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Bridge Scour Evaluation: Screening, Analysis, & Countermeasures



Bridge Scour Evaluation: Screening, Analysis, & Countermeasures

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INTRODUCTION

Scour, defined as “the erosion or removal of streambed or bank material from bridge foundations due to flowing water” is the most common cause of highway bridge failures in the United States. The Forest Service, U.S. Department of Agriculture, administers 7,650 bridges on National Forest lands and virtually all of them are over water. Scour is also the single most common cause for bridge damage and failure on National Forest lands (Figure 1). Many bridges will experience floods which can cause damage each year. To minimize future bridge flood damage and ensure public safety requires developing and implementing improved procedures for designing bridges and inspecting them for scour. “Every bridge over water, should be assessed as to its vulnerability to scour in order to determine the prudent measures to be taken for that bridge and the entire inventory” (Richardson and Davis 1995).

Realizing this need, the Federal Highway Administration (FHWA) issued a Technical Advisory in 1988 revising the National Bridge Inspection Standards (NBIS) to require evaluation of all bridges for susceptibility to damage resulting from scour. In accordance with the Memorandum of Understanding between the Forest Service and the Federal Highway Administration, the Forest Service is required to implement the Technical Advisory, establish a scour evaluation program, and submit reports to FHWA discussing the progress of the evaluation program.

Prior to 1998, the Forest Service had not implemented a scour evaluation program. In 1998, an Engineering Technology Development Proposal was funded to develop a scour evaluation program, specifically for the Forest Service, that all Regions of the Forest Service could implement. The project was to outline a single process and establish criteria, methods, and guidelines that would ensure consistency throughout the agency and eliminate duplication of effort.

The project was completed in cooperation with the Regional Bridge Engineers and was organized into three phases.

- Phase 1. Review the FHWA guidelines and existing public road agency scour programs.
- Phase 2. Develop a scour evaluation program specifically for the Forest Service based on the information from Phase 1.
- Phase 3. Provide support for the program during implementation by the Regions.

This document is the culmination of Phases 1 and 2.

Implementing this process will provide valuable information and initiate pro-active management of our bridge inventories. Managers will be able to prioritize needs and avoid many future bridge problems and failures. In addition, the process will provide valuable training, experience, and tools that will enhance the skills of employees who implement the program. This will benefit many future projects in our role of “Caring For The Land, and Serving People.”



R9800110

Figure 1—Little Salmon River Bridge, Nez Perce National Forest. A January 1997 flood event scoured the abutment and one of the intermediate piers causing failure.

SCOUR EVALUATION REFERENCE STANDARDS

The Technical Advisory issued by FHWA in 1988 provided recommendations for developing and implementing a scour evaluation program. Since that time, FHWA developed two additional documents that have become the reference standards for all scour evaluation programs. These documents are:

1. Hydraulic Engineering Circular No. 18 (HEC-18)
- Evaluating Scour at Bridges. (Richardson and Davis 1995)
2. Hydraulic Engineering Circular No. 20 (HEC-20)
- Stream Stability at Highway Structures. (Lagasse et al. 1995)

HEC-18 is the technical standard for knowledge and practice in the design, evaluation, and inspection of bridges for scour. HEC-20 provides guidelines for identifying stream instability problems at stream crossings that may cause scour damage to bridges or culverts (Figure 2).

The Scour Evaluation Program outlined within this document also uses the two HEC documents as the primary reference standards. Successful implementation of the program will require knowledge, understanding, and use of these references.

FOREST SERVICE SCOUR EVALUATION PROGRAM

The Forest Service Scour Evaluation Program has been developed into a four-step process similar to the five-step process recommended in HEC-18, Chapter 5. The objective of the process is to provide a consistent, efficient method to review and evaluate all bridges over water, determine the scour potential of each bridge, assist in establishing priorities and identifying appropriate countermeasures, and documenting the results. Figure 3 presents a flow chart of the process. The four steps are:

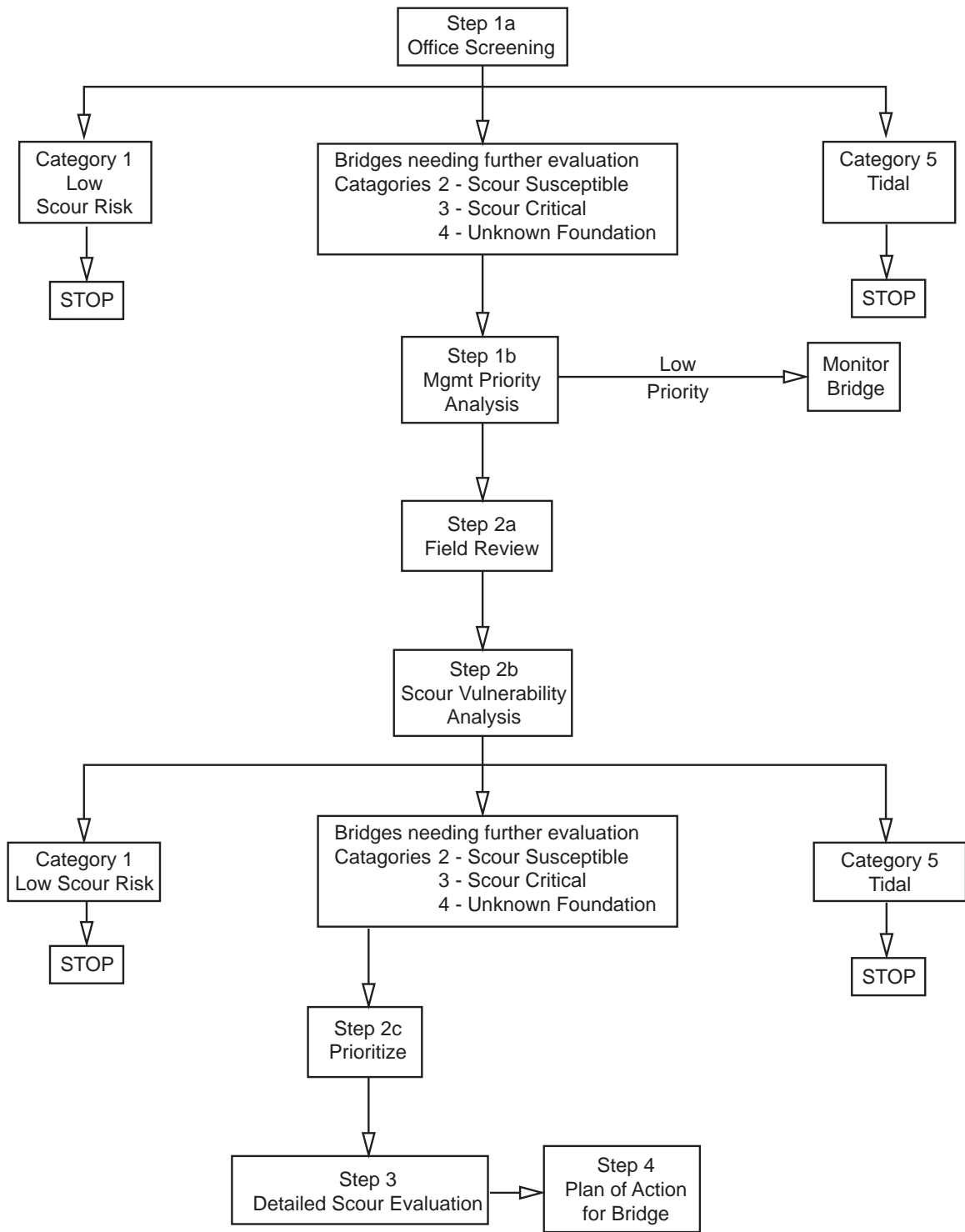
- Step 1 - Office Screening and Management Priority Analysis
- Step 2 - Field Review, Scour Vulnerability Analysis, and Prioritizing.
- Step 3 - Detailed Scour Evaluation.
- Step 4 - Plan of Action.

Each step will be discussed in more detail in the following sections. Within each step of the process, bridges or major culverts are categorized with respect to the determined scour potential. (Categories are discussed under section Step 1) These categories also correspond to the Scour Critical Bridge field on the Structure Inventory and Appraisal form, Item 113. As a bridge proceeds through the evaluation process, a structure may be placed in a different category from the previous step



R9800111

Figure 2—Left - HEC 18, *Evaluating Scour at Bridges*; Center - *An Assessment Methodology for Determining Historical Changes in Mountain Streams*; Right - HEC 20, *Stream Stability at Highway Structures*.



R9800107

Figure 3—Forest Service Scour Evaluation Program Four Step Process.

and the Scour Critical Bridges field code may also change. The process will be complete for a bridge when the coding of the Scour Critical Bridges field on the Structure Inventory and Appraisal form, Item 113, is any value other than code 6, which is "Scour calculation/evaluation has not been made."

Steps 1 and 2 provide guidelines and criteria to efficiently and economically screen as many bridges and major culverts as possible into the appropriate categories, identify proper Scour Critical Bridge codes, and prioritize bridges. Step 3, Detailed Scour Evaluations, requires an experienced interdisciplinary team. In most instances, this team will include technical expertise outside the Forest Service and is anticipated to be expensive. Steps 1 and 2 can be completed by Forest Service personnel or consultants.

All bridges should be first evaluated using Steps 1 and 2 since appropriate countermeasures can often be easily identified before proceeding to Step 3 on many of the single-span, smaller bridges that are rated scour critical.

Required FHWA Reporting

In addition to coding the Scour Critical Bridges field on the Structure Inventory and Appraisal form, Item 113, for each bridge, FHWA requires the Forest Service to submit progress reports outlining the progress of the evaluation program. In Appendix A is an outline of the format of the report and explanations for the different reporting categories. The progress reports are to reflect the number of bridges and the appropriate coding for each bridge.

Documentation and Program Monitoring

Documentation is recommended for each bridge at each step of the process. Recommended documentation methods are described for each step in this report. In addition, INFRAstructure-Bridge and Major Culvert (INFRA-BMC) will remain the database and inventory for all Forest Service bridges and major culverts. Monitoring of each bridge through the scour evaluation process should be possible using INFRA-BMC with a few proposed changes. The proposed changes are as follows:

Revise Scour Critical Bridge, Item 113:

- Add new code "U" for Unknown Foundation.
- Add new code "T" for Tidal.
- Add new code "LP" for Low Priority. (This code will reflect bridges that are identified as low priority in Step 1b - Management Priority Analysis, in the proposed Forest Service scour evaluation process).

Add new field "Scour Vulnerability" to the Appraisal fields. This field will assist in prioritizing the bridges during Step 2c of the scour evaluation process. Proper codes are:

- H High Scour Vulnerability
- M/H Moderate to High Scour Vulnerability
- M Moderate Scour Vulnerability
- M/L Moderate to Low Scour Vulnerability
- L Low Scour Vulnerability
- ND Not Determined

With the revisions to INFRA-BMC proposed, various reports can be generated from the data to assist in monitoring the program process. A supplement to this report will be a standard report to query INFRA-BMC for the data needed to generate FHWA progress reports. Maintaining the proper coding of INFRA-BMC for each bridge during the scour evaluation process should result in adequate monitoring capability.

STEP 1 - OFFICE SCREENING AND MANAGEMENT PRIORITY ANALYSIS

STEP 1A - OFFICE SCREENING

Objective

The objective of Step 1a is to quickly review the current available documents within the bridge or major culvert file and screen them into five categories. As mentioned above, each category has corresponding codes with respect to the Scour Critical Bridge field on the Structure Inventory and Appraisal form, Item 113. It should be noted, that any bridge which has not proceeded to Step 1 in the process, should have a code 6 for the Scour Critical Bridge field (scour calculation/evaluation has not been made). The five categories and corresponding Scour Critical Bridge (Item 113) codes are as follows:

1. Low Scour Risk
Item 113 corresponding codes 4, 5, 7, 8, 9
2. Scour-susceptible
Item 113 corresponding codes 6, LP
3. Scour-critical
Item 113 corresponding codes 0, 1, 2, 3
4. Unknown Foundations
Item 113 corresponding codes U
5. Tidal
Item 113 corresponding codes T

These five categories are the same as recommended in HEC-18, Chapter 5.

Office Screening Flow Chart

Figure 4 provides a flow chart of Step 1 indicating the recommended steps in an office screening and the criteria for placing bridges and major culverts into the five categories. Documents needed are bridge plans and past inspection reports. Below is some discussion on several of the various decision nodes within the flow chart.

Pier/Abut/Ftg in Channel or Floodplain: Plans that indicate all foundations are outside the channel and flood plain and well above flood water elevations can be categorized as Low Scour Risk (Figure 5).

Pier/Abut/Ftg on Scourable Material: Plans that indicate all foundations are on non-scourable material can be categorized as Low Scour Risk. Non-scourable material is considered to be durable rock that is not susceptible to significant deterioration due to weathering and that scours at such a slow rate that changes occur over a long period of time (measured in centuries).

Stream Velocity: "Slow" is generally associated with lakes, tidal zones, or ditches and canals which experience very slow moving, predominately static-flow conditions. All other streams, creeks, and rivers should be considered rapid (Figure 6).

Foundations: The foundation type is a primary influencing factor in determining the vulnerability to scour damage. Deep foundations such as long piles or drilled shafts are considered to have low vulnerability to scour damage and may be placed in the low risk category upon review of the inspection reports, thus eliminating the bridges further from the scour evaluation process. Shallow foundations such as spread footings, short piles, mud sills, or cribs are considered to have high vulnerability to scour and are not recommended to be considered low risk without proceeding to the Field Review, Step 2a. Lengths defining a long pile vs. a short pile have not been provided. Guidance should be provided on a Regional basis, however, in the predominately glacier till soils of the Rocky Mountain States, 15 to 20 feet is being used to distinguish between deep and shallow pile foundations.

Bridges and major culverts are separated prior to reviewing the foundations. Major culverts usually have no foundations or are on shallow spread footings and are not recommended to be considered low risk without proceeding to the Field Review, Step 2a.

Unknown foundations should be placed in the same category as shallow foundations, requiring further review.

Inspection Reports: Prior to placing any structure in Category 1, Low Scour Risk, the inspection reports should be reviewed for indications of past or current scour problems. Scour damage should include not only damage to the structure itself, but also to approach fills. An abutment on a deep foundation may have a low vulnerability to scour damage structurally, but the approach fills may scour away leaving a serious safety hazard even though the bridge itself is not damaged. Specific items in the inspection reports to be reviewed are the Substructure, Channel & Channel Protection, and Waterway Adequacy fields. A numeric code of 5 or less in any of these fields (substructure must be due to observed scour) indicates potential scour problems and those bridges should proceed to the next step of the process. If a bridge has deep foundations, and the inspection reports do not indicate any potential scour problems, the bridges are placed in Category 1, Low Scour Risk and no further review is necessary.

Suggested Responsible Person(s)

The office screening can be completed by Forest Service Bridge Inspection Team Leaders or Program Managers or consultants with assistance from the Regional Bridge Engineer.

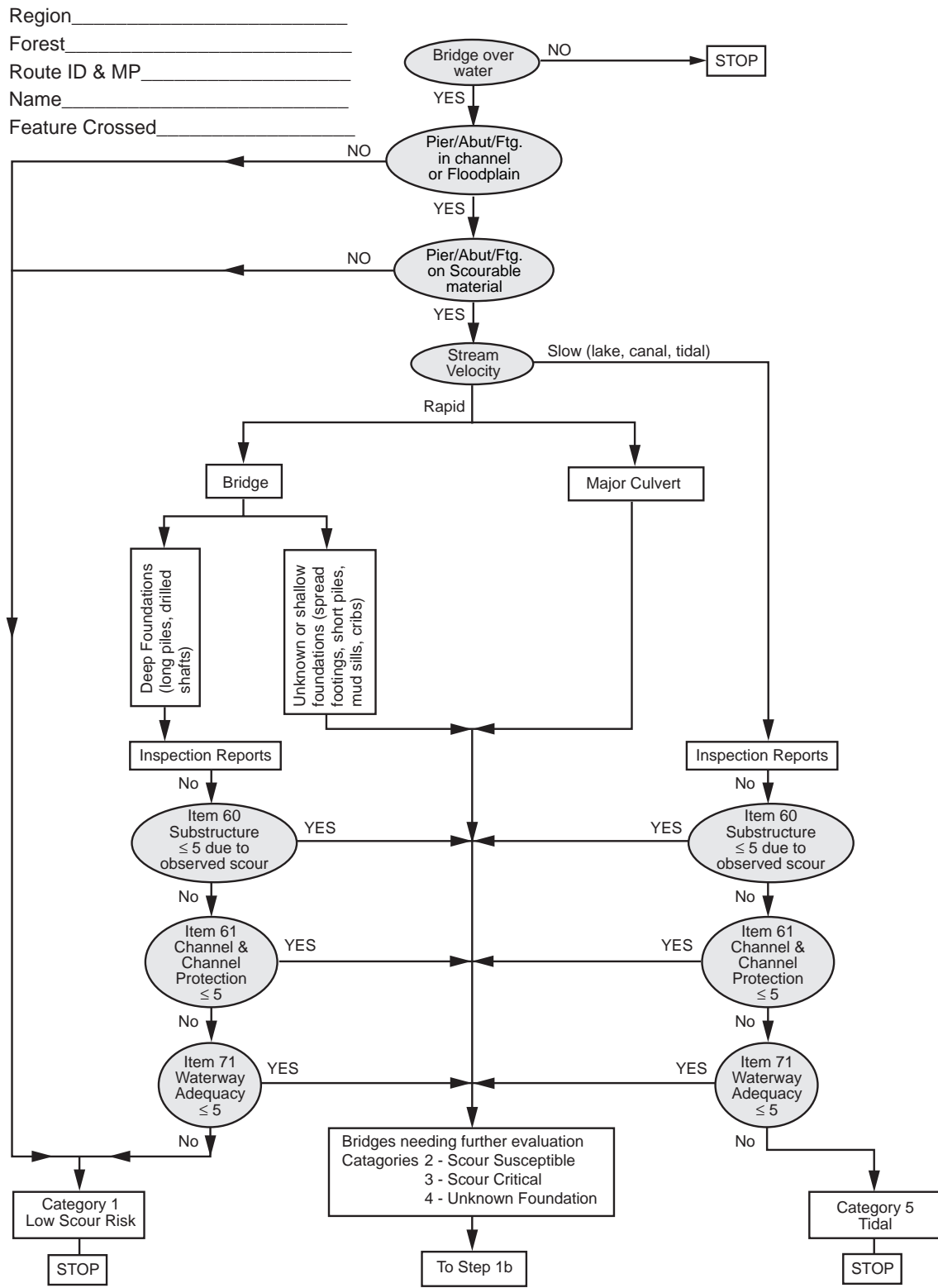
Recommended Documentation

A simple method of documenting the office screening step is to highlight the decisions, path, and ending Category that the bridge was placed in on the Office Screening Flow Chart, Figure 4. A flow chart should be prepared for each individual bridge. Notes could also be written on the flow chart. If electronic documentation is preferred, highlighting, shading, and typed notes can be added to the flow chart indicating the decisions, path, and ending Category that the bridge was placed in.

STEP 1B - MANAGEMENT PRIORITY ANALYSIS

Objective

Realizing that funding and resources for detailed field reviews, scour evaluation studies, and implementing on-site scour countermeasures will be limited, the objective of Step 1b is to recognize that some Forest Service bridges and major culverts will have a much lower priority, regardless of the bridge's scour vulnerability rating. Many Forest Service bridges are



R9800108

Figure 4—Forest Service Scour Evaluation Program -Office Screening Flow Chart. This figure breaks down step 1a from the overall diagram in Figure 3.



R9800112

Figure 5—Libby Creek Bridge, Kootenai National Forest. Bridge footings are set into non-erodible bedrock as well as being outside the channel and well above flood waters. Bridge is categorized as Low Scour Risk.



R9800113

Figure 6—Lake Kootenai Bridge, Kootenai National Forest. Illustration of bridge crossing a body of water with “slow” stream velocities.

behind locked gates, have low traffic volumes, are not vital access routes, are older, or are small bridges with low present-worth values, where scour damage or complete washout would not create significant resource damage. These structures are of low priority and do not economically justify further evaluation or installation of any scour countermeasures. An acceptable mitigation plan for these structures is monitoring after flood events and closure if necessary. Figure 7 outlines a process for Step 1b in which bridges and major culverts that have been screened into Categories 2, 3 or 4 in Step 1a, are quickly evaluated with respect to priority. Structures meeting certain criteria can be considered low priority without further review or evaluation. The action plan for these structures is monitoring.

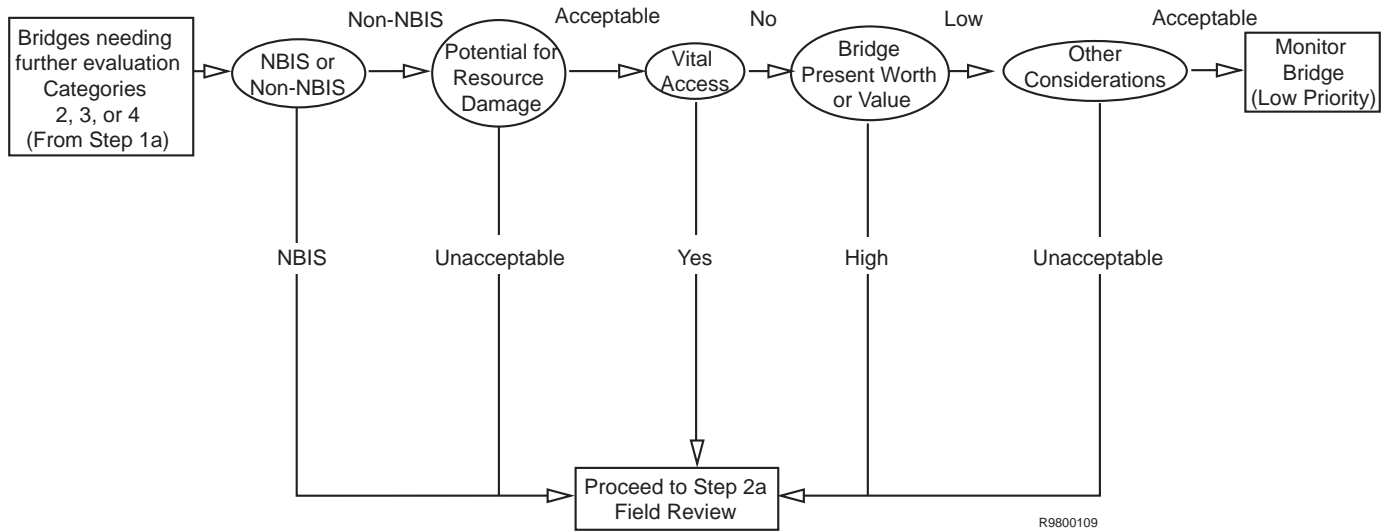
Management Priority Analysis Flow Chart

Figure 7 presents a flow chart of the recommended process and criteria for the Management Priority Analysis. Below is some discussion on several of the various decision nodes within the flow chart.

NBIS vs. Non-NBIS Structure: To evaluate bridges and major culverts with respect to traffic volumes and public use, distinguishing between a NBIS (National Bridge Inspection Standards) or Non-NBIS bridge is recommended. (A NBIS bridge or major culvert is one that is considered “open to public travel” and subject to the National Bridge Inspection Standards). A NBIS structure should remain in the scour evaluation process and proceed to the Field Review of Step 2.

Potential For Resource Damage: The bridge or major culvert should be reviewed for potential to resource damage if significant scour or complete washout occurs. Several possibilities to consider are:

- The amount of sediment that would be added to the creek or river with scour damage. In general, sediment comes from the approach fills, which many times are small; however, major culverts may be buried in high fills that would contribute much more sediment (Figure 8).
- The debris from a bridge or major culvert that may damage other structures below.



Region _____
 Forest _____
 Route ID & MP _____
 Name _____ Completed by _____
 Feature Crossed _____ Date _____

Figure 7—Forest Service Scour Evaluation Program - Management Priority Analysis. This figure breaks down Step 1b from the overall diagram shown in Figure 3.



R9800114

Figure 8—Moss Creek, Idaho Panhandle National Forest. Piping and subsequent scour of this culvert resulted in failure of the entire fill introducing a large amount of sediment into the stream. With Step 1b, Management Priority Analysis, the potential for resource damage at similar sites could be considered as unacceptable.

The potential resource damage should be evaluated as Acceptable or Unacceptable. Structures with unacceptable potential for resource damage should remain in the scour evaluation process and proceed to the Field Review of Step 2.

Vital Access: A bridge or major culvert that may be closed to public travel (Non-NBIS) but is on a vital administrative route and would severely impact access to critical management areas should remain in the scour evaluation process and proceed to the Field Review of Step 2.

Bridge Present Worth / Value: Non-NBIS bridges that are large, in good condition, or can be economically rehabilitated and would have a high replacement cost should remain in the scour evaluation process and proceed to the Field Review of Step 2. However, Non-NBIS bridges that are small, in poor condition, or can not be economically rehabilitated and would have a low replacement cost would be good bridges to rate as low priority and monitor.

Suggested Responsible Person(s)

The Management Priority Analysis should be the responsibility of the Engineering Forest Staff Officer, with assistance from the Forest Bridge Inspection Team Leader or Program Manager, Forest Transportation Planner, and Resource Specialists.

Recommended Documentation

A simple method of documenting the Management Priority Analysis is to highlight the decisions and path for the bridge on the Management Priority Analysis Flow Chart, Figure 7. Notes could also be written on the flow chart. If electronic documentation is preferred, highlighting, shading, and typed notes can be added, indicating the decisions.

STEP 2 - FIELD REVIEW, SCOUR VULNERABILITY ANALYSIS, & PRIORITIZE

The bridges and major culverts placed in Categories 2, 3, and 4 in Step 1a and identified to proceed to Step 2 in Step 1b, may be screened further by completing Field Reviews and Scour Vulnerability Analyses. In addition, bridges are prioritized for further evaluation and/or implementation of scour countermeasures.

STEP 2A - FIELD REVIEW

Objective

The objective of the Field Review is to verify the inspection report information used during Step 1 and to gather additional field data necessary to complete a Scour Vulnerability Analysis. The Field Review is a comprehensive study of current scour problems as well as an analysis of the fluvial geomorphology of the stream.

Suggested Responsible Person(s)

The Field Review can be completed by Forest Service Bridge Inspection Team Leaders, or consultants. With some training, Forest Service Bridge Inspection Team Leaders should be able to gather the information in conjunction with the regularly scheduled bridge inspections.

Recommended Documentation

Documentation of the Field Review will be necessary to provide pertinent information for the Scour Vulnerability Analysis. More information is provided in the Step 2b discussion.

STEP 2B - SCOUR VULNERABILITY ANALYSIS

Objective

With the information provided by the Field Review, bridges and major culverts may be further screened into appropriate categories and proper Scour Critical Bridge field codes. In addition, for many single-span, smaller bridges, the Scour Vulnerability Analysis may be adequate to determine the nature of a scour problem and the appropriate countermeasure or mitigation.

Scour Vulnerability Appraisal

Scour vulnerability is defined as “the degree to which a bridge is open to attack or damage from forces and conditions causing scour.” Scour vulnerability is related to the scour critical codes but are not the same. If appropriate countermeasures are installed, the degree of scour vulnerability will probably decrease. Also, over time, site conditions may change, generating new factors that effect the degree of scour vulnerability. In addition, a bridge’s scour vulnerability will influence a manager’s priority decision. Therefore, a new field in the INFRA-BMC inventory has been proposed that will indicate the degree of scour vulnerability. The codes are:

- H High Scour Vulnerability
- M/H Moderate to High Scour Vulnerability
- M Moderate Scour Vulnerability
- M/L Moderate to Low Scour Vulnerability
- L Low Scour Vulnerability
- ND Not Determined

Available Methodologies

Various scour vulnerability analyses have been used by many other agencies at similar points in their scour evaluation programs. A number of methodologies are available to complete the analysis and to estimate scour potential with limited information and

without completing a full scour evaluation with an interdisciplinary team. Of the methodologies reviewed, a computer program developed by the University of Washington, called CAESAR, is recommended to the Forest Service at this step in the program. A discussion of the CAESAR program and two alternative methodologies follows.

CAESAR

The University of Washington has developed a computer program called Cataloging and Expert Evaluation of Scour Risk and River Stability at Bridge Sites (CAESAR). The program operates in a Windows environment and is structured in a question and answer format. Basic bridge data and Field Review data are required as input. The program outputs weighted recommendations pertaining to scour vulnerability, stream stability, and waterway adequacy. The program has two parts:

1. The user interface, through which site information is collected, stored, and retrieved. Textual and visual (graphs and photographs) help is provided. The Field Review data can be documented and stored within the program.
2. An evaluation module assesses the site conditions and provides recommendations (with confidence values) and suggested actions.

The program has been “beta” tested on several Forest Service bridges and was found to be an efficient and effective tool for completing and documenting the Field Review and Scour Vulnerability Analysis.

Colorado Highway Department Scour Vulnerability Ranking Flow Charts

The Colorado Highway Department developed a series of Scour Vulnerability Ranking Flow Charts as part of their scour evaluation program. The flow charts outline a method to determine a vulnerability score for general site conditions, abutment scour vulnerability, and pier scour vulnerability. The flow charts are not as comprehensive as the CAESAR analysis and do not document the site conditions of the Field Review. Appendix B provides a copy of the flow charts and accompanying documentation.

Rapid-Estimation Method For Assessing Scour at Highway Bridges Based on Limited Site Data

The Montana U.S. Geologic Survey (USGS), in cooperation with the Montana Department of Transportation, developed a methodology for

estimating scour depths that would (1) require only limited on-site data, (2) provide estimates of scour depth that would be reasonably comparable to estimates from more detailed methods and would tend to overestimate rather than underestimate scour depths, and (3) provide estimates for each site in a few hours or less (Holnbeck and Parrett 1997). The method was developed using calculated scour depths from 122 detailed scour evaluations of bridge sites in 10 states and formulating relationships between scour depth and hydraulic variables that can be rapidly measured in the field. "Although the method was developed specifically for bridges in Montana, it is believed to be valid for a wide range of hydrologic and hydraulic conditions throughout the United States" (Holnbeck and Parrett 1997). The method uses a Standardized Scour Analysis and Reporting Form which includes a worksheet for calculating the scour depths and a general summary sheet for general field investigation information.

This method will provide a good assessment of scour vulnerability for a bridge with good documentation. The method will require more time than either the CAESAR program or the Colorado flow charts, good judgement, and a high level of expertise.

Suggested Responsible Person(s)

- The CAESAR program can be used by field personnel with little formal training in river mechanics and scour processes. Forest Service Bridge Inspection Team Leaders, Program Managers, or consultants can complete the Scour Vulnerability Analysis. Completion of a training session in stream stability and bridge scour is recommended.
- Colorado DOT scour vulnerability ranking flow charts should be completed by Forest Service Bridge Inspection Team Leaders, Program Managers, or consultants. Completion of a training session in stream stability and bridge scour is recommended.
- Rapid-Estimation Method For Assessing Scour at Highway Bridges Based on Limited Site Data, developed by USGS, requires a higher degree of expertise than the CAESAR program or the Colorado flow charts. To complete the vulnerability analysis using this method, qualified Forest Service hydraulic or bridge engineers or qualified consultants are recommended.

Recommended Documentation

Documentation will be dependant on the method used. An advantage of the CAESAR program is that the Field Review report and any subsequent Field

Review data can be stored electronically along with the evaluation of the bridge. The proposed new field in INFRA-BMC (Scour Vulnerability) will provide a means for documentation within the bridge inventory.

STEP 2C - PRIORITIZE BRIDGES

Objective

Throughout the scour evaluation process, bridge program managers will need to evaluate available resources, personnel, and the funding required to complete more detailed bridge evaluations and implement countermeasures. Step 1b provides an initial priority screening. At this point in the process, after the Scour Vulnerability Analysis, bridges remaining in Categories 2, 3, and 4, which require more detailed evaluations, need to be prioritized with respect to safety. Safety will be evaluated with respect to the determined scour vulnerability, the functional classification, and the road the bridge resides on, along with National Forest road management policies. Due to the varied road management policies within the National Forests, a strict method for developing a prioritized list is not provided or recommended. Some general guidelines and criteria are suggested.

Priority Guidelines and Criteria

Each National Forest will need to determine how to prioritize and evaluate the safety risks of a bridge. A simple listing of bridges separated between those on arterial, collector, or local roads and sorted by scour vulnerability from high to low will provide managers with a basis to plan for needed resources and prioritize individual bridges for further evaluation. Additional information accompanying the listing, such as the scour critical code, substructure condition code, and average daily traffic (ADT) values may be helpful. A supplement to this document will be a standard report to query INFRA-BMC as described above.

Suggested Responsible Persons

Prioritizing bridges should be the responsibility of the Forest Staff Officer for engineering activities with assistance from the Forest Bridge Inspection Team Leader or Program Manager, Forest Transportation Planner, and Resource Specialists.

STEP 3 - DETAILED SCOUR EVALUATION

Objective

Bridges that have gone through Steps 1 and 2 and remain in Categories 2, 3 and 4 will require a Detailed Scour Evaluation. HEC-18 indicates this

evaluation is to be completed by an interdisciplinary team of hydraulic, geotechnical and structural engineers. The evaluation typically includes a detailed site review, estimated scour calculations, structural evaluation of the foundations under the estimated scour conditions, and the design of any necessary scour countermeasures. In addition, the results of a Detailed Scour Evaluation will subsequently establish proper Scour Critical Bridge field codes for the INFRA-BMC database.

Evaluation Criteria, and Tools

Criteria and guidelines for a Detailed Scour Evaluation are outlined in the reference, HEC-18. FHWA recommends that a bridge be evaluated for the design flood and superflood conditions and have suggested the 500-year flood event.

HEC-18 presents the state-of-the-art in scour calculation methods and equations. There are a number of hydraulic computer programs available for assisting in the calculation of scour depths, such as WSPRO, HEC-RAS, and BRI-STARS. Most of these programs use one-dimensional models and do not have the capability to evaluate lateral flows and channel instabilities or meanders of the stream. Engineers must account for these effects separately, as well as evaluate the structure foundations for instability at the calculated scour depths.

For many streams and rivers, typically associated with mountainous bridge sites of the Forest Service, the evaluation of scour at a site is considered more of an art than a science. At these sites, stream morphology is a significant factor. Also, hydrologic estimates of these mountainous stream flood-event flows can have significant error. Therefore, in addition to the criteria and guidelines outlined in HEC-18 for a Detailed Scour Evaluation, the following is recommended:

- The interdisciplinary team should include a person with expertise in stream morphology such as a Wildland Hydrologist or a Fluvial Geomorphologist to assist in evaluating the potential of scour from lateral stream instabilities, long-term aggregation, or degradation, etc.
- The scour evaluation should envelop estimated scour depths by calculating depths for the 50-year, 100-year, and 500-year flood events and apply engineering judgement to achieve a reasonable and prudent evaluation of the bridge.

Suggested Responsible Person(s)

In most instances, the Detailed Scour Evaluation is recommended to be completed by consultants with the interdisciplinary expertise required. Depending on the Forest or Region the responsible person may be the National Forest Bridge Program Manager, Forest Engineer, or Regional Bridge Engineer.

STEP 4 - PLAN OF ACTION

Objective

The final step in the Forest Service Scour Evaluation Process is to develop a Plan of Action for a bridge to correct scour problems. The Plan of Action is the tool that “closes the loop” from evaluating and studying a bridge, to acknowledging and recognizing a problem, and, finally, to implement field corrective measures. The Plan of Action may include interim scour countermeasures until permanent measures are installed, monitoring plans and/or inspections after flood events, and procedures for closing bridges if necessary.

Suggested Responsible Person(s)

Depending on the Forest or Region, the responsible person to prepare the Plan of Action for a bridge may be the Forest Bridge Program Manager, Forest Engineer, or Regional Bridge Engineer.

Recommended Documentation

A simple Plan of Action form is included in Appendix C. The form is to be completed for each bridge and retained in the bridge file. The form includes:

- Basic bridge identification information.
- The BMC/INFRA Scour Critical field coding.
- The proposed Scour Vulnerability coding with a brief description of the critical elements vulnerable to scour.
- Recommended scour countermeasures and implementation plan. Any design or drawings should be referenced. If scour countermeasures have been completed, some basic information should be included for future reference.
- Bridge Closure Plan. A bridge closure plan should identify the acceptable method of closing the bridge, such as gates or barricades, and any needed detour or safety signing.

TYPICAL FOREST SERVICE BRIDGE

The Forest Service road system is similar in some ways to other public road systems because it includes roads “open to the public” with standards and traffic volumes similar to local county systems.

But the Forest Service road system is also unique because it includes many roads not open to the public, which have reduced standards and very low traffic volumes. Forest Service bridges also reflect this diversity with some major, important, arterial bridges and many small, local road bridges. One objective in developing the Forest Service Scour Evaluation Program was to maintain flexibility in the process so that the wide variety of bridges could be evaluated efficiently with practical results.

The most significant difference in this program, when compared to the programs developed by each state, is Step 1b - Management Priority Analysis. This step recognizes the fact that many Forest Service bridges are of a low priority, regardless of the scour vulnerability of the bridge. The step provides flexibility early in the process to assess priorities and resources needed to complete the program.

Even though there are a wide variety of bridges in the Forest Service, a review of the Forest Service inventory indicates a few basic characteristics of a typical Forest Service bridge (Figure 9).

- Typically a single-span bridge.
- Virtually all cross a stream or river.
- Average span is 50 feet with 80% of the inventory under 80 feet.
- Most common abutment substructure type is vertical walls supported on spread footings or mud sills.
- Bridges are on typically low volume roads with ADT's less than 100.

The majority of Forest Service stream crossings are on mountain streams with channel gradients between 0.01 and 0.10. "Mountain streams are subject to highly variable discharges and are susceptible to large sediment loads from slope failures and debris flows" (Smelser and Schmidt 1998). The streams typically flow between steep forest slopes with incised channels and nearly vertical, non-cohesive banks composed of gravel and cobbles before entering valleys where the streams flow into larger streams and rivers. As the channel gradient drops, stream transport drops, causing aggradation and channel braiding. Meandering, slow moving streams also occur in the large flatter valley bottoms as well as occasionally in higher elevation open parks and swamps. Each of these stream channel types (steep incised, braiding, and meandering) have their own scour problems. Steep incised streams experience long-term degradation, braided streams (occurring at gradient changes) experience aggradation and stream instability, and meandering streams experience lateral channel migration and have very wide flood plains.

Scour associated with typical Forest Service bridges in similar channel types will many times be of similar nature and cause. Therefore, it is also reasonable to assume that there may be common solutions or countermeasures. The following is a discussion of some of the most common problems and characteristics that may be evident on a typical Forest Service bridge.



R9800115

Figure 9—LaMarche Creek Bridge, Beaverhead National Forest. Typical single-span, treated timber bridge supported on vertical wall abutments, with wingwalls, on mudsills crossing a mountainous stream.

COMMON PROBLEMS AND CHARACTERISTICS

Stream Channel Instability

As described above, stream channel instability is a problem most commonly associated with braiding streams. Many Forest Service roads are located adjacent to larger rivers, and thus, many Forest Service bridges cross the tributaries. As described above, many of these tributaries have grade changes as they approach the flood plain of the larger rivers, have braiding characteristics, and experience shifting and lateral migration. Bank erosion and changing angles of attach of the stream to the bridge cause local scour problems.

Bridge Geometry and Scour

Scour depth equations in HEC-18 use a coefficient for abutment shape. The coefficients are (Richardson and Davis 1995):

- Vertical wall abutment 1.00
- Vertical wall abutment with wingwalls 0.82
- Spill-through abutment 0.55

The coefficients indicate that spill-through abutments (trapezoidal-shaped channel through a bridge) decrease local scour depths significantly, compared to vertical wall abutments. Spill through abutments provide a smoother transition through a bridge opening, eliminating abrupt corners that cause turbulent areas. Recent stream mechanics theory suggests that bridge abutments should span outside the “bankfull” stage of the stream, which “corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of the channels” (Rosgen 1996). Flows above the “bankfull” stage are accommodated with adequate freeboard through the bridge or overflow channels. Again, spill-through abutments are more efficient hydraulically at higher flood stages, allowing more area and capacity than a vertical wall abutment (Figure 10).



R9800116

Figure 10—Independence Creek Bridge, Idaho Panhandle National Forest. Example of a spill through (trapezoidal) abutment configuration. See Figure 9 for an example of a vertical wall abutment with wingwalls.

Aggradation

Mountainous streams generally will have variable grades. Many will have steep grades, yet flatten out substantially within a short distance of their confluence with a larger river. Aggradation within this flatter stream section can be a problem as the stream transports bedload off the steeper grades and deposits it as velocities slow along the flatter grades. High flows in a larger river where a smaller tributary joins can cause back-water in the smaller tributary, which can also cause aggradation. Over time, the aggradation may be balanced by isolated storm events which will flush (downgrade) out the tributary stream section. However, in the short term, this aggradation can be a problem to bridges. Continued aggradation can minimize clearance for debris passage, cause overtopping or scour damage to the bridge, and approach roadways (Figure 11).

Long-Term Degradation

Another characteristic of mountainous streams is long-term degradation. Steep, incised channels will experience long-term degradation. When evaluating bridges for scour vulnerability, long-term degradation should be a factor. Many typical Forest Service bridges were built on spread footings with an embedment depth of only a few feet. Today, many of these bridges are of the age in which these footings will be exposed or undermined, mainly due to long-term channel degradation (Figure 12).

Contraction Scour

Contraction scour occurs when a channel narrows and stream velocities increase. Many Forest Service bridge spans are undersized by today's standards and contraction scour is present (Figure 13).

Abutment Scour

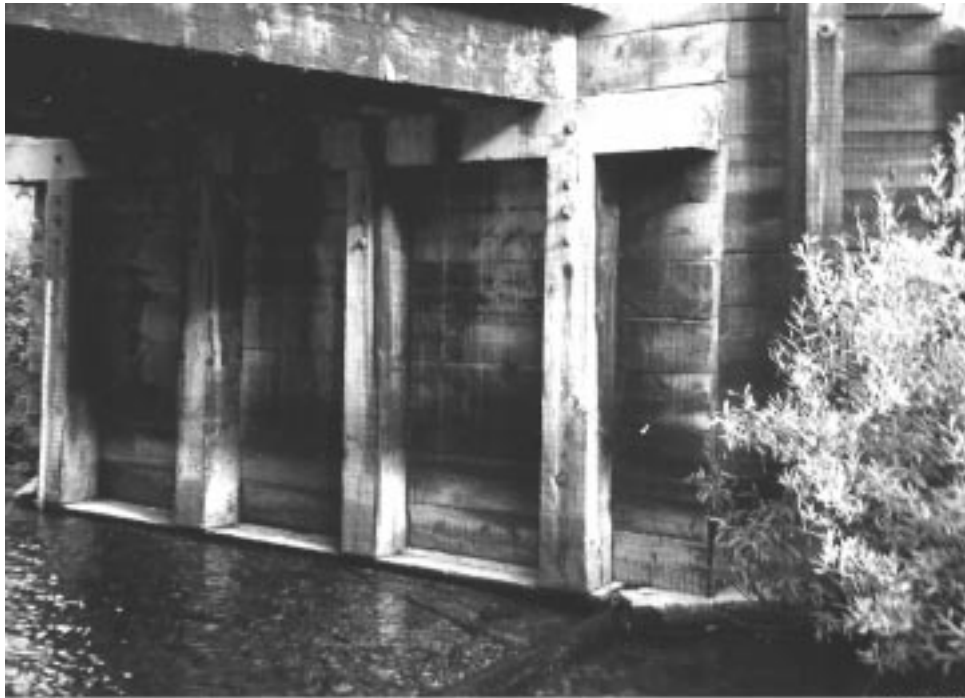
Abutment Scour is commonly termed local scour. Local scour involves removal of material from isolated areas caused by an acceleration of flow past an obstruction and the subsequent turbulent water (vortices). Local scour is accentuated by debris buildup or stream instabilities that shift the stream towards one abutment or change the angle of attack. The most common locations for local scour on a typical Forest Service single-span bridge with vertical wall abutments is adjacent to the upstream and downstream corners intersecting the wingwalls.

HEC-18 provides equations for predicting abutment scour, however, HEC-18 also states that the laboratory research to date has failed to replicate field conditions and these equations generally give excessively conservative estimates of scour depths. Therefore, engineering judgement is required in the use of these equations when evaluating or designing abutment foundations for scour.



R9800115

Figure 11—Eagle Creek Bridge, Idaho Panhandle National Forest. Backwater effects from the main river caused aggradation at the mouth of this tributary and inadequate clearance for the bridge. Note, the following year the tributary flushed and the stream re-established the normal channel depth.



R9800118

Figure 12—Shepherd Creek Bridge, Flathead National Forest. Long-term degradation has exposed the mudsill of this treated timber bridge with vertical wall abutments.



R9800119

Figure 13—Vigilante Bridge, Beaverhead-Deerlodge National Forest. This 40 foot bridge constricts the channel and has caused upstream aggradation and contraction scour through and below the bridge.



R9800120

Figure 14—Irene Bridge over Cascade River, Mt. Baker - Snoqualmie National Forest, Region 6. Drift build-up on upper side of pier.

Debris

Debris can have a significant impact on bridge scour in a number of ways (Figure 14):

- A buildup of debris can reduce a bridge's waterway opening causing contraction scour of the channel.
- A buildup of debris can increase the obstruction area of a pier or abutment and increase local scour.
- Debris can deflect the flow of the water, changing the angle of attack, and increase local scour or shift the entire channel around the bridge altogether.
- Action of water against debris can place a substantial lateral force on the bridge.

In general, debris is associated with many scour problems on a typical Forest Service bridge and must be considered carefully. However, debris problems and the associated scour are difficult to anticipate and remedy on existing bridges. New bridge designs can account for potential debris problems by oversizing spans, providing additional freeboard, and minimizing or eliminating piers in the channel. Typical countermeasures for an existing bridge with a debris problem include:

- Monitoring debris buildup for prompt removal.
- Clearing upstream debris.
- Installing debris catchers/deflectors.

A debris catcher/deflector on mountainous streams requires maintenance and its use must be carefully considered with respect to stream mechanics, since a catcher/deflector could cause the stream channel to shift, resulting in other scour problems.

Abutment Fill Failures

During many flood events, the structure and foundations of the bridge will not be damaged, but the fill behind an abutment will scour (Figure 15). This commonly occurs on a typical Forest Service single-span bridge with vertical wall abutments. Local scour occurs around the wingwalls or undermines the abutment footing and subsequently scours the approach fill away. To a user on the road, an abutment fill failure can be just as hazardous as a bridge failure. For this reason, abutment fill failures due to scour should be included in determining the scour vulnerability of a bridge.



R9800121

Figure 15—Monture Bridge, Lolo National Forest. An example of abutment fill failure with little damage to the bridge.

COMMON COUNTERMEASURES

The Federal Highway Administration saw the need to identify common scour countermeasures and provide guidelines for their use. They recently published HEC-23, Bridge Scour and Stream Instability Countermeasures (Lagasse et al. 1997). HEC-23 provides guidance for scour countermeasure applicability, design, installation, and maintenance, highlighted by a countermeasure matrix. Many of the countermeasures that will apply to typical Forest Service bridges are included.

Riprap

Within HEC-18, riprap is included under Local Scour Armoring. Riprap is, and probably will remain, one of the primary scour countermeasures to resist local scour forces at abutments of typical Forest Service bridges. Riprap is generally abundant, inexpensive, and requires no special equipment. However, proper design and placement is essential. HEC-18 and HEC-23 provide guidelines for proper sizing and placement (Figure 16).

When designing riprap countermeasures, maintaining an adequate hydraulic opening through the bridge must be considered. Many times,

improperly placed riprap will reduce the hydraulic opening significantly and create contraction scour problems.

The use of riprap to protect intermediate piers is now considered only a temporary solution. Again, if placed improperly, riprap can increase local scour forces.

Spur Dikes, Barbs, Groins, Vanes

Spur dikes, barbs, groins and vanes are considered river training structures that alter stream hydraulics to mitigate undesirable erosional and/or depositional conditions. They are commonly used on unstable stream channels to redirect stream flows to a more desirable location through the bridge (Figure 17).

Foundation Strengthening

On a typical Forest Service bridge, foundation strengthening requires extending the footing deeper to offset long-term degradation, providing additional tiebacks on a vertical wall abutment if scour has caused loss of support and the abutments have begun to “kick in,” or installing a new abutment with deeper footings or piles.



R9800122

Figure 16—Monture Bridge, Lolo National Forest. Repair of abutment fill failure and use of riprap as a scour countermeasure.



R9800123

Figure 17—Fisher River Bank Stabilization, Kootenai National Forest. Use of rock vanes to protect the stream bank from scour.

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APPENDICES

APPENDIX A

FHWA Scour Report

REQUIRED FHWA REPORTING

ENCLOSURE A

BRIDGE NEEDING UNDERWATER INSPECTION

REGION

DATE

REPORTING CATEGORIES	NBI CODE	NUMBER OF BRIDGES		TOTAL NUMBER
		NBIS	NON-NBIS*	
In Master List Initial Inspection Completed	92B			
Observed to Have Structural Problems	93B			
Observed to Have Scour Problems	---			
Corrective Actions Completed	---			

* Includes bridges over waterways which are less than 20' in length.

Note 1: The total number of bridges needing underwater inspection is for those bridges requiring special manpower, techniques or equipment for determining the condition of underwater elements with certainty. This total would not include bridges that can be examined from above by wading, probing, or adequate visual inspection.

REQUIRED FHWA REPORTING

ENCLOSURE B

BRIDGES SCOUR EVALUATIONS

REGION

DATE

REPORTING CATEGORIES	NBI ITEM 113 CODE	NUMBER OF BRIDGES		
		NBIS	NON-NBIS*	TOTAL NUMBER
1. Over waterways	---			
2. Evaluation Total	---			
A. Low Risk Total	4,5,7,8,9			
B. Scour Susceptible	6			
C. Unknown Foundations	U			
D. Scour Critical	0 - 3			
E. Tidal	T			
3. Analyzed for Scour	---			
4. Countermeasures Installed	7			
5. Monitoring Planned	---			

NOTE: LOW RISK TOTAL IS INCLUDED ABOVE REPORTING CATEGORIES	NBI ITEM 113 CODE	NUMBER OF BRIDGES		
		NBIS	NON-NBIS	TOTAL NUMBER
2A. Low Risk Total	---			
(1) Calculated or Assessed	4, 5, & 7-9			
(2) Screened	6			
(3) Culverts	8			

* Includes bridges over waterways which are less than 20' in length.

Notes for Enclosures A and B

The following notes are keyed to the National Bridge Inventory (NBI) as documented in the Recording and Coding Guide for the Structure Inventory and Appraisal of the Nations Bridges, December 1995 (metric version). Item numbers and codes are described in the coding guide. Category number refer to the reporting form categories.

CATEGORY EXPLANATION

- 1 Equals sum of bridges with NBI Item 42B, coded 5-9.
- 2 Equals the sum of Categories 2A, 2B, 2C, 2D, and 2E. This sum should also equal Category 1, Over Waterways, when screening is complete. A bridge should be included in only one of the categories under 2.
- 2A Equals the sum of Categories 2A (1), 2A(2) and 2A(3).
- 2A(1) Equals the sum of (a), (b), and (c) described below:
 - (a) bridges assessed during scour screening with code 8 (spread footing on competent rock) code 9 (foundation well above flood elevations)
 - (b) bridges analyzed as stable : codes 4, 5, and 8 and
 - (c) bridges protected by countermeasures, code 7
- 2A(2) Bridges assessed as low risk during scour screening activity, code 6. (These bridges are candidates for scour analysis, but lower priority than category 2B)
- 2A(3) Culverts assessed during scour screening as code 8.
- 2B Bridges assessed during scour screening as requiring scour analysis, code 6
- 2C Bridges assessed with unknown foundations, code 6
- 2D Bridges analyzed as scour critical, codes 0-3
- 3 Total number of bridges that have been analyzed for scour
- 4 Scour critical bridges that have been protected with a structural countermeasure (riprap, paving, etc.)
- 5 Scour critical bridges to be monitored. (structural countermeasures have not been constructed.)
- 4&5 The sum of categories 4 and 5 should equal category 2D, scour critical bridges.

Definitions

- Assessed The structure has been screened for obvious conditions and evaluated using engineering judgement.
- Analyzed The structure has received a full engineering evaluation which includes calculation of hydrology, hydraulics, scour and foundation stability.

APPENDIX B

Scour Vulnerability Ranking Flow Charts taken from:

**Colorado Bridge Safety Assurance
Procedure for Colorado Highway Department**

April 1990

Ref. 1514

Pages 15-24

2. Step Two

Ranking the bridges in each category as to scour vulnerability.

a. Scour Vulnerability Ranking Flow Charts.

The ranking of the scour vulnerability of those bridges determined to be scour susceptible, is obtained by flow charts that evaluate the vulnerability on the basis of the bridges geologic, hydraulic and river conditions as well as the conditions of the bridges foundation (abutments and piers).

The purpose of the Vulnerability Ranking Flow Charts is to provide a procedure to prioritize the list of scour susceptible bridges by determining the relative scour vulnerability of all bridges in each scour susceptibility category. The numerical values included in the flow chart were selected to give the relative effect of each parameter on the potential to produce scour. For example, the river slope/velocity parameter for steep, medium and mild conditions is valued at "2," "1" and "0" respectively because a steep slope will produce deeper scour than a mild slope. The values in each parameter are such that the most scour vulnerable bridge will have the largest value. More than one bridge can have the same value of vulnerability.

The value of the vulnerability ranking is that it orders a bridge relative to other scour vulnerable bridges, and other things being equal (traffic counts for example) determines what bridge should be repaired or replaced first.

The Scour Vulnerability Ranking has three flow charts. They are: 1) General Considerations, 2) Abutments and 3) Piers, which proceed sequentially. It is expected that field evaluation of the bridge will be required to complete the ranking.

b. General Conditions Flow Chart.

The General Conditions Flow Chart addresses parameters that have a general impact on the potential scour depth. The need for intermediate scour countermeasures is included in the flow chart to remind the evaluator to identify this need. No vulnerability ranking value is assigned to this parameter because it is expected that the countermeasures will be implemented before the detailed scour evaluation and installation of remedial measure is complete. The intermediate scour countermeasures are intended to protect the bridge from catastrophic failure until the design and construction of remedial measures is completed.

The remaining parameters are included for the following reasons:

- (1) River Slope/Velocity - A steeper/faster flowing stream is expected to experience more severe scour than one with a medium or mild slope. The stream slope is defined as follows:
 - i) Steep $S > 0.0015$ ft/ft
 - ii) Medium $0.0015 < S < 0.0004$ ft/ft
 - iii) Mild $S < 0.0004$ ft/ft
- (2) Channel Bottom - An aggrading condition is given a value of 0 because the slight deposition represented reflects a decrease in scour potential. Severe deposition that restricts capacity is addressed later in the flow chart. A stable channel condition is, therefore, given a value of 1 because it represents a more scour prone condition than aggradation. Similarly, a degrading channel is given a value of 2.
- (3) The channel bed material are ranked because rock would take more time to erode to maximum scour than sand. The other material also would take more time. Thus, in ranking bridges to scour vulnerability the bridge that takes longer for scour to reach its maximum value would be less vulnerable.
- (4) Channel Configuration - A meandering or braided channel is given a value of 2 because they have the most potential to have scour problems. A straight channel, defined as exhibiting a sinuosity of less than 1.5, is given a value of 0 because it is the least likely to affect scour. However, if a straight channel has bar formations that shift the thalweg, it should be given a values of 1.0.
- (5) Debris/Ice Problem - Watershed, river conditions or pier and abutment configurations that promote debris

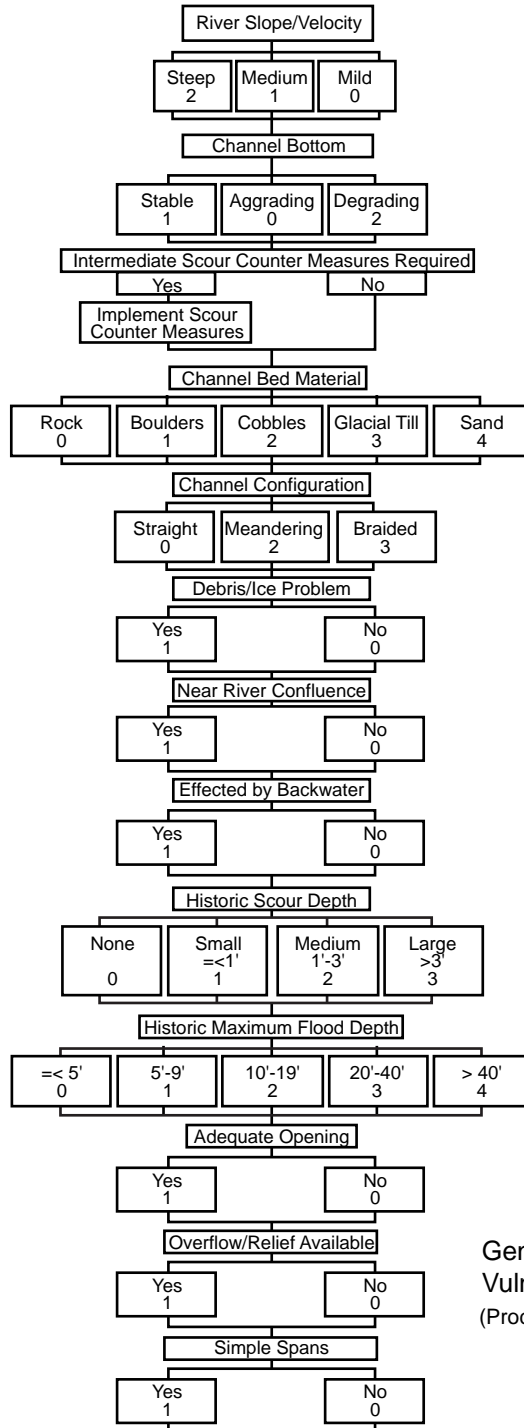
and ice accumulation, primarily as indicated by historic records or field observations, warrant a value of 1 because the accumulation increases potential scour depth by either reducing the conveyance area or by increasing the effective pier width.

- (6) Near River Confluence - The potential for increased flow and river velocity near a river confluence and the resultant scour potential, warrants use of the value of 1 for this condition.
- (7) Affected by Backwater - Locations affected by backwater for all flow conditions, primarily resulting from proximity to a dam, warrants use of a value of 0. For this condition backwater from a downstream waterway should not be considered because it may not occur concurrently with peak flow and velocity on the tributary and at the location being studied.
- (8) Historic Scour Depth - Historic scour indicates a clear potential for continued and increased scour activity. Historic scour depths in excess of 3' are a concern because spread footings are seldom deeper than this.
- (9) Historic Maximum Flood Depth - Flow depth is a parameter in the scour prediction equations. Deeper flow is expected to produce greater scour.
- (10) Adequate Opening - An inadequate opening is expected to produce greater scour than a restricted one, therefore, a value of 2 is assigned to this condition. This parameter also addresses the deposition of material in the channel at the structure to the point that the capacity of the bridge opening is restricted. Bridges that experience overtopping and thus have pressure flow should also be given a 2.
- (11) Overflow/Relief Available - The ability of the design flow to proceed downstream by a means other than through the structure, usually by way of a relief structure or by overtopping the roadway embankment, reduces the scour potential at the structure being evaluated because the resultant discharge and velocity are less than would otherwise be the case.
- (12) Simple Spans - This parameter recognizes that the ramifications of scour at simple span structures is more severe than would occur for structures with alternate load paths that probably would not experience catastrophic failure due to the loss of some foundation material.

The sum of the vulnerability ranking scores is tabulated at the bottom of the form before proceeding to the abutment vulnerability ranking flow chart.

General Conditions Scour Vulnerability Ranking Flow Chart

Bridge # _____ Feature Carried _____ Stream _____
 Community _____ County _____
 Bridge Type _____ Spans _____



General Condition
 Vulnerability Score _____
 (Proceed to Abutment Scour Vulnerability
 Ranking Chart)

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Figure B-1—General Conditions Scour Vulnerability Ranking Flow Chart

c. Abutment Vulnerability Flow Chart.

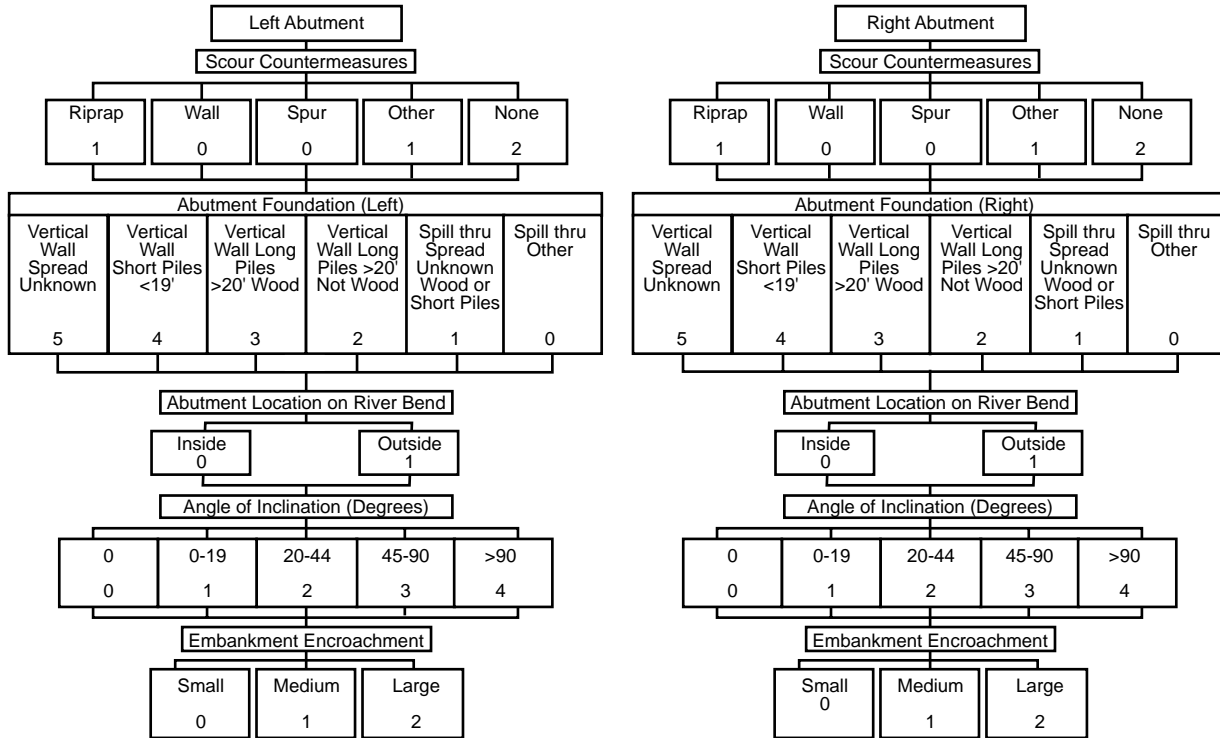
The abutment vulnerability assessment flow chart is intended to evaluate the relative vulnerability of a bridge to scour considering factors that affect abutment scour. A separate evaluation is provided for each abutment because the scour producing parameters may vary at each one, although it is expected that the abutment foundation configuration will remain the same. The left and right directions are established looking downstream. The parameters evaluated in the abutment vulnerability ranking flow chart reflect their relative effect on scour vulnerability as discussed for the office review flow chart. The rationale for their use follow:

- (1) Scour Countermeasures - Installation of a wall or spur dike (guide bank) represent a relatively permanent countermeasure and are, therefore, provided the lowest value. Riprap and other countermeasures are considered temporary and are, therefore, given a higher value. The absence of scour countermeasures warrant assignment of the highest value. Location that do not require scour countermeasures, as indicated in the general conditions flow chart, should be given a value of 0 for this parameter.
- (2) Abutment Foundation - The value assigned to each classification of abutment configuration and foundation type reflects their relative susceptibility to scour as discussed for the office review flow chart.
- (3) Abutment Location on River Bend - An abutment located on the outside of a bend is more susceptible to scour than one on the inside of the bend or one on a straight channel and is, therefore, given a higher value than the other conditions.
- (4) Angle of Inclination - The angle of inclination is determined in accordance with Figure 4.11 of the Technical Advisory. Relative values are assigned to each range of angles.
- (5) Embankment Encroachment - The magnitude of the scour encroachment is reflected in most of the abutment scour equations, therefore, this parameter is included in the chart. A large encroachment would be considered one that substantially reduces the overbank flow area available for the conveyance of peak discharges. A small encroachment would be considered one that impacts less than 10 percent of the total discharge for the design discharge.

The abutment vulnerability score for each abutment is tabulated and summarized at the bottom of the form. The intermediate vulnerability score from the general conditions flow chart is also tabulated and added to the total abutment score to yield the subtotal, which is the final score, if the bridge does not have any piers. The presence of piers necessitates continuation of the evaluation by proceeding to the pier vulnerability ranking flow chart.

Abutment Scour Vulnerability Ranking Flow Chart

Bridge # _____ Feature Carried _____ Stream _____
 Community _____ County _____
 Bridge Type _____ Spans _____



Left Abutment
Vulnerability Score _____

Right Abutment
Vulnerability Score _____

Left and Right are established looking downstream

Abutment Scour Vulnerability

Left Abutment _____ Right Abutment _____ Total _____

General Conditions Vulnerability Score _____ Total _____

Subtotal _____
(Final score if there are points)

Proceed to Pier Scour Vulnerability Ranking Flow Chart if Necessary

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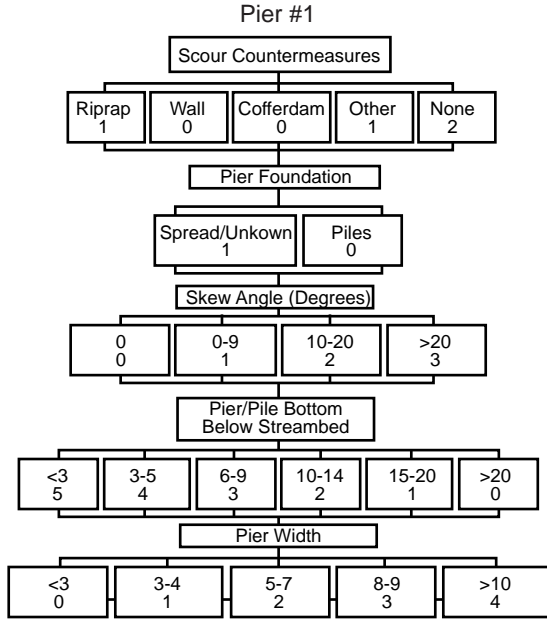
Figure B-2—Abutment Scour Vulnerability Ranking Flow Chart

Pier Vulnerability Ranking Flow Chart

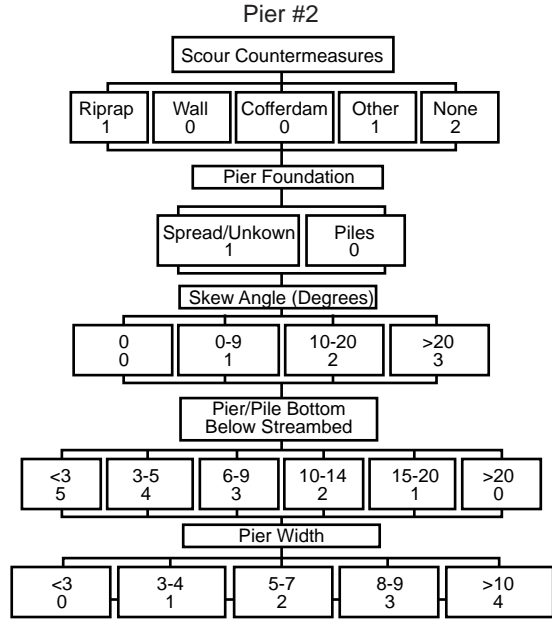
Bridge # _____ Feature Carried _____ Stream _____

Community _____ County _____

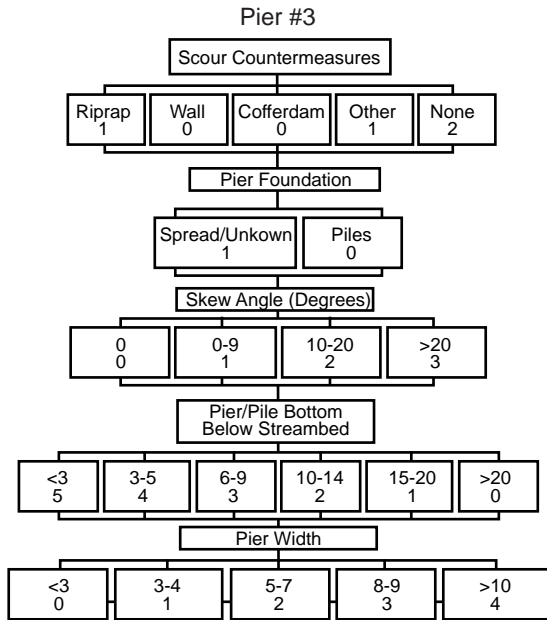
Bridge Type _____ Spans _____



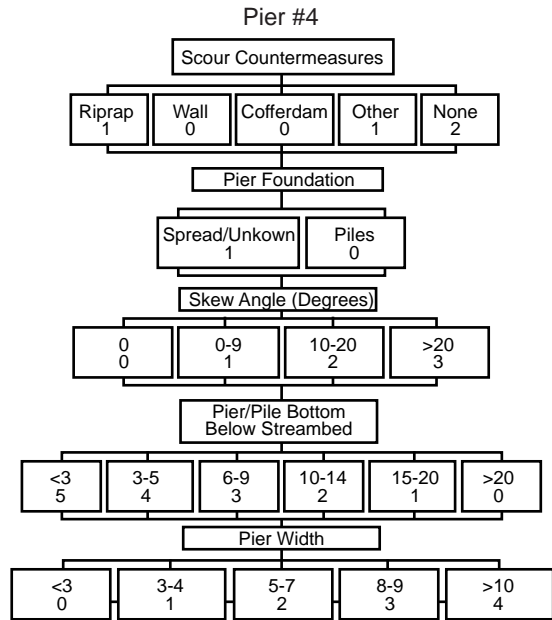
Pier #1 Vulnerability
Score: _____



Pier #2 Vulnerability
Score: _____



Pier #3 Vulnerability
Score: _____



Pier #4 Vulnerability
Score: _____

Pier Vulnerability Ranking Score Summary

Pier #1 _____ Pier #2 _____ Pier #3 _____ Pier #4 _____

Pier with maximum score: Pier # _____

Subtotal from abutment scour vulnerability: _____

Total Vulnerability Score: _____

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Figure B-3—Pier Vulnerability Ranking Flow Chart

d. Pier Vulnerability Flow Chart.

The pier vulnerability assessment flow chart is intended to evaluate the relative vulnerability of a bridge to scour considering factors that affect pier scour. A separate evaluation is provided for each pier because the scour producing parameters may vary at each one. The piers are numbered sequentially from the left abutment, with the left side established looking downstream.

The parameters evaluated in the pier vulnerability ranking flow chart reflect their relative effect on scour. The rationale for their use follows:

- (1) Scour Countermeasures - The rationale is the same as presented for the abutment flow chart.
- (2) Pier Foundation - A spread footing or unknown foundation condition warrants a higher value than a pile foundation.
- (3) Skew Angle - The skew angle ranges reflect the relative effect on scour potential as indicated in Table 4.3 of the Technical Advisory (FHWA 1987).
- (4) Pier/Pile Bottom Below Streambed - This parameter reflects the relative susceptibility to scour based on the depth of the footing or pile bottom to the streambed elevation. The highest value is assigned to a depth of three feet or less because this is the normal depth of spread footings. Deeper footing or pile bottom elevations warrant lower ranking values. Depths greater than twenty feet are arbitrarily assigned the lowest value.
- (5) Pier Width - The pier width reflects the maximum expected scour in accordance with pier scour questions as indicated in the Technical Advisory. The range of three to five feet in the pier width represents the normal dimensions expected. No adjustment for debris or ice accumulation is used here because it is reflected in the general conditions flow chart.

The pier vulnerability score is tabulated for each pier evaluated. The values are summarized and the value of the most vulnerable pier added to the subtotal from the abutment vulnerability flow chart to determine the total vulnerability score.

APPENDIX C

FOREST SERVICE SCOUR EVALUATION PROCESS
PLAN OF ACTION

Region _____
Forest _____
Route ID & MP _____
Name _____
Feature Crossed _____
NBIS / Non-NBIS _____

BMC / INFRA Codes

Scour Critical _____
Scour Vulnerability _____

Description of Bridge Vulnerability

Recommended Scour Countermeasures

Implementation Plan

Bridge Closure Plan

