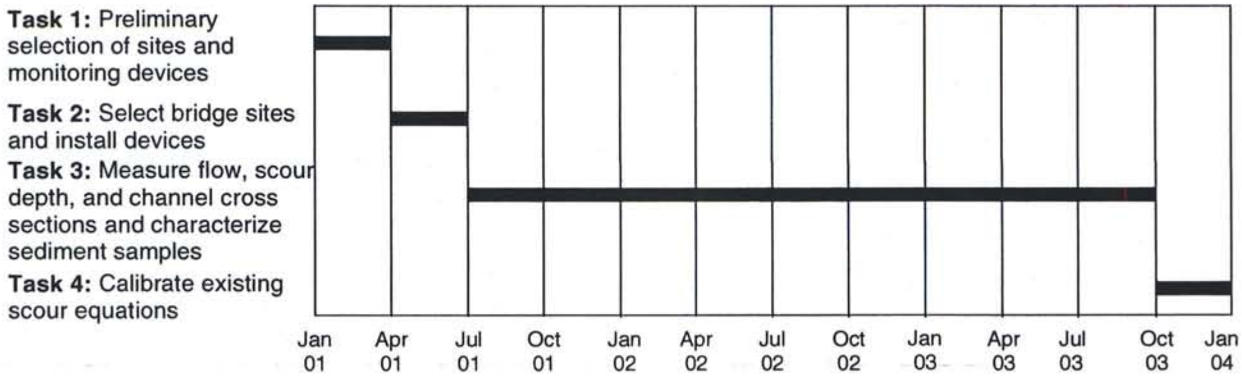


Figure 1.1. Proposed Project Schedule

The work performed to accomplish the various tasks defined in the original scope of work for this project can be categorized into four specific sections. These sections include:

Section 1 – The selection of specific bridge sites for scour monitoring;

Section 2 – The reevaluation of predicted scour depths for selected bridges using the fourth edition of HEC-18 (Richardson and Davis, 2001);

Section 3 – The evaluation of various commercially available scour monitoring devices; and

Section 4 – The proposed geotechnical investigations at selected bridges.

The work completed pertaining to each of these sections is described in the remainder of this document.

SECTION 1 – SELECTION OF BRIDGE SITES FOR SCOUR MONITORING

The project team met initially in January 2001 to discuss the scope of work and schedule for the project.

The initial phase of the project involved a preliminary field survey of bridges crossing the Truckee River between Lockwood and Verdi. Based on the field survey, available historical information for selected bridges was gathered from NDOT. This information included geotechnical reports, previous scour studies, and bridge maintenance reports.

1.0 Field Survey

All bridges crossing the Truckee River from Verdi to Lockwood were examined during a preliminary field survey in order to determine their suitability for long-term scour monitoring. Portable sonar instrumentation provided by NDOT was tested at five bridge sites (i.e., Lockwood, East McCarran, Highway 395/Interstate 580, Kietzke, and Kunezli). Channel cross-sections obtained at these bridges are included in Appendix A.

Some of the initial criteria for selecting bridges for this study included:

- bridge classified as scour critical based on the third edition of HEC-18 (Richardson and Davis, 1995)
- favorable site access
- piers located in main channel
- varying pier types and shapes and angle of attack of the approach flow
- river morphology
- availability of geotechnical information, inspection reports, and previous scour studies

Access to the abutments and piers was fair to good for the bridges listed in Table 1.1. The I-80 bridge at East Verdi (G-772) presented challenges due to right-of-way (ROW) constraints.

Table 1.1. Summary of Bridge Pier Type and Site Access

Bridge	Pier Type	Potential for Scour	Site Access
East McCarran (B-1300)	Continuous	Scour Critical	Good
Lockwood (B-1490)	Continuous	Scour Critical	Good
Hwy 395 (H-1234)	Continuous	Scour Critical	Fair
Kietzke (B-578)	Rectangular	Scour Critical	Fair
I-80 at East Verdi (G-772)	Circular	Scour Critical	Fair
Kuenzli (B-1327W)	Rectangular	Scour Critical	Fair

1.1 Office Research

The main office of NDOT in Carson City was visited to gather available historical information on the six bridges selected for initial evaluation. The available information included bridge inspection and maintenance reports, record drawings, soils investigation reports, and previous scour studies. The staff at NDOT was extremely helpful in locating existing information. A summary of the available information has been compiled in Table 1.2 and is described below.

Table 1.2. Summary of Historical Information for Selected Bridges

STRUCTURE	PIER TYPE	SOILS REPORT	SOIL DESCRIPTION	SCOUR STUDY	SCOUR* CODE	SCOUR REPORT SUMMARY	MAINTENANCE REPORT SUMMARY
Kietzke B-578	Square piers on spread footings	No Report Available		CH^2M Hill, Feb. 1997	3 (Bridge is scour critical)	Piers offset in flow alignment. Used HEC-18 and assumed D_{50}=0.48'. Contraction scour and long term scour not anticipated. Abutment scour potential. Local pier scour calculated at 14.84'.	Severe erosion south bank paving prior to 1990. Aug 2000 - south bridge column footings exposed up to 1.5' (vertical face), mud line measurement close to June 1998 inspection. Aug. 31, 2000 – Mud line measured 1' more than 4/96 measurements and 0.4' more than 6/98 measurements.
Kuenzli B-1327W	Short 14' long pier wall on spread footing	No Report Available		CH^2M Hill, Feb. 1997	3 (Bridge is scour critical)	D_{50}=0.48' (assumed) Contraction scour calc. at 0.68' Assumed no long term scour Abutments at risk Local pier scour = 21.93'	Feb. 5, 1997 – Moderate localized scour at upstream edge of pier. Approx. 4' remaining bury depth to top of footing.
I-580 / US 395 H-1234	Pier wall on spread footings	No Report Available		NDOT Letter, 1/10/96	5 (Bridge is stable)	Local pier scour calculated at 13.5' (bottom footing 15' deep). No report found.	12/27/00- Scour monitor not yet replaced. Some scour (1.4') observed on upstream edge.
I-80 at East Verdi G-772	Round piers on spread footings	Minimal information on plans	Sandy gravel, decomposed granite, many cobbles/boulders	NDOT, 1994	3 (Bridge is scour critical)	Long term and contraction scour not anticipated. Local scour at piers: bent 4 of both structures are at risk. Scour hole calculated below bottom of footings.	Sept 1997 – Underwater inspection revealed little flood induced scour at bridge piers.
East McCarran B-1300	Pier walls on spread footings with piles	Minimal report – 4 boring logs on plans	Course sands, gravels with some cobbles and boulders.	No report available	6 (Not evaluated)	N/A	02/21/01 – Slight trend towards aggradation. Mudline Pier 1 – 0.3' change from 4/96 to 6/98 Mudline Pier 2 – 2.0' scour from 4/96 to 6/98 Some embank. Erosion noted at SE quadrant.
Lockwood B-1490	Pier walls on spread footings	Report 1976	Miscellaneous soils over shallow bedrock.	No report available	6 (Not evaluated)	N/A	4/28/98 – South pier undermined (possibly due to eddying water)

* Scour code rating per FHWA *1995 Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*

1.2 Geotechnical Data

As shown in Table 1.2, there is a minimal amount of geotechnical information available for the selected bridges. Soils boring data was available for the bridges at I-80 in East Verdi, East McCarran, and Lockwood. Of this information, there were only general classifications made, such as "coarse sands and gravel with some cobbles and boulders". Reports for other bridges crossing the Truckee River in Reno had similar general soil descriptions.

In general, the predominant soil type along the reach of the Truckee River between Verdi and Lockwood is consistent with glacial outwash geomorphology as identified in a study conducted for NDOT by Miller *et al.* (1994). Other pertinent information summarized from this study includes:

- There has been limited channel migration between Verdi and Steamboat. Immediately upstream of Steamboat, the bed consists of fine grain cohesive materials (i.e., lacustrine deposits), which restrict channel migration. Upstream of the East McCarran Bridge to Verdi, the bed consists of coarse sediment (glacial outwash).
- The riverbed has been generally stable during the last several decades. However, there is a potential for vertical instability between the Vista Reefs and East McCarran Bridge. Further down cutting may be experienced due to historical lowering of the channel in the Vista Reef area.
- D_{50} particle sizes were estimated, however the method or detail of classification was not clear. As shown in Table 1.3, the particle size varied from 0.3 feet to 0.5 feet for the selected bridges.

Table 1.3. Mean Particle Size of Bed Material at Selected Bridges (Miller et al., 1994)

Bridge No.	Bridge	D_{50} (ft)
B-578	Kietzke	0.5
B-1327W	Kuenzli	0.5
H-1234	I-580/US-395	0.5
G-772	E. Verdi	0.4
B-1300	E. McCarran	0.3
B-1490	Lockwood	0.3

1.3 Previous Scour Studies

Recent scour studies were available for the bridges crossing the Truckee River at I-80 in East Verdi, Kuenzli, and Kietzke. These studies utilized the third edition of HEC-18 (Richardson and Davis, 1995) to predict the depth of contraction and local pier scour. In each report the contraction and long-term scour was identified as being negligible. However, the local pier scour was calculated as being below the bottom of footings in all cases. These studies assumed a D_{50} particle size of 0.48 feet.

The fourth edition of HEC-18 (Richardson and Davis, 2001) was published since these scour studies were performed. This publication includes changes to the K_4 factor in the local pier scour equation to account for size of coarse bed material. As shown in Section 2, this parameter can have a significant effect on the predicted depth of scour.

1.4 NDOT Bridge Inspection and Maintenance Reports

The maintenance reports were reviewed for the six selected bridges. With exception to the Lockwood bridge, there was no evidence of severe pier scour from the last major runoff event (January 1997). The south pier of the bridge at Lockwood was partially undermined by eddying currents. Minor pier scouring problems (i.e., less than 2 feet) were encountered at the Kietzke, Kuenzli, I-580, I-80 at East Verdi, and East McCarran bridges.

SECTION 2 – REEVALUATION OF PREDICTED SCOUR DEPTHS

2.0 Background

A bridge scour evaluation program was developed and implemented by NDOT in November 1993 in order to comply with recommendations from the Federal Highway Administration (FHWA) (Soltani *et al.*, 1993). Under this evaluation program, all of the bridges owned by NDOT were evaluated and the vulnerability of these bridges to scour was estimated.

Bridges are classified as either "stable" or "scour critical" according to their vulnerability to scour using a rating system developed by the FHWA (FHWA, 1995). A "scour critical" bridge is one that has abutment or pier foundations that are considered unstable due to (1) observed scour at the bridge site or (2) the potential for scour as determined from a scour evaluation study (FHWA, 1995).

A scour evaluation study may consist of three parts identified as Level 1, Level 2, and Level 3 (Williams *et al.*, 1997). A Level 1 study is a qualitative evaluation of the stability of a streambed at a bridge crossing and an examination of the bridge structure for evidence of scour. A Level 1 study is often used to identify bridges that require more detailed study. A Level 2 study involves the collection of field data, hydraulic modeling, and prediction of the estimated maximum depth of scour for a selected design flood. A Level 3 study typically involves sediment transport modeling.

The currently accepted expressions for predicting the amount of sediment transport and potential for scour around bridge piers (e.g., HEC-18) have been successfully applied in many locations (Richardson and Davis, 1995). However, when these expressions are applied to channel reaches along the Truckee River, they seldom provide results that are consistent with observed field measurements of scour. This may be due to a combination of geomorphic, hydrologic, and hydraulic conditions in the Truckee River.

Based on the results of the bridge scour evaluation program conducted in 1993, hydraulic engineers at the Nevada Department of Transportation (NDOT) concluded that the accepted mathematical methods used to predict bridge pier scour (i.e., HEC-18) are likely to substantially overestimate the potential for scouring around bridge piers in the Truckee River. This was evidenced by the fact that most of the bridges classified as "scour critical" by these methods withstood a significant flood (a 100+ year storm event) in 1997 with little or no detectable damage.

A preliminary analysis of the scour equations presented in HEC-18 has indicated limitations in predicting scour depths when the riverbed consists mainly of large diameter particles (+0.4 ft). The bed of the Truckee River consists mainly of coarse gravels, cobbles, and boulders which is consistent with glacial outwash geomorphology.

One of the main purposes of this project was to attempt to determine why the currently accepted method for predicting the depth of scour around bridge piers (i.e., HEC-18) usually overestimates the depth. The ultimate goal of this study was to determine how the currently accepted scour equation could be modified or calibrated to obtain more accurate predictions of scour depths for the conditions in the Truckee River.

2.1 Equation for Predicting Scour Depth

The scour depths for selected bridges along the Truckee River were reevaluated using the fourth edition of HEC-18 (Richardson and Davis, 2001). The equation for predicting scour in the fourth edition was intended to account for the presence of coarse-grained bed material. This version of the equation incorporates a correction factor K_4 which conceptually accounts for the effects of armoring in riverbeds and streambeds consisting of coarse-grained material.

The maximum depth of pier scour may be predicted using the expression (Richardson and Davis, 2001):

$$\frac{y_s}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{y_1} \right)^{0.65} Fr_1^{0.43}$$

where:

y_s = depth of scour (ft)
y_1 = depth of flow directly upstream from pier (ft)
K_1 = correction factor for pier nose shape
K_2 = correction factor for angle of attack of flow
K_3 = correction factor for bed condition
K_4 = correction factor for armoring by bed material
a = width of pier (ft)
L = length of pier (ft)
Fr_1 = Froude number directly upstream of pier
V_1 = mean velocity of flow directly upstream of pier (fps)
g = gravitational acceleration (32.2 ft/s^2)

Typical values for the various correction factors (i.e., K_1, K_2, K_3, and K_4) can be found in HEC-18 (Richardson and Davis, 2001). The correction factor K_4 decreases the predicted scour depths due to armoring of the scour hole for bed materials that have a D_{50} equal to or larger than 2.0 mm and D_{95} equal to or larger than 20 mm. The minimum value of K_4 is 0.4.

2.2 Scour Code Ratings

The Federal Highway Administration developed the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995) to systematically gather and report information related to the condition of bridges in the national bridge inventory. Item 113 is designated as the scour rating code. The purpose of this code is to indicate the status of a bridge with regard to its vulnerability to scour. Common rating codes related to the potential for or occurrence of bridge scour are summarized in Table 2.1.

Table 2.1. National Bridge Inventory Codes Related to Scour

Code	Description
N	Bridge not over waterway.
U	Bridge with "unknown" foundation that has not been evaluated for scour. Since risk cannot be determined, flag for mentoring during flood events and, if appropriate, closure.
T	Bridge over "tidal" waters that has not been evaluated for scour, but considered low risk. Bridge will be monitored with regular inspection cycle and with appropriate underwater inspections. ("Unknown" foundations in "tidal" waters should be coded U).
9	Bridge foundations (including piles) on dry land well above flood water elevations.
8	Bridge foundations determined to be stable for assessed or calculated scour conditions; calculated scour is above top of footing.
7	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical.
6	Scour calculation/evaluation has not been made.
5	Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footings or piles.
4	Bridge foundations determined to be stable for calculated scour conditions; field review indicates action is required to protect exposed foundations from effects of additional erosion and corrosion.
3	Bridge is scour critical; bridge foundations determined to be unstable for calculated scour conditions: 3(B) – Scour within limits of footings or piles. 3(C) – Scour below spread-footing base or pile tips.
2	Bridge is scour critical; field review indicates that extensive scour has occurred at bridge foundations. Immediate action is required to provide scour countermeasures.
1	Bridge is scour critical; field review indicates that failure of piers/abutment is imminent. Bridge is closed to traffic.
0	Bridge is scour critical. Bridge has failed and is closed to traffic.

2.3 Summary of Geotechnical Data Needed for Scour Analyses

Gradation curve data (i.e., D_{50} and D_{90}) are used to estimate the critical velocity needed to initiate the transport of bed material. The critical velocity is subsequently compared to the mean approach velocity of the flow to estimate the value of the K_4 factor.

Gradation curve data for the selected bridges were obtained from the previous bridge scour reports prepared by CH2M Hill and are summarized in Table 2.2. The original soil boring log is only available for bridge B-1530 (Keystone). For the other bridges, the boring logs available for nearby bridges were examined in an attempt to find additional information. These data were used to estimate scour depths using the fourth edition of HEC-18.

Table 2.2. Summary of Geotechnical Data Used for Scour Analyses

Bridge No.	Availability of Boring Log	D_{50} (feet)	D_{90} (feet)
B-578N (Kietzke)	Not Available	0.48	0.88
B-578S (Kietzke)	Not Available	0.48	0.88
B-1530 (Keystone)	Available	0.48	0.88
B-1487 (Mayberry)	Not Available	0.49	1.2
B-1327 (Kuenzli Ave.)	Not Available	0.48	0.88

2.4 Preliminary Evaluation of Scour Equations

When the equation in the third edition equation of HEC-18 (Richardson and Davis, 1995) was used to predict the depth of scour, each of the selected bridges considered in this study was rated as 3(C) for the scour code rating (i.e., Item 113 of the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (FHWA, 1995)). This is indicative of scour depths below the bottom of the footings.

When the equation in the fourth edition was used, the depth of scour predicted for each bridge was significantly less than the depth predicted by the third edition equation. Results are summarized in Table 2.3 and sample spreadsheets used to predict the depth of scour are included in Appendix B. Further, the scour rating code was less severe for the bridges located at Kietzke and I-80 in East Verdi. For the Kietzke bridge, the predicted depth of scour was less than the footing depth and the scour rating was either 3(B) or 5, depending on the results of the structural analysis of the foundation. For Bent #4 of the I-80 bridge in East Verdi, the predicted depth of scour was less than the top of the footing depth and the scour rating was 8. The foundations are considered stable if there is no evidence of active scour. For the Kuenzli bridge, the predicted depth of scour was much lower when the fourth edition equation of HEC-18 was used. However, the predicted depth of scour was still below the bottom of the footing, so the scour rating remained critical at 3(C).

Table 2.3. Comparison of Pier Scour Depths for Selected Bridges

Bridge and Equation	Bridge Number	K_4	Scour Depth Y_s (ft)	Footing Depth (ft)	Scour Code Rating
Kietzke HEC-18, third edition	B-578	0.79	14.8	8.5	3 (C)
Kietzke HEC-18, fourth edition	B-578	0.40	7.5	8.5	5 or 3 (B)
Kuenzli HEC-18, third edition	B-1327W	1.00	22.6	9.8	3 (C)
Kuenzli HEC-18, fourth edition	B-1327W	0.48	10.5	9.8	3 (C)
I-80 in East Verdi HEC-18, third edition (100 year flow)	G-772E*	1.00**	17.5	13.8	3 (C)
I-80 in East Verdi HEC-18, fourth edition (100 year flow)	G-772E*	0.42	7.4	13.8	8
I-80 in East Verdi HEC-18, third edition (500 year flow)	G-772E*	1.00**	18.5	13.8	3 (C)
I-80 in East Verdi HEC-18, fourth edition (500 year flow)	G-772E*	0.42	8.1	13.8	8

* The values shown are for the East Bridge, Bent #4. The scour differences for Bent #4 of the West Bridge were very similar. Bent #3 was not evaluated since it was not determined to be scour critical when the equation in the third edition of HEC-18 was used.

** Computations performed by NDOT did not include a K_4 factor, so the value was assumed to be 1.00 for the purposes of comparison.

These results suggested that the scour ratings for some bridges in the NDOT inventory may be revised to a less severe rating by using the equation in the fourth edition of HEC-18. However, subsequent evaluations by hydraulic engineers at NDOT indicated that other bridges in the NDOT inventory remained scour critical. These results were consistent with those reported following the scour evaluations performed by CH^2M Hill in February 1997. Only bridge B-304 could be revised to 3(B) (scour critical – scour within limits of footing or piles). Results of these evaluations for three additional bridges of interest in this study are summarized in Table 2.4.

Table 2.4. Revised Scour Code Ratings for Selected Bridges

Bridge and Equation	Bridge Number	Scour Code Rating for 3rd edition of HEC-18	Revised Scour Code Rating for 4th edition of HEC-18
Keystone Avenue	B-1530	3	3 (C)
Lake Street	B-304	3	3 (B)
Mayberry Drive	B-1487	3	3 (C)

2.5 Sensitivity Analysis and Limitations of K_4 Factor

A sensitivity analysis was performed using the fourth edition equation in HEC-18 (Richardson and Davis, 2001) to determine the effect of the size of bed material on the predicted scour depth. As shown in Figure 2.1, the results indicated that the scour depth consistently decreased as the size of the bed material increased until a size of approximately 0.4 feet was reached. For particle sizes greater than 0.4 feet, the results indicated that the depth of scour remained constant at 7.5 feet. Evidently, this is due to the K_4 factor limitations in the equation (e.g., minimum value of K_4 is 0.4). To address this limitation and to clarify some of the parameters included in the fourth edition equation of HEC-18, Dr. Larry Arneson at the Federal Highway Administration was contacted. However, he did not respond to the inquiry as of yet. Further analysis of this limitation is recommended.

Other references on the development of the K_4 factor need to be consulted. A recent study by Mueller and Jones (1999), entitled *Evaluation of Recent Field and Laboratory Research on Scour at Bridge Piers in Course Bed Materials*, concluded that the coefficients (e.g., K_4) based on laboratory data do not provide sufficient reduction in computed scour depths to compare favorably with observed depths. Further research was recommended to improve scour predictions in nonuniform, coarse bed material. Therefore, it is possible that the scour rating for other bridges may be reduced further with additional study and refinement of the scour coefficients.

2.6 Revised Scour Analyses for Selected Bridges Using HEC-RAS Model

Four bridges crossing the Truckee River were more thoroughly evaluated using the equations in the fourth edition of HEC-18 to estimate the total scour depths. The equations in the fourth edition of HEC-18 divide the total scour depth into three major components:

(1) Pier stem scour depth (HEC-18, 4th edition, page 6.10)
(2) Pile cap (footing) scour depth (HEC-18, 4th edition, page 6.11)
(3) Pile group scour depth (HEC-18, 4th edition, page 6.14)

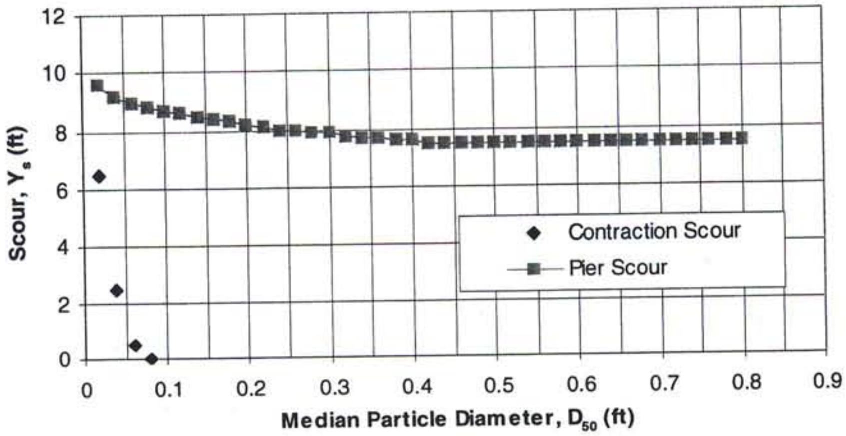


Figure 2.1 Scour Sensitivity for the Kietzke Bridge

The pile cap (footing) scour depth component occurs when the sum of long-term degradation, contraction scour, and pier stem scour reaches a depth that is at or below the footing. The pile group scour depth component is included when the sum of long-term degradation, contraction scour, pier stem scour, and footing scour depth component reaches a depth that is at or below the piles.

In the scour analyses discussed above in Section 2.4, only the pier scour depth component was considered to determine the scour depth. In the revised scour analyses described here, the total scour depth has been estimated by considering the pier stem scour, pile cap scour, and pile group scour components.

Four bridges that were evaluated included B-578N (Kietzke), B-578S (Kietzke), B-1530 (Keystone), and B-1487 (Mayberry). The selected bridge sites are those where Level 1 and/or Level 2 scour analyses were previously conducted and the results identified the sites as "scour critical" bridges.

Cross-sections of the Truckee River after the 1997 flood were incorporated into a HEC-RAS model of the Truckee River. This HEC-RAS model was used to determine the major geometric and flow parameters (e.g., top width, average and maximum velocity, depth of flow, and cross-sectional area of flow) at one or more channel sections upstream from the selected bridges over a range of flow conditions. The new thalweg elevation near selected bridges was determined using the post-1997 channel cross-sections and current data available from NDOT bridge maintenance reports. The dimensions of footings and other structural components for each of the selected bridges were obtained from the plans and drawings provided by the NDOT. The data obtained from the HEC-RAS model was then used to estimate the total scour depths for a range of flow conditions.

The results indicated that bridges B-1487 (Mayberry) and B-578N (Kietzke) showed the potential for critical scour (i.e., scour depth which exceeds the foundation depth). The scour depths for these two bridges were calculated over a range of discharges in order to identify the critical discharge resulting in excessive scour. The variation of total scour depth with discharge for bridges B-578N and B-1487 is given in Figures 2.2 and 2.3, respectively. The cross-sectional area of flow and velocity at the pier were determined using a HEC-RAS model and are summarized in Tables 2.5 and 2.6 for B-578N and B-1487, respectively.

As shown in Figure 2.2 for B-578N, the predicted scour depth abruptly increases after the flow exceeds 20,000 cfs. Below a flow of 20,000 cfs, only pier scour was considered. As soon as the scour depth reaches the top of the foundation, foundation scour increases the overall scour depth.

As shown in Figure 2.3 for B-1487, the scour depth increases linearly as discharge increases from 16,000 cfs to 22,000 cfs. At a flow of 24,000 cfs, the scour depth decreased by 0.2 ft since the flow begins overtopping the bridge section. Under actual conditions, scour is likely to be increase as flow increases. It is recommended that B-1487 should be analyzed further for pressure flow conditions.

The revised scour depths indicated that bridges B-1487 (Mayberry) and B-578N (Kietzke) showed potential for critical scour (i.e., scour depth which exceeds the foundation depth) and even failure at higher flows. In order to refine the results of the evaluation, additional geotechnical investigations should be conducted to more thoroughly characterize the soil profile with depth adjacent to the piers of these bridges. These geotechnical investigations are described further in Section 4.

The two other bridges that were evaluated using both HEC-RAS and HEC-18 were B-1530 (Keystone) and B-578S (Kietzke). Neither of these bridges showed potential for excessive scour at higher discharges. Overall, the predicted scour depths for these two bridges were above the footings and, thus, these bridges should be considered safe. Table 2.7 summarizes the total scour depths at maximum discharge conditions for the third and fourth editions of HEC-18.

Table 2.5. Variation of Scour Depth with Discharge for B-578N

Discharge (cfs)	Total Scour (ft)	Flow area (ft^2)	Flow Velocity (ft/s)
16000	10.84	1562.99	10.10
18000	11.15	1667.08	10.62
20000	11.34	1764.17	11.10
22000	17.31	1857.19	11.56
24000	17.26	2255.57	10.20

Table 2.6. Variation of Total Scour Depth with Discharge for B-1487

Discharge (cfs)	Total Scour (ft)	Flow area (ft^2)	Flow Velocity (ft/s)
16000	6.8	1497.81	10.68
20000	9.9	1497.81	12.02
22000	11.8	1497.81	14.69
24000	11.6	1600.62	14.99

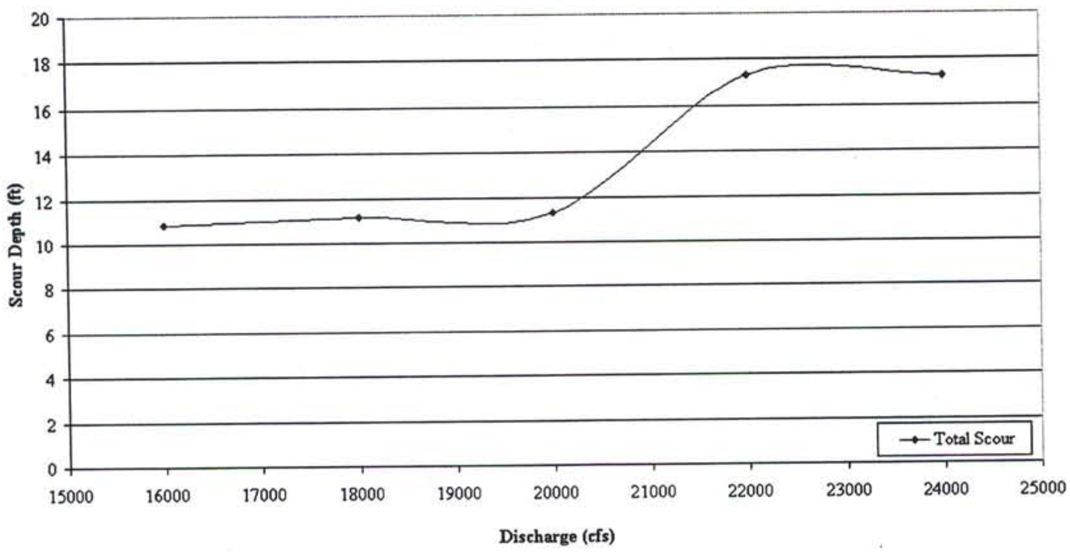


Figure 2.2. Variation of total scour depth with discharge for Bridge B-578N

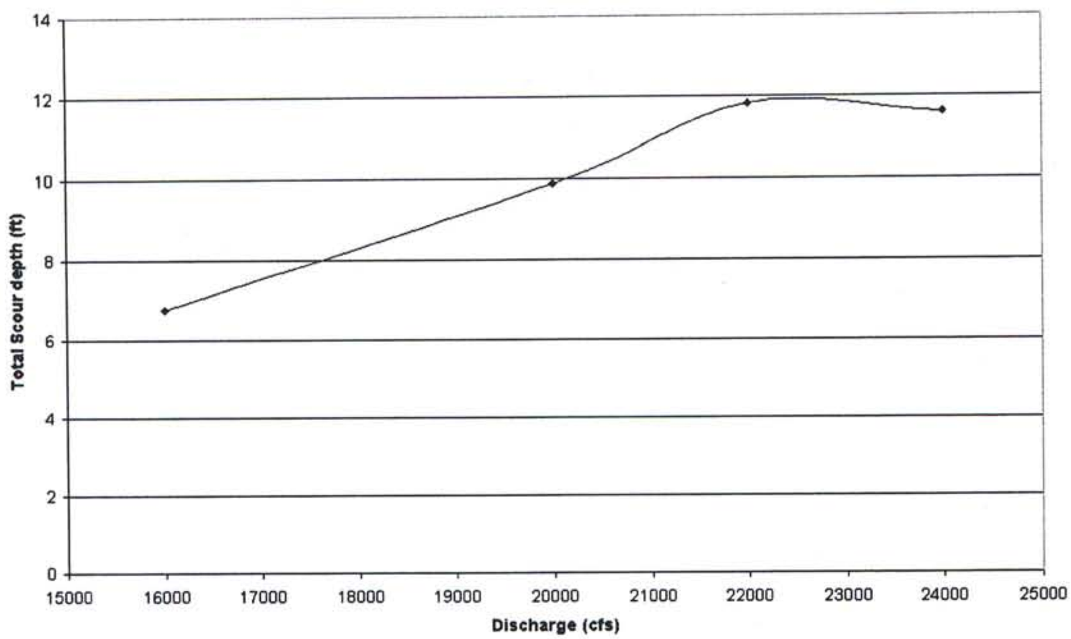


Figure 2.3. Variation of total scour depth with discharge for Bridge B-1487

Table 2.7. Comparison of Predicted Scour Depths using the Third Edition and the Fourth Edition of HEC-18

Bridge No.	Scour depth (ft) at Discharge (cfs) (Third Edition)	Scour depth (ft) at Discharge (cfs) (Fourth Edition)
B-578S (Kietzke)	18.37 ft at 17,550 cfs	12.49 ft at 24,000 cfs
B-1530 (Keystone)	11.75 ft at 52,500 cfs	9.42 ft at 60,000 cfs

SECTION 3 – EVALUATION OF SCOUR MONITORING DEVICES

One objective of this project was to install permanent scour monitoring devices at three bridges based on pier type, scour risk level, location to stream gages, and site accessibility in order to provide long-term scour monitoring.

The advantages and disadvantages of various types of scour monitoring devices (e.g., fixed and portable) were examined in an attempt to identify the most suitable devices for bridges crossing the Truckee River. The use of geophysical methods (e.g., ground penetrating radar) as either a primary or secondary technique for identifying historical scour depths as well as active scour measurements (similar to sonar) was also considered.

3.0 Evaluation of Portable Scour Monitoring Device

A portable scour monitoring device shown in Figure 3.1 was evaluated in several field trials. The device, which consists of a sonar instrument mounted on a kneeboard, needed to be modified slightly to deliver consistent results. These modifications, including a PVC frame and balancing weight, are temporary and may be easily removed, if necessary.

After several trials of different measuring techniques and board configurations, streambed elevations were effectively obtained with this device. The board is manually pulled across the channel on a guide cable attached to fence posts installed on either side of the river. The sonar cable should be lengthened to facilitate measurements when the channel section is wider than 100 feet. As the river rises, the guide cable may be raised on the posts to maintain the proper height for the kneeboard. Additional fence posts may be necessary if the river reaches an elevation 2 to 3 feet higher than present.

The device was tested at five bridge sites (i.e., Lockwood, East McCarran, Highway 395/Interstate 580, Kietzke, and Kunezli). The device should provide adequate streambed data to evaluate contraction scour conditions as well as provide some information on local pier scour. Preliminary cross sectional data obtained are included in Appendix A.

Figure 3.1 Kneeboard with portable sonar device

3.1 Evaluation of Fixed and Portable Scour Monitoring Devices

Scour Monitoring and Instrument Demonstration Project 97 (FHWA, 1997) and *Instrumentation for Measuring Scour at Bridge Piers and Abutments*, NCHRP Report 396 (Lagasse *et al.*, 1997) summarized the advantages and disadvantages of various commercially available pier scour monitoring devices.

Selection of the appropriate scour monitoring devices for a monitoring program depends on site conditions and operational limitations of particular instrumentation. Site conditions that affect monitoring include streambed composition, bridge height, flow depth, and flow velocity. Operational limitations relate to high sediment transport, debris, and ice flow as well as specialized training needed to operate a piece of equipment.

Monitoring programs will typically involve a combination of fixed, portable, and geophysical instrumentation to collect data in the most efficient manner. Furthermore, portable instrumentation should be used to "ground truth" fixed instruments to insure accurate results and to evaluate potential shifting of the location of maximum scour. Survey positioning equipment will also be required to set benchmarks and locate the instrumentation.

3.1.1 Fixed Instrumentation – Fixed instrumentation includes sonar, sounding rods, and driven rod devices. Table 3.1 summarizes the various devices and conditions for application. It should be noted that no scour measuring device is without some deficiency, especially for the conditions encountered in the Truckee River.

The channel bed in the Truckee River consists generally of large material that may require pre-drilling or track-hoe excavation for the installation of embedded rod devices (sliding collar and piezoelectric). The cost and/or right-of-way (ROW) constraints may make these expensive alternatives. However, the installation of these rods could be performed in conjunction with the proposed geotechnical investigations in Section 4, which would require similar equipment. The primary advantage of these devices is that the readings are not directly affected by debris, which is the primary deficiency with sonar devices.

Further review of the ROW, physical access, and permitting constraints will be necessary to ascertain the feasibility of installing the embedded rod type device (as well as performing a detailed geotechnical investigation). Table 3.2 summarizes the degree of physical access to the piers by heavy equipment for a geotechnical investigation and fixed scour instrumentation. The comments represent the results of a visual on-site inspections of the site conditions. A heavy equipment specialist should be consulted to verify access requirements. Additionally, a review of ROW constraints should be made by NDOT to complete the access evaluation.

The cobble-type bed of the Truckee River is ideal for physical probe devices. However, the seasonal high flows and velocities will probably exclude its use due to problems with the unsupported length.

Table 3.1. Summary of Fixed Scour Monitoring Devices

Device Type	Streambed Characteristics			Flow Characteristics			Advantages	Disadvantages
	Sand Bed	Cobble* Boulder	Silt/Clay Cohesive	Perennial *	Ephemeral	Tidal		
Sonar	Yes	Yes	Yes	Yes	Yes	Yes	Relatively accurate, time-history, off-the- shelf components. Effective in deep water. Measures aggradation.	Erroneous readings from debris, high sediment load and air entrainment.
Sounding Rod	No	Yes	Yes	Yes	Yes	No	Simple mechanical device. Measures aggradation.	Unsupported length, binding, augering. Inaccurate readings in sand and with debris present.
Sliding Collar Rod (Mechanical)	Yes	Large bed material may exclude installation	Cohesive bed material may inhibit driving	Yes	Yes	Yes	Simple mechanical device. Resistant to debris impact	Unsupported length, binding, may require pre-drilling in coarse-bed channels. Does not measure aggradation.
Piezoelectric Sensor Rod (Electro-mechanical)	Yes	Large bed material may exclude installation	Cohesive bed material may inhibit driving	Unknown	Yes	Unknown	Relatively simple in concept and low cost. Readings not directly affected by debris.	May require pre-drilling in coarse-bed channels. Unsupported length and vibration. Sensor damage during installation. Sensor damage by debris impact.
Piezoelectric Sensor Rod (Electric)	Yes	Large bed material may exclude installation	Cohesive bed material may inhibit driving	Unknown	Yes	Unknown	Readings not directly affected by debris.	Problems discriminating changes in conductivity. May require pre-drilling in coarse-bed channels. Sensor damage during installation. Mostly experimental.

* Cobble boulder and perennial characteristic of the Truckee River.

Table 3.2. Heavy Equipment Access (Rolling Stock)

BRIDGE	HEAVY EQUIPMENT ACCESS TO THE RIVER	HEAVY EQUIPMENT ACCESS TO PIER (S)	OVERALL RATING
Kietzke B-578-N	Access via the park parking on the northwest quadrant achievable with some bank re-grading.	Northwest Pier: located in the river approximately 1 foot from the edge of water and is the most accessible pier – would require a small diversion. Northeast Pier: located in the river approximately 20 feet from the edge of water and is closer to thalwag of river – would require a large diversion and low overhead equipment under bridge (overhead clearance appears to be 10 to 15 feet).	Good Poor
Kuenzli B-1327W	Access is not very feasible from ROW. Access via private property may be the only option. Large trees lining the bank may have to be removed. Further review is necessary.	Single pier is located in the center of the river and is setback from the face of the bridge so low overhead equipment and a major diversion would be necessary.	Poor
I-580 / US 395 H-1234	Access on the north side from the asphalt path from the east? – Need to investigate further.	Single pier located in the river approximately 20 to 30 feet from the south edge of water – would require a large diversion.	Poor
I-80 in East Verdi G-772	Access on the east side via private property – requires major grading a temporary road down to river. Verbal permission obtained to utilize SPPCo access road. Need key for second gate. Access on the west side via private property. Verbal permission granted from homeowner.	Bent 4 Piers, South Bridge: located at the edge of river – would require a small diversion. These are the best piers to study (closer to thalwag than bent 3 piers). Bent 3 Piers, South Bridge: located on dry land – would require minor road grading to access.	Poor Fair
East McCarran B-1300	Access on the north side in NDOT ROW would require extensive grading and tree removal. Access from private property (Accurate Concrete) more feasible. Access from south side may not be feasible due to a concrete retaining wall.	North Pier: located in the river approximately 10 ft. from edge of water and is the most accessible – would require a moderate diversion. South Pier: located in the river approximately 15 feet from the edge of water – would require a large diversion.	Fair Poor
Lockwood B-1490	Access on the both sides in NDOT ROW from SR 45 requires temporary ramp grading of bank.	West Pier: located in the river approximately 5 feet from the edge of water – would require a minor diversion. East Pier: located in the river approximately 10 feet from the edge of water – would require a moderate diversion.	Good Fair

Sonar devices should be relatively easy to install, are one of the more accurate types of devices, and provide good data results (e.g., time-history and aggradation measurements). Installation by equipment on the bridge deck may be possible on some of the lower bridges. A major shortcoming of these devices is that excessive debris can inhibit their ability to make accurate streambed measurements during higher flow conditions.

For additional evaluation of the fixed instrumentation, Table 2 from NCHRP Report 396 (Lagasse *et al.*, 1997), "Comparison of Devices Tested with Mandatory and Desirable Criteria", has been included in Appendix C.

3.1.2 Portable Instrumentation – Portable instrumentation, which should be used for ground-truthing of the fixed instrumentation, includes physical probes and sonar devices. Table 3.3 summarizes the applications, advantages and limitations of these devices.

Table 3.3. Summary of Portable Scour Monitoring Devices

DEVICE	BEST APPLICATION	ADVANTAGES	LIMITATIONS
Physical Probes	Small bridges and channels	Simple Technology	Accuracy and high flow applications
Sonar	Large bridges and channels	Accurate point data or complete mapping	High flow application and debris.

As discussed above, the cobble-type bed of the Truckee River is ideal for physical probes. However, the seasonal high flows and velocities will probably exclude their use due to problems with the unsupported length.

Sonar devices appear to be the best option among portable scour monitoring devices. Although their functionality during high flows is suspect, they can be used as secondary devices for confirmation of the results from fixed device during lower flows. As reported earlier in this section, the portable sonar device from NDOT was field tested by UNR with good results during lower flow conditions.

Pedestrian access to the river to operate portable sonar devices is achievable for all bridges. However, some accesses are easier than others as described in Table 3.4.

Table 3.4. Pedestrian Access to Selected Bridge Sites

BRIDGE	ACCESS TO RIVER	SONAR SET-UP	COMMENTS
Kietzke B-578	Good	Fair	Access via park parking. Cannot walk sonar guide cable across on bridge – must use a projectile.
Kuenzli B-1327W	Fair	Good	Access from Kuenzli via stairs on both sides. Can walk guide cable across bridge.
I-580 / US 395 H-1234	Difficult	Difficult	Access on south side difficult due to steep rip-rapped stream bank. Due to extreme height of bridge, sonar guide cable must be extended across by the use of a projectile.
I-80 in East Verdi G-772	Difficult	Fair	Access on west side via private gravel road (permission verbally granted). Access on east side via SPPCo maintenance access road (permission and key obtained). This site will take longer to set-up because of the distance between access points. Due to the extreme height of the bridge, the sonar guide cable must be extended across by the use of a projectile.
East McCarran B-1300	Good	Good	Access on both sides from East McCarran. Can walk guide cable across on bridge.
Lockwood B-1490	Good	Good	Access on both sides from Lockwood Road. Can walk guide cable across on bridge.

3.1.3 Data Logging and Telemetry of Devices – According to NCHRP Report 396 (Lagasse *et al.*, 1997), existing data logging systems, with some exceptions, are adequate to meet the needs available scour monitoring devices. Once the data has been logged in a datalogger, the telemetry of the data is relatively straightforward because the protocol for the data transmission using telephone modem, radio, and satellite transmission is well established. However, additional effort will be required to define and match datalogging and telemetry capabilities to the sensors used to measure scour depth at the bridge piers.

<u>3.1.4 Preliminary Cost Comparisons</u> – A cost analysis of scour measuring devices was presented in NCHRP Report 396 (Lagasse *et al.*, 1997) to compare the costs of various types of instrumentation. Wherever possible, actual reported costs from projects prior to 1997 were used. Table 3.5 summarizes the approximate costs of installations including labor, material, and equipment. Reference Tables 3 and 4 in Appendix C for additional details. Costs have been adjusted to 2001 dollars assuming 5% inflation.

Table 3.5. Cost Comparison of Scour Monitoring Devices

Device	Materials ($)	Labor ($)	Equipment ($)	Total ($)
Sounding Rod (Brisco)	10000	5000	3700	18700
Sonar - Eagle DDS-1 (USGS)	5000	7300	1200	13500
Sonar - Eagle Z9500 (NCGRP)	5000	2500	700	8200
Sonar - Data Sonics (USGS)	7500	7300	1200	16000
Magnetic Collar (Manual)	3000	2500	1800	7300
Magnetic Collar (Automated)	5000	2500	1200	8700
Driven Rod (Piezoelectric)	6200	5000	2000	13200
Driven Rod (Tip Switch)	5600	5000	2000	12600

Actual costs will vary depending on site conditions and the type of device type used. However, costs due to site conditions (e.g., labor and equipment) may be the governing factor since the most of the bridges have challenging access issues.

3.2 Evaluation of Scour Monitoring Devices

Surface geophysical techniques that utilize ground penetrating radar were also examined. These techniques would offer an alternative to gathering additional pier scour data if a sizable flow event resulting in measurable pier scour does not occur during the duration of this project. Instead of monitoring future pier scour, previous scour depths could conceivably be correlated to historical flow events. In addition to obtaining historical scour depths, this technique could potentially be useful in determining unknown pier depths. However, because of the associated costs and the specialized expertise required to use this instrumentation as well as the ability to interpret results, this type of instrumentation was eliminated from further consideration.

It was also determined that if geophysical methods of correlating previous scour depths to historical runoff events were used, geotechnical sampling as described in Section 4 would be needed at the bridge sites in order to confirm the results.

SECTION 4 – PROPOSED GEOTECHNICAL INVESTIGATIONS

The reevaluation of predicted scour depths described in Section 2 indicated that bridges B-1487 (Mayberry) and B-578N (Kietzke) showed potential for critical scour (i.e., scour depth which exceeds the foundation depth) and even failure at higher flows. In order to refine the results of the evaluation, additional geotechnical investigations should be conducted for the bridges B-578N and B-1487 to more thoroughly characterize the soil profile with depth adjacent to the piers of these bridges.

A detailed geotechnical investigation of the soil profile at each pier would:

- provide valuable information regarding the variation of size distribution with depth.
- determine whether the soil profile at the bridge piers differs greatly from the profile of the native soil
- provide evidence on the occurrence of bed armoring
- provide some qualitative evidence of whether scour followed by infilling of scour holes has occurred historically.

Characterizing the soil profiles at the riverbank has been suggested as an alternative to determining the soil profiles adjacent to the bridge piers. This would greatly reduce the impact to the river, simplify permitting, reduce overall costs, and shorten the timeframe for soil sampling. A pit approximately 10 to 12 feet deep should be sufficient to characterize the soil to a depth below the bridge piers.

However, because of the expense and time required for permitting, the proposed geotechnical investigations to determine the size distribution of the bed material with depth was put on hold by NDOT.

Required Permits

In order to perform the proposed geotechnical investigations to determine the size distribution of the bed material with depth, both 401 and 404 environmental permits will be needed in order to enter the Truckee River. Both of these permits are from the Army Corps of Engineers. In addition, to the 401 and 404 permits, a rolling stock permit would be required from NDEP. Generally, permitting is handled by the Environmental Services Division of NDOT. The specific locations where entry into the river is desired must be identified. Quantities of cut and fill and the size of the impacted area must be determined. The permitting process can be simplified if the equipment and construction areas are kept out of the water (i.e., a rolling stock permit may not be required, and lesser restrictions may apply to the 401 and 404 permits).

For projects involving sites in or near rivers and streams, it is important to distinguish if the watercourses fall under the classification of jurisdictional waters, which are navigable waters as determined by the US Army Corps of Engineers (COE). Watercourses which are tributary to navigable waters may also have certain restrictions. If the waters are jurisdictional waters or "Waters of the U.S.", they fall under the federal regulations 401 and 404. For any work done within the limits of "Ordinary High Water" within jurisdictional waters, 401 and 404 permits will be required with few exceptions.

A 401 permit is concerned with water quality or "water quality certification". For typical NDOT projects, NDOT Environmental Services Division will apply for a 401 permit with the COE. As part of the review process, the COE will coordinate with the Nevada Division Environmental Protection (NDEP). This is roughly a 30-day process.

A 404 permit is also known as the "nationwide" permit or the "dredge and fill" permit. It deals with quantities of cut and fill, and areas of disturbance. When the application is submitted by NDOT, a copy is also forwarded to the NDEP for review. As part of the review process, the NDEP grants a "state blessing" on the 401 certification for a nationwide permit. This is roughly a 60-90 day process.

A "rolling stock" permit (i.e., temporary authorization to discharge/dewater) is a state requirement. A contractor must apply directly to the NDEP. This permit may require best management practices (BMPs) to be installed while the work is being performed. The contractor will need to provide the following:

- the purpose of the project and what it involves
- the timeframe of the proposed project and the expected duration
- the type of equipment to be used, how it will be operated and in which location(s)
- a description of the site and its physical location (e.g., stream, wetland, wash, low gradient stream, steep drainage, mainstream river, or tributary)
- a description of the work to be performed—where and how—for each stream reach or individual site or area
- township, range and section(s), latitude and longitude
- topographic map
- site plan
- detailed description of BMPs
- fee

NDOT Environmental Services Division also deals with "Section 7" where fish and wildlife are concerned.

Evaluation of Site Access at Selected Bridges

The bridge sites were evaluated for ease of access by UNR and NDOT. All of the bridges are fairly accessible. However, equipment safety still needs to be evaluated by NDOT personnel. Several issues for access (e.g., physical and ROW), soil classification, and environmental permitting need to be addressed.

Some general considerations for the site access plans include:

1. NDOT safety personnel should review the proposed access at each of the selected bridge sites for equipment safety.
2. NDOT Environmental Service Division personnel should review the proposed work area at each of the selected bridge sites for extent of disturbance and for permitting requirements.
3. Soil characterization techniques and procedures should be reviewed.
4. ROW, access easements, and property owners in the access areas should be identified.

5. City of Reno personnel should be contacted for ROW/easements access permission and permitting, as required.
6. A topographic and boundary survey may be necessary for plan preparation for permit submittal. This would include base topography, boundaries, existing improvements and vegetation areas. Areas of disturbance, fill, and excavation should be identified. Best management practices would also be described. A traffic control plan would also need to be prepared.
7. A preliminary field review should be conducted by all affected parties (e.g., NDOT, City of Reno, UNR, USACE).

Issues relevant to the proposed geotechnical investigations at each of the selected bridges are summarized below.

Kietzke Bridge

1. Access to northwest bank from the existing park paving looks feasible for a trackhoe. May need rubber tracks or temporary cover on the pavement (e.g., soil or wood). A riprap bank would need to be constructed to level out the hoe for excavating at the bank. This riprap could then be used later to fill in some exposed areas under the bridge.
2. The vegetation in the area appears to be minimal.
3. Digging a 12-foot hole appears to be feasible, casting the soil to a clear spot under the bridge for bagging or characterization onsite. Need to determine how and where the size distribution would be characterized (e.g., onsite or in laboratory). NDOT geotechnical engineers should be consulted.
4. ROW – Need to review ownership in area – probably City of Reno – and obtain permission for access and operations.
5. Environmental – Need site review by NDOT Environmental Services Division. Dewatering should not be necessary and encroachment into the surface water can likely be avoided.
6. Renting clean equipment may be necessary.
7. Future plans – NDOT reportedly plans the installation of pier riprap at this site which may require a water diversion. This may provide a convenient opportunity to characterize the soil profile adjacent to the pier as well as install scour monitoring devices.

Kuenzli Bridge

1. Two access points were examined. The first one was from the apartment site on the northeast side of the river. There is a gate access to a storm drain manhole next to the river, so there is probably a City easement through the apartment site. This needs to be verified. The bank is steep but may be accessible with some ramping. The second access is between the two bridges, but this appears to be too steep.
2. There are trees to maneuver around and there would be vegetation disturbed.
3. Digging a 12-foot deep hole appears to be feasible, casting the soil to a clear spot for bagging or characterization onsite. Need to determine how and where the size distribution would be characterized (e.g., onsite or in laboratory). NDOT geotechnical engineers should be consulted.
4. ROW – Need to review ownership and easements and obtain permission for access and operations.

5. Environmental – Need site review by NDOT Environmental Services Division. Dewatering should not be necessary and encroachment into the surface water can likely be avoided.
6. Renting clean equipment may be necessary.

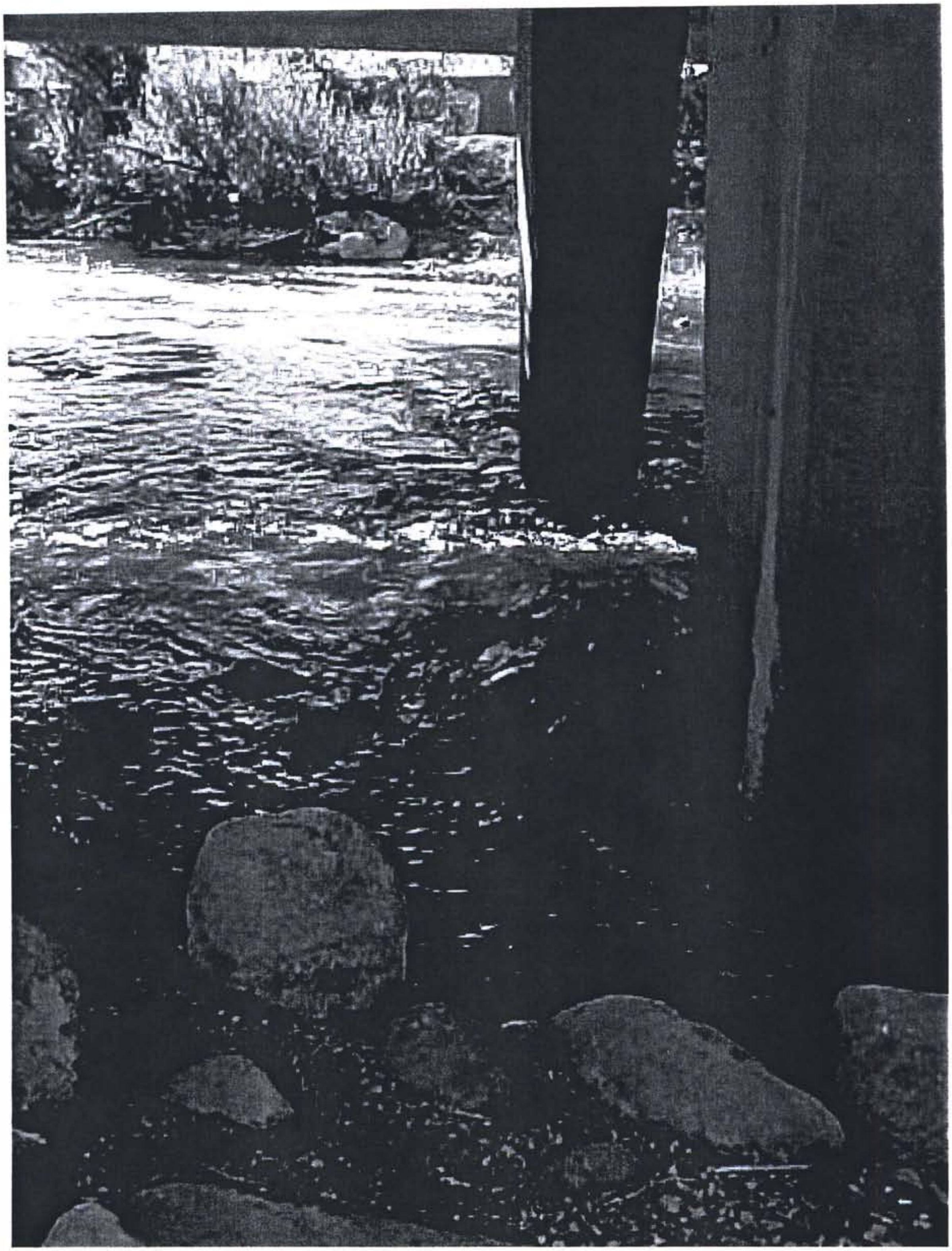
Keystone Bridge

1. Access to the northwest bank from Riverside Drive appears to be feasible. The riverbank is flat in this area. The trackhoe would have to cross the City park strip, which consists of a concrete path and a narrow strip of grass.
2. Minimal vegetation would be disturbed at the riverbank.
3. Digging a 12-foot deep hole appears to be feasible, casting the soil to a clear spot under the bridge for bagging or characterization onsite. Need to determine how and where the size distribution would be characterized (e.g., onsite or in laboratory). NDOT geotechnical engineers should be consulted.
4. ROW – Need to review ownership and easements and obtain permission for access and operations.
5. Environmental – Need site review by NDOT Environmental Services Division. Dewatering should not be necessary and encroachment into the surface water can likely be avoided.
6. Renting clean equipment may be necessary.

Mayberry Bridge

1. Access to the northwest bank from the sewer access road off of Mayberry Drive appears to be feasible. Some earthwork would be required to grade an access to the riverbank, but appears to be minimal.
2. Some vegetation would be disturbed at the riverbank.
3. Digging a 12-foot deep hole appears to be feasible, casting the soil to a clear spot under the bridge for bagging or characterization onsite. Need to determine how and where the size distribution would be characterized (e.g., onsite or in laboratory). NDOT geotechnical engineers should be consulted.
4. ROW – Need to review ownership and easements and obtain permission for access and operations.
5. Environmental – Need site review by NDOT Environmental Services Division. Dewatering should not be necessary and encroachment into the surface water can likely be avoided.
6. Renting clean equipment may be necessary.

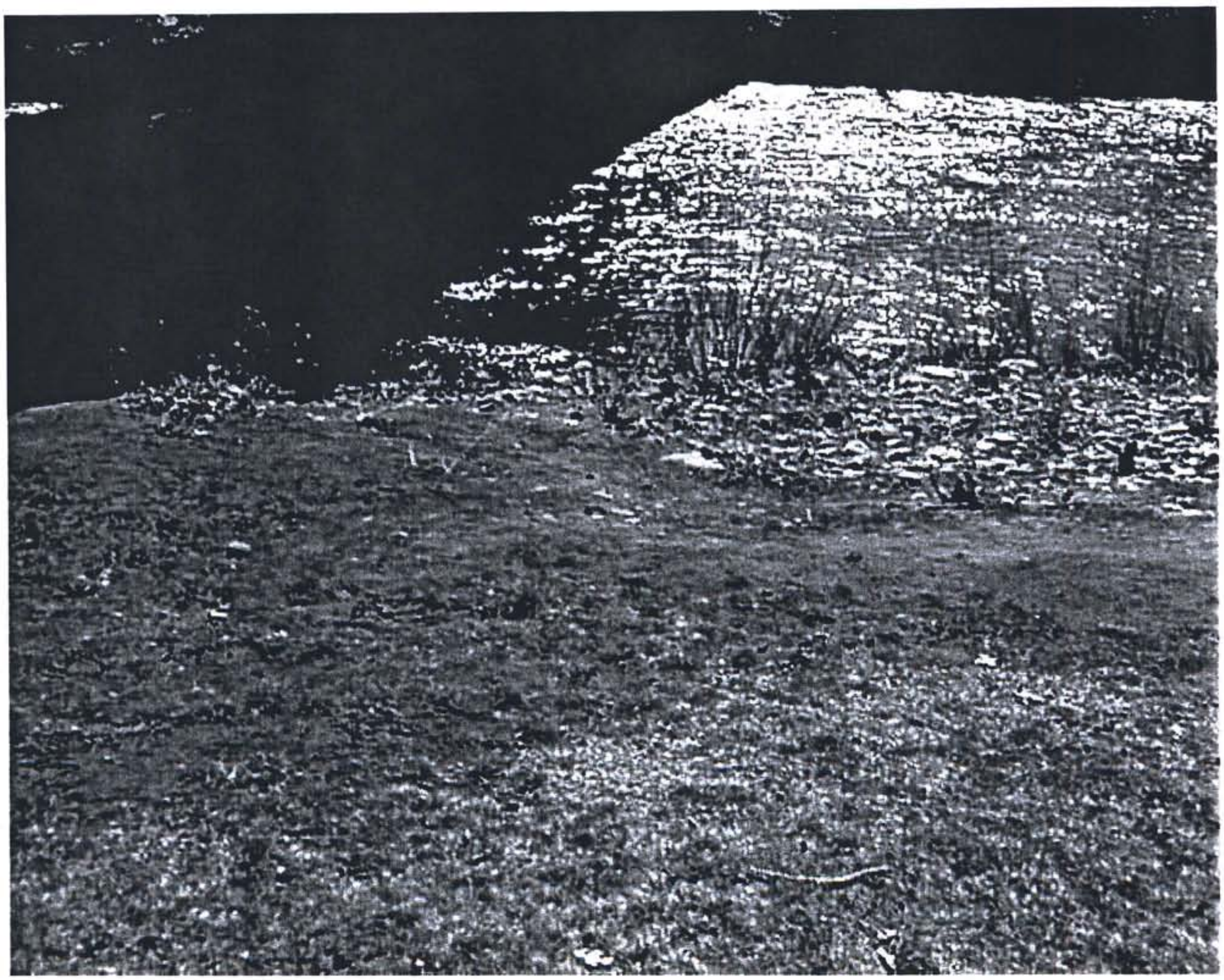
Kietzke Bridge, north bank looking north at possible equipment access. (parking lot for fishermans park)



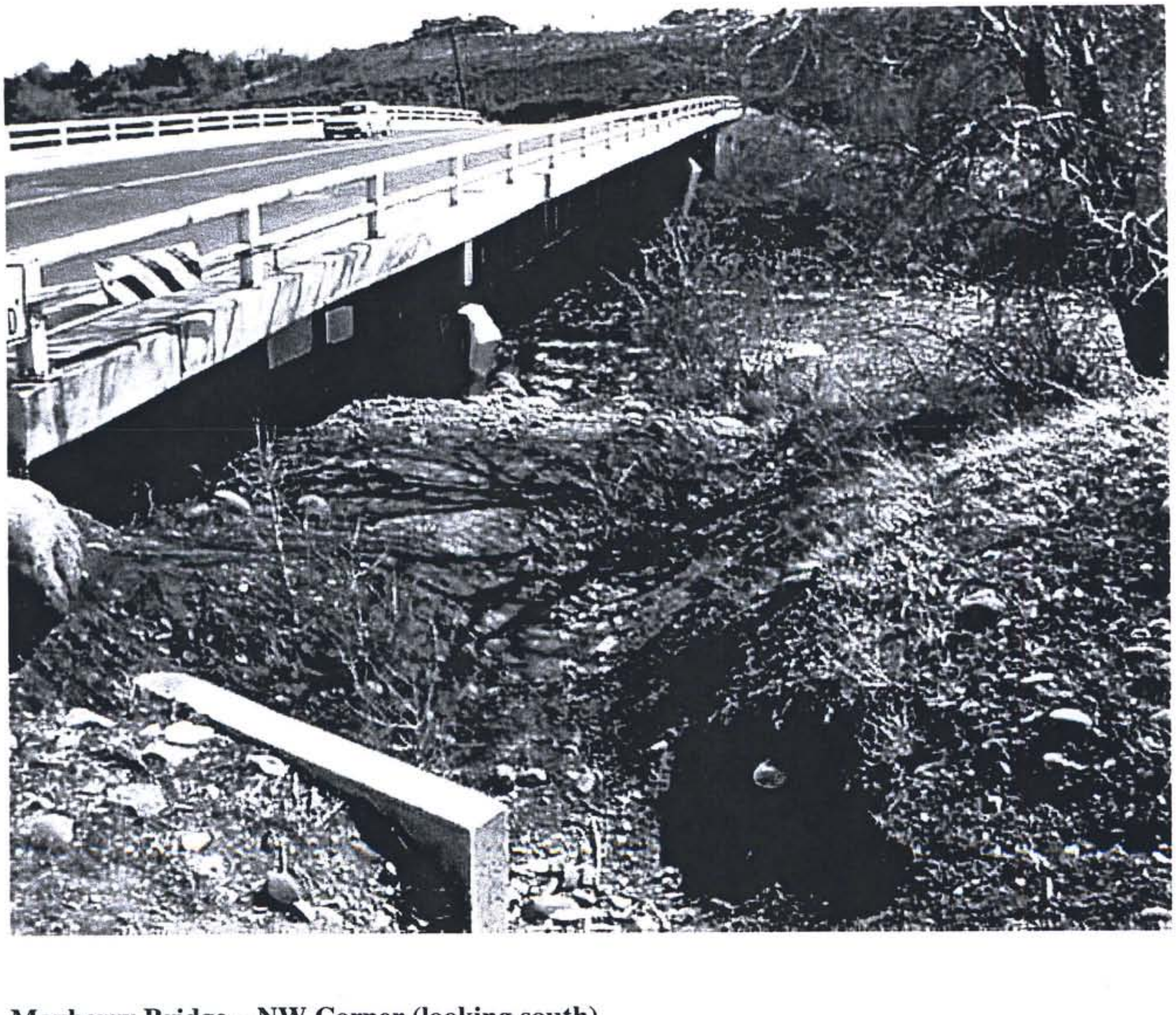
Kietzke bridge north bank looking across and downstream at piers for upstream bridge.

Kuenzli bridge from west bank looking east.

Keystone Bridge – NW Corner (looking north)



Keystone Bridge – NW Corner (looking south)



Mayberry Bridge – NW Corner (looking south)

Mayberry Bridge – NW Corner (looking north)

APPENDICES

Appendix A – Channel Cross Section Data from Field Surveys

Appendix B – Sample of Predicted Scour Depth Calculations

Appendix C – Scour Instrumentation Summary

Appendix A

Channel Cross Section
Data from Field Surveys

NDOT Keitzke Bridge B-578 S
Cross Section 1 Across Bridge

Station (ft)	Depth, d (ft)	Water Elev (ft)	Bed Elev (ft)	COMMENTS
0	na			north post
3	0.0		0.0	
5	0.0		0.0	
10	0.0		0.0	north edge of water
15	1.9		-1.9	
20	3.5		-3.5	
25	4.0		-4.0	pier-north side
30	4.7		-4.7	pier-south side
35	4.3		-4.3	
40	3.5		-3.5	
45	2.7		-2.7	
50	3.4		-3.4	
55	1.4		-1.4	
60	1.7		-1.7	
65	2.4		-2.4	
70	2.2		-2.2	
73	0.0		0.0	south edge of water
80	0.0		0.0	
85	0.0		0.0	
90	0.0		0.0	
95	0.0		0.0	
100	0.0		0.0	
105	0.0		0.0	
110	0.0		0.0	
115	0.0		0.0	
120	0.0		0.0	
125	0.0		0.0	

NDOT Kuenzli Bridge B-1327 W
Cross Section South Side of Bridge

Benchmark top west side metal post = 100.0

Water Elev. = 94.37

Station (ft)	Depth, d (ft)	Water Elev (ft)	Bed Elev (ft)	COMMENTS
0	na			metal post west side
9	0.0	94.4	94.4	west edge of water
14	1.3	94.4	93.1	
19	1.4	94.4	93.0	
25	1.9	94.4	92.5	
30	2.5	94.4	91.9	
35	1.6	94.4	92.8	
40	1.8	94.4	92.6	
44	1.9	94.4	92.5	
48	2.2	94.4	92.2	
50	2.1	94.4	92.3	
55	2.3	94.4	92.1	
60	2.3	94.4	92.1	
65	3.4	94.4	91.0	
70	3.7	94.4	90.7	pier
74	2.4	94.4	92.0	
81	2.3	94.4	92.1	no reading beyond this station due to cable too short
85	na			
90	na			
95	na			
100	na			

NDOT 395 Bridge B-1234
Cross Section West Edge Bridge

Bench: Top of steel reference post = 100.00

Water elev= 93.38

Station (ft)	Depth, d (ft)	Water Elev (ft)	Bed Elev (ft)	COMMENTS
0	na			north post
5	0.0	93.4	93.4	north edge of water
10	1.5	93.4	91.9	assumed depth
15	2.0	93.4	91.4	assumed depth
20	2.2	93.4	91.2	assumed depth
25	2.2	93.4	91.2	assumed depth
30	2.2	93.4	91.2	assumed depth
35	2.2	93.4	91.2	assumed depth
40	2.2	93.4	91.2	assumed depth
45	2.2	93.4	91.2	assumed depth
50	2.2	93.4	91.2	assumed depth
55	2.2	93.4	91.2	
60	2.2	93.4	91.2	
65	2.1	93.4	91.3	
70	2.2	93.4	91.2	
75	2.4	93.4	91.0	
80	2.4	93.4	91.0	
82	2.4	93.4	91.0	north edge of pier
85	2.6	93.4	90.8	center of pier
90	2.5	93.4	90.9	south edge of pier
95	2.7	93.4	90.7	
100	3.4	93.4	90.0	
105	4.0	93.4	89.4	
110	3.5	93.4	89.9	
115	3.2	93.4	90.2	
120	2.1	93.4	91.3	
125	1.8	93.4	91.6	
129	0.0	93.4	93.4	south edge of pier

Appendix B

Sample of Predicted Scour Depth Calculations

PIER SCOUR CALCULATION SHEET

(for worst-case scour conditions)

Bridge: **B578N**

Consultant: ____________ Project # 137081 **Sheet # 1 of 2**

References: FHWA's HEC-18 (fourth edition)

Project Name: NDOT Bridge Scour Evaluation - Level 2 Analysis

Engineer: P. Fritchel Checked: ____________ Date: 7/10/01

INPUT DATA

Discharge (Q)	17,550	cfs
Return Interval	NA	yrs.
Overtopping Flow (y/n)	Y	
Maximum Free-Surface Flow (y/n)	Y	
Water Surface Elev.	4452.34	ft.
Thalweg Elevation (before long-term scour)	4430.77	ft.
Max. Depth of Flow (Ym)	21.57	ft.
or, Ym =	6.58	m
Contraction Scour Depth	0.0	ft.
Long-Term Scour Depth	0.0	ft.

Hydraulics Source: HEC-RAS

Bed Material:

D50	0.480	ft. =	0.146	m
D90	0.880	ft. =	0.268	m
Angle of Repose	26.6	degrees		

Flow Tube:

Left Sta.	Rt. Sta.	Width (T)	
NA due to pier in the tube			ft.

Flow Area (A)	111.49	ft^2
Max. Velocity (Vm)	11.71	ft/s
=	3.57	m/s
Avg. Depth in Flow Tube, Da = A/T	21.23	ft.
=	6.47	m
Froude Number for pier scour (Fr)	0.45	= Vm/(Da*g)^0.5

Piers:

Pier Type (enter): Column (Stemwall, Columns, Piles)

Note: pier bent was not treated as a stemwall because the piers in the bent were not in line due to the attack angle of the flow.

Foundation Type (enter): Spread footing (Spread Ftng, Piles, Sheet Piles, Drilled Shaft)

Elev. @ Bottom of Footing = 4422.27 ft.

Elev. @ Min. Tip of Pile = NA ft.

Angle of Attack (theta) = 0 (15 degree min. for stemwall piers if there is potential channel meandering)

Pier Width (Wp) = 3.7 ft. = 1.12 m

Number of Columns/Piles per bent: 2

Dist. Between Columns = NA ft. (if clear space is <16 ft or 5 pier diameters (whichever is less) treat as a stemwall)

Debris Blockout (Wd) = 4 ft. (Based on debris potential; light = 2 ft., moderate = 3 ft., heavy = 4 ft.;
Note: W in HEC-18 is for debris width on one side of pier so W = Wd/2)

Length of Pier (L) = 3.7 ft.

PIER SCOUR CALCULATION SHEET
(for worst-case scour conditions)

Bridge: **B578N**

Consultant: **CH2M HILL** Project # **137081** **Sheet # 2 of 2**

References: **FHWA's HEC-18 (fourth edition)**

Project Name: **NDOT Bridge Scour Evaluation - Level 2 Analysis**

Engineer: **P. Fritchel** Checked: ____ Date: **7/10/01**

PIER SCOUR CALCULATIONS

Effective Pier Length (L') = 3.7 ft., L' = L or 12*Wp whichever is less.

Nose width = Wp*cos(theta)+Wd = 7.67 Skewed width = Wp*cos(theta)+Wd/2+L'sin(theta) = 5.67

Effective Pier Width (a) = 7.67 ft. (The greater of either the nose width or the skewed width)
= 2.34 m

K1 = 1.1 Correction factor for pier nose shape, see below.

K1 Decision:	Nose-width governs	Skewed-width governs
no debris on pier:	see HEC-18	1.0
debris on pier:	1.1	1.0

K2 = 1.0 (For stemwall, multiple column, and single column piers K2=1.0)

K3, Coefficient for bed condition = 1.1

K4 :

Vc50 = 4.5 m/s
Vc90 = 5.5 m/s

Vc = 6.19*Y^(1/6)*D50^(1/3)
Y = avg. depth in flow tube, Da, m
Dc in meters

Vi 50 2.58 m/s Vi 90 = 3.3 m/s

Calculated VR = 0.8
Use 0.830

K4 = 0.40 if K4<0.40 use 0.40

Colorado State University Equation (HEC-18)

$$Y_s = Y_m 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_m}\right)^{0.65} Fr^{0.43}$$

Depth of Pier Scour, Ys = 2.3 m
= 7.5 ft.

Ratio, Ys/effective pier width = 1.0

Scour Hole Width at Bottom = 0.0 m
= 0.0 ft.

Distance from Edge of Top of Scour Hole to Pier Face = 4.6 m
= 15.1 ft.

Please Note:
The above calculations are for the maximum free-surface discharge at this bridge. Pressure flow occurs for greater flows and may substantially increase scour depths in these cases.

SCOUR VULNERABILITY - LEVEL 1 BRIDGES
(for worst-case scour conditions)

Bridge: **B578N**

Consultant: ______________ Project # 137081 **Sheet # 1 of 1**

Project Name: NDOT Bridge Scour Evaluation - Level 2 Analysis

Engineer: P. Fritchel Checked: ______________ Date: 7/10/01

Pier Type (enter): Column

Foundation Type (enter): Spread footing

Thalweg Elevation (before long-term scour)	4430.77	ft.
- Contraction + Long-Term Scour Depth =	0.00	ft.
Thalweg Elevation (after Cont + L-T scour)	4430.77	ft.
- Depth of Pier Scour =	7.55	ft.
Elev. @ Btm of Scour Hole =	4423.22	ft.
Scour Hole Top Radius =	15.1	ft.
(Sum of Scours =	7.55	ft.)

Elev. @ Bottom of Footing =	4422.27	ft.
Elev. @ Min. Tip of Pile =	NA	ft.
Pile Length =	0.0	ft.
Pile Length Unsupported =	0.0	ft.
Allowable Unsupported Length =	0.0	ft.
Pile Length Embedded =	0.0	ft.

Please Note:
The above calculations are for the maximum free-surface discharge at this bridge. Pressure flow occurs for greater flows and may substantially increase scour depths in these cases.

Is Bridge Scour Critical? **Yes**

If Yes, Why (per criteria)? **Scour within limits of footing**
Conduct foundation structural analysis

NBI 113 Code = 3
(Case: B)

B578N(newK4) *8/1/01*

RIPRAP: MINIMUM RECOMMENDED ABUTMENT PROTECTION SIZE

Bridge: **B578N**

Consultant: ______ Project # 137081 **Sheet # 1 of 1**

References: FHWA's HEC-18 (fourth edition)

Project Name: NDOT Bridge Scour Evaluation - Level 2 Analysis

Engineer: P. Fritchel Checked: ______ Date: 7/10/01

HYDROLOGIC/HYDRAULIC PARAMETERS

Cross-section ID	324		Hydraulics Source	HEC-RAS	
Discharge (Q)	17,550	cfs	Flow Top Width (T)	182.25	ft.
Return Interval	NA	yrs.	Flow Area (A)	2836.11	ft^2
Water Surface Elev.	4453.26	ft.	Avg. Depth, Da = A/T	15.56	ft.
Thalweg Elevation	4432.67	ft.	=	4.74	m
Max. Depth of Flow (Ym)	20.59	ft.	Avg. Velocity (Va=Q/A)	6.19	ft/sec
=	6.28	m	=	1.89	m/s
			Froude Number (Fr)	0.28	Va/(Da*g)^0.5

ABUTMENT PARAMETERS

Abutment Type: 1
(1=spill-through, 2=vertical wall)

Specific Gravity, Ss, (assumed): 2.65

Existing D50 (ft.) or countermeasure:
- Left Bank: 2 ft. and slope paving
- Right Bank: Slope paving

Set-Back Ratio:
- Left Bank: < 5
- Right Bank: < 5

RIPRAP SIZING CALCULATIONS

Coeff. K = 0.89

Recommended D50* = 0.20 m
= 0.64 ft.

Does Existing Meet Requirements?
- Left Bank: Y Paving is being undermined
- Right Bank: NA Paving is being undermined

* Note: D50 = Ym*(K/(Ss-1))*(Va^2/(9.81*Ym))

*Note: Flow depth, y, in D50 equation is the maximum depth.
Calculations performed using metric input converted from the data that was in English units

B578N(newK4) *8/1/01*

PIER SCOUR CALCULATION SHEET

(for worst-case scour conditions)

Bridge: **B578N**

Consultant: **CH2M HILL** Project # **137081** **Sheet # 1 of 2**

References: **FHWA's HEC-18 (third edition)**

Project Name: **NDOT Bridge Scour Evaluation - Level 2 Analysis**

Engineer: **H. Allen** Checked: ________ Date: **2/6/97**

INPUT DATA

Discharge (Q) **17,550** cfs
Return Interval **NA** yrs.
Overtopping Flow (y/n) **Y**
Maximum Free-Surface Flow (y/n) **Y**

Water Surface Elev. **4452.34** ft.
Thalweg Elevation (before long-term scour) **4430.77** ft.
Max. Depth of Flow (Ym) **21.57** ft.
or, Ym = **6.58** m

Contraction Scour Depth **0.0** ft.
Long-Term Scour Depth **0.0** ft.

Hydraulics Source **HEC-RAS**

Bed Material:

D50	0.480	ft. =	0.146	m
D90	0.880	ft. =	0.268	m
Angle of Repose	26.6		degrees	

Flow Tube:

Left Sta. Rt. Sta. Width (T)
NA due to pier in the tube ft.
Flow Area (A) **111.49** ft^2

Max. Velocity (Vm) **11.71** ft/s
= **3.57** m/s
Avg. Depth in Flow Tube, Da = A/T **21.23** ft.
= **6.47** m
Froude Number for pier scour (Fr) **0.45** = Vm/(Da*g)^0.5

Piers:

Pier Type (enter): **Column** (Stemwall, Columns, Piles)

Note: pier bent was not treated as a stemwall because the piers in the bent were not in line due to the attack angle of the flow.

Foundation Type (enter): **Spread footing** (Spread Ftng, Piles, Sheet Piles, Drilled Shaft)

Elev. @ Bottom of Footing = **4422.27** ft.
Elev. @ Min. Tip of Pile = **NA** ft.

Angle of Attack (theta) = **0** (15 degree min. for stemwall piers if there is potential channel meandering)

Pier Width (Wp) = **3.7** ft.
= **1.12** m

Number of Columns/Piles per bent: **2**

Dist. Between Columns = **NA** ft. (if clear space is <16 ft or 5 pier diameters (whichever is less) treat as a stemwall)

Debris Blockout (Wd) = **4** ft. (Based on debris potential; light = 2 ft., moderate = 3 ft., heavy = 4 ft.;
Note: W in HEC-18 is for debris width on one side of pier so W = Wd/2)

Length of Pier (L) = **3.7** ft.

PIER SCOUR CALCULATION SHEET

(for worst-case scour conditions)

Bridge: **B578N**

Consultant: **CH2M HILL** Project # **137081** **Sheet # 2 of 2**

References: **FHWA's HEC-18 (third edition)**

Project Name: **NDOT Bridge Scour Evaluation - Level 2 Analysis**

Engineer: **H. Allen** Checked: ______ Date: **2/6/97**

PIER SCOUR CALCULATIONS

Effective Pier Length (L') = **3.7** ft., L' = L or 12*Wp whichever is less.

Nose width = Wp*cos(theta)+Wd = **7.67** Skewed width = Wp*cos(theta)+Wd/2+L'sin(theta) = **5.67**

Effective Pier Width (a) = **7.67** ft. (The greater of either the nose width or the skewed width)
= **2.34** m

K1 = **1.1** Correction factor for pier nose shape, see below.

K1 Decision:	Nose-width governs	Skewed-width governs
no debris on pier:	see HEC-18	1.0
debris on pier:	1.1	1.0

K2 = **1.0** (For stemwall, multiple column, and single column piers K2=1.0)

K3, Coefficient for bed condition = **1.1**

K4 :

Vc50 = 4.5 m/s
Vc90 = 5.5 m/s

Vc = 6.19*Y^(1/6)*D50^(1/3)
Y = avg. depth in flow tube, Da, m
Dc in meters

Vi = 2.6 m/s
Calculated VR = 0.3
Use **0.345**

K4 = **0.79**

Colorado State University Equation (HEC-18)

$$Y_s = Y_m 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{Y_m}\right)^{0.65} Fr^{0.43}$$

Depth of Pier Scour, Ys = **4.5** m
= **14.8** ft.

Ratio, Ys/effective pier width = **1.9**

Scour Hole Width at Bottom = **0.0** m
= **0.0** ft.

Distance from Edge of Top of Scour Hole to Pier Face = **9.0** m
= **29.6** ft.

Please Note:
The above calculations are for the maximum free-surface discharge at this bridge. Pressure flow occurs for greater flows and may substantially increase scour depths in these cases.

SCOUR VULNERABILITY - LEVEL 1 BRIDGES
(for worst-case scour conditions)

Bridge: **B578N**

Consultant: **CH2M HILL** Project # **137081** **Sheet # 1 of 1**

Project Name: **NDOT Bridge Scour Evaluation - Level 2 Analysis**

Engineer: **H. Allen** Checked: ____________ Date: **2/6/97**

Pier Type (enter): **Column**

Foundation Type (enter): **Spread footing**

Thalweg Elevation (before long-term scour)	**4430.77**	ft.
- Contraction + Long-Term Scour Depth =	**0.00**	ft.
Thalweg Elevation (after Cont + L-T scour)	**4430.77**	ft.
- Depth of Pier Scour =	**14.84**	ft.
Elev. @ Btm of Scour Hole =	**4415.93**	ft.
Scour Hole Top Radius =	**29.6**	ft.
(Sum of Scours =	14.84	ft.)

Elev. @ Bottom of Footing =	**4422.27**	ft.
Elev. @ Min. Tip of Pile =	**NA**	ft.
Pile Length =	**0.0**	ft.
Pile Length Unsupported =	**0.0**	ft.
Allowable Unsupported Length =	**0.0**	ft.
Pile Length Embedded =	**0.0**	ft.

Please Note:
The above calculations are for the maximum free-surface discharge at this bridge. Pressure flow occurs for greater flows and may substantially increase scour depths in these cases.

Is Bridge Scour Critical? **Yes**

If Yes, Why (per criteria)? **Scour below footing.**

NBI 113 Code = **3**
(Case: **C**)

RIPRAP: MINIMUM RECOMMENDED ABUTMENT PROTECTION SIZE

Bridge: **B578N**

Consultant: **CH2M HILL** Project # **137081** **Sheet # 1 of 1**

References: **FHWA's HEC-18 (third edition)**

Project Name: **NDOT Bridge Scour Evaluation - Level 2 Analysis**

Engineer: **H. Allen** Checked: ________ Date: **2/6/97**

HYDROLOGIC/HYDRAULIC PARAMETERS

Cross-section ID	324		Hydraulics Source	HEC-RAS	
Discharge (Q)	17,550	cfs	Flow Top Width (T)	182.25	ft.
Return Interval	NA	yrs.	Flow Area (A)	2836.11	ft^2
Water Surface Elev.	4453.26	ft.	Avg. Depth, Da = A/T	15.56	ft.
Thalweg Elevation	4432.67	ft.	=	4.74	m
Max. Depth of Flow (Ym)	20.59	ft.	Avg. Velocity (Va=Q/A)	6.19	ft/sec
=	6.28	m	=	1.89	m/s
			Froude Number (Fr)	0.28	Va/(Da*g)^0.5

ABUTMENT PARAMETERS

Abutment Type: **1**
(1=spill-through, 2=vertical wall)

Specific Gravity, Ss, (assumed): **2.65**

Existing D50 (ft.) or countermeasure:
- Left Bank: **2 ft. and slope paving**
- Right Bank: **Slope paving**

Set-Back Ratio:
- Left Bank: **<** 5
- Right Bank: **<** 5

RIPRAP SIZING CALCULATIONS

Coeff. K = **0.89**

Recommended D50* = **0.20** m
= **0.64** ft.

Does Existing Meet Requirements?
- Left Bank: **Y** **Paving is being undermined**
- Right Bank: **NA** **Paving is being undermined**

* Note: D50 = Ym*(K/(Ss-1))*(Va^2/(9.81*Ym))

*Note: Flow depth, y, in D50 equation is the maximum depth.
Calculations performed using metric input converted from the data that was in English units

Appendix C

Comparison of Scour Monitoring Devices, Equipment Costs, and Installation Costs

Table 2. Comparison of Devices Tested with Mandatory and Desirable Criteria (from NCHRP Report 396 by Lagasse *et al.* (1997))

	Mandatory Criteria								Desirable Criteria								
	1a	1b	1c	1d	2	3a	3b	4	5	6	7a	7b	8	9	10	11	12
Device	Install on or near Vert. Pier	Install on or near Sloping Piers or Piers w/Footings	Install on or near Vert. Abut.	Install on or near Spill-thru Abut.	Measure Scour to ± 1'	Read from Above Water Line	Remote Data Collection	Operable During Floods	Ease of Installation	Range of Discharges	Withstand Ice and Surface Debris Impact	Obtain Scour Data with Ice/Debris	Low Cost	Vandal Resistant	Operation and Maintenance	Reliability	Unknown Foundation or Sub-Surface Condition
Sounding Rod	G	F	G	P	G	G	P	G	F	G	G	F	F	F	G	P	F
Sliding Collar																	
Manual	G	G	G	P	G	G	NA	G	G	G	F	F	G	G	G	G	F
Automated	G	G	G	G	G	G	G	G	G	G	G	G	G	F	G	G	F
Low-Cost Sonar	G	G	G	F	G	G	G	G	G	G	G	P	G	F	G	G	G
Piezo Electric Driven Rod	G	G	G	U	G	G	G	G	U	G	G	G	U	F	U	U	F

G = Good
F = Fair
P = Poor
U = Unknown at present
NA = Not Applicable

Table 3. Equipment Costs Assuming Basic Level of Functionality and Assumed Level of Research and Development (from NCHRP Report 396 by Lagasse *et al.* (1997))

Approximate Equipment Costs @ BLF and ALRD for Cost Comparison								
Device Type Installation Method	Basic Instrument	Mounting Hardware	Power Supply	Cable	Datalogger	Shelter/ Enclosure	Total Equipment Costs	Remarks
Brisco (NCHRP)	5,000	600	300	N/A	2,100	200	8,200	Using third party datalogger
Sonic Fathometers								
Eagle DDS-1 (USGS)	500	400	300	100	2,500	200	4,000	Using existing USGS gage shelter . Operating off batteries
Eagle Z9500 (NCHRP)	500	1,000	300	Incl.	2,000	200	4,000	Continuous Power Supply Datalogger Interface
Data Sonics (USGS)	3,000	700	500	Incl.	2,000	200	6,400	Complete integrated system, system costs reduced to consider datalogging only
Magnetic Sliding Collar (Manual)	2,000	500	N/A	N/A	N/A	N/A	2,500	Basic instrument cost for ALRD
Magnetic Sliding Collar (Automated)	2,000	N/A	300	100	1,500	200	4,100	Basic instrument cost for ALRD
Driven Rod								
Piezoelectric	3,000	N/A	300	100	1,500	200	5,100	Estimated basic instrument cost for ALRD
Tip Switch	2,500	N/A	300	100	1,500	200	4,600	Estimated basic instrument cost for ALRD

Table 4. Estimated Installation Cost for Scour Measuring Systems (from NCHRP Report 396 by Lagasse *et al.* (1997))

Estimated Installation Costs Less Traffic Control									
Device Type	Estimated Crew Size	Estimated Days to Install	Estimated Man Days		Labor Costs (@$500/Man Day)		Special and Heavy Equip. Costs	Total ($)	Remarks
			Min	Max	Min ($)	Max ($)			
Sounding Rod									
Brisco	4	1-2	4	8	2,000	4,000	3,000	5,000 to 7,000	Crane/hoist, power drill in concrete special workers platform
Sonic Fathometers									
Eagle DDS-1 (USGS)	4	2-3	8	12	4,000	6,000	1,000	5,000 to 7,000	Hydraulic lift required 400/day x 2.5 days
Eagle Z9500 (NCHRP	4	1	4	4	2,000	2,000	500	2,500	Small front-end loader, simple installation
Data - Sonics (USGS	4	2-3	8	12	4,000	6,000	1,000	5,000 to 7,000	Hydraulic lift required
Magnetic Sliding Collar (Manual and Automated)	4	1	4	4	2,000	2,000	1,500	3,500	Hydraulic lift required
Other Driven Rod Devices									
Driven	4	1-2	4	8	2,000	4,000	1,000	3,000 to 5,000	Vibratory driver and crew/2 days
Augered	4	1-2	4	8	2,000	4,000	1,600	3,600 to 5,600	Auger - 2 days includes crew

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