Evaluation of Bridge Vulnerability to Hydraulic Forces, Stream Instability, and Scour

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The principal causes of failure of bridges over rivers and streams are scour at the foundations, channel movement and hydraulic forces. Scour is the removal of material from around piers and abutments due to extreme flows, ice jams or debris which destroy the foundation support and result in excessive settlement or movement and loss of support for the superstructure. Channel movement is the natural realignment of the river channel so that the stream encroaches on a pier, abutment or bent, resulting in failure from scour as described above. In addition, channel movement can erode the approaches to the bridge. Hydraulic forces from the impact of ice or debris against a pier, abutment or superstructure can cause dislocation of the bridge elements. Buoyancy and flotation, as the result of submergence, can also dislodge bridge decks off of their supports. A procedure for conducting a comprehensive hydraulic evaluation of existing bridges to determine their vulnerability to scour, stream instability, and hydraulic forces is given in this paper. The procedure is based on the five step process recommended in the September 1988 FHWA Technical Advisory on Scour (1).

The September 1988 FHWA Technical Advisory titled "Scour at Bridges" (1) recommended that the states develop and implement a program to evaluate every bridge over a stream, whether existing or under design, to determine its vulnerability to floods in order to determine prudent measures to be taken for its protection. The Advisory stated:

"Most waterways can be expected to experience scour over a bridge's service life (which is now approaching 100 years). Exceptions might include waterways in massive, competent rock formations where scour and erosion occur on a scale that is measured in centuries..... The added cost of making a bridge less vulnerable to scour is small when compared to the total cost of a failure which can easily be two or three times the original cost of the bridge itself. Moreover, the need to ensure public safety and to minimize the adverse effects stemming from bridge closures requires our best effort to improve the state-of-practice of designing and maintaining bridge foundations to resist the effects of scour."

The Advisory and accompanying document titled "Interim Procedures for Evaluating Scour at Bridges" further recommended that the evaluation of existing bridges should be carried out by an interdisciplinary team comprised of structural, hydraulic, and geotechnical engineers. The risk of failure should be determined for scour resulting from a superflood with a recurrence interval of once in 500 years. The five step procedure contained in the Interim Procedures should be used by the states to identify bridges most susceptible to scour damage, establish a priority list for evaluation, and develop a plan of action for those bridges determined to be scour critical. The plan of action "should include instructions regarding the type and frequency of inspections to be made at the bridge, particularly in regard to monitoring the performance and closing of' the bridge, if necessary, during and after flood events. ...The plan of action should include a schedule for timely design and construction of scour countermeasures determined to be needed for the protection of the bridge." It was left to the states to develop their own procedures for evaluating the vulnerability of existing bridges to scour. A procedure developed by the Minnesota Department of Transportation was given in the Interim Procedures.

This paper presents a procedure that was developed for the New York State Department of Transportation and the Colorado Highway Department to evaluate and categorize the scour vulnerability of their existing bridges.(2,3) Methods of calculating scour, or scour countermeasures, are not given in the paper as these were given in the Interim Procedures (1), HEC 18 (4), HEC 20 (5) and Highways in the River Environment (6).

OVERVIEW

All the bridges over water are to be evaluated. However it is crucial that the

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most scour critical bridges be identified first and either replaced or provided with interim protection. To do this it was decided to divide all bridges over water into four categories on the basis of their scour susceptibility and then rank them in each category by their scour vulnerability. The four categories are 1) MOST SCOUR CRITICAL, 2) MEDIUM SCOUR CRITICAL, 3) LOW SCOUR CRITICAL, and 4) NOT SCOUR CRITICAL. Bridges in category 1 would be replaced or receive interim protection first. Then the next category and so on. Flow charts were developed to help in evaluating the bridges as to their scour susceptibility and to rank the bridges in each category. The ranking is based only on scour susceptibility.The evaluation is a five step procedure. The steps are as follows:

- o Step 1. Screening the entire bridge population to compile a list of those bridges with actual or potential scour vulnerability.
- o Step 2. Establish priorities, by conducting a preliminary office and field examination to categorize the bridges identified in step 1 as to scour susceptibility and then ranking the bridges in each category as to scour vulnerability. The following factors are to be used as a guide:
  - (a) The potential for bridge collapse or for damage to the bridge in the event of a major flood.
  - (b) The functional classification of the highway on which the bridge is located, and the effect of a bridge collapse on the safety of the travelling public and on the operation of the overall transportation system for the area or region.
- o Step 3. Determine a plan of action and interim protection for correcting the scour problem for bridges identified as most scour critical in step 2 (Category 1).
- o Step 4. Perform a detailed hydraulic, structural and geotechnical evaluation of the most scour critical bridges as determined in step 2 to determine final action to repair or replace the bridge and design appropriate scour countermeasures. This detailed evaluation is to be done taking in consideration the developed priority list.
- o Step 5. Evaluate the bridges in the other categories in accordance with the priority list.

Note 1. In the above procedure, some of the activities can be conducted concurrently.

Note 2. The above procedure should be carried out for all bridges, regardless of ownership.

DETAILED PROCEDURE

I. Step 1. Compile a list of potential scour vulnerable bridges.

Determine all bridges that are over water on the basis of the bridge inventory data.

II. Step 2. Prioritize the list determined in step 1.

The priorities would be established in a two part process. Part one would categorize the bridges as to scour vulnerability and Part two would rank the bridges as to scour vulnerability in each category.

Part One

Divide the list derived in Step 1 into four categories. (1) MOST SCOUR CRITICAL, 2) MEDIUM SCOUR CRITICAL, 3) LOW SCOUR CRITICAL, and 4) NOT SCOUR CRITICAL.)

The procedure consists of the following:

1. Office review of the data base to divide the bridges into the four scour susceptibility categories.
2. Field inspection of bridges in the medium scour category or indeterminate from the office review.

Office Review

The office review would divide the bridges into the four categories on the basis of the following criteria.

1. Bridges over water with piers whose foundations are on spread footing without piles and not on solid rock.
2. Bridges with piers in water with foundations on shallow piles.
3. Bridges over water with vertical wall abutments with foundations on spread footing without piles and not on solid rock.
4. Bridges over water with vertical wall abutments with foundations on shallow piles.
5. Bridges over streams with lateral movement that may erode abutments, piers or bents.
6. Bridges with piers in water with foundations on wood piles.
7. Bridges over water with vertical wall abutments with foundations on wooden piles.
8. Bridges over water with spill-through or stub abutments with foundations on spread footing without piles and not on solid rock or have shallow or wooden piles.
9. Bridges over water where the water is a lake, canal, ditch or other slow

<u>moving water that will not cause scour.</u>

10. Bridges over water with abutments and piers with foundations on solid rock or with adequate piles.

Category 1 bridges are those that fall in classifications 1, 2 and 3.
Category 2 bridges are those that fall in classifications 4, 5, 6 and 7.
Category 3 bridges are those that fall in classification 8 and 9.
Category 4 bridges are all others.

The office review would also compile the following data on the bridges.

1. Bridge over water or relief bridge subject to water.
2. Type of water and name.
   a. River
   b. Canal
   c. Estuary
   d. Lake
   e. Swamp
3. Geologic area or region.
4. Stream Slope at bridge. From USGS map.
5. Pier or piers in the flow.
6. Abutment in flow or subject to flow. (yes, no)
7. Abutment Type
8. Foundations
   a. Piers on piles. (yes, no) Depth ______
   b. Abutments on piles. (yes, no) Depth ______
   c. Scour countermeasures. (yes, no) Type ______
9. Debris possible problem. (yes, no)
10. Ice possible problem. (yes, no)
11. Channel movement possible problem. (yes, no)
12. River characteristics.
    a. Slope.Steep ($S > .0015$ ft/ft)_____ Medium ($.0015 < S < .0004$)_____ or Mild ($S < .0004$)_____
    b. Flash floods (peaks in hours not days).
    c. Meandering, straight or braided.
    d. Incised, floodplain.
    e. Size (Use Drainage Area).
    f. Stream bed (rock, glacial till, or alluvium).
13. Floods.
    a. Q_{50}
    b. Q_{100}
    c. Largest observed Q and date.
    d. Next Largest observed Q and date.
    e. Flood studies. Who?
14. Traffic volume.

Field Review

Examine in the field those bridges identified as category 2 scour susceptible or bridges for which the office review does not provide sufficient data to clearly determine the proper category. On some of the bridges, this examination could determine the interim scour protection asked for in step 3.

The field review should be made by staff knowledgeable about hydraulics and river mechanics. In some cases (bridges) it may be necessary for the Geotechnical and/or Structural Engineers to examine the site. An example of the latter would be if the Hydraulic Engineers were not sure of the resistance to scour of the rock the foundation is set in.

The criteria for the classification into most, medium, least and not scour critical would be the same as in the office review.

The field review would examine each site to determine the following:

1. Is there evidence of scour or deposition at the piers or abutments?
2. Are there channel conditions, such as a bend, that increases the scour risk?
3. Is there deposition in part of the bridge section that decreases the flow area?
4. Does the angle of attack of the flow on a pier or abutment increase the scour risk?
5. Are there conditions at the bridge that decrease its vulnerability to scour? For example, local aggradation of the bed, downstream controls that decrease scour, foundations in bed rock, etc.
6. What is the potential for contraction scour? That is, are the overbank flow area and the natural banks so vegetated that the discharge and the velocity of the returning flow would be small? Or do the conditions represent the laboratory conditions from which the equations were developed.
7. What is the potential for long term scour or deposition?
8. What is the potential for local scour at the abutments?
9. What is the potential for local scour at the piers?
10. What is the potential for movement undermining abutments, piers or bents in the channel or floodplains.

The field examination could also determine the type and extent of field data measurement needed for the detailed evaluation called for in step 4. In addition, the type of intermediate scour protection could be decided. It is estimated that this field examination would take about a few hours per bridge. To aid in this office and field review, scour susceptibility flow charts are given in the next section.

Scour Susceptibility Flow Charts

The scour susceptibility of bridges is to be evaluated by the use of two flow charts: The Office Review Flow Chart, followed by the Field Review Flow Chart.

It is expected that information required to complete the Office Review Flow Chart is available in the bridge data base. The primary function of the Office Review Flow Chart is to quickly identify those bridges that are clearly the most scour susceptible, as well as those which are clearly not scour prone. For bridges identified as the most susceptible (Category 1) and least susceptible (Category 3) to scour, proceed to the Vulnerability Ranking Flow Chart following the Office Review. For bridges identified with medium susceptibility to scour (Category 2) proceed to the Field Review prior to the Vulnerability Ranking Flow Chart. The purpose of the Field Review is to refine the Office Review to identify bridges in Category 2 that should be placed in Category 1, 2 or 4.

Office Review Screening Flow Chart The Office Review Flow Chart eliminates from further consideration structures that are not over water, structures that do not have a pier or abutment in the floodplain, those bridges that lateral movement of the stream would not scour abutments, piers or bents and those whose foundations are placed on non-scourable foundation material. 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. If the response to all of these parameters is other than above or unknown, the path proceeds to evaluation of stream velocity.

Structures that are concrete box culverts with bottom slabs and structures that experience predominately static flow conditions or slow velocities, such as expected for a lake, canal or ditch, etc., warrant additional evaluation to identify scour prone facilities, primarily based on historic scour problems.

It is expected that the bi-annual inspection, underwater reports and bridge folders will provide the required information. A scour rating above 5, with no notes describing previous scour or potential scour producing problems, eliminates the structure from further consideration. However, a rating below 5 or the presence of notes describing scour history or potential, yields the need for further evaluation. For bridges, the evaluation proceeds to the assessment of pier and abutment foundations. Culverts requiring further evaluation are placed in category 3 and ranked at the highest priority in this category.

Bridges with foundations (abutments, piers or bents) that are not in the channel or floodplain and not subject to scour from lateral movement of the stream are eliminated from consideration. If the above is not true then proceed with the office review.

Recognizing that scour susceptibility is primarily a function of the foundation type, evaluation of pier and abutment foundation data expected to be contained in the data base and bridge folder permits separation of the bridges into the three scour susceptibility categories. Pier foundations with spread or unknown footing conditions and vertical wall abutments on spread or unknown footings or with piles less than 20 feet long are considered most susceptible to scour. This is because the worst case pier scour depth is approximately 2.3 times the pier width, accounting for debris and ice jams, and is, therefore, usually greater than the normal depth of spread footings, and usually exceeds five feet. Similarly, piles less than twenty feet long are considered scour prone because the embedment remaining subsequent to scour may be inadequate to provide the required support.

Pier foundations on solid wood piles greater than 20 feet long and vertical wall abutments on long piles are considered to be of medium scour susceptibility because the additional embedment is expected to provide adequate support during a flood and inspection after will determine if countermeasures are needed prior to the next flood. Spill-through abutments with spread or unknown footing conditions or short or wooden piles are included in the medium category because the expected scour is approximately one half the amount experienced at vertical wall abutments. All other pier and abutment configurations are considered to be the least susceptible to scour.

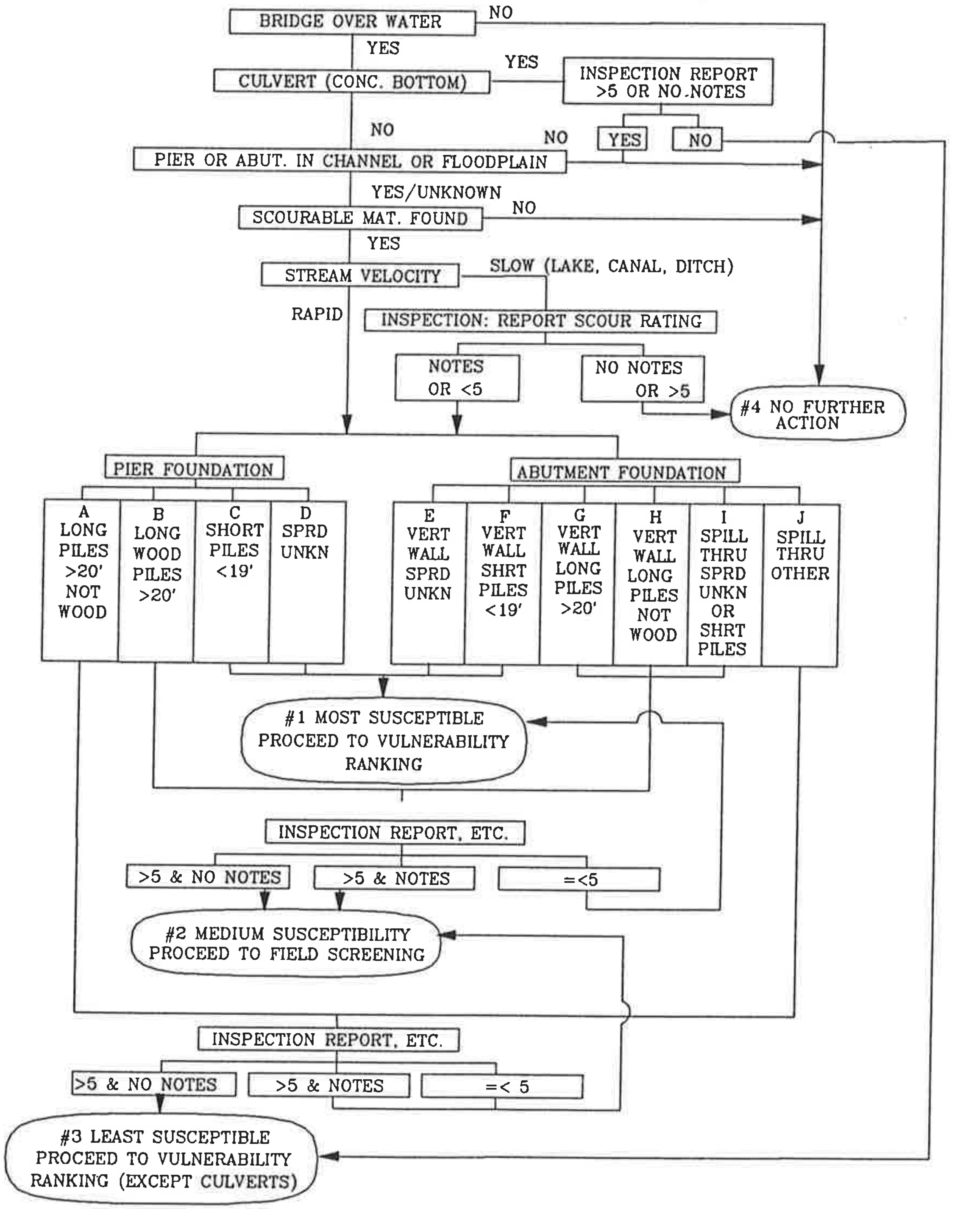
Bridges classified as having medium susceptibility to scour are further evaluated using the bi-annual inspection report and scour notes, in a manner similar to that previously described for streams with slow velocity, to identify locations that should be in the most susceptible category because of historic or potential scour problems. Bridges considered the least susceptible to scour are similarly evaluated. The bridges that are thus elevated to the next higher susceptibility category will, therefore, receive a more detailed vulnerability ranking earlier than otherwise.

OFFICE REVIEW
SCREENING FLOWCHART TO DETERMINE SCOUR SUSCEPTIBILITY OF EXISTING BRIDGES

BRIDGE # ______ FEATURE CARRIED ________________ STREAM ___________________

COMMUNITY ________________________________ COUNTY _________________________

BRIDGE TYPE ___________________ SPANS ___________________



It is expected that the detailed vulnerability ranking will be performed for the most susceptible bridges as soon as possible after their identification in this category. Similarly, the field Screening and vulnerability ranking of bridges with medium susceptibility should proceed as soon as possible after their identification in this category. Vulnerability ranking of the least susceptible bridges (Category 3) may be postponed until the ranking of the other two categories is complete.

Field Review Screening Flow Charts The Field Review Screening Flow Chart for bridges with medium susceptibility to scour provides an intermediate step for these bridges prior to the detailed vulnerability ranking to identify bridges in this category that should be elevated to the most susceptible category. The field review will permit the identification of bridges whose abutments and piers are located beyond the floodplain, have abutments, piers or bents not subject to scour by lateral stream movement or whose foundation is on non-scourable material and, therefore, do not warrant further consideration. Presence of the other parameters warrants leaving the structure in category 2 or elevating it to the most scour susceptible category.

Evidence of a limited amount of previous scour or deposition of material does not warrant a change in the category. However, evidence of one foot or more of scour warrants elevation to the higher category because the actual scour depth is probably larger, although the magnitude is uncertain. Similarly, extensive deposition, particularly where it appears to restrict flow, warrants elevation.

Intensification of the potential for scour as a result of the following parameters warrants elevation to the most susceptible category for the following reasons:

1. Angle of Attack - The pier scour equation includes the angle of attack that clearly increases the expected scour depth.
2. River Bend - The abutment or pier on the outside of a bend clearly experiences higher velocity and resultant potential scour depth.
3. Potential Pier Scour - The maximum expected scour can be approximated using the method developed by Chang (1) from a study of all relevant data and equations.
4. Recognizing that spread footings are normally approximately three or four feet below the stream bed, potential pier scour exceeding this amount is a concern. Similarly, pile supported structures that experience material removed from the majority of the pile length are a concern.
5. Potential for Abutment Scour - Extensive vegetation on the encroachment embankment and on the stream overbank, particularly at the top of bank parallel to the direction of stream flow, limits potential abutment scour.
6. Potential for Contraction Scour - Severe restriction of the floodplain, particularly where relief is not possible through a structure or by overtopping, is a concern.
7. Stream movement that could undermine abutments, piers or bents.

Completion of the Field Review Screening Flow Chart increases confidence in the division of structures into the three scour susceptibility categories. It is recommended that the field data required for the scour vulnerability ranking should be gathered concurrently with the data for the Field Review Flow Chart to maximize the value of the field evaluation.

Part Two

Ranking the bridges in each category as to scour vulnerability.

Scour Vulnerability Ranking Flow Charts

The ranking of the scour vulnerability of bridges in each scour category 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 charts 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 medium slope, which is more likely to have 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.

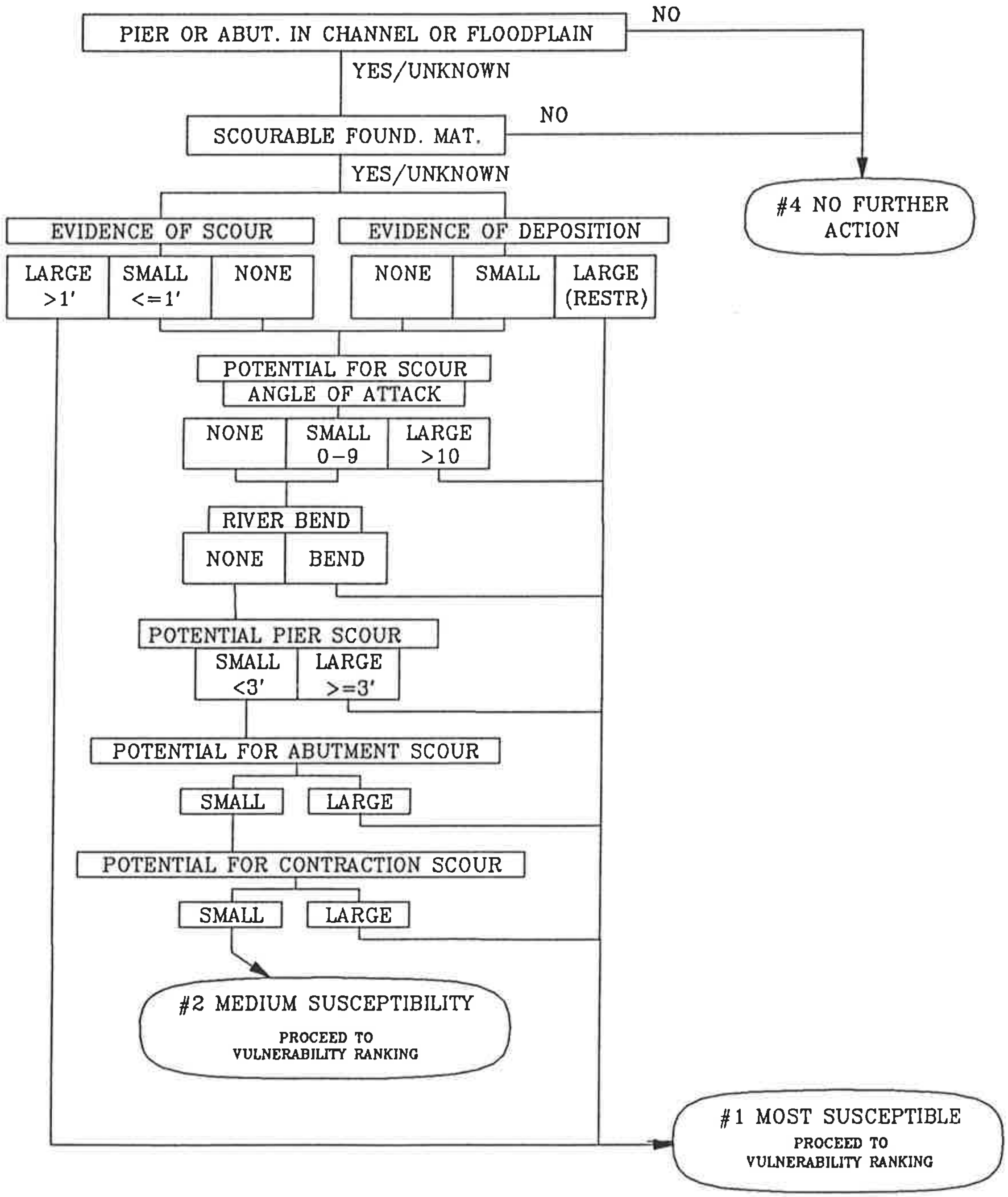
The value of the vulnerability ranking is that it orders a bridge relative to other scour vulnerable bridges, and other things being equal (traffic counts for example)

FIELD REVIEW
SCREENING FLOWCHART TO DETERMINE SCOUR SUSCEPTIBILITY OF EXISTING BRIDGES

BRIDGE # ______ FEATURE CARRIED ________________ STREAM ___________________

COMMUNITY ________________________________ COUNTY ____________________

BRIDGE TYPE _____________________ SPANS ___________________



determines what bridge should be repaired or replaced first.

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

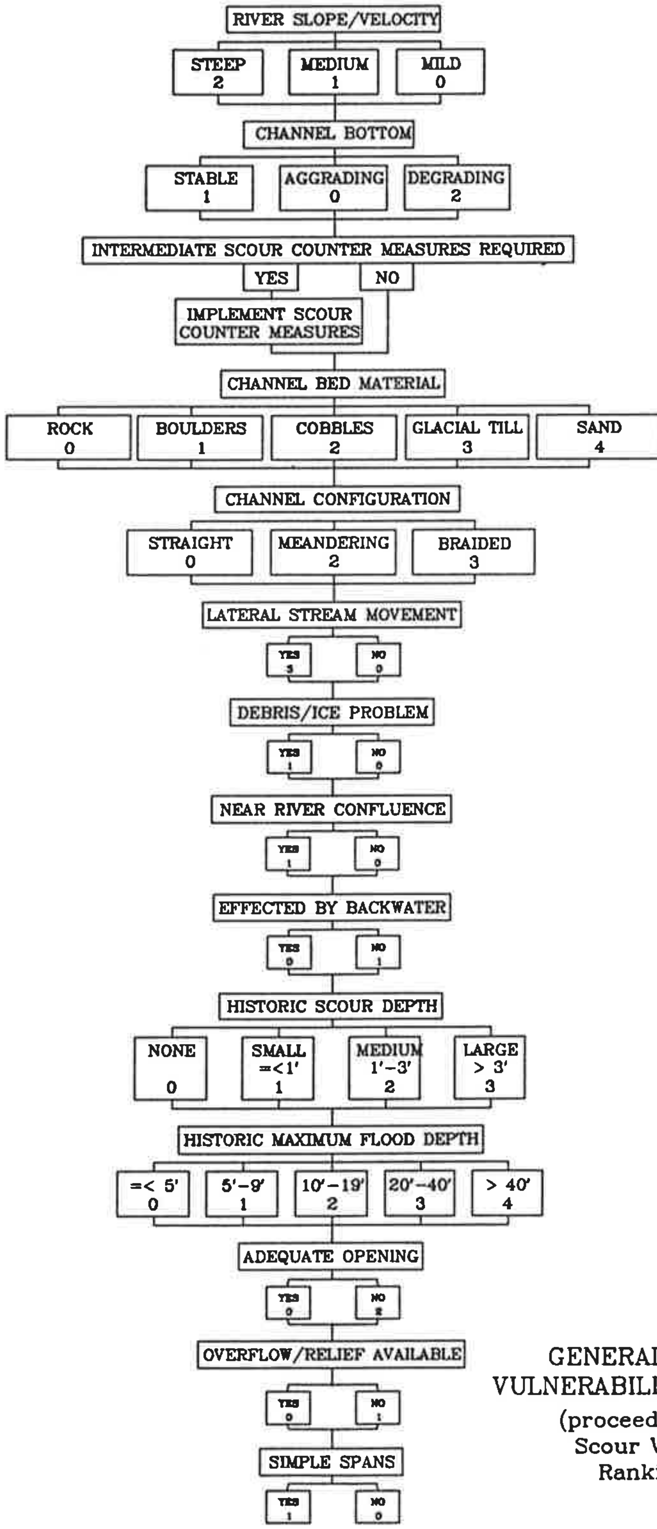
General Conditions Flow Chart The General Conditions Flow Chart addresses parameters that have a general impact on the potential scour depth. The need for intermediate scour countermeasures is included in the flow chart to remind the evaluator to identify this need. No vulnerability ranking value is 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:
   a. Steep $S > 0.0015$ ft/ft
   b. Medium $0.0015 < S > 0.0004$ ft/ft
   c. Mild $S < 0.0004$ ft/ft
2. Channel Bottom - An agrading 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 is ranked because rock would take more time to erode to maximum scour than sand. The other materials indicated also would take more time to erode. 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 channel is given a value of 2 and a braided channel is given a value of 3 to reflect the relative scour potential of each. 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 value of 1.0.
5. Channel Migration - Channel migration can undermine abutments, piers or bents in the channel, on the floodplain or near the floodplain and thus warrant a 3.
6. 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.
7. 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.
8. 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.
9. Historic Scour Depth - Historic scour indicates a clear potential for continued and increased scour activity. Historic scour depths in excess of 3 feet are a concern because spread footings are seldom deeper than this.
10. Historic Maximum Flood Depth - Flow depth is a parameter in the scour prediction equations. Deeper flow is expected to produce greater scour.
11. Adequate Opening - An inadequate opening is expected to produce greater scour than an adequate 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.
12. 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,

GENERAL CONDITIONS
SCOUR VULNERABILITY RANKING FLOW CHART

BRIDGE # _____ FEATURE CARRIED ___________________ STREAM __________________



GENERAL CONDITION
VULNERABILITY SCORE_____
(proceed to Abutment
Scour Vulnerability
Ranking Chart)

reduces the scour potential at the structure being evaluated because the resultant discharge and velocity are less than would otherwise be the case.

13. 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. Structures with alternate load paths 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.

Abutment Vulnerability Flow Chart The Abutment Vulnerability 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 warrants assignment of the highest value. Locations 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 (1). 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.

Pier Vulnerability Flow Chart The Pier Vulnerability 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.(1)
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

ABUTMENT SCOUR VULNERABILITY RANKING FLOW CHART

BRIDGE # ______ FEATURE CARRIED ________________ STREAM ________________

COMMUNITY ____________________________ COUNTY ______________________

BRIDGE TYPE ________________ SPANS ________________

LEFT ABUTMENT

SCOUR COUNTERMEASURES

RIPRAP	WALL	SPUR	OTHER	NONE
1	0	0	1	2

ABUTMENT FOUNDATION (LEFT)

VERTICAL WALL SPREAD UNKN	VERTICAL WALL SHORT PILES <19'	VERTICAL WALL LONG PILES >20' WOOD	VERTICAL WALL LONG PILES >20' NOT WOOD	SPILL THRU SPREAD UNKNOWN WOOD OR SHORT PILES	SPILL THRU OTHER
5	4	3	2	1	0

ABUTMENT LOCATION ON RIVER BEND

INSIDE	OUTSIDE
0	1

ANGLE OF INCLINATION (DEGREES)

0	0-19	20-44	45-90	> 90
0	1	2	3	4

EMBANKMENT ENCROACHMENT

SMALL	MEDIUM	LARGE
0	1	2

LEFT ABUTMENT VULNERABILITY

SCORE: ______

RIGHT ABUTMENT

SCOUR COUNTERMEASURES

RIPRAP	WALL	SPUR	OTHER	NONE
1	0	0	1	2

ABUTMENT FOUNDATION (RIGHT)

VERTICAL WALL SPREAD UNKN	VERTICAL WALL SHORT PILES <19'	VERTICAL WALL LONG PILES >20' WOOD	VERTICAL WALL LONG PILES >20' NOT WOOD	SPILL THRU SPREAD UNKNOWN WOOD OR SHORT PILES	SPILL THRU OTHER
5	4	3	2	1	0

ABUTMENT LOCATION ON RIVER BEND

INSIDE	OUTSIDE
0	1

ANGLE OF INCLINATION (DEGREES)

0	0-19	20-44	45-90	> 90
0	1	2	3	4

EMBANKMENT ENCROACHMENT

SMALL	MEDIUM	LARGE
0	1	2

RIGHT ABUTMENT VULNERABILITY

SCORE: ______

* LEFT AND RIGHT ARE ESTABLISHED LOOKING DOWNSTREAM

ABUTMENT SCOUR VULNERABILTIY

LEFT ABUTMENT______ RIGHT ABUTMENT______ TOTAL______

GENERAL CONDITIONS VULNERABILITY SCORE TOTAL______

SUB TOTAL: ______

(FINAL SCORE IF THERE ARE NO PIERS)

[PROCEED TO PIER VULNERABILITY RANKING FLOW CHART, IF NECESSARY]

PIER VULNERABILITY RANKING FLOW CHART

BRIDGE # _____ FEATURE CARRIED ____________ STREAM ________________

COMMUNITY __________________________ COUNTY ____________________

BRIDGE TYPE ___________________ SPANS ________________

PIER #1

SCOUR COUNTERMEASURES

RIPRAP	WALL	COFFER-DAM	OTHER	NONE
1	0	0	1	2

PIER FOUNDATION

SPREAD/UNKNOWN	PILES
1	0

SKEW ANGLE (DEGRESS)

0	0-9	10-20	>20
0	1	2	3

PIER/PILE BOTTOM BELOW STREAMBED

<3	3-5	6-9	10-14	15-20	>20
5	4	3	2	1	0

PIER WIDTH

<3	3-4	5-7	8-9	>10
0	1	2	3	4

PIER #1 VULNERABILITY SCORE: ________

PIER #2

SCOUR COUNTERMEASURES

RIPRAP	WALL	COFFER-DAM	OTHER	NONE
1	0	0	1	2

PIER FOUNDATION

SPREAD/UNKNOWN	PILES
1	0

SKEW ANGLE (DEGRESS)

0	0-9	10-20	>20
0	1	2	3

PIER/PILE BOTTOM BELOW STREAMBED

<3	3-5	6-9	10-14	15-20	>20
5	4	3	2	1	0

PIER WIDTH

<3	3-4	5-7	8-9	>10
0	1	2	3	4

PIER #2 VULNERABILITY SCORE: ________

PIER #3

SCOUR COUNTERMEASURES

RIPRAP	WALL	COFFER-DAM	OTHER	NONE
1	0	0	1	2

PIER FOUNDATION

SPREAD/UNKNOWN	PILES
1	0

SKEW ANGLE (DEGRESS)

0	0-9	10-20	>20
0	1	2	3

PIER/PILE BOTTOM BELOW STREAMBED

<3	3-5	6-9	10-14	15-20	>20
5	4	3	2	1	0

PIER WIDTH

<3	3-4	5-7	8-9	>10
0	1	2	3	4

PIER #3 VULNERABILITY SCORE: ________

PIER #4

SCOUR COUNTERMEASURES

RIPRAP	WALL	COFFER-DAM	OTHER	NONE
1	0	0	1	2

PIER FOUNDATION

SPREAD/UNKNOWN	PILES
1	0

SKEW ANGLE (DEGRESS)

0	0-9	10-20	>20
0	1	2	3

PIER/PILE BOTTOM BELOW STREAMBED

<3	3-5	6-9	10-14	15-20	>20
5	4	3	2	1	0

PIER WIDTH

<3	3-4	5-7	8-9	>10
0	1	2	3	4

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: ________

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.

III. Step 3. Plan of action and interim countermeasures.

The plan of action for correcting the scour problem includes the following:

1. Interim protection for scour critical bridges until countermeasures are designed and constructed or the bridge is replaced. This could include:
   a. Timely installation of interim scour countermeasures such as riprap.
   b. Plans for monitoring scour critical bridges during and inspection after flood events and for blocking traffic if need be until scour countermeasures are installed.
   c. Immediate bridge replacement or the installation of permanent scour countermeasures.
2. Establishing a time table for step 4 below.

Note. **Monitoring a bridge during a flood can not at this time determine if the bridge is about to collapse. Thus, the need to provide scour protection (riprap, grade control, etc) on an interim basis if the bridge cannot be closed during high water.** Many bridges could be closed during high flow without disrupting traffic too much because the traffic volume is low, there are alternate routes or both.

IV. Step 4. Detailed evaluation and design of scour countermeasure.

In the detailed evaluation the following are recommended:

1. THE PROCEDURES AND EQUATIONS GIVEN IN FHWA SEPT. 1988 TA (1) BE FOLLOWED, EXCEPT IN THE CASE OF ABUTMENT SCOUR.
2. FOR ABUTMENT SCOUR, USE RIPRAP OR CONSTRUCT A SPUR DIKE TO PROTECT ABUTMENTS THAT STEP 2 HAS IDENTIFIED AS SCOUR CRITICAL.

   The reason for this recommendation is that equations for predicting scour depths at abutments are based on laboratory studies with no field verification. The conditions of the experiments do not represent field conditions. The experiments were for abutments projecting into a channel with no vegetation on the banks, the elevation of the bed in the overbank area was the same as the channel in the experiments and the velocity in the experimental overbank area was almost the same as in the main experimental channel. Also, only recently has the volume of flow in the overbank area, rather than the encroachment length, been considered in the equations. (7,8)

   ONE FACTOR THAT THE EXPERIMENTS DO SHOW IS THAT SCOUR DEPTHS AT VERTICAL WALL ABUTMENTS ARE TWICE THAT OF SPILL THROUGH ABUTMENTS.

   Use Froehlich's live-bed abutment scour equation to calculate scour depths, if it is desired to calculate potential scour depths in the design of foundations or countermeasures.(4, 6)
3. SIMPLE SPANS WITHOUT ALTERNATE LOAD PATHS (WITHOUT REDUNDANCY)SHOULD BE ELIMINATED IN THE REPAIR OR REPLACEMENT OF SCOUR CRITICAL BRIDGES. THIS WOULD ELIMINATE INSTANTANEOUS COLLAPSE IF A PIER OR ABUTMENT SHIFTED.

V. Step 5. Evaluate the other bridges over water in the inventory.

The procedure would be to evaluate the most scour critical bridges, then the medium scour critical bridges and last the least scour critical bridges. However, in Step 2 many of the bridges identified in Step 1 would be eliminated from further evaluation and would depend on the inspection program to determine problems.

SUMMARY

This paper presents a method for screening and placing in priority bridge vulnerability to hydraulic forces, stream instability and scour.

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