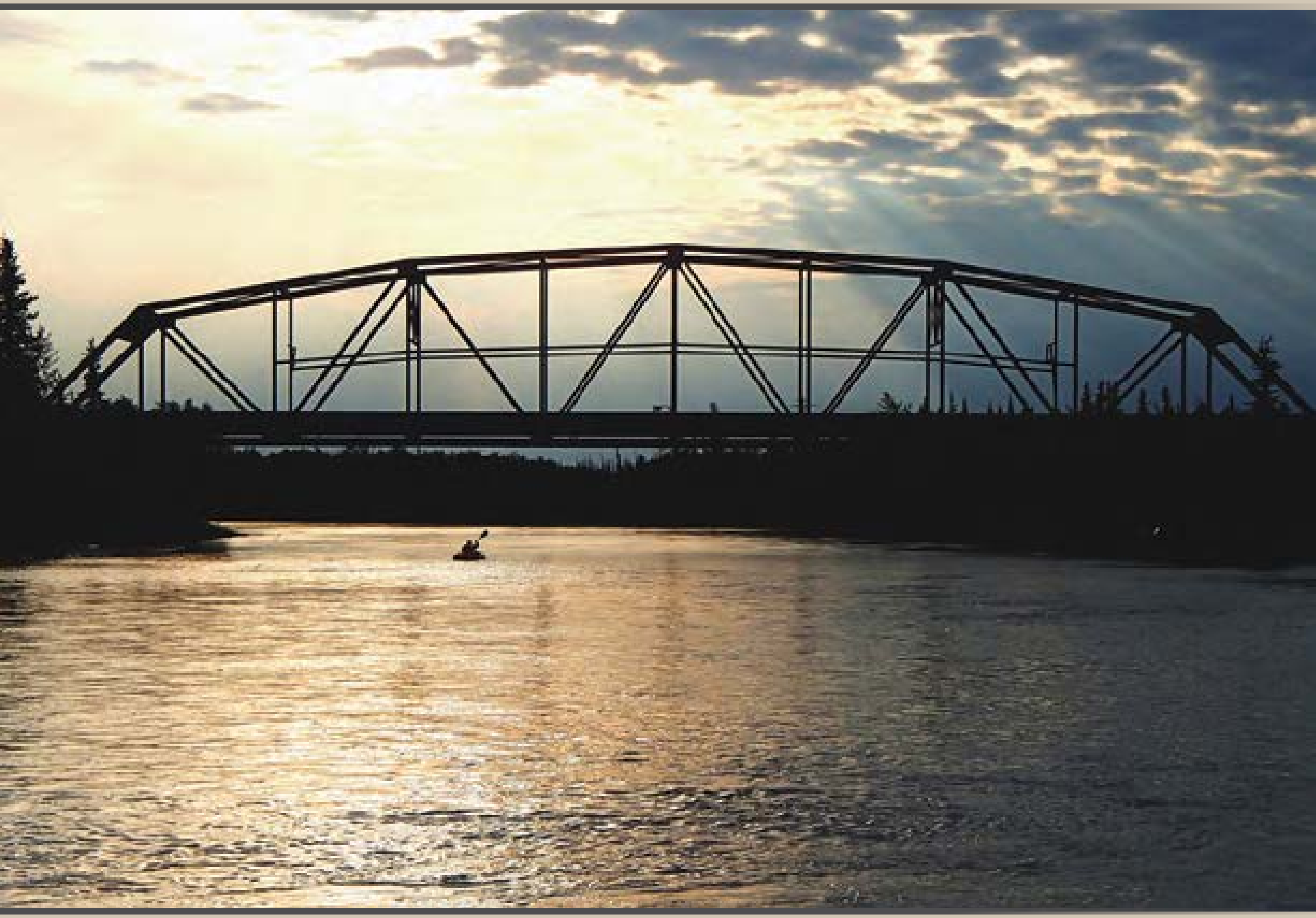
Prepared in cooperation with the Alaska Department of Transportation and Public Facilities

Streambed Scour Evaluations and Conditions at Selected Bridge Sites in Alaska, 2013–15



Scientific Investigations Report 2017–5149

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph showing U.S. Geological Survey scientist measuring water depth and velocity with a kayak-mounted acoustic Doppler current profiler beneath the Chisana River Bridge near Northway, Alaska. Photograph by Robin A. Beebee, U.S. Geological Survey, June 15, 2015.

Streambed Scour Evaluations and Conditions at Selected Bridge Sites in Alaska, 2013–15

By Robin A. Beebee, Karenth L. Dworsky, and Schyler J. Knopp

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U.S. Department of the Interior
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U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
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exercising the authority of the Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
square foot per second (ft^2/s)	0.0929	square meter per second (m2/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Acceleration		
foot per square second (ft/s^2)	0.3048	meter per square second (m/s^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as

$$°C = (°F – 32) / 1.8.$$

Datums

Vertical coordinate information is site specific and, in most cases, is referenced either to as-built elevations on bridge plans (if available) or to a reference mark with an assumed elevation of 100 feet established during the survey on or near the bridge deck. Other geographic data (for example, lidar) are adjusted to match the bridge datum, unless otherwise noted.

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Abbreviations

ADCP	acoustic Doppler current profiler
ADOT&PF	Alaska Department of Transportation and Public Facilities
AEP	annual exceedance probability
EMA	Expected Moments Algorithm
FERC	Federal Energy Regulatory Commission
HEC-RAS	Hydrologic Engineering Center River Analysis System (U.S. Army Corps of Engineers)
IfSAR	Interferometric synthetic aperture radar
lidar	light detection and ranging
USGS	U.S. Geological Survey

Streambed Scour Evaluations and Conditions at Selected Bridge Sites in Alaska, 2013–15

By Robin A. Beebee, Karenth L. Dworsky, and Schyler J. Knopp

Abstract

Streambed scour potential was evaluated at 52 river- and stream-spanning bridges in Alaska that lack a quantitative scour analysis or have unknown foundation details. All sites were evaluated for stream stability and long-term scour potential. Contraction scour and abutment scour were calculated for 52 bridges, and pier scour was calculated for 11 bridges that had piers. Vertical contraction (pressure flow) scour was calculated for sites where the modeled water surface was higher than the superstructure of the bridge. In most cases, hydraulic models of the 1- and 0.2-percent annual exceedance probability floods (also known as the 100- and 500-year floods, respectively) were used to derive hydraulic variables for the scour calculations. Alternate flood values were used in scour calculations for sites where smaller floods overtopped a bridge or where standard flood-frequency estimation techniques did not apply. Scour also was calculated for large recorded floods at 13 sites.

Channel instability at 11 sites was related to human activities (in-channel mining, dredging, and channel relocation). Eight of the dredged sites are located on active unstable alluvial fans and were graded to protect infrastructure. The trend toward aggradation during major floods at these sites reduces confidence in scour estimates.

Vertical contraction and pressure flow occurred during the 0.2-percent or smaller annual exceedance probability floods at eight sites. Contraction scour exceeded 5 feet (ft) at four sites, and total scour at piers (pier scour plus contraction scour) exceeded 5 ft at four sites. Debris accumulation increased calculated pier scour at six sites by an average of 2.4 ft. Total scour at abutments exceeded 5 ft at 10 sites. Scour estimates seemed excessive at two piers where equations did not account for channel armoring, and at four abutments where failure of the embankment and attendant channel widening would reduce scour.

Introduction

Bridge foundations, including abutments and piers, depend on being embedded a certain depth into the streambed for stability. Scour refers to the removal of streambed material beneath a bridge, generally by hydraulic stresses exerted on the streambed and bridge foundation during floods (fig. 1). Scour has the potential to damage bridges by undermining or destabilizing the bridge foundation and is the leading cause of bridge failure in the United States (Lagasse and others, 2012). In 1998, the Federal Highway Administration established a policy that all bridges be assessed for scour potential. It is standard engineering practice for bridge engineers to evaluate scour potential during the design process and to plan foundations accordingly. However, a national inventory of bridges and engineering plans indicated that numerous bridges in Alaska lacked quantitative scour assessments and (or) detailed foundation information needed to categorize the vulnerability of the structure to damage or failure by scour. Some of these bridges are old and plans may have been lost, some were emergency replacements after floods, and others were intended to be temporary structures. A hydraulic assessment of streambed scour potential is needed in every case. The Alaska Department of Transportation and Public Facilities (ADOT&PF) intends to use these assessments to prioritize sites with a high potential for streambed scour for further investigation.

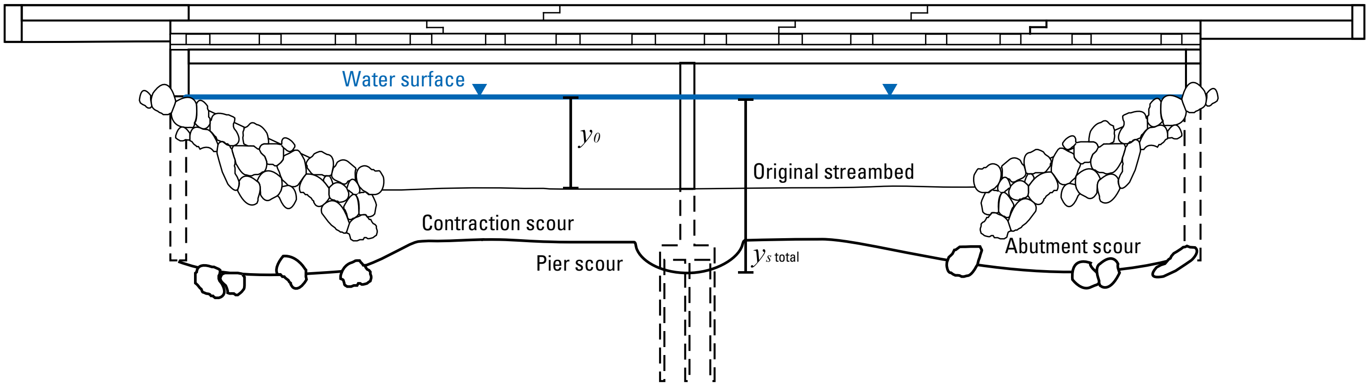


Figure 1. Example of streambed scour around a bridge foundation.

Scour is primarily a symptom of an undersized or misaligned bridge, and its severity depends on the extent to which a bridge is blocking natural flow paths during floods. Other factors include the mobility of streambed material, the magnitude of flood events that occur in the reach, embankment stability, debris accumulation, channel stability, and upstream sediment supply. Standard engineering methods do not account for every riverine process that influences scour (Conaway, 2007).

Purpose and Scope

This report describes methods and results of scour investigations at 52 bridges with unknown foundations or incomplete scour assessments and addresses geomorphic and human factors that may influence scour but are not accounted for in the calculations. Hydraulic models were developed and scour calculations were completed for all bridges following the guidance of Arneson and others (2012). Types of scour addressed include channel-wide scour caused by contraction of the channel width through the bridge, local scour around piers and abutments, and larger-scale instability of the river reach.

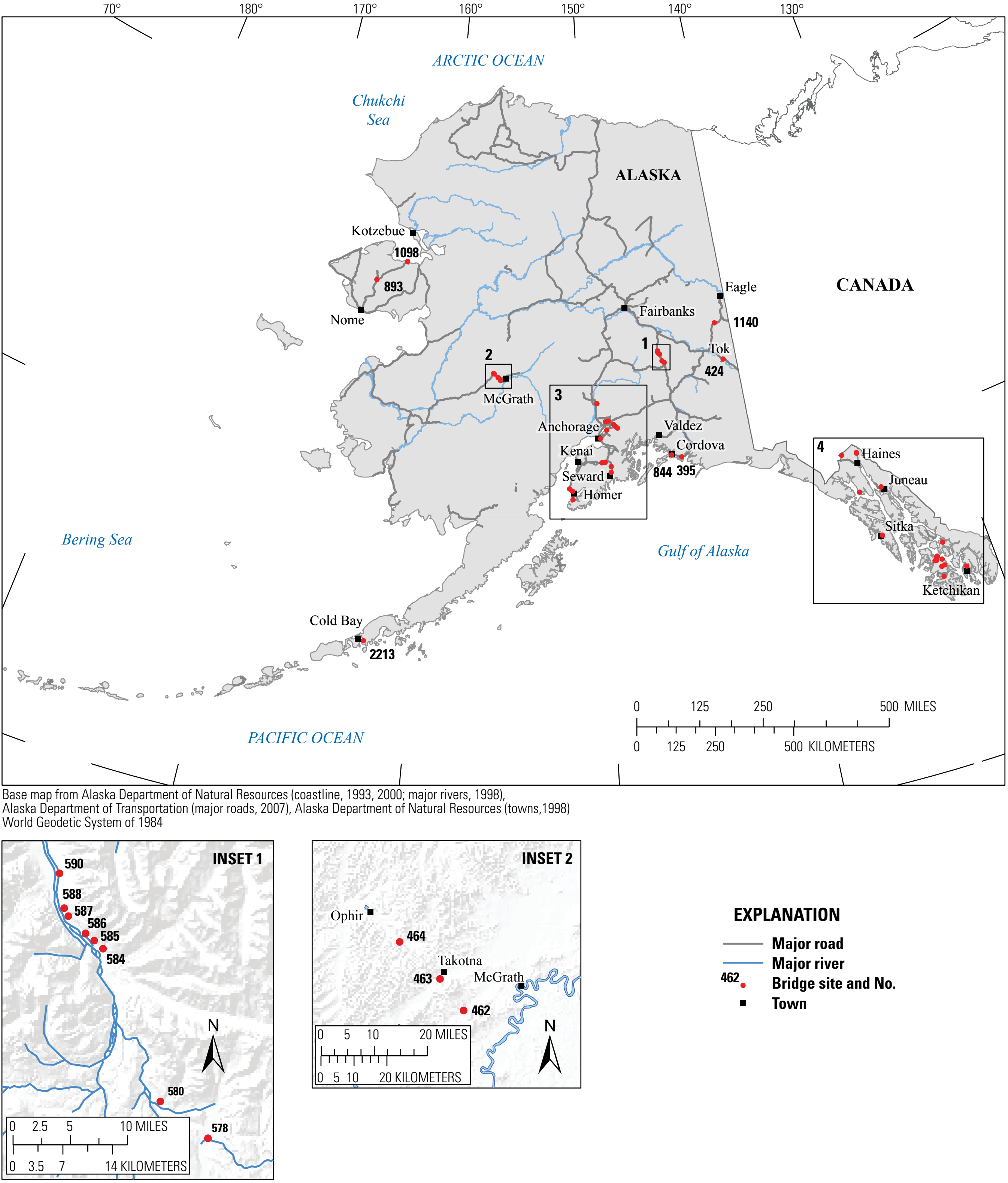
The U.S. Geological Survey (USGS) has been studying scour at bridges in Alaska since 1964 (Norman, 1975). In cooperation with the ADOT&PF, the USGS began a phased process in 1994 to provide hydraulic assessments of scour for bridges throughout Alaska (Heinrichs and others, 2001; Conaway, 2004; Conaway and Schauer, 2012; Beebee and Schauer, 2015). This study follows the approach of Beebee and Schauer (2015), using one-dimensional models and site-specific information, but includes updated methods for addressing unsteady flow, channel stability, flood frequency, abutment scour, and scour at piers in coarse-bedded streams.

The 52 sites selected by ADOT&PF for scour assessments are located throughout Alaska in different geographic and hydrologic settings (table 1 and fig. 2).

Table 1. Descriptions of selected bridge sites evaluated for scour in Alaska, 2013–15.

[**WGS 84:** World Geodetic System of 1984. **NBI Code 113:** The National Bridge Scour Critical code for bridge. T, bridge over tidal waterways with no scour analysis; U, bridge with unknown foundations and no scour analysis; 6, bridge with no scour analyses]

Bridge No. (fig. 2)	Stream name	Latitude (WGS 84)	Longitude (WGS 84)	Year built	NBI Code 113	Bridge length (feet)
395	Alaganik Slough	60°26′48″N	145°12′46″W	1987	T	160
433	Barabara Creek	59°28′42″N	151°38′42″W	1968	U	72
2213	Barney Creek	55°09′ 00″N	162°25′48″W	2006	U	100
1935	Bodenburg Creek	61°33′30″N	149°02′12″W	2002	U	39
588	Boulder Creek	63°26′48″N	145°51′06″W	1954	6	37
645	Campbell at Old Seward	61°10′12″N	149°52′18″W	1982	6	81
1140	Chicken Creek	64°04′48″N	141°57′30″W	1962	6	26
424	Chisana River	63°00′24″N	141°48′12″W	1944	6	252
2282	Coffman Creek	55°59′31″N	132°52′19″W	2006	6	80
674	Cooper Creek	60°32′12″N	150°45′18″W	1955	6	68
1021	Crescent Creek	60°29′48″N	149°40′42″W	1959	U	56
2283	Dog Creek	56°00′08″N	132°49′34″W	2006	6	38
2279	Dog Creek Tidal	56°00′43″N	132°46′19″W	1995	6	60
1463	Falls Creek	55°42′30″N	132°36′48″W	1975	U	57
586	Flood Creek	63°26′42″N	145°48′0″W	1954	6	37
1899	Georges Creek	61°28′00″N	148°48′12″W	1997	U	32
1900	Georges Creek	61°28′06″N	148°48′06″W	1997	U	32
445	Good River	58°24′54″N	135°46′18″W	1984	6	76
1821	Grouse Creek	60°11′18″N	149°23′18″W	1988	6	37
578	Gunn Creek	63°10′12″N	145°31′42″W	1954	6	81
590	Gunny Sack Creek	63°29′18″N	145°51′24″W	1954	6	47
2264	Harriet Hunt Creek	55°26′19″N	131°34′06″W	1961	6	53
3000	Hatchery Creek	55°54′29″N	132°55′52″W	2003	6	120
2129	Hatchery Creek Tributary	55°44′31″N	132°55′23″W	2006	6	93
844	Heney Creek	60°31′24″N	145°46′54″W	1936	6	56
1253	Hunter Creek	61°27′06″N	148°48′0″W	1995	6	80
1685	Jordan Creek	58°23′12″N	134°39′54″W	1982	U	77
893	Kougarok River	65°26′06″N	164°39′42″W	1941	U	183
1713	Little Susitna River Braid	61°40′42″N	149°18′48″W	1974	6	41
1717	Log Jam Creek	55°54′18″N	133°00′25″W	2003	6	96
580	McCallum Creek	63°14′18″N	145°38′54″W	1954	6	33
585	Michael Creek	63°26′06″N	145°46′48″W	1954	6	33
1669	Montana Creek	62°00′0″N	150°00′0″W	1988	U	202
1641	Nataga Creek	59°33′48″N	136°10′54″W	1984	U	48
1457	Newlunberry Creek	55°41′48″N	132°46′12″W	1975	U	54
1018	North Fork Anchor River	59°46′42″N	151°49′0″W	1965	6	43
1409	Pats Creek	56°20′06″N	132°20′12″W	1973	U	104
1501	Peters Creek	61°24′42″N	149°31′48″W	1989	U	61
432	Sawmill Creek	57°03′6″N	135°13′48″W	1962	6	165
1098	Smith Creek	66°04′18″N	162°43′24″W	1979	6	116
1199	South Fork Anchor River	59°42′06″N	151°37′54″W	1966	U	72
2138	Swiftwater Creek	61°39′00″N	149°30′24″W	2004	U	47
309	Taiya River	59°30′48″N	135°20′42″W	1946	U	205
463	Takotna River	62°58′06″N	156°05′24″W	1941	U	255
462	Tatalina River	62°53′6″N	155°56′24″W	1947	6	61
584	Trims Creek	63°25′24″N	145°45′18″W	1954	U	37
1731	Trocodero Creek	55°24′16″N	132°49′33″W	1964	U	92
2281	Trumpeter Creek	55°58′59″N	132°52′19″W	2006	6	95
607	Victor Creek	60°21′30″N	149°20′54″W	1952	6	198
1490	West Creek	59°31′36″N	135°21′0″W	1992	U	163
587	Whistler Creek	63°26′12″N	145°50′30″W	1954	6	37
464	Yankee Creek	63°03′54″N	156°20′24″W	1937	6	44



Base map from Alaska Department of Natural Resources (coastline, 1993, 2000; major rivers, 1998),
Alaska Department of Transportation (major roads, 2007), Alaska Department of Natural Resources (towns,1998)
World Geodetic System of 1984

Figure 2. Locations of selected bridge sites in Alaska where scour was evaluated.

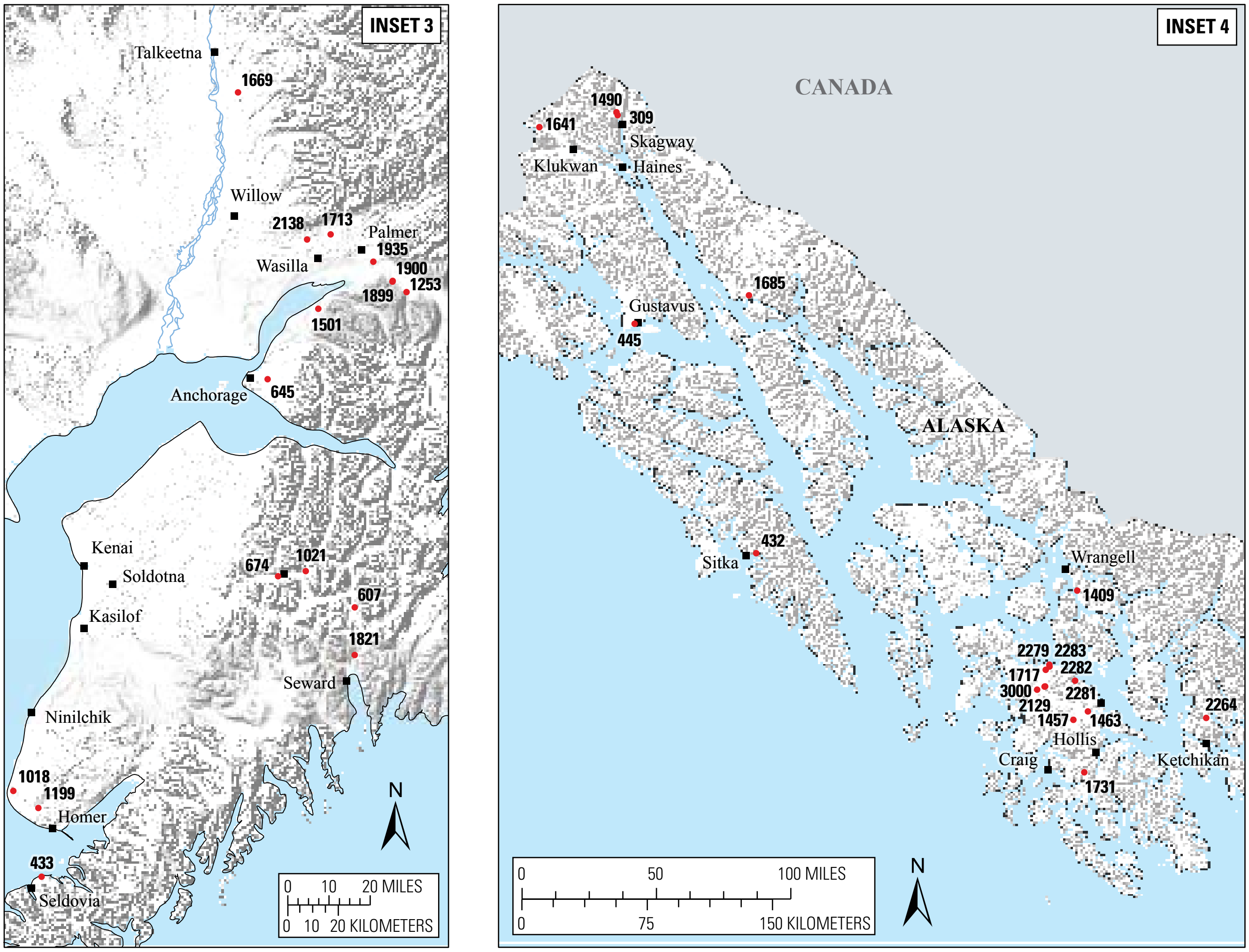


Figure 2.—Continued

Methods

Stream Stability and Geomorphic Assessment

Arneson and others (2012) recommended that a general assessment of stream stability, aggradation, or degradation following guidelines in Lagasse and others (2012) be done as a first step in a scour assessment. Many streams in Alaska are naturally unstable because of high gradient, large sediment supply, lack of containment, or relatively frequent overbank floods. Some also have been either destabilized or stabilized by human activity, including dredging, in-stream mining, and erosion control. These factors may influence the vulnerability of structures and embankments to scour and erosion. The general geomorphic setting of each stream channel was determined using aerial photographs, light detection and ranging (lidar), ADOT&PF bridge inspection reports, and on-site assessments by USGS personnel. Stream stability was classified qualitatively based on evidence of channel change, active sediment sources, and human disturbance (excluding the bridge).

Since 1998, ADOT&PF has done biannual soundings (depth-from-bridge measurements) on the upstream side of bridges in conjunction with bridge inspections. The USGS did soundings on the upstream and downstream sides of bridges for this study. Because ADOT&PF inspectors and the USGS personnel typically took depth measurements at different locations along the bridge face and used slightly different techniques, only the minimum bed elevation was compared between surveys done by the different agencies. The average change in minimum bed elevation between successive soundings (1–2 years apart) was used to look for evidence of channel aggradation or degradation, and the maximum change from the highest minimum bed elevation and the lowest minimum bed elevation was used to determine relative stream stability. Divisions in relative stream stability categories were based on natural breaks in the data. Stream size determines changes in bed elevation to some extent (Lagasse and others, 2012). In order to compare different sized streams, elevation changes were normalized by modeled 100-year channel width at the bridge opening. Sites with less than ±0.4 ft of relative change per 10 ft of channel width between surveys were considered stable, sites with greater than or equal to ±0.4 ft of change per 10 ft of channel width were considered less stable, and sites with greater than or equal to ±0.8 ft of change in minimum bed elevation per 10 ft of channel width were considered least stable.

Flood Frequency Calculations

It is standard engineering practice to design bridges to safely withstand the hydraulic conditions encountered during a large, rare flood, referred to as the design flood. Scour at the bridge site also is calculated for an even larger flood, known as the check flood or super flood. The design flood and check flood typically are 1- and 0.2-percent annual exceedance probability (AEP) floods (also referred to as “100- and 500-year recurrence interval floods”), respectively (Arneson and others, 2012). The AEP is the probability that a select flow will be equaled or exceeded annually. For example, a 0.01 AEP flow has a 1-percent chance of being equaled or exceeded in any given year. Smaller AEP (higher probability) floods also may be used as design floods or check floods if they exceed the channel capacity and intersect the superstructure of the bridge, causing pressure flow (Arneson and others, 2012). Scour was calculated for the 1- and 0.2-percent AEP floods or pressure flow floods, based on flood frequency calculations, with a few exceptions. The flood magnitudes used in this report may differ from the original design flood for the bridge.

Regional regression equations developed by Curran and others (2016) were used to calculate the 1- and 0.2-percent AEP floods. For sites with streamgages or crest-stage gages at or near the bridge, PeakFQ version 7.0 software (Veilleux and others, 2013) was used to do a modified Bulletin 17B flood-frequency analysis (Interagency Advisory Committee on Water Data, 1982). The modifications include the use of an Expected Moments Algorithm (EMA) and a multiple Grubbs-Beck test (Veilleux and others, 2013). The EMA allows more flexibility in incorporating observations and floods outside of the streamgage record. The multiple Grubbs-Beck test identifies and disregards low peak flows that may substantially influence the shape of the flood-frequency curve. The 1- and 0.2-percent AEP flows calculated for gaged sites with the EMA analysis were then combined with the regional regression analysis results to obtain a final weighted value as described in Curran and others (2016). The regression variables (drainage area and mean annual precipitation) used for each site and gaged period of record are shown in table 2.

Table 2. Variables used in the flood frequency analysis for selected bridges in Alaska, 2013–15.

[**Abbreviations and symbol:** in., inch ; mi^2, square mile; –, variables either are unavailable or are not used in flood frequency analysis]

Bridge No. (fig. 2)	Stream name	Streamgage No.	Period of record for peak streamflow analysis	Number of peaks	Drainage area (mi^2)	Mean annual precipitation (in.)
395	Alaganik Slough	–	–	–	24.7	166
433	Barabara Creek	15238820	1972–92, 2002	21	20.6	71
2213	Barney Creek	–	–	–	6.0	59
1935	Bodenburg Creek	–	–	–	0.6	15
588	Boulder Creek	–	–	–	3.5	47
645	Campbell at Old Seward	15274600	[1]2006–15	10	43.1	32
1140	Chicken Creek	–	–	–	17.6	13
424	Chisana River	15470000	1950–71	22	2,960.0	16

Table 2. Variables used in the flood frequency analysis for selected bridges in Alaska, 2013–15.—Continued

Bridge No. (fig. 2)	Stream name	Streamgage No.	Period of record for peak streamflow analysis	Number of peaks	Drainage area (mi²)	Mean annual precipitation (in.)
2282	Coffman Creek	–	–	–	4.8	94
674	Cooper Creek	15261000	1962–2012	23	49.3	62
1021	Crescent Creek	15254000	1950–83	34	31.6	56
2283	Dog Creek	–	–	–	2.1	90
2279	Dog Creek Tidal	–	–	–	3.0	87
1463	Falls Creek	–	–	–	3.4	126
586	Flood Creek	–	–	–	3.8	47
1900	Georges Creek	–	–	–	3.9	23
1899	Georges Creek	–	–	–	3.7	23.3
445	Good River	–	–	–	33.2	66
1821	Grouse Creek	15237730	1998–2015	17	5.9	66
578	Gunn Creek	–	–	–	50.6	29
590	Gunny Sack Creek	–	–	–	4.6	51
2264	Harriet Hunt Creek	–	–	–	3.0	156
3000	Hatchery Creek	–	–	–	38.2	106
2129	Hatchery Creek Tributary	–	–	–	1.8	110
844	Heney Creek	–	–	–	1.5	200
1253	Hunter Creek	–	–	–	69.3	41
1685	Jordan Creek	–	–	–	1.1	88
893	Kougarok River	–	–	–	53.5	15
1713	Little Susitna Braid	15290000	1949–2015	67	76.0	42.3
1717	Log Jam Creek	–	–	–	37.5	102
580	McCallum Creek	15478050	1967–91	25	15.0	36
585	Michael Creek	–	–	–	3.6	48
1669	Montana Creek	15292800	1963–72, 1986, 2005–15	20	157.3	34
1641	Nataga Creek	–	–	–	32.8	76
1457	Newlunberry Creek	–	–	–	0.8	69
1018	North Fork Anchor River	–	–	–	29.7	29
1409	Pats Creek	–	–	–	7.0	105
1501	Peters Creek	15277410	1974–95	22	86.9	108
432	Sawmill Creek	15088000	[2]2002–15	13	38.7	198
1098	Smith Creek	–	–	–	23.9	12
1199	South Fork Anchor River	–	–	–	120.2	31
2138	Swiftwater Creek	–	–	–	4.9	32
309	Taiya River	15056210	1967–2012	19	184.0	76
463	Takotna River	–	–	–	242.7	19
462	Tatalina River	15303700	1987–2012	25	75.8	17
584	Trims Creek	–	–	–	5.2	50
1731	Trocodero Creek	–	–	–	5.0	146
2281	Trumpeter Creek	–	–	–	15.8	109
607	Victor Creek	–	–	–	13.0	102
1490	West Creek	15056200	1962–77	16	43.0	74
587	Whistler Creek	–	–	–	3.0	35
464	Yankee Creek	–	–	–	24.0	19

[1] Campbell Creek streamgage (downstream of bridge) also operated between 1978 and 1992. However, this was prior to much of the urbanization of the basin, so these years were not used.

[2] Sawmill Creek streamgage also operated from 1921 to 1957. This was prior to the construction of the Blue Lake Dam and peaks measured after construction were significantly different.

Field Surveys and Data Sources

In addition to flood flows, the basic data needed for a scour evaluation using a one-dimensional model include:

1. Bridge geometry as measured in the field;
2. Channel and overbank geometry, including approach and exit cross sections located outside the expansion and contraction zone of the bridge and cross sections immediately upstream and downstream of the bridge;
3. Water-surface slope for boundary conditions;
4. Bed-material size for determination of live-bed or clear-water scour;
5. An estimate of the channel and flood plain Manning's roughness coefficients (n); and
6. A discharge measurement for model calibration.
7. Geometric, grain size, and Manning's n data and sources for each site are listed in table 3**.**

Stream Cross Sections and Bridge Geometry Surveys

A datum point established at each site was used to determine relative elevations of the channel cross sections and bridge geometry. Streambed elevations were measured at the upstream and downstream face of each bridge using either sounding weights on cable reels, weighted measuring tapes, or acoustic Doppler current profilers (ADCPs), depending on the depth and current. Channel cross sections and water-surface slopes were surveyed with either a total station or an optical level with a stadia rod and range finder. ADCPs were used to survey bathymetry where channels were too deep to wade. Bridge-deck elevation and slope, low-chord elevation, bridge width, and the location and dimensions of piers and footings also were measured if construction plans were insufficient. Overbank areas were sometimes either inaccessible or too thickly vegetated to survey. In these cases, elevations derived from lidar or USGS Digital Raster Graphic topographic maps supplemented the data on overbank geometry. Where stream gradients were low relative to errors in surveying, gradients were measured from lidar or topographic maps.

Discharge Measurements for Calibration

USGS crews measured discharge at every site except Chicken Creek Bridge 1140, which was dry at the time of the visit, and Yankee Creek Bridge 464, where flow was blocked by beaver dams. Discharge was measured with a current meter or an ADCP, depending on the size of the stream. All discharge measurements were obtained during low water conditions, except at Taiya River Bridge 309 and West Creek Bridge 1490, where discharge measurements were obtained during moderate flow conditions.

Grain-Size Analysis

Grain-size distribution, which is needed to check for live-bed or clear-water scour conditions and to calculate clear-water scour, was determined at all gravel-bedded sites using either a gravelometer or digital image analysis software (Bergendahl and Arneson, 2014). At eight sites, both methods were used. A sieve analysis was used for the four sand-bedded sites. Streambed material at all sites was greater than the 0.2-mm median diameter grain-size (D_{50}) threshold for cohesive behavior.

Hydraulic Model Development

The Hydrologic Engineering Center River Analysis System version 5.03 (HEC-RAS) (Brunner, 2016) was used to compute water-surface profiles and hydraulic variables needed for scour equations. HEC-RAS is a one-dimensional step-backwater model with steady- and unsteady-flow components.

HEC-RAS requires a flow file and geometry file to run. Steady-flow files include design floods and discharge measurements for model calibration and boundary conditions. Unsteady-flow files include a hydrograph for each flow and a downstream boundary condition. All sites used normal depth for the downstream boundary conditions for floods. The water-surface slope that was surveyed at low water initially was used as a downstream boundary condition. If the simulated water-surface profile showed a downturn or upturn at the downstream-most cross section, the slope was adjusted within reasonable limits to better match the simulated high-flow water-surface slopes. Subcritical, supercritical, or mixed-flow regime modes can be modeled. Flow conditions initially were assumed to be subcritical, but if HEC-RAS identified critical flow at a cross section, an upstream normal depth boundary condition was added to steady-flow models and the model was re-run in a mixed-flow regime. Surveyed water-surface elevations were compared to model simulation results and used to validate or refine channel roughness values.

Geometry files included 4–6 cross sections, following the suggestion in the HEC-RAS Hydraulic Reference Guide (Brunner, 2016). For the 2013 and 2014 sites, the channel elevations from the bridge soundings were used both for the internal bridge cross sections and for the two cross sections bounding the bridge, but the sections were shifted upstream and downstream 5–15 ft in the model to allow for contraction and expansion between the cross sections and the bridge and elevations were adjusted to match the gradient of the reach.

Table 3. Hydraulic modeling input data and sources from selected bridges in Alaska, 2013–15.

[D_{50}: Median grain diameter. D_{95}: Grain diameter that is greater than 95 percent of the population. **Abbreviations and symbol:** ADCP, acoustic Doppler current profiler; lidar, light detection and ranging; ifSAR, interferometric synthetic aperture radar; ft, foot; mm, millimeter; –, variables that were not used in analysis for that site]

Bridge No. (fig. 2)	Stream name	Manning's roughness coeffcient		Upstream boundary condition slope (ft/ft)	Downstream boundary condition slope (ft/ft)	Slope source	D_{50} (ft)	D_{50} (mm)	D_{95} (mm) for coarse-bed pier scour	Grain size source	Channel geometry source	Overbank geometry
		Channel	Overbank									
395	Alaganik Slough	0.035	0.09	0.0004	0.0004	Survey	0.0013	0.4	–	Sieve analysis	ADCP and total survey	Survey
433	Barabara Creek	0.05	0.1	0.03	0.0070	Survey	0.1001	30.5	–	Gravelometer	Level and soundings	IfSAR[1]
2213	Barney Creek	0.055	0.075	0.0190	0.0130	Survey	0.1389	42.3	–	Image analysis	Total survey and soundings	Survey
1935	Bodenburg Creek	0.04	0.1	0.0013	0.0045	Survey	0.0968	29.5	–	Gravelometer	Level and soundings	Lidar[2]
588	Boulder Creek	0.043	0.075	0.075	0.07	Survey	0.2560	78.0	–	Average of image analysis and gravelometer	Total survey and soundings	Lidar[3]
645	Campbell at Old Seward	0.052	0.075	0.0035	0.0035	Survey	0.0541	16.5	–	Gravelometer	Level and soundings	Lidar[4]
1140	Chicken Creek	0.06–0.065	0.06–0.065	0.0060	0.0060	Topographic maps	0.1575	48.0	–	Gravelometer	Total survey and soundings	Survey
424	Chisana River	0.032	0.12	0.0003	0.0003	Topographic maps	0.0014	0.4	–	Sieve analysis	ADCP and total survey	Lidar[4]
2282	Coffman Creek	0.045	0.1/0.075	0.007	0.007	Survey	0.0928	28.3	–	Gravelometer	Total survey and soundings	IfSAR[1]
674	Cooper Creek	0.043	0.1	0.0095	0.001	Survey	0.0636	19.4	–	Gravelometer	Level and soundings	Lidar[5]
1021	Crescent Creek	0.057	0.095	n/a	0.0150	Survey	0.0702	21.4	74	Gravelometer	Total survey and soundings	Survey
2283	Dog Creek	0.055	0.1	0.03	0.03	Survey	0.1903	58.0	–	Gravelometer	Total survey and soundings	IfSAR[1]
2279	Dog Creek Tidal	0.050	0.1	0.0127	0.0127	Survey	0.1206	36.8	–	Gravelometer	Total survey and soundings	IfSAR[1]
1463	Falls Creek	0.060	0.1	0.0215	0.0215	Survey	0.1181	36.0	–	Gravelometer	Total survey and soundings	IfSAR[1]

Table 3. Hydraulic modeling input data and sources from selected bridges in Alaska, 2013–15.—Continued

Bridge No. (fig. 2)	Stream name	Manning's roughness coefficient		Upstream boundary condition slope (ft/ft)	Downstream boundary condition slope (ft/ft)	Slope source	D_{50} (ft)	D_{50} (mm)	D_{95} (mm) for coarse-bed pier scour	Grain size source	Channel geometry source	Overbank geometry
		Channel	Overbank									
586	Flood Creek	0.050	0.07	0.0500	0.0300	Survey	0.3309	100.8	–	Average of image analysis and gravelometer	Total survey and soundings	Lidar[3]
1900	Georges Creek	0.055	0.1	0.0666	0.0666	Survey	0.0427	13.0	–	Gravelometer	Level and soundings	Lidar[2]
1899	Georges Creek	0.055	0.1	0.06	0.087	Survey	0.1542	47.0	–	Gravelometer	Level and soundings	Lidar[2]
445	Good River	0.030	0.045	0.0015	0.0015	Survey	0.0010	0.3	–	Sieve analysis	Total survey and soundings	Survey
1821	Grouse Creek	0.030	0.05/0.08	0.0030	0.0030	Lidar	0.0266	8.1	–	Gravelometer	Level and soundings	Lidar[6]
578	Gunn Creek	0.045/0.035	0.075	0.0060	0.0060	Topographic maps	0.0591	18.0	–	Gravelometer	ADCP and total survey	Lidar[3]
590	Gunny Sack Creek	0.055	0.065	0.0300	0.0400	Upstream of topographic map, downstream of survey	0.3353	102.2	–	Average of image analysis and gravelometer	Total survey and soundings	Lidar[3]
2264	Harriet Hunt Creek	0.055	0.15	0.0100	0.0060	Survey	0.0846	25.8	–	Gravelometer	Total survey and soundings	Survey
3000	Hatchery Creek	0.050	0.1	0.0040	0.0040	Topographic maps	0.1575	48.0	–	Gravelometer	Total survey and soundings	IfSAR[1]
2129	Hatchery Creek Tributary	0.055	0.1	0.0100	0.0200	Survey	0.1378	42.0	–	Gravelometer	Total survey and soundings	IfSAR[1]
844	Heney Creek	0.065/0.075	0.1	0.02	0.02	Survey	0.0705	21.5	–	Image analysis	Total survey and soundings	Survey
1253	Hunter Creek	0.035	0.08/0.09	0.0120	0.0120	Survey	0.1542	47.0	–	Gravelometer	Level and soundings	Lidar[2] and survey
1685	Jordan Creek	0.045	0.1	0.004	0.004	Lidar	0.0023	0.7	–	Sieve analysis	Total survey and soundings	Lidar[7]

Table 3. Hydraulic modeling input data and sources from selected bridges in Alaska, 2013–15.—Continued

Bridge No. (fig. 2)	Stream name	Manning's roughness coeffcient		Upstream boundary condition slope (ft/ft)	Downstream boundary condition slope (ft/ft)	Slope source	D_{50} (ft)	D_{50} (mm)	D_{95} (mm) for coarse-bed pier scour	Grain size source	Channel geometry source	Overbank geometry
		Channel	Overbank									
893	Kougarok River	0.040	0.07	0.0020	0.0020	Survey	0.2323	70.8	–	Average of image analysis and gravelometer	Total survey and soundings	Survey
1713	Little Susitna River Braid	0.040	0.1	0.0070	0.0100	Lidar	0.1312	40.0	–	Gravelometer	Level and soundings	Lidar[2]
1717	Log Jam Creek	0.040	0.1	n/a	0.0050	Topographic maps	0.1785	54.4	–	Gravelometer	Total survey and soundings	Survey
580	McCallum Creek	0.043	0.043	0.0190	0.0120	Survey	0.2400	73.1	–	Average of image analysis and gravelometer	Total survey and soundings	Lidar[3]
585	Michael Creek	0.062	0.07	0.0500	0.0500	Survey	0.1624	49.5	–	Average of image analysis and gravelometer	Total survey and soundings	Lidar[3]
1669	Montana Creek	0.04–0.055	0.075–0.1	n/a	0.007	Lidar	0.1739	53.0	–	Gravelometer	Level and soundings	Lidar[2]
1641	Nataga Creek	0.050	0.1	n/a	0.0160	Survey	0.2874	87.6	–	Image analysis	Level and soundings	IfSAR[1]
1457	Newlunberry Creek	0.060	0.1	0.0200	0.0200	Survey	0.1673	51.0	–	Gravelometer	Total survey and soundings	IfSAR[1]
1018	North Fork Anchor River	0.050	0.1	0.0070	0.0070	Survey	0.0994	30.3	–	Gravelometer	Level and soundings	Lidar[5]
1409	Pats Creek	0.045	0.1	n/a	0.0160	Survey	0.1345	41.0	88	Image analysis	Total survey and soundings	IfSAR[1]
1501	Peters Creek	0.050	0.08	n/a	0.017	Survey	0.2083	64.9	–	Image analysis	Level and soundings	Lidar[4]
432	Sawmill Creek	0.045	0.06–0.1	n/a	0.003	Lidar	0.2363	72.0	–	Image analysis	Total survey and soundings	Lidar[8]
1098	Smith Creek	0.040	0.07	0.0010	0.0010	Survey	0.1020	31.1	–	Image analysis	Total survey and soundings	Survey
1199	South Fork Anchor River	0.040	0.095	0.0017	0.0017	Lidar	0.1427	43.5	–	Gravelometer	Level and soundings	Lidar[5]

Table 3. Hydraulic modeling input data and sources from selected bridges in Alaska, 2013–15.—Continued

Bridge No. (fig. 2)	Stream name	Manning's roughness coeffcient		Upstream boundary condition slope (ft/ft)	Downstream boundary condition slope (ft/ft)	Slope source	D_{50} (ft)	D_{50} (mm)	D_{95} (mm) for coarse-bed pier scour	Grain size source	Channel geometry source	Overbank geometry
		Channel	Overbank									
2138	Swiftwater Creek	0.065	0.075/0.1	n/a	0.0300	Survey	0.1493	45.5	–	Gravelometer	Level and soundings	Lidar[2]
309	Taiya River	0.035	0.07	0.0020	0.0020	Topographic maps	0.1083	33.0	–	Image analysis	ADCP and total survey	IfSAR[1]
463	Takotna River	0.035	0.075	0.0005	0.0005	Survey	0.1450	44.2	–	Image analysis	ADCP and total survey	Survey
462	Tatalina River	0.045	0.1	0.0020	0.0020	Survey	0.0827	25.2	–	Gravelometer	Total survey and soundings	Survey
584	Trims Creek	0.063/0.064	0.075	0.0400	0.0400	Survey	0.2428	74.0	–	Average of image analysis and gravelometer	Total survey and soundings	Lidar[3]
1731	Trocodero Creek	0.050	0.1	0.0090	0.0090	Survey	0.1378	42.0	–	Gravelometer	Total survey and soundings	IfSAR[1]
2281	Trumpeter Creek	0.065	0.1	0.0076	0.0076	Survey	0.0853	26.0	–	Gravelometer	Total survey and soundings	IfSAR[1]
607	Victor Creek	0.055	0.1	0.0176	0.0176	Survey	0.1598	48.7	467	Gravelometer	Level and soundings	Lidar[6]
1490	West Creek	0.045	0.1	0.0090	0.0090	Survey	0.1083	33.0	–	Image analysis	Total survey and soundings	IfSAR[1]
587	Whistler Creek	0.058	0.075	n/a	0.0360	Survey	0.1870	57.0	–	Average of image analysis and gravelometer	Total survey and soundings	Lidar[3]
464	Yankee Creek	0.045	0.07	0.0033	0.0033	Topographic maps	0.0742	22.6	–	Image analysis	Total survey and soundings	Survey, with endpoints extended to contain flow

[1] IfSAR.

[2] 2011 Matanuska-Susitna Lidar.

[3] 2011 infrastrucutre Corridor Lidar.

[4] 2015 Anchorage Lidar.

[5] Kenai Peninsula Lidar.

[6] Seward Area Lidar.

[7] Juneau Area Lidar.

[8] Blue Lake Hydroelectric Area Lidar.

For the 2015 sites, additional cross sections upstream and downstream of the bridge were surveyed, and the soundings were only used for the internal bridge cross sections. The approach and exit sections were located during the survey outside the probable contraction and expansion zones upstream and downstream of the bridge.

Channel roughness coefficients at the discharge measurement sites were computed using Manning's equation. Roughness coefficient values for the overbanks were determined using visual methods following Chow (1959) and Hicks and Mason (1998). In most cases, measured discharge was extremely low relative to flood discharges, and channel roughness coefficients derived from Manning's roughness equation were unrepresentative of expected conditions. The channel roughness coefficients also were estimated using visual methods (Chow, 1959; Hicks and Mason, 1998). Because Manning's roughness coefficient can change with flow, it was varied within a reasonable range to improve model stability at the 1- and 0.2-percent AEP flows. Manning's roughness varied from cross section to cross section if there were significant changes in overbank vegetation.

In most cases, geometry was compiled from survey data and entered manually in HEC-RAS. However, where overbank flow was significant, and water-surface profiles depended on topographic detail in the flood plains, the geometry was supplemented with overbank elevations from lidar data, georeferenced topographic maps, or IfSAR (interferometric synthetic aperture radar)-derived elevation data. Incorporating overbank data from other sources is primarily helpful in identifying preferential flow paths in complex flood plains and determining where overflow of the bridge approaches might occur.

Scour Calculations

Methods for calculating scour varied with site conditions. Sediment transport conditions upstream of the bridge determined whether live-bed or clear-water equations were used. Pier-scour methods included both simple and complex pier scour, depending on the geometry of the exposed pier, and accounted for the effects of debris accumulations. Pier scour is additive with contraction scour. A single abutment scour method that incorporates contraction scour was used for all sites to estimate total scour depth at each abutment.

Contraction Scour

Contraction scour can have horizontal and vertical components. Horizontal contraction scour is caused by road approach embankments and abutments in the flood plain or main channel that intercept flow and direct it through the bridge opening. Vertical contraction scour occurs when the superstructure of the bridge (girders, deck, curb, and railing) intercepts the water surface, creating pressure flow conditions. In both cases, contraction scour occurs because, as flow accelerates through a smaller cross section, velocity and shear stress increase and transport streambed material downstream. As scour deepens a channel, cross-sectional area increases and shear stress and velocity decrease until scour reaches equilibrium depth (also referred to as the depth of maximum scour). Contraction scour is calculated and presented as a uniform lowering of the streambed across the channel cross section (fig. 3), but it rarely actually works that way because some areas of the streambed are more erodible than other areas, and flow is not evenly distributed across the channel. Contraction scour is calculated differently depending on the sediment transport properties of the approach channel, whether pressure flow is present, and whether streambed material is cohesive or non-cohesive. All methods assume that the simulated flood lasts long enough to cause maximum scour, and that the width of the contracted section remains constant and only depth increases until equilibrium depth is reached. In practice, erosion of embankments under a bridge often causes the channel to widen and deepen during a flood.

Clear-Water Compared with Live-Bed Contraction Scour

Cohesionless contraction scour is calculated differently depending on whether the approach channel is transporting sediment into the bridge section (live-bed scour) or not (clear-water scour). For live-bed conditions, maximum scour depth is reached when sediment transported out of the bridge section equals the sediment transported in from the approach section. For clear-water conditions, maximum scour depth is reached when the shear stress in the bridge section decreases to the critical shear stress of the bed material in the section and sediment transport ceases.

Live-bed or clear-water conditions for each simulated flow were determined by using equation 1 to compare the simulated velocity in the approach cross section with the critical velocity necessary to transport the median grain size (D_{50}). If the simulated velocity in the approach cross section did not exceed the critical velocity needed to transport the median grain size, then clear-water scour equations were used. If the simulated velocity at the approach cross section exceeded the critical velocity needed to transport the median grain size, then live-bed equations were used to calculate scour. If physical evidence of either live-bed or clear-water conditions were observed in the field, these observations were used to determine which equation to use. For instance, in some cases, scour holes were evident in the field, but the applicable equation predicted no scour. In cases of extreme backwater, such as those that occur when flow reaches the superstructure of the bridge, the velocity in the approach section will drop below the critical velocity for sediment transport, and scour will change from a live-bed to a clear-water condition at the bridge (Arneson and others, 2012). This can cause conditions at a site to change from live-bed to clear-water between the design and check floods.

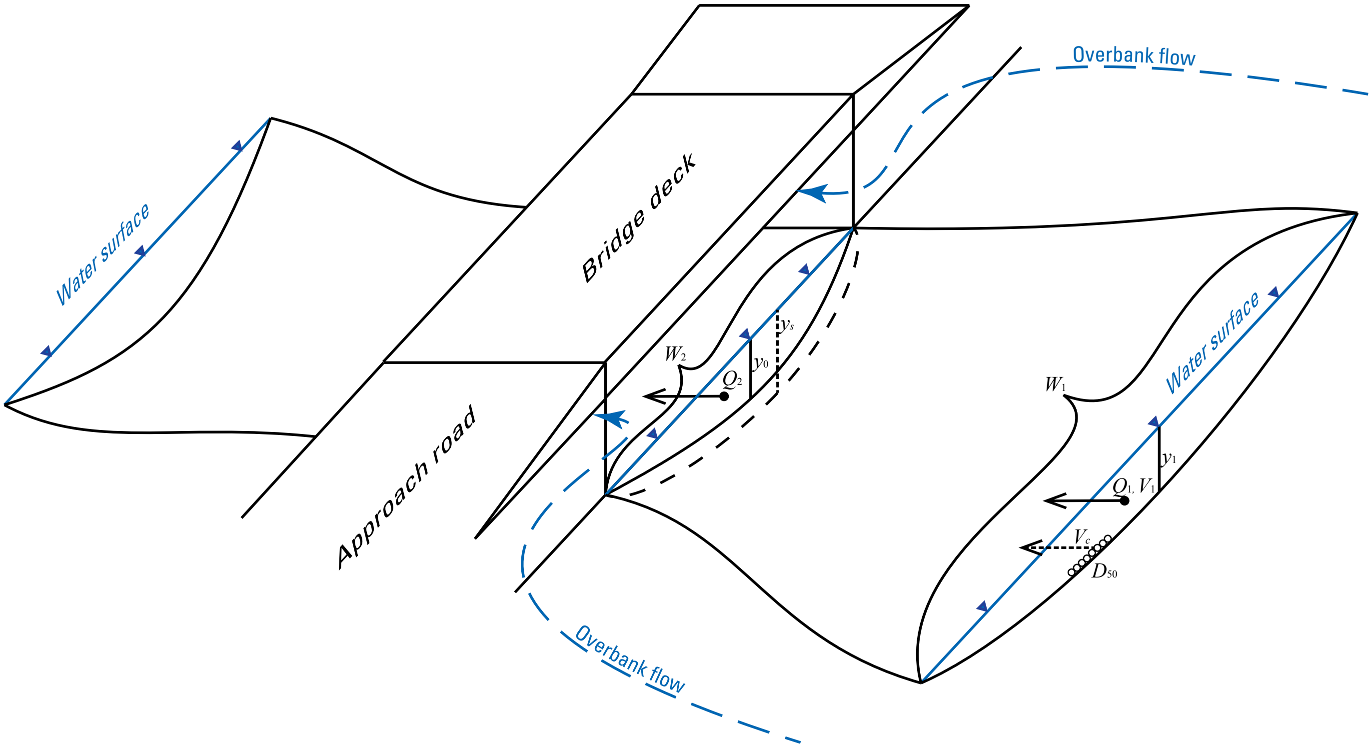


Figure 3. Basic contraction scour conditions and variables defined in equations 1–3.

$$V_c = 11.17 y^{1/6} D_{50}{}^{1/3} \qquad (1)$$

where

V_c is the critical velocity above which D_{50} grain size and smaller will be transported, in feet per second;
y^1 is the average depth of flow upstream of the bridge, in feet; and
D_{50} is the median diameter of bed material, in feet.

Live-Bed Contraction Scour

Live-bed contraction scour is calculated using equation 2 (Arneson and others, 2012). The equation depends on the ratios of discharge and width between the approach section and the contracted section, as well as the depths in the approach section and contracted section. The live-bed equation will only estimate scour if there is a decrease in width and (or) an increase in discharge between the approach channel and the bridge section. Because it does not include grain size, the live-bed equation may overestimate actual scour when the contracted section is armored.

$$y_s = y_1 \left[\left(\frac{Q_2}{Q_1} \right)^{\frac{6}{7}} \left(\frac{W_1}{W_2} \right)^{k_1} \right] - y_0 \qquad (2)$$

where

y_s is the live-bed average contraction scour depth, in feet;
y_1 is the average depth in the main channel of the approach section, in feet;
y_0 is the average depth in the contracted section before scour, in feet;
Q_1 is the discharge in the main channel of the approach section that is transporting sediment, in cubic feet per second;
Q_2 is the discharge in the contracted section (bridge), in cubic feet per second;
W_1 is the width of the main channel of the approach section that is transporting sediment, in feet;
W_2 is the width (less pier widths) of the of the main channel in the contracted section (bridge) that is transporting sediment, in feet; and
k_1 is a coefficient determined by comparing shear velocity to the fall velocity of the D_{50} bed material (see Arneson and others, 2012, p 6.10), which varies from 0.59 to 0.69.

Clear-Water Contraction Scour

If the velocity in the approach channel is less than the critical velocity for sediment transport, Arneson and others (2012) recommended using the clear-water contraction scour equation (eq. 3). The clear-water equation depends only on conditions in the contracted section, and will calculate increasing scour for decreasing median sediment size. The clear-water equation will overestimate scour when the approach section velocity is less than the critical velocity, but the bridge section is narrow and deep, or when the bridge channel is armored with gravel significantly larger than the median. The clear-water equation does not take into account the relative widths of the approach channel and bridge section, so no physical contraction is necessary to produce contraction scour.

$$y_s = \left[\frac{0.0077Q^2}{\left(1.25D_{50}\right)^{2/3} W^2} \right]^{3/7} - y_0 \qquad (3)$$

where

y_s is the clear-water average contraction scour depth, in feet;
y_0 is the average depth in the contracted section before scour, in feet;
Q is the discharge in the contracted section, in cubic feet per second;
W is the width (less pier widths) of the of the main channel in the contracted section that is transporting sediment, in feet; and
D_{50} is the median diameter of bed material, in feet.

Vertical Contraction Scour

When flow is intercepted by the superstructure of a bridge and, therefore, no longer has a free surface, it undergoes vertical and horizontal contraction. These pressure flow conditions produce additional forces on the streambed and greater stress on the bridge (fig. 4). New bridges are designed with freeboard above the design scour floods to avoid vertical contraction, but some existing bridges are undersized relative to flooding that has occurred since they were designed and built. The 1- or 0.2-percent AEP (or historical) flows produced vertical contraction conditions at eight of the study sites. Vertical contraction scour without overtopping is calculated for live-bed and clear-water conditions using equations 4 and 5, respectively (Arneson and others, 2012 and Shan and others, 2012). The equations are similar to those for horizontal contraction scour, but include a term comparing the depth of flow upstream of the bridge with the vertical opening of the bridge. The second term of both equations represents the estimated thickness of the separation zone, or zone of no flow, that forms under the downstream bridge superstructure (t in fig. 4). The separation zone further contracts the flow and increases scour. Equations 4 and 5 assume that the flow depth upstream of the bridge is greater than the

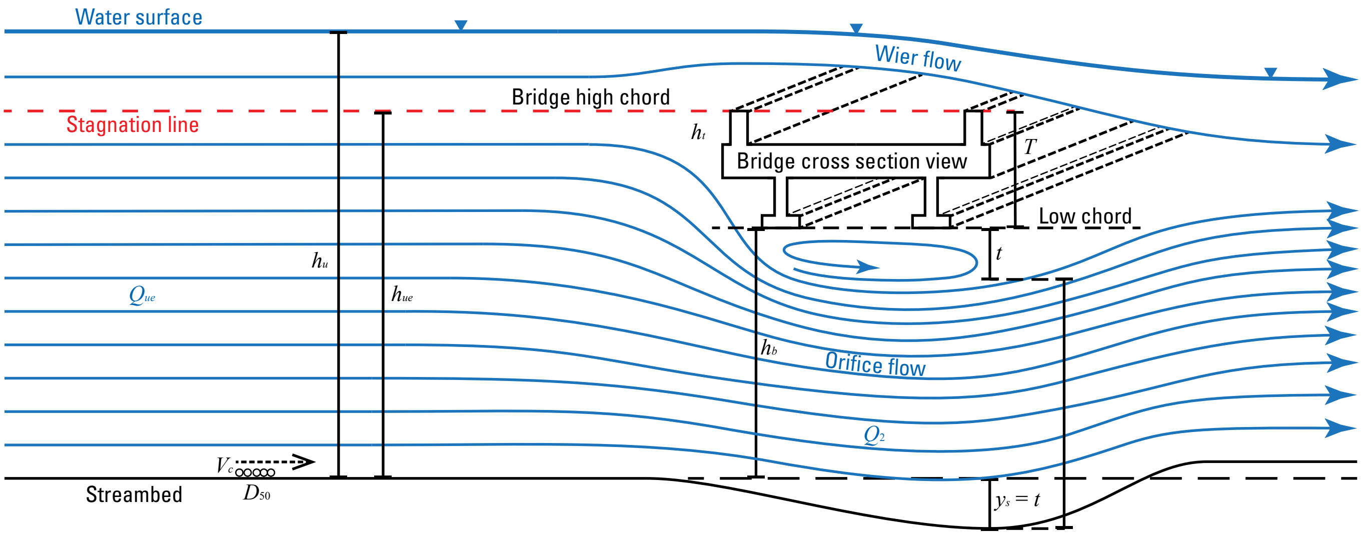


Figure 4. Example of vertical contraction scour and variables used to calculate scour.

flow depth under the bridge (thus vertical contraction occurs). At four sites, scour had already occurred under the bridge, making the second term negative. For these sites, we assumed that the unscoured channel elevation was equivalent to the channel elevation immediately upstream, as with the illustration in figure 4, and adjusted the bridge opening height (*hb*) accordingly. One site was overtopped and had weir flow over the deck of the bridge. Equation 6 describes clear-water scour for overtopping situations, where separation zone thickness *t* is calculated with an additional term to account for the depth of flow over the bridge (eq. 6).

$$y_s = \left[\left(\frac{Q_2}{Q_1} \right)^{6/7} \left(\frac{W_1}{W_2} \right)^{k_1} h_u \right] + \left[0.5 \left(\frac{h_b \left(h_u - h_b \right)}{h_u^{\,2}} \right)^{0.2} h_b \right] - h_b \tag{4}$$

where

y_s is the live-bed average vertical contraction scour depth, in feet;

Q_1 is the discharge in the main channel of the approach section that is transporting sediment, in cubic feet per second;

Q_2 is the discharge in the contracted section, in cubic feet per second;

W_1 is the width of the main channel of the approach section that is transporting sediment, in feet;

W_2 is the width (less pier widths) of the of the main channel in the contracted section that is transporting sediment, in feet;

h_u is the average depth in the upstream channel, in feet;

h_b is the vertical size of the bridge opening (low chord to average bed elevation) prior to scour, in feet; and

k_1 is a coefficient determined by comparing shear velocity to the fall velocity of the D_{50} bed material (see Arneson and others, 2012, p 6.10), which varies from 0.59 to 0.69.

$$y_s = \left[\frac{0.0077 Q_2^{\,2}}{(1.25 D_{50})^{2/3} W_2^{\,2}} \right]^{3/7} + \left[0.5 \left(\frac{h_b \left(h_u - h_b \right)}{h_u^{\,2}} \right)^{0.2} h_b \right] - h_b \tag{5}$$

where

y_s is the clear-water average vertical contraction scour depth, in feet;
Q_2 is the discharge in the contracted section, in cubic feet per second;
W_2 is the width (less pier widths) of the of the main channel in the contracted section, in feet;
D_{50} is the median diameter of bed material, in feet;
h_b is the vertical size of the bridge opening (low chord to average bed elevation) prior to scour, in feet; and
h_u is the average depth in the upstream channel, in feet.

$$y_s = \left[\frac{0.0077 Q_2^{\,2}}{(1.25 D_{50})^{2/3} W_2^{\,2}} \right]^{3/7} + \left[0.5 \left(\frac{h_b (h_u - h_b)}{h_u^{\,2}} \right)^{0.2} \left(1 - \frac{(h_u - h_b - T)}{(h_u - h_b)} \right)^{-0.1} h_b \right] - h_b \qquad (6)$$

where

T is the height of the obstruction caused by the bridge superstructure, including the girders, deck, and parapet, in feet.

Pier Scour

The undermining of bridge piers from scour is a major cause of bridge failure. During floods, piers obstruct flow and cause water to pile up at the upstream end of the pier (fig. 5). This creates horseshoe-shaped vortices that plunge downward around the nose of the pier, scouring bed material from around the base. Scour continues until it reaches an equilibrium depth where the vortices are no longer strong enough to move bed material, similar to contraction scour. Arneson and others (2012) recommended use of equation 7 for most conditions. Tables for each of the correction factors K_1 to K_3 are in Arneson and others (2012, chap. 7). Pier scour depends primarily on flow depth immediately upstream of the pier, velocity at the pier, and the width of the pier. Bridges with elongated piers or closely spaced multiple columns are vulnerable to pier scour when the pier is not aligned with the flow direction. This increases the obstruction to flow caused by the pier, similar to increasing the width of the pier. An upper bound for scour depths at cylindrical or round-nosed piers aligned to flow is 2.4 times the pier width (Arneson and others, 2012). Equation 7 does not include the wide pier correction factor (K_w in Arneson and others, 2012) because no piers met the wide pier criteria, or the effects of armoring by coarse bed material (formerly accounted for with the K_4 coefficient).

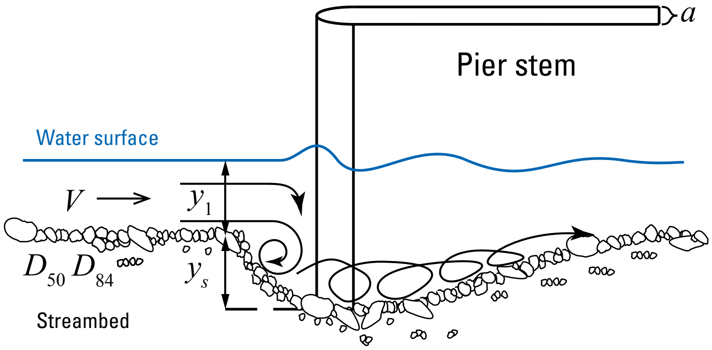


Figure 5. Example of pier scour with variables used to calculate scour.

$$y_s = 2y_1K_1K_2K_3\left(\frac{a}{y_1}\right)^{0.65}\left(\frac{V_1}{\sqrt{gy_1}}\right)^{0.43} \tag{7}$$

where

y_s is the pier scour depth, in feet;
K_1 is the correction factor for pier nose shape;
K_2 is the correction factor for angle of attack of flow;
K_3 is the correction factor for bed condition;
y_1 is the flow depth directly upstream of the pier, in feet;
a is the pier width, in feet;
V_1 is the mean velocity directly upstream of the pier, in feet per second; and
g is the acceleration of gravity, 32.2 feet per square second.

Coarse-Bed Pier Scour

Equation 8 is for the special case of pier scour in clear-water conditions where the D_{50} grain size is 20 mm or greater and the ratio of D_{84} to D_{50} is 1.5 or greater.

$$y_s = 1.1K_1K_2a^{0.62}y_1^{0.38}\tanh\left(\frac{H^2}{1.97\sigma^{1.5}}\right) \tag{8}$$

$$H = \left(\frac{V_1}{\sqrt{g\left(S_g - 1\right)D_{50}}}\right) \tag{8.1}$$

$$\sigma = \frac{D_{84}}{D_{50}} \tag{8.2}$$

where

H is the densimetric particle Froude number (eq. 8.1);
S_g is the sediment specific gravity (assumed to be 2.65);
σ is the sediment gradation coefficient, must be 1.5 or greater (eq. 8.2); and
D_{84} is the grain diameter of which 84 percent are smaller, in feet.

Pier Scour With Debris

When debris accumulates on piers, it obstructs flow and may direct flow downward, resulting in additional scour. Arneson and others (2012) recommend doing a debris analysis for bridges with piers and incorporating the effects of debris accumulations in the pier-scour estimate. Of the 11 bridge sites with piers, 5 have noted debris accumulations in ADOT&PF inspection reports, or had debris on the pier during field surveys. The size and shape (rectangular or triangular) of the debris accumulation are the most important factors influencing the hydraulics around piers with debris. A reasonable debris length, width, and shape for each site were determined using ADOT&PF site inspection reports and photographs. Equation 9 was then used to calculate an effective pier width (a^*_d) to replace a in equation 7 or 8.

$$a^{*}_{d} = \frac{K_1(HW) + (y - K_1 H)a}{y} \tag{9}$$

where

a^{*}_{d} is the effective width of a pier with debris present, in feet;
a is the width of the pier, without debris, perpendicular to the flow, in feet;
K_1 is a debris shape factor (0.79 for rectangular debris and 0.21 for triangular debris);
H is the height, or thickness, of the debris, in feet;
W is the width of debris perpendicular to the flow direction, in feet; and
y is the depth of approach flow, in feet.

Complex Pier Scour

Piers with footings that are exposed to streamflow undergo greater scour owing to complex hydraulics around the footing and pile group (fig. 6). Footings are wider and longer than the area of the pier designed to be in the flow, and when they are exposed to streamflow they have greater hydraulic resistance to flow and can amplify local scour. Bridge 432 over Sawmill Creek and Bridge 607 over Victor Creek have shallow footings, and the complex pier-scour equations were used to evaluate total pier scour (eqs. 10–14). Complex piers are broken down into a pier stem component, a footing component, and a pile group component, which are added together to get total pier scour. Each component is calculated using the basic pier-scour equation 7, with variables including pier width, depth, and velocity adjusted for each component in a different way. The coefficients K_1, K_2, and K_3 are determined the same way as in equation 7. Pile cap scour is calculated differently depending on whether the pile cap is above the streambed with an exposed pile group. The pile cap is expected to be undermined at Victor Creek Bridge 607; thus, equation 12 is used to calculate pile cap scour and equation 14 is used to calculated pile group scour. Sawmill Creek Bridge 432 is on a footing with no piles; thus, pile cap scour is calculated using equation 13. Many of the same variables are used in the complex pier equations. Each variable is defined the first time it is used in equations 10–14. Variables shown are applicable to the two sites with complex piers in this study. Slightly different versions of the equations would be used for very wide piers or sand-bedded channels.

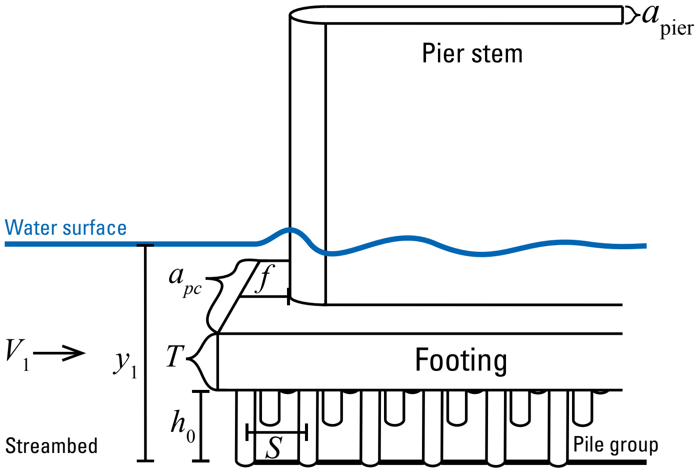


Figure 6. Example of complex pier-scour components and variables used to calculate scour using equations 10–14.7.

Total Complex Pier Scour

$$y_s = y_{s\ pier} + y_{s\ pc} + y_{s\ pg} \tag{10}$$

where

y_s is the complex pier-scour depth, in feet;
$y_{s\ pier}$ is the pier-stem scour depth, in feet (eq. 11);
$y_{s\ pc}$ is the pile cap or footing-scour depth, in feet (eq. 12 or 13); and
$y_{s\ pg}$ is the pile group scour depth, in feet (eq. 14).

Pier Stem Scour

$$y_{s\ pier} = y_1 K_{hpier}\left[2K_1K_2K_3\left(\frac{a_{pier}}{y_1}\right)^{0.65}\left(\frac{V_1}{\sqrt{gy_1}}\right)^{0.43}\right] \tag{11}$$

$$\begin{aligned} K_{hpier} = {} & \left(0.4075 - 0.0669\frac{f}{a_{pier}}\right) - \left(0.4271 - 0.0778\frac{f}{a_{pier}}\right)\frac{h_1}{a_{pier}} \\ & + \left(0.1615 - 0.0455\frac{f}{a_{pier}}\right)\left(\frac{h_1}{a_{pier}}\right)^2 - \left(0.0269 - 0.012\frac{f}{a_{pier}}\right)\left(\frac{h_1}{a_{pier}}\right)^3 \end{aligned} \tag{11.1}$$

$$h_1 = h_0 + T \tag{11.2}$$

where

f is the distance between the front edge of the pile cap or footing and the pier, in feet;
a_{pier} is the pier width, in feet;
h_0 is the pile cap above the bed at the beginning of the calculation, in feet;
T is the thickness of the pile cap or footing, in feet;
k_1 is the correction factor for the pier nose shape;
k_2 is the correction factor for the angle of attack of flow;
k_3 is the correction factor for bed condition;
y_1 is the approach flow depth at the beginning of the calculation, in feet;
V_1 is the approach velocity used at the beginning of the calculation, in feet per second; and
g is the acceleration of gravity, 32.2 feet per square second.

Pile Cap Scour (Case 1, Pile Cap above Streambed)

$$y_{2\ pc} = y_2 2K_1K_2K_3\left(\frac{a*_{pc}}{y_2}\right)^{0.65}\left(\frac{V_2}{\sqrt{gy_2}}\right)^{0.43} \tag{12}$$

$$y_2 = y_1 + \frac{y_{spier}}{2}\cdots\left(y_2 \le 3.5a_{pc}\right) \tag{12.1}$$

$$a^*_{pc} = a_{pc} e^{\left\{ -2.705 + 0.51 \ln\left(\frac{T}{y_2}\right) - 2.783\left(\frac{h_2}{y_2}\right)^3 + \frac{1.751}{e^{\frac{h_2}{y_2}}} \right\}} \qquad (12.2)$$

$$V_2 = V_1 \left(\frac{y_1}{y_2} \right) \qquad (12.3)$$

$$h_2 = h_0 + \frac{y_{spier}}{2} \qquad (12.4)$$

where

y_2 is the adjusted depth of flow upstream of the pier, including contraction scour and one-half of the pier stem scour, in feet (eq. 12.1);

a^*_{pc} is the adjusted pile cap width, in feet (eq. 12.2);

a_{pc} is the pile cap or footing width, in feet;

e is the natural logarithm base 2.71828…;

V_2 is the adjusted approach velocity approaching the pier, in feet per second (eq. 12.3); and

h_2 is the adjusted height of the pile cap above the bed after pier scour, in feet (eq. 12.4).

Pile Cap Scour (Case 2 Pile Cap on or below Streambed)

$$y_{spc} = y_f \, 2K_1K_2K_3 \left(\frac{a_{pc}}{y_f} \right)^{0.65} \left(\frac{V_f}{\sqrt{g y_f}} \right)^{0.43} \qquad (13)$$

$$y_f = h_1 + \frac{y_{spier}}{2} \qquad (13.1)$$

$$V_f = V_2 \frac{\ln\left(10.93 \frac{y_f}{3.5D_{84}} + 1 \right)}{\ln\left(10.93 \frac{y_2}{3.5D_{84}} + 1 \right)} \qquad (13.2)$$

where

ln is the natural logarithm,

y_f is the distance from the bed to the top of the footing, after contraction scour and half the pier stem scour, in feet; and

V_f is the average velocity in the flow zone below the top of the footing, in feet per second.

Pile Group Scour for Case of Piles Aligned with Flow

$$y_{spg} = y_3 K_{hpg}\left[2K_1K_3\left(\frac{a^*_{pg}}{y_3}\right)^{0.65}\left(\frac{V_3}{\sqrt{gy_3}}\right)^{0.43}\right] \tag{14}$$

$$y_3 = y_1 + \frac{y_{s\,pier}}{2} + \frac{y_{s\,pc}}{2}(y_3 \le 3.5a^*_{pg}) \tag{14.1}$$

$$K_{hpg} = \left\{3.08\left(\frac{h_3}{y_3}\right) - 5.23\left(\frac{h_3}{y_3}\right)^3 - 2.1\left(\frac{h_3}{y_3}\right)^4\right\}^{1.538} \tag{14.2}$$

$$h_3 = h_0 + \frac{y_{s\,pier}}{2} + \frac{y_{s\,pc}}{2} \tag{14.3}$$

$$a^*_{pg} = maK_{sp}K_m \tag{14.4}$$

$$V_3 = V_1\left(\frac{y_1}{y_3}\right) \tag{14.5}$$

$$K_m = 0.9 + 0.1m - 0.0741(m-1)\left[2.4 - 1.1\left(\frac{S}{a}\right) + 0.1\left(\frac{S}{a}\right)^2\right] \tag{14.6}$$

$$K_{sp} = 1 - \frac{4}{3}\left[1 - \frac{1}{m}\right]\left[1 - \left(\frac{S}{a}\right)^{-0.6}\right] \tag{14.7}$$

where

y_3	is the adjusted flow depth for pile group scour (eq. 14.1);
K_{hpg}	is the pile group factor (eq. 14.2);
h_3	is the height of the pile group above the lowered streambed after pier and pile cap scour have been computed in feet (eq. 14.3);
a^*_{pg}	is the effective width of the pile group in feet (eq. 14.4);
V_3	is the adjusted velocity for pile group scour in feet per second (eq. 14.5);
K_m	is the coefficient for number of aligned rows (eq. 14.6);
m	is the number of aligned rows;
S	is the center to center distance between piles in feet;
a	is the diameter of each pile in feet; and
K_{sp}	is the coefficient for pile spacing (eq. 14.7).

Abutment Scour

Scour at bridge abutments is a common cause of bridge failure, but estimates of abutment scour have been left out of past scour studies because the available equations produced scour estimates that did not agree well with observed scour (Heinrich and others, 2001; Ettema and others, 2010). A study by the National Cooperative Highway Research Program (NCHRP 24-20) resulted in updated methods for estimating scour around abutments and a better understanding of the hydraulics around abutments and approach embankments (Ettema and others, 2010). These methods are now recommended in HEC-18 (Arneson and others, 2012). The NCHRP 24-20 methods treat abutment scour as a local concentration of contraction scour, rather than a separate process. The contraction creates flow separation vortices adjacent to abutments when they encroach on the active flow area (fig. 7; Ettema and others, 2010). The NCHRP 24-20 study also concluded that abutment scour is limited by the geotechnical stability of the embankments, which fail and fill in scour holes when they are undercut. Minor embankment failures are common features of the bridge sites in this study, especially at the nine sites where the embankments were not adequately protected by riprap according to the most recent ADOT&PF inspection report.

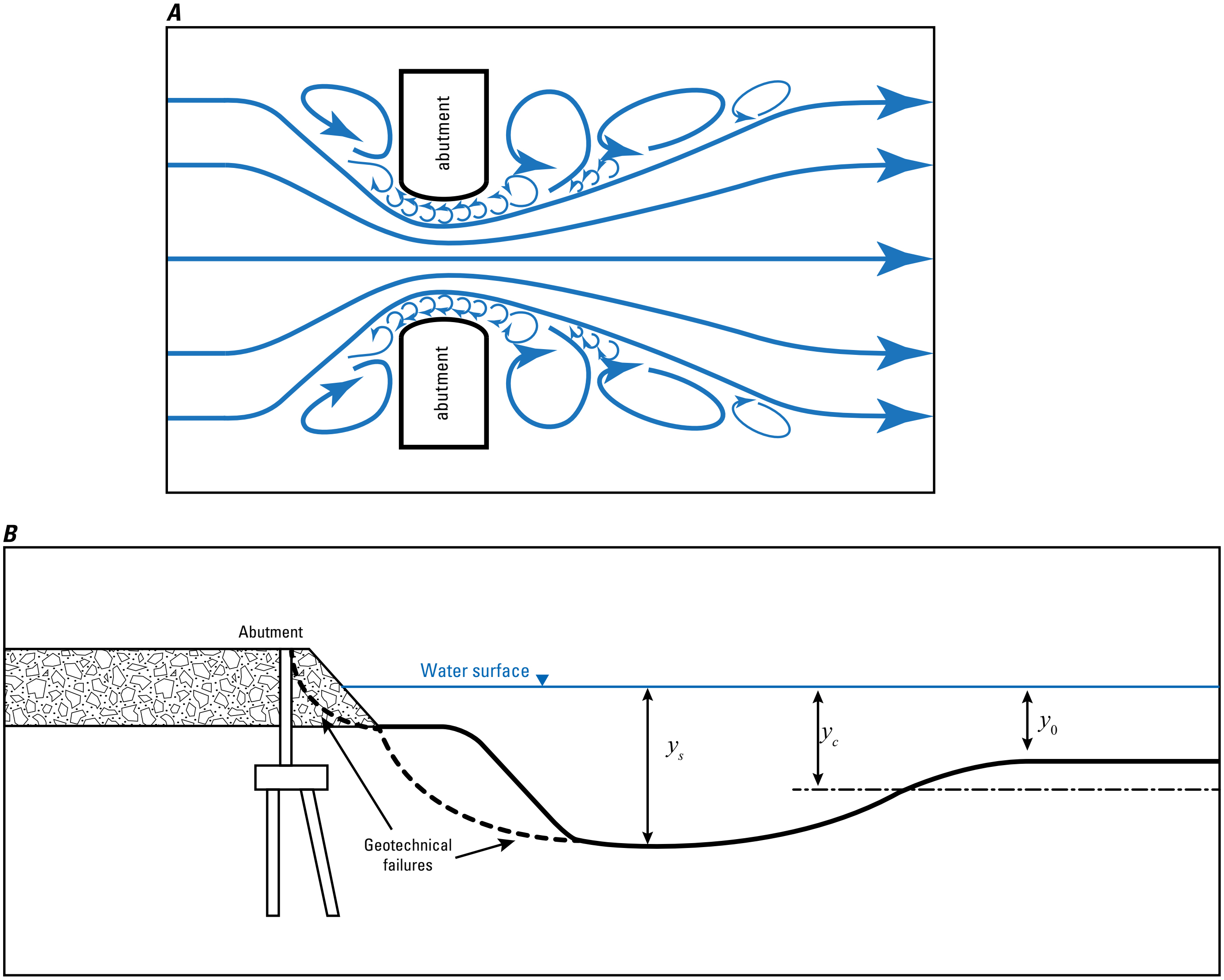


Figure 7. Examples of abutment (*A*) scour plan and (*B*) cross-section views. Modified from Ettema and others (2010).

All sites in this study resemble condition A, defined in NCHRP 24-20 as where the abutment is located at or near the main channel. Equation 15 includes an estimate of contraction scour and an amplification factor related to the relative concentration of flow under the bridge for condition A. Arneson and others (2012) suggested using a live-bed equation to calculate contraction scour for condition A, but critical velocity computations show that clear-water contraction scour occurred at several sites. Equation 15 was used with the contraction scour value calculated separately, whether live-bed, clear-water, or vertical contraction equations were used. The amplification factor is determined using figure 8, which consists of empirically derived curves relating relative contraction (q_2/q_1) as calculated in equation 16 to α_A for spill-through and wingwall type abutments. The amplification factor peaks for wingwall and spill-through abutments at just under 1.8 and 1.7 when relative contraction is about 1.3 and 1.2, respectively (fig. 8). The physical reason for this is that flow separation dominates the abutment scour process at moderate contraction ratios, whereas contraction scour dominates at higher contraction ratios. Thus, equation 15 will produce large abutment scour estimates for sites with modest contraction and deep channels, regardless of other scour-limiting conditions such as low velocities or bed armoring, or even if the floodwaters do not reach the abutments in the hydraulic model. These cases are flagged as likely overestimates.

$$y_s = \left(\alpha_A y_c\right) - y_0 \qquad (15)$$

where

y_s is the abutment scour depth, in feet;
α_A is the amplification factor for live-bed conditions (fig. 8);
y_c is the average flow depth at the bridge including contraction scour, in feet; and
y_0 is the flow depth at the bridge prior to scour, in feet.

$$\frac{q_2}{q_1} = \frac{Q_1/W_1}{Q_2/W_2} \qquad (16)$$

where

q_1 is the unit discharge at the approach cross section, in square feet per second;
q_2 is the unit discharge at the bridge, in square feet per second;
Q_1 is the discharge at the bridge, in cubic feet per second;
Q_2 is the discharge at the approach section, in cubic feet per second;
W_1 is the flow top width at the bridge, in feet; and
W_2 is the flow top width at the approach section, in feet.

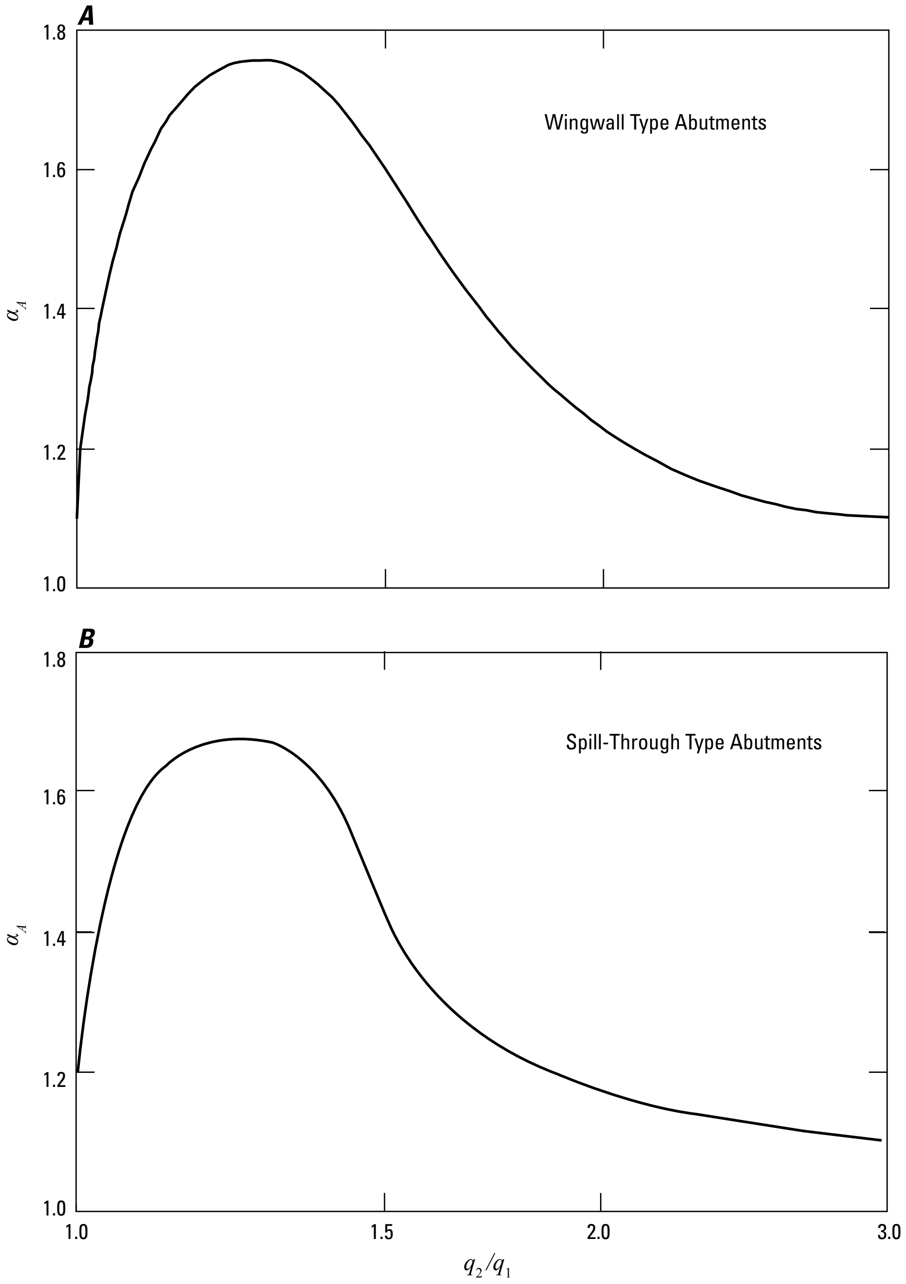


Figure 8. Amplification factor (*A*) for live-bed abutment scour (q_2/q_1, relative contraction) for wingwall (*A*) and (*B*) spill-through type abutments.

Results of Flood Frequency and Scour Assessments

Flood Frequency Estimates

Input variables and estimated frequencies for the 1- and 0.2-percent AEP floods are presented in tables 2 and 4. Table 4 also includes the measured site discharges used for model calibration (labeled "discharge measurement") and any large measured floods that also were used to estimate scour. An example of output from the weighted regression and EMA analysis for Tatlina River is shown in figure 9.

Observed Floods

A flood greater than the estimated 1-percent AEP flood occurred at six of the bridge sites with nearby streamgages during the period of record:

- Chisana River (424),
- Montana Creek (1669),
- Peters Creek 1501,
- Taiya River (309),
- Tatalina River (462), and
- West Creek (1490).

These bridges were in place at all sites except Montana Creek and West Creek. Hunter Creek did not have a streamgage during the flood of record in 1995, but the bridge in place at the time failed from abutment scour, as did a bridge upstream of Bridge 1501 on Peters Creek.

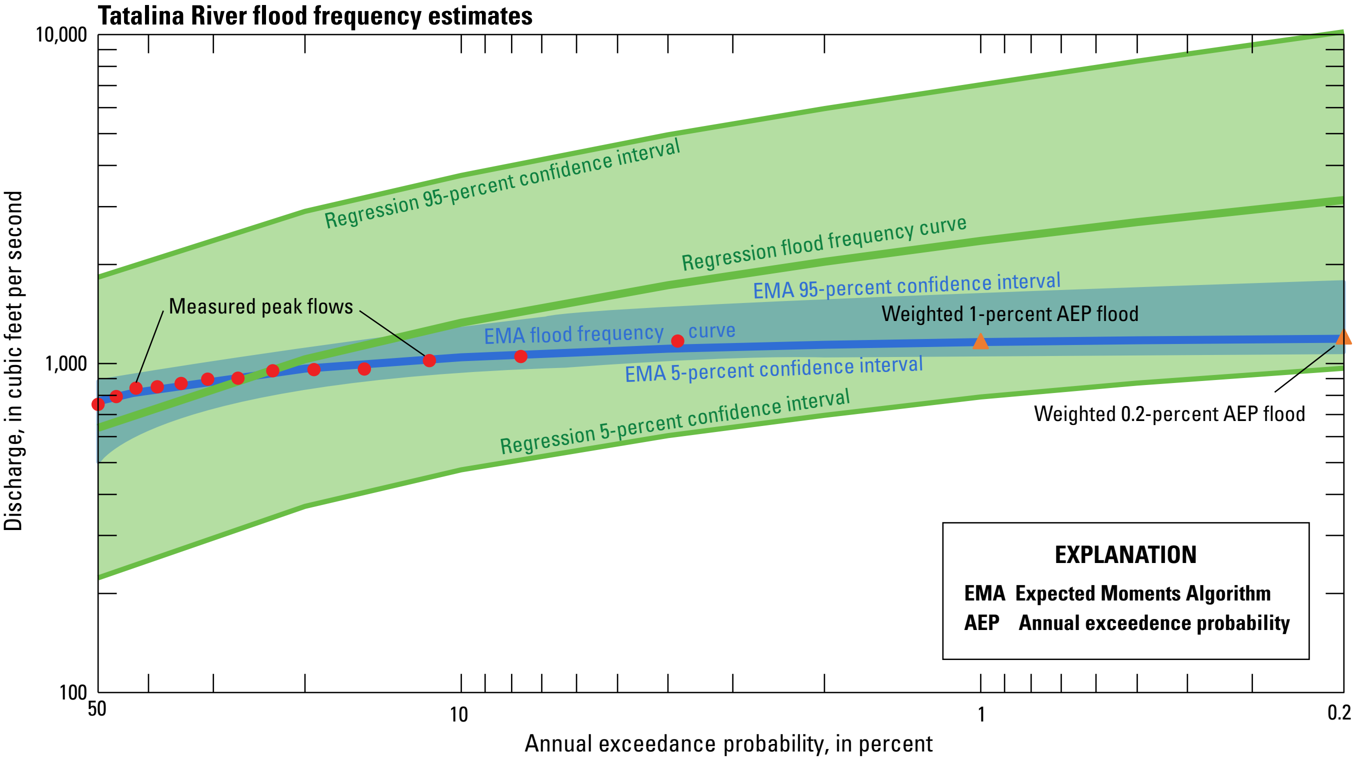


Figure 9. Flood frequency curves used to calculate the weighted 1- and 0.2-percent annual exceedance probability floods, with 5- and 95-percent confidence intervals for each analysis and measured peak flows at Tatalina River near Takotna, Alaska.

Table 4. Discharges used to estimate scour at selected bridge sites in Alaska.

[All discharge values are in cubic feet per second. **Abbreviation and symbol:** ft^3/s, cubic foot per second; –, variables that were not used in analysis for that site]

Bridge No. (fig. 2)	Stream name	Discharge measurement	Annual exceedance probability discharge		Additional discharge	Year of additional flood discharge	Bridge in place during flood?
			1-percent	0.2-percent			
395	Alaganik Slough	474	5,920	7,310	–	–	–
433	Barabara Creek	56	2,680	3,640	2,050	1983	Yes
2213	Barney Creek	24	960	1,270	–	–	–
1935	Bodenburg Creek[1]	38	62	91	[1]1,500	–	–
588	Boulder Creek	808	540	730	–	–	–
645	Campbell at Old Seward	48	2,190	2,940	–	–	–
1140	Chicken Creek	0	660	920	–	–	–
424	Chisana River	1,970	12,700	15,000	14,500	1997	Yes
2282	Coffman Creek	2.2	1,150	1,510	–	–	–
674	Cooper Creek	41	1,390	2,190	1,230	2003	Yes
1021	Crescent Creek	105	1,640	2,640	1,500	1969	Yes
2283	Dog Creek	0.3	620	820	–	–	–
2279	Dog Creek Tidal	1	770	1,020	–	–	–
1463	Falls Creek	7.9	1,130	1,460	–	–	–
586	Flood Creek	35	560	780	–	–	–
1900	Georges Creek	4.4	340	470	–	–	–
1899	Georges Creek	10	330	460	–	–	–
445	Good River	11	3,640	4,650	–	–	–
1821	Grouse Creek	16	1,350	1,960	1,160	2012	Yes
578	Gunn Creek	262	2,640	3,460	–	–	–
590	Gunny Sack Creek	65	700	950	–	–	–
2264	Harriet Hunt Creek	14.1	1,190	1,540	–	–	–
3000	Hatchery Creek	62	5,790	7,220	–	—	–
2129	Hatchery Creek Tributary	1.6	640	850	–	–	–
844	Heney Creek	30	870	1,130	–	–	–
1253	Hunter Creek	1,536	4,330	5,560	–	–	–
1685	Jordan Creek	4.4	380	500	–	–	–
893	Kougarok River	39	1,660	2,240	–	–	–
1713	Little Susitna River Braid[2]	78	6,840	9,370	[2]5,450	–	–
1717	Log Jam Creek	202	5,540	6,930	–	–	–
580	McCallum Creek	202	1,280	1,710	1,010	1967	Yes
585	Michael Creek	23	560	760	–	–	–
1669	Montana Creek	1,026	13,500	18,200	15,300	1987	No
1641	Nataga Creek	116	4,010	5,100	–	–	–
1457	Newlunberry Creek	1.8	330	450	–	–	–
1018	North Fork Anchor River	127	1,790	2,370	–	–	–
1409	Pats Creek	31	1,700	2,190	–	–	–
1501	Peters Creek	243	4870	7,130	5,000	1995	Yes
432	Sawmill Creek	895	15,440	15,720	11,500	2005	–
1098	Smith Creek	15	780	1,080	–	–	–
1199	South Fork Anchor River	86	5,230	6,730	–	–	–
2138	Swiftwater Creek	15	520	700	–	–	–
309	Taiya River	3,756	22,000	28,100	25,000	1967	Yes
463	Takotna River	733	6,020	7,800	–	–	–
462	Tatalina River	60	1,170	1,210	1,170	1998	Yes
584	Trims Creek	43	760	1,010	–	–	–
1731	Trocodero Creek	32	1,680	2,150	–	–	–
2281	Trumpeter Creek	7.3	3,090	3,930	–	–	–
607	Victor Creek	141	2,550	3,260	–	–	–
1490	West Creek	967	7,500	9,670	9,800	1967	No
587	Whistler Creek	20	390	530	–	–	–
464	Yankee Creek	0	1,110	1,500	–	–	–

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[1] Bodenburg Creek is a groundwater-fed stream with very little drainage area, and thus very low predicted floods. See report body text for discussion of overflow flooding.

[2] Little Susitna River Braid is a short distributary channel of the main Little Susitna River. See report body text for discussion of how the design flood was determined.

Design Floods Other than the 1- and 0.2-Percent Annual Exceedance Probability and Flood Frequency Estimates for Regulated Streams

The design and check floods typically are 1- and 0.2-percent AEP floods, respectively (Arneson and others, 2012). For Little Susitna River Bridge 1713 and Bodenburg Creek Bridge 1935, alternative flood values listed in the “Additional discharge” column of table 4 were used as either the design or check floods. Flood frequency analyses for Cooper Creek Bridge 674 and Sawmill Creek Bridge 432 accounted for site-specific regulation scenarios (table 4).

Little Susitna River Bridge 1713

Bridge 1713 crosses a sub-channel of the braided Little Susitna River several miles below where the channels diverge. The modeled 1-percent and 0.2-percent AEP floods (6,840 and 9,370 $\mathrm{ft^3/s}$, respectively) on the Little Susitna River at Bridge 1713 both substantially overtop the bridge and channel banks. An unknown portion of these flows would occupy other channels in the braid plain. Scour was assessed using the modeled flow that forced the maximum discharge underneath the bridge and created the maximum velocity through the bridge opening. This flow was determined to be 5,450 $\mathrm{ft^3/s}$ through iterative modeling with a 250 $\mathrm{ft^3/s}$ flow interval. It is unlikely that this great of a proportion of flow would find its way to Bridge 1713, but there is evidence of channel change and flow redistribution elsewhere along the Little Susitna River. Additionally, flows greater than 7,000 $\mathrm{ft^3/s}$ have been measured twice upstream.

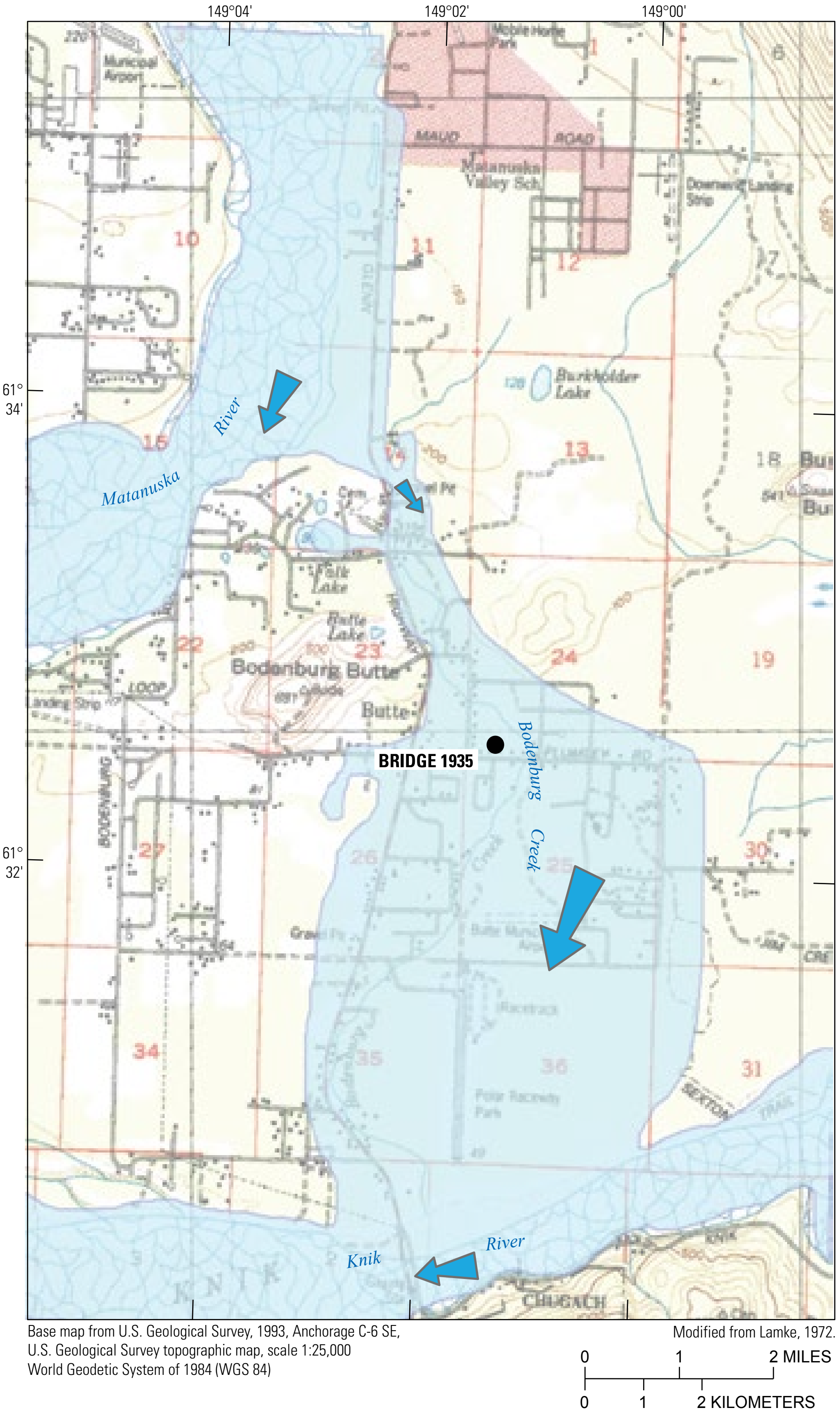
Bodenburg Creek Bridge 1935

Bodenburg Creek is a mostly groundwater-fed stream that occupies and abandoned channel linking the Matanuska and Knik Rivers near Palmer, Alaska (fig. 10). It has a small drainage area and estimated 1-percent and 0.2-percent AEP flows of 62 and 91 $\mathrm{ft^3/s}$, respectively, although these flows do not include groundwater. However, because of its position on a historical floodplain between two larger rivers, Bodenburg Creek historically has carried much more flow. In August 1971, the Matanuska River breached the Old Glenn Highway and followed Bodenburg Creek to the Knik River. The flow spread significantly, but Lamke (1972) estimated that 1,000 $\mathrm{ft^3/s}$ reached the Knik River at the peak from observations and discharge measurement notes. As of 2017, the Matanuska River is eroding the Old Glenn Highway again, so there is a potential for overflow during a flood. Bridge 1935 is located at a relatively narrow part of that flood path (fig. 10), and there is no easy way to constrain the overflow that could go under the bridge. As with Bridge 1713, an iterative approach was used to determine the maximum pressure flow discharge of 1,500 $\mathrm{ft^3/s}$.

Regulated Streams

Two sites, Bridge 674 on Cooper Creek and Bridge 432 on Sawmill Creek, are located downstream of hydroelectric dams that regulate river flow. The dam on Cooper Lake upstream of Bridge 674 captures all inflow to the lake and diverts it through a tunnel to Kenai Lake. The lake level is regulated to avoid spill over the spillway, and no spill has occurred (other than testing of the spillway) since the dam was completed in 1962 (Chugach Electric Association, 2005). The flood frequency analysis assumed that the basin upstream of the lake outlet would not contribute to floods downstream at the bridge. The regression analysis used the basin downstream of the lake outlet to calculate flood frequency, and the EMA analysis used the post-dam peak flows recorded at USGS streamgage 15261000 near Bridge 674.

Sawmill Creek below Blue Lake Dam is a more complicated case. The Blue Lake Hydroelectric Dam was built between 1958 and 1961, and was expanded in 2012. Blue Lake spills annually during high-flow periods. Stream gaging records from 1921 to 1957, before the dam was built, show a different flood regime than those after the dam was built. The highest measured pre-dam flood was 7,100 $\mathrm{ft^3/s}$. The highest measured post-dam flood was 11,500 $\mathrm{ft^3/s}$ in 2005. Two floods estimated to be 12,000 $\mathrm{ft^3/s}$ in 1972 and 1993 are reported in Federal Energy Regulatory Commission (FERC) licensing documents (City and Borough of Sitka Electric Department, 2010). An EMA analysis for the pre- and post-dam periods show significantly different results (fig. 11). The 1-percent AEP flood varies from 8,700 $\mathrm{ft^3/s}$ using pre-dam peak flows to 16,990 $\mathrm{ft^3/s}$ using post-dam peak flows. However, the maximum spillway capacity at Blue Lake Dam is 14,000 $\mathrm{ft^3/s}$ and the FERC licensing documents suggest that the dam is operated in order to regulate spill during floods (City and Borough of Sitka Electric Department, 2010). The 1- and 0.2-percent AEP floods used in this analysis consist of the 14,000 $\mathrm{ft^3/s}$ maximum spillway flood added to the maximum powerhouse output of 520 $\mathrm{ft^3/s}$, and the respective regression-analysis-derived flood numbers for the drainage basin below Blue Lake.



Base map from U.S. Geological Survey, 1993, Anchorage C-6 SE,
U.S. Geological Survey topographic map, scale 1:25,000
World Geodetic System of 1984 (WGS 84)

Modified from Lamke, 1972.

Figure 10. Bodenburg Creek overflow during floods in south-central Alaska, August 1971.

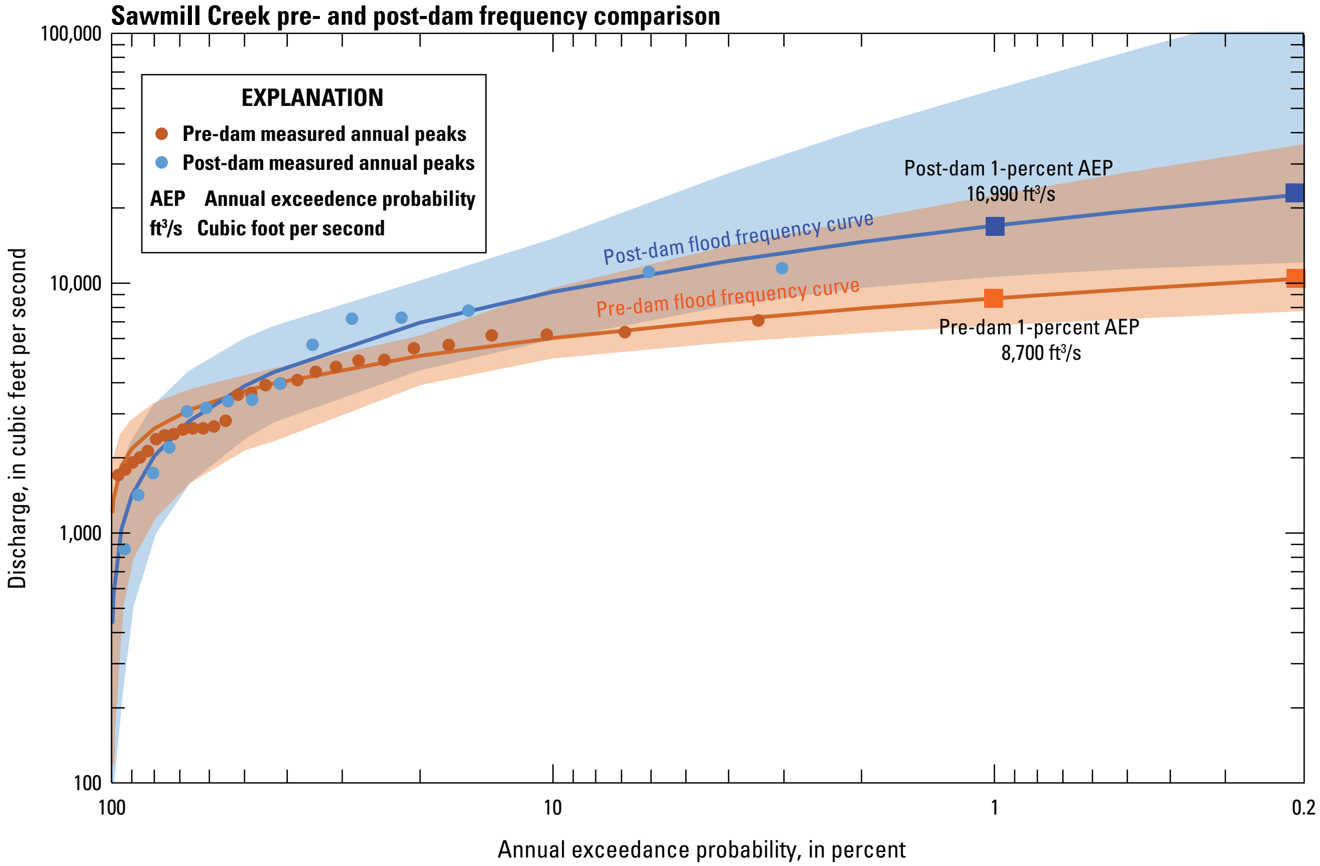


Figure 11. Flood frequency curves for the pre- and post-dam periods at Sawmill Creek near Sitka, Alaska.

Stream Stability and Geomorphic Assessment

Stream stability at the reach scale was assessed using geomorphic observations and sounding records (table 5, fig. 12). With the exception of bedrock-dominated Newlunberry Creek Bridge 1457, all sites are at least partially alluvial with streambeds and banks composed of sediment, and thus have the potential to shift, erode, or aggrade if disturbed. However, most of the sites are classified as stable or moderately stable, with little evidence of reach-scale channel change, significant sediment sources, or human disturbance beyond road embankments or bank stabilization. Moderately unstable sites showed evidence of active sediment sources and natural channel change. Unstable sites—which have active sediment source areas, evidence of channel change, and human disturbance—include 10 sites on active alluvial fan landforms, 1 site with an active tributary fan just upstream of the bridge, 1 site with active in-channel mining, and 1 site with a shifting tributary confluence just upstream of the bridge. Most sites have more than 10 years of sounding data, whereas 9 of the 52 sites have 5 or fewer years of sounding data. All of these nine sites are classified as stable based on the short available record, and most of them are in geomorphically stable settings; however the short record reduces confidence in the results.

Evidence for geomorphic or anthropogenic instability did not always correspond to variation in streambed elevations in the sounding record. However, of the 10 least stable sites from the sounding record, 8 sites were on active alluvial fans with evidence of significant geomorphic instability, and 1 site was actively mined. Three additional alluvial fan sites were classified as "less stable" (figs. 12 and 13). Where channel geometry is unstable, scour evaluations (which rely on a model of the static channel) have a larger margin of error than those for stable channels. Instability also can contribute to scour by increasing the flow angle of attack on piers and abutments and redirecting flow to road approaches.

Table 5. Stream stability as assessed using geomorphic evidence and repeat sounding records at selected bridge sites in Alaska.

[Vertical coordinate information is site-specific and, in most cases, is referenced either to as-built elevations on bridge plans (if available) or to a reference mark with an assumed elevation of 100 feet established during the survey on or near the bridge deck. **Abbreviations:** ADOT&PF, Alaska Department of Transportation and Public Facilities; ft, foot]

Bridge No. (fig. 2)	Stream name	Natural sediment sources	Evidence of channel change	Human disturbance	Qualitative geomorphic stability
395	Alaganik Slough	Minor, lake upstream	Minor	Boat launch, old bridge pilings, railroad ballast in channel	Moderately stable
433	Barabara Creek	Minor	Minor	Road embankments, trails, yards, gravel pit upstream	Stable
2213	Barney Creek	Minor	Braided channels	Minor	Moderately stable
1935	Bodenburg Creek	Minor	Minor	Road embankments, yards, houses	Stable
588	Boulder Creek	Alluvial fan and eroding gullies	Multiple abandoned channels, bare gravel	Dredging	Unstable
645	Campbell at Old Seward	Minor	urbanization and rechannelization	Road embankments, yards, houses	Stable
1140	Chicken Creek	Minor	extensive bare gravel area in streambed	Dredge minng throughout streambed	Unstable
424	Chisana River	Minor, distal glacial input	Meander cut offs, abandoned channels, migrating meanders	Boat launch upstream	Moderately stable
2282	Coffman Creek[1]	Minor	Minor	Makeshift fence upstream in the channel	Stable

Bridge No. (fig. 2)	Available soundings	Average low bed elevation change between site visits (ft)	Maximum low bed elevation change		100-year channel width (ft)	Adjusted bed elevation change (ft per 10 ft of channel)	Sounding-based Stability	ADOT&PF inspection notes
			Bed elevation change (ft)	Date range				
395	1998, 2000, 2004–14 biennial, 2011, 2015	-0.3	3.5	1998–2008	119.9	0.3	Stable	Underwater inspection notes scour holes 1.5–4 feet deep.
433	2001–13 biennial	0.1	1.4	2009–13	55.5	0.3	Stable	Erosion behind wingwall
2213	2006–14 biennial, 2015	-0.3	2.3	2006–08	58.6	0.4	Moderately unstable	Bank undercut and slumping
1935	2002–12 biannual, 2013	0.1	0.7	2004–13	25.9	0.3	Stable	Bank erosion, erosion at corners of bridge
588	2001–15 biennial	0.1	2.6	2001–05	27.2	1.0	Unstable	Scour undercutting, fill loss behind wing walls
645	2001–15 biennial, 2012	-0.1	-1.6	2005–15	64.6	-0.2	Stable	Pier scour holes 1.5 ft deep, debris on pier
1140	2001–15 biennial, 2010, 2012	-0.2	2.9	2001–11	24.0	1.2	Unstable	Bank erosion
424	1998, 2002–14, 2015	-0.2	3.1	2008–10	208.9	0.1	Stable	Bank erosion under bridge owing to boat launch and deck drains
2282	2011–15 annual	0.1	1.5	2012–15	44.7	0.3	Stable	Sharp bend upstream impacting approach roadway

Table 5. Stream stability as assessed using geomorphic evidence and repeat sounding records at selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Natural sediment sources	Evidence of channel change	Human disturbance	Qualitative geomorphic stability
674	Cooper Creek	Minor	Minor	Regulated upstream, developed campground	Stable
1021	Crescent Creek	Minor	Abandoned channels	Gravel pits near stream	Moderately stable
2283	Dog Creek[1]	Minor	Minor	Minor	Stable
2279	Dog Creek Tidal[1]	Minor	Minor	Road embankments, yards, houses	Moderately stable
1463	Falls Creek	Minor	Bank erosion	Minor	Stable
586	Flood Creek	Alluvial fan and eroding gullies	Abandoned channels	Dredging and grading	Unstable
1900	Georges Creek	Evidence of old debris flows upstream	Bank erosion	Road embankments, yards, houses	Moderately stable
1899	Georges Creek	Evidence of old debris flows upstream	Bank erosion	Road embankments, yards, houses	Moderately stable
445	Good River	Minor	Minor	Road embankments, yards, houses	Stable
1821	Grouse Creek	Alluvial fan and eroding gullies	Confluence with Lost Creek downstream has moved	Dredging and grading	Unstable
578	Gunn Creek	Minor	Multiple channels upstream of bridge	Road embankment along upstream main channel, old road fill	Moderately stable

Bridge No. (fig. 2)	Available soundings	Average low bed elevation change between site visits (ft)	Maximum low bed elevation change		100-year channel width (ft)	Adjusted bed elevation change (ft per 10 ft of channel)	Sounding-based Stability	ADOT&PF inspection notes
			Bed elevation change (ft)	Date range				
674	2003, 2007–13 biennial	0.3	0.8	2003–09	47.5	0.2	Stable	Minor bank undercutting
1021	2001–15 biennial, 2012, 2014	-0.1	1.1	2007–16	36.2	0.3	Stable	Bank erosion. Scour hole forming at abutment wingwall
2283	2011–15 annual	0	0.6	2013–14	37.6	0.2	Stable	Light to medium debris
2279	2011–15 annual	-0.1	0.5	2014–15	20.0	0.3	Stable	Light to medium debris
1463	2001–13 biennial, 2012, 2014	0.2	0.9	2001–15	43.8	0.2	Stable	Bank erosion, abutment scour, and over steepened embankment
586	2001–15 biennial	-0.3	4.7	2003–09	27.4	1.7	Unstable	Bank erosion, fill loss behind wingwall
1900	2000–12 biennial, 2013	0.1	0.8	2000–08	22.4	0.4	Moderately unstable	Bank erosion under the bridge
1899	2000–12 biennial, 2013	0.0	1	2002–10	23.0	0.4	Moderately unstable	Bank erosion
445	2001–15 biennial	0	1.4	2003–07	66.6	0.2	Stable	Bank erosion, fill loss behind wingwall
1821	2001–13 biennial, 2012	0.3	2.3	2003–13	30.5	0.8	Unstable	Light drift
578	2001–15 biennial, 2012	0.1	2.2	2013–15	56.0	0.4	Moderately unstable	Light drift

Table 5. Stream stability as assessed using geomorphic evidence and repeat sounding records at selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Natural sediment sources	Evidence of channel change	Human disturbance	Qualitative geomorphic stability
590	Gunny Sack Creek	Alluvial fan and eroding gullies	Abandoned channels	Dredging and grading	Unstable
2264	Harriet Hunt Creek[1]	Minor, lake upstream	Minor	Logging upstream	Stable
3000	Hatchery Creek[1]	Minor, lake upstream	Minor	Minor	Stable
2129	Hatchery Creek Tributary[1]	Minor	Minor	Logging upstream	Stable
844	Heney Creek	Minor	Bare gravel bars	Gravel pits, road embankments, yards, houses	Moderately stable
1253	Hunter Creek	Alluvial fan, gravel braided channel	Extensive bare gravel bar with channel braids	Minor	Unstable
1685	Jordan Creek	Minor	Lateral channel shift upstream reported by local resident	Yards, trailer park, road embankments	Moderately stable
893	Kougarok River	Minor bank erosion from ice jams	Minor	Minor	Stable
1713	Little Susitna River Braid[1]	Minor	On extensive, forested braidplain. Abandoned channels.	Road embankments, yards, houses	Moderately stable
1717	Log Jam Creek[1]	Minor	Minor	Minor	Stable

Bridge No. (fig. 2)	Available soundings	Average low bed elevation change between site visits (ft)	Maximum low bed elevation change		100-year channel width (ft)	Adjusted bed elevation change (ft per 10 ft of channel)	Sounding-based Stability	ADOT&PF inspection notes
			Bed elevation change (ft)	Date range				
590	2001–15 biennial	-0.4	3.9	2005–09	28.2	1.4	Unstable	Bank erosion and fill loss behind wingwalls
2264	2013–15 annual	0	0.4	2014–15	47.0	0.1	Stable	Bank erosion, moderate debris, only three soundings.
3000	2011–15 annual	0	0.4	2011–12, 2012–13	120.0	0.0	Stable	Moderate debris
2129	2011–15 annual	0.2	0.9	2012–15	40.9	0.2	Stable	Heavy debris
844	2000–14 biennial, 2015	0	2.5	2006–15	31.0	0.8	Unstable	Bank erosion, undermining of abutments, light debris
1253	2000–12 biennial, 2013	0.1	3.7	2002–08	75.0	0.5	Moderately unstable	Bank erosion/undercutting, light debris
1685	2001, 03, 2007–15 biennial	-0.1	1.2	2001–11	68.25	0.2	Stable	Light debris
893	2000–14 biennial, 2015	0	0.9	2002–14	140.1	0.1	Stable	Bank erosion, ice jam scour
1713	2012–14 biennial	0.3	0.5	2012–14	60.0	0.1	Stable	Bridge replaced in 2011, only three soundings
1717	2011–15 annual	0	1.8	2012–14	78.9	0.2	Stable	Bank undercutting and scour holes. Heavy debris.

Table 5. Stream stability as assessed using geomorphic evidence and repeat sounding records at selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Natural sediment sources	Evidence of channel change	Human disturbance	Qualitative geomorphic stability
580	McCallum Creek	Alluvial fan, glacial outwash	Multiple abandoned channels, bare gravel	Dredging and grading	Unstable
585	Michael Creek	Alluvial fan below eroding gullies	Multiple abandoned channels, bare gravel	Dredging and grading	Unstable
1669	Montana Creek	Cut bank upstream	Confluence upstream of bridge has moved	Guide bank upstream. Road erosion.	Unstable
1641	Nataga Creek	Large alluvial fan braidplain	Channel location upstream and downstream changed between field visits	Deforestation, old logging roads	Unstable
1457	Newlunberry Creek	Minor, bedrock channel	Minor. Bedrock channel	Minor	Stable
1018	North Fork Anchor River	Minor	Abandoned channels, old meander cut offs	Road embankments, yards, houses	Moderately stable
1409	Pats Creek	Minor, lake upstream	Minor	Old road and bridge remnants, logging upstream	Stable
1501	Peters Creek	Minor	Levees, abandoned channels	Road embankments, yards, houses	Moderately stable
432	Sawmill Creek	Landslides and tributary alluvial fans	Powerhouse operator reports aggradation during floods	Regulated, fill and extensive rockwork for powerhouse outfall upstream	Unstable
1098	Smith Creek	Minor	Old meander cut offs	Accumulation of riprap and debris in channel downstream of bridge	Moderately stable

Bridge No. (fig. 2)	Available soundings	Average low bed elevation change between site visits (ft)	Maximum low bed elevation change		100-year channel width (ft)	Adjusted bed elevation change (ft per 10 ft of channel)	Sounding-based Stability	ADOT&PF inspection notes
			Bed elevation change (ft)	Date range				
580	2001–15 biennial	0.1	2	2005–15	27.2	0.7	Moderately unstable	Fill loss behind abutment, possible iciing
585	2001–15 biennial	0.2	3.6	2005–15	26.5	1.4	Unstable	Fill loss behind abutment, grading downstream of bridge
1669	2000–12 biannual, 2013	0.3	1.3	2002–04	198.9	0.1	Stable	Road approach washed out in 2006 flood, repaired in 2007
1641	2000–10 biennial, 2013	-0.2	5.1	2004–08	48.0	1.1	Unstable	Light debris
1457	2001–15 biennial, 2014	0	0.5	2001–14	26.7	0.2	Stable	Bank undercutting, fill loss, light debris
1018	2001–11 biennial, 2012, 2013	0.1	2	2003–09	30.0	0.7	Moderately unstable	Bank erosion/undercutting, gabion failure
1409	2001–15 biennial, 2012	-0.1	1.2	2003–05	65.46	0.2	Stable	No relevant comments
1501	2000–10 biennial, 2013	0	3.1	2000–02	54.5	0.6	Moderately unstable	Bank erosion. Erosion behind gabion
432	1999, 2003–15 biennial, 2012	-0.2	2.4	2007–15	135.2	0.2	Stable	Erosion at right abutment, tree under span
1098	2000–14 biennial, 2015	0	0.9	2002–08	85.1	0.1	Stable	Erosion at abutments

Table 5. Stream stability as assessed using geomorphic evidence and repeat sounding records at selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Natural sediment sources	Evidence of channel change	Human disturbance	Qualitative geomorphic stability
1199	South Fork Anchor River	Minor	Minor bank erosion	Camping area on bank, houses nearby	Stable
2138	Swiftwater Creek	Minor	Minor	Road embankments and gravel pit upstream	Moderately stable
309	Taiya River	Minor, distal glacial input	Multiple abandoned channels	Downstream boat launch	Moderately stable
463	Takotna River	Minor	Abandoned channels	Minor	Stable
462	Tatalina River	Minor	Old meander cut offs	Minor	Stable
584	Trims Creek	Glacial outwash, alluvial fan and eroding gullies	Multiple abandoned channels, bare gravel	Dredging and grading	Unstable
1731	Trocodero Creek	Minor	Minor	Logging both up and downstream.	Stable
2281	Trumpeter Creek[1]	Minor, lake upstream	Minor	Minor	Stable
607	Victor Creek	Cut into old glacial fan, distal glacial input	Minor	Minor	Moderately stable
1490	West Creek	Active glaciers and eroding slopes upstream	Minor	Old bridge piers	Moderately stable

Bridge No. (fig. 2)	Available soundings	Average low bed elevation change between site visits (ft)	Maximum low bed elevation change		100-year channel width (ft)	Adjusted bed elevation change (ft per 10 ft of channel)	Sounding-based Stability	ADOT&PF inspection notes
			Bed elevation change (ft)	Date range				
1199	2001–13 biennial	-0.3	1.8	2003–13	68.7	0.3	Stable	Bank/abutment erosion, light debris
2138	2006–10 biennial, 2013	-0.3	1.1	2010–13	25.4	0.4	Moderately unstable	Erosion of fill around abutments during 2006 flood
309	2002–14 biennial, 2015	-0.3	6	2004–14	205.0	0.3	Stable	Bank erosion and slumping, light debris
463	2000–14 biennial, 2011	-0.1	2.2	2000–12	225.2	0.1	Stable	Bank erosion, light debris, fish weir US of bridge
462	2000–14 biennial, 2011	0.3	3.3	2004–11	56.7	0.6	Moderately unstable	Light debris, minor bank scour, equipment ford immediately US of bridge
584	2001–15 biennial	0.5	4.6	2001–11	32.4	1.4	Unstable	Bank erosion, fill loss behind wingwalls, light debris
1731	1997–15 biennial, 2014	0	2.4	2007–14	52.5	0.5	Moderately unstable	Minor bank undercutting, heavy debris
2281	2011–15 annual	0.1	0.8	2011–15	65.8	0.1	Stable	Moderate debris
607	2001, 2003, 2007–15 biennial, 2012	-0.5	5.0	2001–07	47.2	1.1	Unstable	Bank erosion, some debris
1490	2000–14 biennial, 2015	-0.1	2.7	2000–02	144.6	0.2	Stable	Bank erosion, heavy debris

Table 5. Stream stability as assessed using geomorphic evidence and repeat sounding records at selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Natural sediment sources	Evidence of channel change	Human disturbance	Qualitative geomorphic stability
587	Whistler Creek	Alluvial fan and eroding gullies	Multiple abandoned channels, bare gravel	Dredging and grading	Unstable
464	Yankee Creek	Beaver dam breaches	Beaver dams, abandoned channels and meander cut offs	Equipment ford at bridge, dredge mining several miles upstream	Unstable

Bridge No. (fig. 2)	Available soundings	Average low bed elevation change between site visits (ft)	Maximum low bed elevation change		100-year channel width (ft)	Adjusted bed elevation change (ft per 10 ft of channel)	Sounding-based Stability	ADOT&PF inspection notes
			Bed elevation change (ft)	Date range				
587	2001–15 biennial	-0.3	3	2001–11	27.1	1.1	Unstable	Bank erosion, light debris
464	2000–14 biennial	0	0.9	2006–14	165.9	0.1	Stable	Minor bank undercutting, heavy debris, equipment crossing, beaver dams

[1] These sites have 5 or fewer years of soundings.

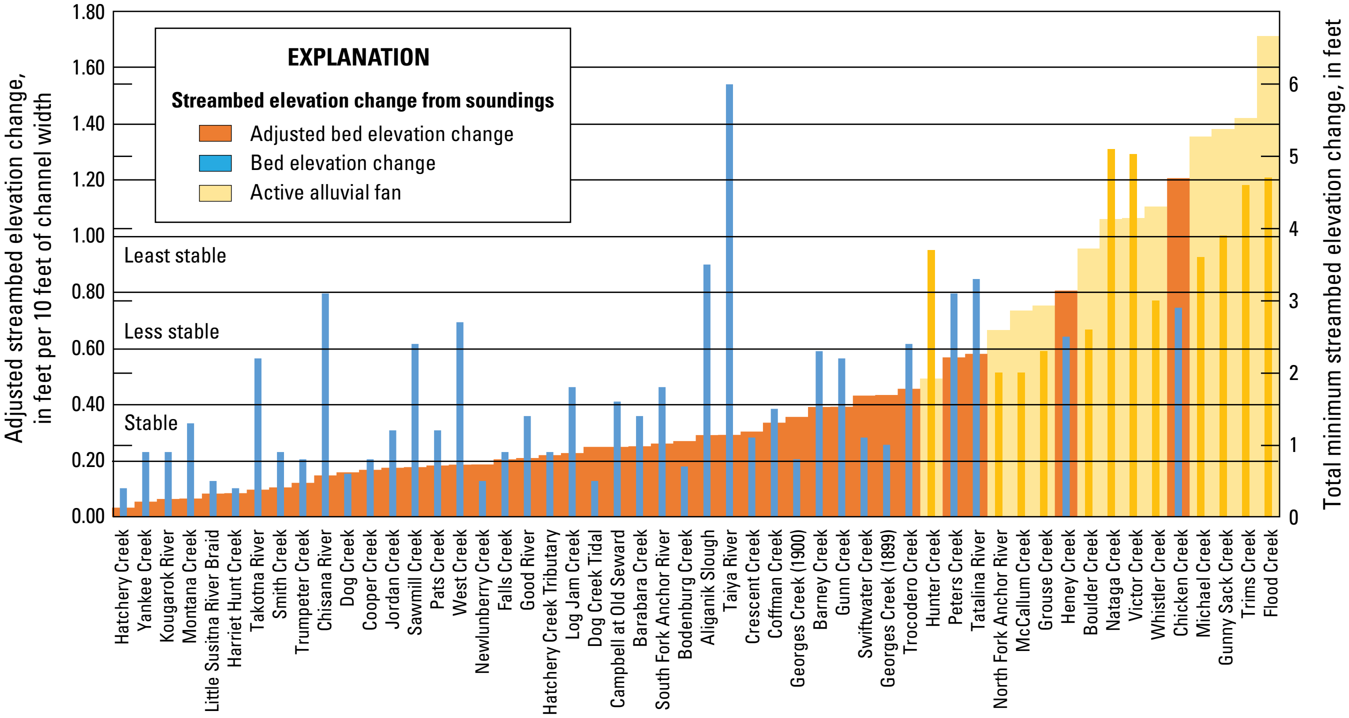


Figure 12. Sounding-based stream stability at 52 river- and stream-spanning bridges in Alaska.

Soundings did not show definitive signs of either long-term aggradation or degradation at any study sites, although evidence for degradation at Victor Creek is presented in section, "Unstable Sites—Victor Creek Bridge 607." The average change in minimum bed elevation between successive soundings was less than or equal to 0.5 ft at all sites. Most sites had 0.1 ft or less cumulative change. However, numerous sites on alluvial fans showed evidence of dredging, which typically is done to combat aggradation and would prevent aggradation from appearing in the sounding record.

Repeat cross-section soundings are useful in identifying instabilities but cannot be used to rule out vulnerability to scour or other responses to flooding. Scour and fill often are short-lived and are evident only during and shortly after a flood (Conaway, 2007). Soundings taken at 2-year intervals, even if a flood occurs between soundings, may not indicate the transient effects of the flood on the channel cross section. Some bridges have only 3–5 years of soundings. Short sounding records are less likely to capture long-term trends or responses to infrequent flood events. All measured cross sections for study sites are in appendix 1.

Unstable Sites

Alluvial Fan Channels along the Richardson Highway

Seven of the 52 sites in this study are located on outwash fans of tributaries to the Delta River:

- McCallum Creek Bridge 580,
- Trims Creek Bridge 584,
- Michael Creek Bridge 585,
- Flood Creek Bridge 586,
- Whistler Creek Bridge 587,
- Boulder Creek Bridge 588, and
- Gunny Sack Creek Bridge 590.

Figure 13. "Less stable" alluvial fans at (*A*) Gunny Sack Creek Bridge 590 and (*B*) Whistler Creek upstream of Bridge 587, Alaska.

The Richardson Highway crosses these fans near the upper or middle part of the depositional area. The Trans-Alaska Pipeline crosses underneath each stream about 500 ft downstream of the highway. All these channels are geomorphically unstable, and instability is reflected in the sounding record for all but McCallum Creek. All these streams are relatively steep and high velocity, and are composed of cobble and boulder beds (fig. 13). Boulder weirs are used to prevent trenching at the pipeline crossing, and guidebanks or simple berms are used to stabilize channels at the bridge. The risk of catastrophic contraction or abutment scour at these sites is minimized by high sedimentation rates, grade control downstream, and armoring in the bridge channel. The most common problems are fill loss around the abutment wingwalls, which are steep and subject to high velocities and contraction-related flow separation during floods. Aggradation during a flood also could lead to overtopping of the road approaches and more rapid abutment loss.

Chicken Creek Bridge 1140

Chicken Creek Bridge 1140 is perennially destabilized by dredge mining and in-stream grading to combat aggradation caused by floods. If the channel is lowered downstream, this instability could lead to scour. However, the dominant regime at Chicken Creek seems to be aggradation.

Victor Creek Bridge 607

Victor Creek Bridge 607 seems to be degrading based on visual inspection, according to 1952 as-built plans (hereinafter referred to as “as-builts”), and soundings since 1999. The as-builts show a low streambed of 475 ft. The first sounding record available in 1999 shows a low streambed of 467.6 ft. After a regional flood in 2006 (Victor Creek is ungaged), the minimum streambed dropped to 464.5 ft, and as of 2015 had increased to 465.6 ft. Although the visible streambed is mostly cobbles, gravel, and boulders, as-builts indicate that at an elevation of 465 ft and below the streambed is composed of firm gravelly silt that probably has some cohesive properties. The footing is exposed to flow and significantly affects pier-scour estimates. In addition to channel degradation, ADOT&PF has noted bank erosion in most inspection reports. Scour at the site has either reached an equilibrium since the bridge was built, or armoring and cohesive properties of the firm gravel noted in the as-builts have limited degradation below an elevation of 465 ft.

Nataga Creek Bridge 1641

Bridge 1641 crosses Nataga Creek on an alluvial fan about 200 ft upstream of the confluence with the Kelsall River. Nataga is a steep, cobble-bedded creek flowing through a 200-ft-wide braidplain. The active channel moved from the far left side of the braidplain to the far right side between July and October 2013. Fresh debris in 2014 indicated that the stream had moved across the braidplain recently again. Soundings indicate more than 5 ft of vertical change in the low streambed, which is significant given that there is, on average, less than 10 ft of vertical distance between the low chord and the stream bed. The instability at Nataga Creek likely will continue and may lead to abutment or approach road loss.

Heney Creek Bridge 844

Heney Creek Bridge 844 does not appear to be geomorphically unstable or destabilized by human activity. However, the sounding record shows changes in bed elevation. Inspection photographs show a large gravel bar upstream of the bridge, and the main channel occupying either side or the middle of the gravel bar in different years. In 2015, the main channel was split into two channels with the gravel bar in the middle, and the two channels met at the sounding location. The instability seen in the repeat soundings may relate to the upstream channel shifting around the gravel bar and is not indicative of a reach-scale problem.

Scour Calculations

Contraction, Abutment, and Pier Scour

Clear-water and live-bed scour estimates for 49 sites with horizontal contraction scour at the design and (or) check floods where the water surface did not reach the low chord of the bridge are shown in table 6. These estimates range from no scour to a maximum of 3.7 ft, and are split about evenly between live-bed and clear-water conditions, although both estimates are shown for each site. Vertical contraction scour is predictably higher, as much as 8.0 ft for the design and (or) check floods at eight bridges where the water surface reaches the low chord (table 7). Abutment scour, which is treated as an amplification of contraction scour, ranges from 0.3 to 13.1 ft (table 8).

Pier scour and total scour at piers (pier scour plus contraction scour) are listed in table 9 for eleven bridges with simple piers, in table 10 for two bridges with complex exposed foundations, and in table 11 for three bridges with coarse beds and clear-water conditions. Pier scour ranged from 0.1 to 8.9 ft, before adding contraction scour. Pier scour with debris was calculated for five bridges with debris accumulation noted in site visits. Debris increased pier scour by an average of 2.5 ft. All scour estimates (contraction, abutment, and pier) for each bridge are summarized in table 12.

Table 6. Hydraulic variables and estimates of contraction scour for selected bridge sites in Alaska with no pressure flow.

[D_{50}: Median grain diameter. **Abbreviations:** AEP, annual exceedance probability; ft, foot; ft/s, foot per second; ft³/s, cubic foot per second]

Bridge No. (fig. 2)	Stream name	Event	Width of approach channel (ft)	Discharge at approach channel (ft³/s)	Flow depth in approach (ft)	Discharge at bridge channel (ft³/s)	Width of channel at bridge (ft)	Depth of flow at bridge (ft)	D_{50} (ft)	Critical velocity for D_{50} (ft/s)	Modeled velocity in the approach channel (ft/s)	Likely type of scour	Depth of live-bed contraction scour (ft)	Depth of clear-water contraction scour (ft)
395	Alaganik Slough	1-percent AEP flood	109.5	5,887	14.3	5,814	98.0	12.0	0.00	1.9	3.8	Live	3.2	13.8
		0.2-percent AEP flood	109.5	7,244	15.7	7,112	98.0	13.5	0.00	1.9	4.2	Live	3.0	17.1
433	Barabara Creek	1-percent AEP flood	64.6	2,622	4.3	2,557	40.0	6.9	0.10	6.6	9.4	Live	0.0	1.1
		0.2-percent AEP flood	64.6	3,519	5.8	3,419	40.0	8.4	0.10	6.9	9.5	Live	0.0	1.8
		1983 flood	64.6	2,021	3.4	1,981	40.0	5.8	0.10	6.4	9.2	Live	0.0	0.6
2213	Barney Creek	1-percent AEP flood	76.8	959	2.3	960	58.4	2.0	0.14	6.7	5.4	Clear	0.7	0.2
		0.2-percent AEP flood	76.8	1,268	3.0	1,253	59.0	3.5	0.14	6.9	5.6	Clear	0.0	0.0
1935	Bodenburg Creek[1]	1-percent AEP flood	27.2	62	1.9	61	23.9	0.9	0.10	5.7	1.2	Clear	1.2	0.0
		0.2-percent AEP flood	27.2	91	2.2	89	24.5	1.0	0.10	5.9	1.5	Clear	1.3	0.0
588	Boulder Creek	1-percent AEP flood	30.4	540	1.5	540	27.2	1.6	0.26	7.6	11.9	Live	0.0	0.6
		0.2-percent AEP flood	34.2	730	1.7	730	27.7	2.0	0.26	7.7	12.8	Live	0.0	0.8
645	Campbell at Old Seward	1-percent AEP flood	35.1	1,767	7.5	1,315	20.6	10.2	0.05	5.9	6.7	Live	0.0	0.0
		0.2-percent AEP flood	35.1	2,223	8.8	1,659	20.6	11.9	0.05	6.1	7.2	Live	0.0	0.0
1140	Chicken Creek	1-percent AEP flood	60.5	622	3.9	653	22.0	3.1	0.16	7.6	2.7	Clear	4.2	0.6
		0.2-percent AEP flood	60.5	844	5.0	901	22.0	5.0	0.16	7.9	2.8	Clear	4.6	0.0
424	Chisana River	1-percent AEP flood	324.8	12,568	9.9	12,700	209.1	11.3	0.00	1.8	3.9	Live	1.9	14.6
		0.2-percent AEP flood	325.1	14,673	10.9	15,000	211.8	12.0	0.00	1.8	4.2	Live	2.5	17.5
		1997 flood	325.1	14,222	10.6	14,500	211.2	11.9	0.00	1.8	4.1	Live	2.4	16.8
2282	Coffman Creek	1-percent AEP flood	84.5	929	3.7	1,149	44.7	4.0	0.09	6.3	3.0	Clear	2.4	0.0
		0.2-percent AEP flood	84.5	1,184	4.3	1,502	46.2	4.5	0.09	6.4	3.3	Clear	3.0	0.1
674	Cooper Creek	1-percent AEP flood	67.4	1,377	4.0	1,390	48.0	4.5	0.06	5.6	5.1	Clear	0.4	0.1
		0.2-percent AEP flood	67.4	2,010	6.0	2,181	48.0	6.5	0.06	6.0	5.0	Clear	1.4	0.3
		2003 flood	67.4	1,225	3.6	1,230	47.2	4.1	0.06	5.5	5.1	Clear	0.3	0.1
1021	Crescent Creek	1-percent AEP flood	111.9	1,405	4.3	1,637	35.5	4.2	0.07	5.9	2.9	Clear	5.6	2.5
		0.2-percent AEP flood	111.9	1,927	6.5	2,628	35.5	8.1	0.07	6.3	2.6	Clear	8.6	1.9
		1969 flood	111.9	1,338	3.9	1,497	35.5	3.9	0.07	5.8	3.0	Clear	4.7	2.3
2283	Dog Creek	1-percent AEP flood	50.5	620	1.8	628	37.6	3.5	0.19	7.1	6.7	Clear	0.0	0.0
		0.2-percent AEP flood	50.5	799	2.1	824	37.6	4.0	0.19	7.3	7.4	Live	0.0	0.0
2279	Dog Creek Tidal	1-percent AEP flood	28.6	708	4.0	735	32.0	4.0	0.12	7.0	6.1	Clear	0.0	0.0
		0.2-percent AEP flood	28.6	915	4.8	957	32.0	4.8	0.12	7.2	6.7	Clear	0.0	0.0
1463	Falls Creek	1percent AEP flood	29.9	1,093	4.7	1,130	43.8	3.5	0.12	7.1	7.8	Live	0.3	0.0
		0.2percent AEP flood	29.9	1,449	5.2	1,503	45.2	4.1	0.12	7.2	9.3	Live	0.0	0.2
586	Flood Creek	1-percent AEP flood	35.6	560	1.7	559	26.5	2.4	0.33	8.4	9.3	Live	0.0	0.0
		0.2-percent AEP flood	36.7	780	2.0	777	26.5	3.0	0.33	8.7	10.5	Live	0.0	0.0
1899	Georges Creek	1-percent AEP flood	15.5	307	2.0	330	22.0	1.4	0.15	6.7	10.2	Live	0.3	0.6
		0.2-percent AEP flood	15.5	415	2.3	458	22.0	1.7	0.15	6.9	11.5	Live	0.3	1.0
1900	Georges Creek	1-percent AEP flood	19.5	337	1.7	340	22.4	1.5	0.04	4.3	10.0	Live	0.1	1.5
		0.2-percent AEP flood	19.5	465	2.1	470	23.5	1.7	0.04	4.4	11.4	Live	0.2	2.0

Table 6. Hydraulic variables and estimates of contraction scour for selected bridge sites in Alaska with no pressure flow.—Continued

Bridge No. (fig. 2)	Stream name	Event	Width of approach channel (ft)	Discharge at approach channel (ft^3/s)	Flow depth in approach (ft)	Discharge at bridge channel (ft^3/s)	Width of channel at bridge (ft)	Depth of flow at bridge (ft)	D_{50} (ft)	Critical velocity for D_{50} (ft/s)	Modeled velocity in the approach channel (ft/s)	Likely type of scour	Depth of live-bed contraction scour (ft)	Depth of clear-water contraction scour (ft)
445	Good River	1-percent AEP flood	43.0	3,357	10.0	3,064	38.0	10.5	0.00	1.7	7.8	Live	0.0	25.1
		0.2-percent AEP flood	43.0	4,109	11.5	3,787	38.0	12.0	0.00	1.7	8.3	Live	0.0	30.7
1821	Grouse Creek[1]	2012 flood	22.3	454	7.1	1,159	30.5	5.2	0.03	4.6	2.9	Clear	8.0	2.2
578	Gunn Creek	1-percent AEP flood	380.9	2,338	3.2	2,286	56.0	5.2	0.06	5.3	1.9	Clear	4.6	1.1
		0.2-percent AEP flood	380.9	2,989	4.2	2,965	56.0	5.8	0.06	5.5	1.9	Clear	7.1	2.1
590	Gunny Sack Creek	1-percent AEP flood	48.3	700	1.9	700	28.3	2.7	0.34	8.6	7.7	Clear	0.0	0.0
		0.2-percent AEP flood	51.4	950	2.2	950	29.5	3.2	0.34	8.9	8.3	Clear	0.0	0.0
2264	Harriet Hunt Creek	1-percent AEP flood	97.1	1,178	4.0	1,190	47.0	4.1	0.08	6.2	3.1	Clear	2.1	0.0
		0.2-percent AEP flood	97.1	1,515	4.8	1,539	47.0	4.8	0.08	6.4	3.3	Clear	2.7	0.0
3000	Hatchery Creek	1-percent AEP flood	106.9	5,589	10.8	5,782	104.1	8.7	0.16	9.0	4.9	Clear	2.5	0.0
		0.2-percent AEP flood	106.9	6,882	12.2	7,200	105.0	10.0	0.16	9.1	5.3	Clear	2.8	0.0
2129	Hatchery Creek Tributary	1-percent AEP flood	33.7	383	3.4	578	28.0	3.3	0.14	7.1	3.3	Clear	2.2	0.0
		0.2-percent AEP flood	33.7	467	4.1	751	28.0	3.8	0.14	7.3	3.4	Clear	3.0	0.0
844	Heney Creek	1-percent AEP flood	94.2	848	1.5	866	31.0	3.2	0.07	4.9	6.2	Live	0.0	1.1
		0.2-percent AEP flood	94.2	1,097	1.7	1,126	33.4	3.5	0.07	5.1	6.7	Live	0.0	1.6
1253	Hunter Creek	1-percent AEP flood	160.6	3,950	4.5	4,330	79.0	4.8	0.15	7.7	5.5	Live[2]	2.7	1.4
		0.2-percent AEP flood	160.6	4,983	5.7	5,560	79.0	6.6	0.15	8.0	5.4	Live[2]	2.9	1.0
1685	Jordan Creek	1-percent AEP flood	30.4	130	3.0	376	65.5	2.5	0.00	1.8	1.5	Clear	2.0	0.5
		0.2-percent AEP flood	30.4	153	3.4	496	61.8	3.0	0.00	1.8	1.5	Clear	2.8	1.0
893	Kougarok River	1-percent AEP flood	76.2	1,520	5.2	1,660	140.1	3.5	0.23	9.0	3.8	Clear	0.4	0.0
		0.2-percent AEP flood	76.2	1,966	6.0	2,240	146.0	4.2	0.23	9.3	4.3	Clear	0.4	0.0
1713	Little Susitna River Braid			See table 7										
1717	Log Jam Creek	1-percent AEP flood	109.1	5,492	8.3	5,534	75.0	8.4	0.18	9.0	6.1	Clear	2.1	0.0
		0.2-percent AEP flood	109.1	5,865	8.7	5,922	75.0	8.7	0.18	9.0	6.2	Clear	2.3	0.0
580	McCallum Creek	1-percent AEP flood	38.4	1,208	5.2	1,264	25.0	4.5	0.24	9.1	6.0	Clear	2.5	0.5
		0.2-percent AEP flood	38.4	1,574	6.9	1,680	25.0	5.4	0.24	9.6	6.0	Clear	3.9	1.0
		1967 flood	38.4	968	4.4	999	25.0	3.9	0.24	8.9	5.8	Clear	1.9	0.2
585	Michael Creek	1-percent AEP flood	40.2	560	1.8	559	26.0	3.2	0.16	6.7	8.0	Live	0.0	0.0
		0.2-percent AEP flood	41.7	760	2.2	757	26.0	4.5	0.16	7.0	8.2	Live	0.0	0.0
1669	Montana Creek[1]	1-percent AEP flood	199.2	6,531	6.3	13,264	155.2	9.4	0.17	8.5	5.2	Clear	3.9	0.0
		0.2-percent AEP flood	199.2	7,982	8.5	17,504	155.2	9.5	0.17	8.8	4.7	Clear	9.8	0.0
		1987 flood	199.2	7,092	7.1	14,894	155.0	10.3	0.17	8.6	5.0	Clear	5.3	0.0
1641	Nataga Creek	1-percent AEP flood	125.9	3,820	4.1	4,009	47.9	7.4	0.29	9.3	7.3	Clear	0.2	0.0
		0.2-percent AEP flood	125.9	4,487	6.1	5,099	47.9	8.7	0.29	10.0	5.8	Clear	3.3	0.3
1457	Newlunberry Creek	1-percent AEP flood	16.0	308	2.4	285	16.0	3.3	0.17	7.1	7.9	Live	0.0	0.0
		0.2-percent AEP flood	16.0	411	2.9	380	16.0	3.9	0.17	7.4	8.9	Live	0.0	0.0
1018	North Fork Anchor River	1-percent AEP flood	44.0	1,425	5.4	1,790	30.0	5.1	0.10	6.9	6.0	Clear	3.2	2.4
		0.2-percent AEP flood	44.0	1,821	6.4	2,370	30.0	5.8	0.10	7.0	6.5	Clear	4.2	3.7

Table 6. Hydraulic variables and estimates of contraction scour for selected bridge sites in Alaska with no pressure flow.—Continued

Bridge No. (fig. 2)	Stream name	Event	Width of approach channel (ft)	Discharge at approach channel (ft^3/s)	Flow depth in approach (ft)	Discharge at bridge channel (ft^3/s)	Width of channel at bridge (ft)	Depth of flow at bridge (ft)	D_{50} (ft)	Critical velocity for D_{50} (ft/s)	Modeled velocity in the approach channel (ft/s)	Likely type of scour	Depth of live-bed contraction scour (ft)	Depth of clear-water contraction scour (ft)
1409	Pats Creek	1-percent AEP flood	29.1	1,526	4.4	1,699	65.5	4.5	0.13	7.3	11.9	Live	0.0	0.0
		0.2-percent AEP flood	29.1	1,898	5.0	2,189	69.9	5.4	0.13	7.5	13.0	Live	0.0	0.0
1501	Peters Creek	1-percent AEP flood	50.5	4,712	9.7	4,678	44.0	9.7	0.21	9.7	9.6	Live[2]	0.8	0.3
		0.2-percent AEP flood	50.5	6,456	12.1	6,735	44.0	12.8	0.21	10.0	11.1	Live	0.9	0.8
		1995 flood	50.5	4,830	9.8	4,797	44.0	9.9	0.21	9.7	9.7	Live	0.8	0.3
432	Sawmill Creek			See table 7										
1098	Smith Creek	1-percent AEP flood	172.8	748	4.0	777	78.0	3.4	0.10	6.6	1.1	Clear	3.2	0.0
		0.2-percent AEP flood	172.8	1,026	4.7	1,070	78.0	4.0	0.10	6.7	1.3	Clear	3.7	0.0
1199	South Fork Anchor River[1]	1-percent AEP flood	157.1	4,007	6.5	5,223	67.0	7.9	0.14	8.0	4.0	Clear	5.5	0.6
2138	Swiftwater Creek	1-percent AEP flood	16.0	403	4.1	520	25.4	2.5	0.15	7.5	6.2	Clear	1.3	0.2
		0.2-percent AEP flood	16.0	448	4.7	700	26.0	3.0	0.15	7.7	5.9	Clear	2.1	0.4
309	Taiya River[1]	1-percent AEP flood	193.9	21,102	11.8	21,988	196.9	11.6	0.11	8.0	9.2	Live	0.6	1.0
463	Takotna River	1-percent AEP flood	324.7	6,013	6.0	6,000	206.1	8.1	0.15	7.9	3.1	Clear	0.0	0.0
		0.2-percent AEP flood	324.7	7,677	7.2	7,760	206.1	9.3	0.15	8.2	3.3	Clear	0.2	0.0
462	Tatalina River	1-percent AEP flood/1998 Flood	28.9	1,137	7.1	1,122	34.0	6.0	0.08	6.7	5.6	Live[2]	0.4	0.0
		0.2-percent AEP flood	28.9	1,176	7.1	1,159	34.0	6.0	0.08	6.7	5.7	Live[2]	0.3	0.0
584	Trims Creek	1-percent AEP flood	26.8	628	3.6	752	30.0	4.7	0.24	8.6	6.6	Clear	0.0	0.0
		0.2-percent AEP flood	26.8	792	4.2	998	30.0	5.4	0.24	8.9	7.1	Clear	0.0	0.0
1731	Trocodero Creek	1-percent AEP flood	40.4	1,535	4.7	1,626	39.3	6.3	0.14	7.5	8.0	Live	0.0	0.0
		0.2-percent AEP flood	40.4	1,862	5.5	2,064	39.3	7.0	0.14	7.7	8.4	Live	0.0	0.0
2281	Trumpeter Creek	1-percent AEP flood	87.1	2,311	7.9	3,088	60.0	5.7	0.09	6.9	3.3	Clear	7.0	1.2
		0.2-percent AEP flood	87.1	2,552	9.3	3,917	60.0	6.8	0.09	7.1	3.2	Clear	9.9	1.7
607	Victor Creek	1-percent AEP flood	47.5	2,256	9.1	2,462	32.3	7.4	0.16	8.8	5.2	Clear	4.9	0.7
		0.2-percent AEP flood	47.5	2,592	10.4	3,100	32.3	8.4	0.16	9.0	5.3	Clear	6.8	1.4
1490	West Creek	1-percent AEP flood	123.8	7,466	6.3	7,462	122.0	6.0	0.11	7.2	9.6	Live	0.3	1.5
		0.2-percent AEP flood	123.8	9,611	7.3	9,530	122.0	7.2	0.11	7.4	10.7	Live	0.0	2.0
		1967 flood	123.8	9,740	7.3	9,653	122.0	7.3	0.11	7.4	10.8	Live	0.0	2.0
587	Whistler Creek	1-percent AEP flood	46.0	389	1.3	388	26.0	1.9	0.19	6.6	6.8	Live	0.0	0.0
		0.2-percent AEP flood	46.0	527	1.5	527	26.0	2.3	0.19	6.8	7.6	Live	0.0	0.1
464	Yankee Creek			See table 7										

[1] These sites have vertical contraction at higher flows. See table 7.

[2] The live-bed scour equation is used at Hunter Creek, Peters Creek, and Tatalina River because there was evidence of live-bed conditions and scour in the channel.

Table 7. Hydraulic variables and estimates of vertical contraction scour for selected bridge sites in Alaska with pressure flow.

[D_{50}: Median grain diameter. **Abbreviations:** AEP, annual exceedance probability; Max, maximum; ft, foot; ft/s foot per second; ft^3/s, cubic foot per second]

Bridge No. (fig. 2)	Stream name	Event	Top of bridge superstructure elevation (ft)	Low chord elevation (ft)	Water surface elevation at the upstream side of the bridge (ft)	Wier flow	Depth at upstream side of bridge (ft)	Bridge opening height (ft)	Discharge through bridge (ft³/s)	Discharge through approach channel (ft³/s)	Width of approach channel (ft)
1935	Bodenburg Creek	Max pressure flow	102.5	97.0	102.3	No	9.1	4.4	1,500	1,294	27.2
1821	Grouse Creek[1,2]	1-percent AEP flood	60.5	56.7	58.2	No	7.1	5.6	1,350	506	22.3
		0.2-percent AEP flood	60.5	56.7	61.2	Yes	10.1	5.6	1,914	586	22.3
1713	Little Susitna River Braid[1]	Max pressure flow	565.0	562.3	564.8	No	9.0	6.5	5,450	2,976	45.0
1669	Montana Creek[1]	0.2-percent AEP flood	594.0	590.0	590.6	No	10.1	9.5	18,177	7,982	199.2
432	Sawmill Creek[1,3]	1-percent AEP flood	31.0	25.8	30.3	No	16.1	11.8	15,407	15,355	69.9
		0.2-percent AEP flood	31.0	25.8	30.3	No	16.1	11.8	15,688	15,632	69.9
		2005 flood	31.0	25.8	27.9	No	13.7	11.8	11,377	11,479	69.9
1199	South Fork Anchor River	0.2-percent AEP Flood	101.9	95.2	101.5	No	14.4	8.3	7,308	4,541	157.1
309	Taiya River	0.2-percent AEP flood	103.0	97.2	100.5	No	13.9	11.7	28,100	26,670	193.9
		1967 flood	103.0	97.2	99.0	No	12.4	11.7	25,000	23,820	193.9
464	Yankee Creek	1-percent AEP flood	101.0	95.8	97.2	No	6.0	4.3	1,110	406	27.2
		0.2-percent AEP flood	101.0	95.8	99.1	No	7.9	4.3	1,500	466	27.2

Bridge No. (fig. 2)	Stream name	Event	Width of bridge opening (ft)	Live-bed coefficient	D_{50} (ft)	Critical velocity for D_{50} (ft/s)	Velocity at the approach (ft/s)	Vertical contraction scour depth		Indicated type of scour
								Live-bed (ft)	Clear-water (ft)	
1935	Bodenburg Creek	Max pressure flow	29.0	0.59	0.1	7.5	4.4	7.3	3.9	Clear
1821	Grouse Creek[1,2]	1-percent AEP flood	30.5	0.59	0.0	4.6	2.7	10.0	4.8	Clear
		0.2-percent AEP flood	30.5	0.59	0.0	4.9	2.3	19.6	8.0	Clear
1713	Little Susitna River Braid[1]	Max pressure flow	60.0	0.59	0.1	8.2	6.7	8.5	5.8	Clear
1669	Montana Creek[1]	0.2-percent AEP flood	203.0	0.59	0.2	9.1	4.8	13.5	2.3	Clear
432	Sawmill Creek[1,3]	1-percent AEP flood	135.2	0.64	0.2	11.0	12.9	3.1	2.7	Live
		0.2-percent AEP flood	135.2	0.64	0.2	11.0	12.7	3.0	2.9	Live
		2005 flood	132.8	0.64	0.2	10.7	11.4	1.2	0.1	Live
1199	South Fork Anchor River	.2 percent AEP Flood	68.8	0.59	0.1	9.1	2.4	30.1	5.9	Clear
309	Taiya River	0.2-percent AEP flood	205.0	0.59	0.1	8.3	8.8	6.2	7.1	Live
		1967 flood	205.0	0.59	0.1	7.9	8.7	4.0	5.3	Live
464	Yankee Creek	1-percent AEP Flood	45.0	0.59	0.1	6.3	2.3	7.8	1.1	Clear
		0.2-percent AEP Flood	45.0	0.59	0.1	6.6	1.3	13.3	2.3	Clear

[1] The channel underneath the bridge at this site was previously scoured. The channel bed elevation immediately upstream was used as the unscoured condition in the equation.

[2] Grouse Creek is the only site that is predicted to have weir flow during the 0.2-percent AEP flood; h_{ue} (effective upstream depth) and Q_{ue} (effective disharge) are 9.4 feet and 537 ft^3/s, respectively.

[3] Only the right side of the channel at Sawmill Creek will scour more than 2.8 feet. The left side is underlain by bedrock.

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.

[**Abutment type:** ST, spill through; WW, wingwall. **Abbreviations:** AEP, annual exceedance probability; Max, maximum; ft, foot; ft^2/s square foot per second; ft^3/s, cubic foot per second]

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft^2/s)	Discharge at bridge (ft^3/s)	Bridge opening	
					Discharge (ft^3/s)	Width (ft)			Width (ft)	Unit discharge (ft^3/sec)
395	Alaganik Slough	1-percent AEP flood	Yes	ST	5,887	109.5	53.8	5,920	120.5	49.1
		0.2-percent AEP flood			7,244	109.5	66.2	7,310	125.2	58.4
433	Barabara Creek	1-percent AEP flood	Yes	ST	2,622	64.6	40.6	2,680	55.5	48.3
		0.2-percent AEP flood			3,519	64.6	54.5	3,640	63.3	57.5
		1983 flood			2,021	64.6	31.3	2,050	51.6	39.7
2213	Barney Creek	1-percent AEP flood	Yes	ST	959	76.8	12.5	960	58.6	16.4
		0.2-percent AEP flood			1,268	76.8	16.5	1,270	69.2	18.3
1935	Bodenburg Creek	1-percent AEP flood	No	ST	62	27.2	2.3	62	25.9	2.4
		0.2-percent AEP flood			91	27.2	3.4	92	26.7	3.4
		Max pressure flow			1,294	27.2	47.6	1,500	29.0	51.7
588	Boulder Creek	1-percent AEP flood	Yes	WW	540	30.4	17.8	540	27.2	19.9
		0.2-percent AEP flood			730	34.2	21.3	730	27.7	26.4
645	Campbell at Old Seward	1-percent AEP flood	Yes	WW	1,767	35.1	50.3	2,190	69.6	31.5
		0.2-percent AEP flood			2,223	35.1	63.3	2,940	69.7	42.2

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
395	Alaganik Slough	1-percent AEP flood	0.91	3.2	10.3	13.5	1.1	14.8	4.5
		0.2-percent AEP flood	0.88	3.0	11.4	14.4	1.1	15.8	4.4
433	Barabara Creek	1-percent AEP flood	1.19	0.0	5.6	5.6	1.7	9.6	3.9
		0.2-percent AEP flood	1.05	0.0	6.3	6.3	1.5	9.5	3.2
		1983 flood	1.27	0.0	4.9	4.9	1.7	8.4	3.4
2213	Barney Creek	1-percent AEP flood	1.31	0.2	2.0	2.3	1.7	3.7	1.7
		0.2-percent AEP flood	1.11	0.0	3.1	3.1	1.6	5.0	1.9
1935	Bodenburg Creek	1-percent AEP flood	1.05	0.0	0.8	0.8	1.5	1.3	0.4
		0.2-percent AEP flood	1.02	0.0	1.0	1.0	1.4	1.4	0.4
		Max pressure flow	1.09	3.9	4.4	8.3	1.6	13.2	8.8
588	Boulder Creek	1-percent AEP flood	1.12	0.0	1.6	1.6	1.7	2.7	1.1
		0.2-percent AEP flood	1.24	0.0	2.0	2.0	1.7	3.6	1.5
645	Campbell at Old Seward	1-percent AEP flood	0.63	0.0	5.8	5.8	1.1	6.4	0.6
		0.2-percent AEP flood	0.67	0.0	7.1	7.1	1.1	7.8	0.7

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft^2/s)	Discharge at bridge (ft^3/s)	Bridge opening	
					Discharge (ft^3/s)	Width (ft)			Width (ft)	Unit discharge (ft^3/sec)
1140	Chicken Creek	1-percent AEP flood	Yes	WW	622	60.5	10.3	661	24.0	27.5
		0.2-percent AEP flood			844	60.5	14.0	917	24.0	38.2
424	Chisana River	1-percent AEP flood	No	ST	12,568	324.8	38.7	12,700	209.1	60.7
		0.2-percent AEP flood			14,673	325.1	45.1	15,000	211.6	70.9
		1997 flood			14,222	325.1	43.7	14,500	211.0	68.7
2282	Coffman Creek	1-percent AEP flood	Yes	ST	929	84.5	11.0	1,150	44.7	25.8
		0.2-percent AEP flood			1,189	84.5	14.1	1,510	46.2	32.7
674	Cooper Creek	1-percent AEP flood	Fair	WW	1,377	67.4	20.4	1,390	48.7	28.5
		0.2-percent AEP flood			2,010	67.4	29.8	2,190	58.0	37.8
		2003 flood			1,225	67.4	18.2	1,230	47.2	26.0
1021	Crescent Creek	1-percent AEP flood	Fair	WW	1,405	111.9	12.5	1,640	36.2	45.3
		0.2-percent AEP flood			1,927	111.9	17.2	2,640	36.8	71.7
		1969 flood			1,338	111.9	12.0	1,500	36.1	41.6
2283	Dog Creek	1-percent AEP flood	Yes	WW	620	50.5	12.3	629	37.6	16.7
		0.2-percent AEP flood			799	50.5	15.8	825	37.6	21.9

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
1140	Chicken Creek	1-percent AEP flood	2.68	0.6	3.0	3.6	1.1	3.9	1.0
		0.2-percent AEP flood	2.74	0.0	4.9	4.9	1.1	5.4	0.5
424	Chisana River	1-percent AEP flood	1.57	1.9	11.2	13.1	1.3	17.6	6.4
		0.2-percent AEP flood	1.57	2.5	12.0	14.5	1.3	19.4	7.5
		1997 flood	1.57	2.4	11.8	14.2	1.3	19.0	7.2
2282	Coffman Creek	1-percent AEP flood	2.34	0.0	4.0	4.0	1.1	4.6	0.5
		0.2-percent AEP flood	2.32	0.1	4.4	4.5	1.1	5.0	0.7
674	Cooper Creek	1-percent AEP flood	1.40	0.1	4.5	4.5	1.7	7.7	3.2
		0.2-percent AEP flood	1.27	0.3	5.5	5.8	1.7	9.9	4.3
		2003 flood	1.43	0.1	4.1	4.2	1.7	7.0	2.9
1021	Crescent Creek	1-percent AEP flood	3.61	2.5	4.1	6.6	1.1	7.2	3.1
		0.2-percent AEP flood	4.17	1.9	7.9	9.8	1.1	10.8	2.8
		1969 flood	3.47	2.3	3.8	6.1	1.1	6.7	2.9
2283	Dog Creek	1-percent AEP flood	1.36	0.0	3.5	3.5	1.7	6.0	2.5
		0.2-percent AEP flood	1.39	0.0	4.0	4.0	1.7	6.8	2.8

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft²/s)	Discharge at bridge (ft³/s)	Bridge opening	
					Discharge (ft³/s)	Width (ft)			Width (ft)	Unit discharge (ft³/sec)
2279	Dog Creek Tidal	1-percent AEP flood	Yes	ST	708	28.6	24.8	770	41.9	18.4
		0.2-percent AEP flood			915	28.6	32.0	1,020	43.6	23.4
1463	Falls Creek	1-percent AEP flood	No	WW	1,093	29.9	36.5	1,130	43.8	25.8
		0.2-percent AEP flood			1,456	29.9	48.7	1,510	45.3	33.4
586	Flood Creek	1-percent AEP flood	Yes	WW	560	35.6	15.7	560	27.4	20.4
		0.2-percent AEP flood			780	36.7	21.2	780	27.7	28.1
1900	Georges Creek	1-percent AEP flood	No	ST	337	19.5	17.3	340	22.4	15.2
		0.2-percent AEP flood			440	19.5	22.5	470	23.5	20.0
1899	Georges Creek	1-percent AEP flood	No	ST	307	15.5	19.8	330	23.0	14.4
		0.2-percent AEP flood			415	15.5	26.8	460	24.0	19.1
445	Good River	1-percent AEP flood	No	WW	3,357	43.0	78.1	3,640	66.6	54.7
		0.2-percent AEP flood			4,109	43.0	95.6	4,650	71.6	65.0
1821	Grouse Creek	1-percent AEP flood	No	WW	506	22.3	22.7	1,350	30.5	44.3
		0.2-percent AEP flood			586	22.3	26.3	1,914	30.5	62.8
		2012 flood			454	22.3	20.3	1,160	30.5	38.0

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
2279	Dog Creek Tidal	1-percent AEP flood	0.74	0.0	3.4	3.4	1.1	3.7	0.3
		0.2-percent AEP flood	0.73	0.0	4.1	4.1	1.1	4.5	0.4
1463	Falls Creek	1-percent AEP flood	0.71	0.3	3.5	3.8	1.1	4.1	0.7
		0.2-percent AEP flood	0.69	0.0	4.1	4.1	1.1	4.6	0.5
586	Flood Creek	1-percent AEP flood	1.30	0.0	2.4	2.4	1.8	4.2	1.8
		0.2-percent AEP flood	1.32	0.0	2.9	2.9	1.7	4.9	1.9
1900	Georges Creek	1-percent AEP flood	0.88	0.1	1.5	1.6	1.1	1.8	0.3
		0.2-percent AEP flood	0.89	0.2	1.7	1.9	1.1	2.1	0.4
1899	Georges Creek	1-percent AEP flood	0.73	0.3	1.3	1.6	1.1	1.8	0.4
		0.2-percent AEP flood	0.71	0.3	1.6	1.9	1.1	2.0	0.5
445	Good River	1-percent AEP flood	0.70	0.0	8.1	8.1	1.1	8.9	0.8
		0.2-percent AEP flood	0.68	0.0	8.9	8.9	1.1	9.8	0.9
1821	Grouse Creek	1-percent AEP flood	1.95	4.8	5.5	10.3	1.3	12.8	7.4
		0.2-percent AEP flood	2.39	8.0	5.5	13.5	1.1	15.2	9.8
		2012 flood	1.87	2.2	5.2	7.4	1.3	9.5	4.3

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft²/s)	Discharge at bridge (ft³/s)	Bridge opening	
					Discharge (ft³/s)	Width (ft)			Width (ft)	Unit discharge (ft³/sec)
578	Gunn Creek	1-percent AEP flood	No	WW	2,338	380.9	6.1	2,640	56.0	47.1
		0.2-percent AEP flood			2,989	380.9	7.8	3,460	56.0	61.8
590	Gunny Sack Creek	1-percent AEP flood	Yes	WW	700	48.3	14.5	700	28.2	24.8
		0.2-percent AEP flood			950	51.4	18.5	950	29.5	32.2
2264	Harriet Hunt Creek	1-percent AEP flood	Yes	WW	1,178	97.1	12.1	1,190	47.0	25.3
		0.2-percent AEP flood			1,515	97.1	15.6	1,540	47.0	32.8
3000	Hatchery Creek	1-percent AEP flood	Yes	WW	5,589	106.9	52.3	5,790	106.9	54.2
		0.2-percent AEP flood			6,882	106.9	64.4	7,220	111.0	65.0
2129	Hatchery Creek Tributary	1-percent AEP flood	Yes	ST	383	33.7	11.4	640	40.9	15.7
		0.2-percent AEP flood			467	33.7	13.8	850	43.3	19.6
844	Heney Creek	1-percent AEP flood	Yes	WW	848	94.2	9.0	870	31.0	28.1
		0.2-percent AEP flood			1,097	94.2	11.7	1,130	33.3	34.0
1253	Hunter Creek	1-percent AEP flood	No	WW	3,950	160.6	24.6	4,330	75.0	57.7
		0.2-percent AEP flood			4,983	160.6	31.0	5,560	75.0	74.1

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
578	Gunn Creek	1-percent AEP flood	7.68	1.1	4.7	5.8	1.1	6.4	1.7
		0.2-percent AEP flood	7.87	2.1	5.3	7.4	1.1	8.1	2.8
590	Gunny Sack Creek	1-percent AEP flood	1.71	0.0	2.7	2.7	1.4	3.7	1.0
		0.2-percent AEP flood	1.74	0.0	3.2	3.2	1.4	4.3	1.2
2264	Harriet Hunt Creek	1-percent AEP flood	2.09	0.0	4.0	4.0	1.2	4.8	0.8
		0.2-percent AEP flood	2.10	0.0	4.7	4.7	1.2	5.6	0.9
3000	Hatchery Creek	1-percent AEP flood	1.04	0.0	8.5	8.5	1.4	12.2	3.7
		0.2-percent AEP flood	1.01	0.0	9.5	9.5	1.2	11.8	2.3
2129	Hatchery Creek Tributary	1-percent AEP flood	1.38	0.0	2.7	2.7	1.7	4.6	1.9
		0.2-percent AEP flood	1.42	0.0	3.1	3.8	1.7	5.2	2.1
844	Heney Creek	1-percent AEP flood	3.12	0.0	3.2	3.2	1.1	3.5	0.3
		0.2-percent AEP flood	2.92	0.0	3.5	3.5	1.1	3.9	0.4
1253	Hunter Creek	1-percent AEP flood	2.35	2.7	4.8	7.4	1.1	8.4	3.7
		0.2-percent AEP flood	2.39	2.9	6.6	9.5	1.1	10.8	4.2

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft²/s)	Discharge at bridge (ft³/s)	Bridge opening	
					Discharge (ft³/s)	Width (ft)			Width (ft)	Unit discharge (ft³/sec)
1685	Jordan Creek	1-percent AEP flood	No	WW	130	30.4	4.3	380	68.2	5.6
		0.2-percent AEP flood			153	30.4	5.0	500	62.8	8.0
893	Kougarok River	1-percent AEP flood	No	ST	1,520	76.2	19.9	1,660	140.1	11.8
		0.2-percent AEP flood			1,966	76.2	25.8	2,240	146.0	15.3
1713	Little Susitna River Braid	Max pressure flow	Yes	WW	2,976	45.0	66.1	5,450	60.0	90.8
1717	Log Jam Creek	1-percent AEP flood	Yes	WW	5,492	109.1	50.3	5,534	78.9	70.2
		0.2-percent AEP flood			5,865	109.1	53.8	5,922	79.5	74.5
580	McCallum Creek	1-percent AEP flood	Yes	WW	1,208	38.4	31.4	1,280	27.2	47.0
		0.2-percent AEP flood			1,574	38.4	41.0	1,710	27.7	61.8
585	Michael Creek	1967 flood	Yes	WW	968	38.4	25.2	1,010	26.9	37.6
		1-percent AEP flood			560	40.2	13.9	560	26.5	21.1
		0.2-percent AEP flood			760	41.7	18.2	760	27.5	27.7
1669	Montana Creek	1-percent AEP flood	Yes	WW	6,531	199.2	32.8	13,483	198.9	67.8
		0.2-percent AEP flood			7,982	199.2	40.1	18,177	203.0	89.5
		1987 flood			7,092	199.2	35.6	15,282	203.0	75.3

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
1685	Jordan Creek	1-percent AEP flood	1.30	0.5	2.5	3.0	1.8	5.2	2.8
		0.2-percent AEP flood	1.59	1.0	3.0	4.0	1.5	6.0	3.0
893	Kougarok River	1-percent AEP flood	0.59	0.0	3.5	3.5	1.1	3.9	0.4
		0.2-percent AEP flood	0.59	0.0	4.1	4.1	1.1	4.5	0.4
1713	Little Susitna River Braid	Max pressure flow	1.37	5.8	4.3	10.1	1.7	17.4	13.1
1717	Log Jam Creek	1-percent AEP flood	1.39	0.0	8.0	8.0	1.6	12.8	4.8
		0.2-percent AEP flood	1.39	0.0	8.2	8.2	1.6	13.2	5.0
580	McCallum Creek	1-percent AEP flood	1.50	0.5	4.3	4.8	1.6	7.7	3.4
		0.2-percent AEP flood	1.51	1.0	5.2	6.2	1.6	9.8	4.6
585	Michael Creek	1967 flood	1.49	0.2	3.8	4.0	1.6	6.4	2.6
		1-percent AEP flood	1.51	0.0	3.1	3.1	1.5	4.7	1.6
		0.2-percent AEP flood	1.52	0.0	4.3	4.3	1.6	6.8	2.5
1669	Montana Creek	1-percent AEP flood	2.07	0.0	7.7	7.7	1.2	9.3	1.6
		0.2-percent AEP flood	2.24	0.0	9.5	9.5	1.2	10.9	1.5
		1987 flood	2.12	0.0	8.5	8.5	1.2	10.0	1.6

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft²/s)	Discharge at bridge (ft³/s)	Bridge opening	
					Discharge (ft³/s)	Width (ft)			Width (ft)	Unit discharge (ft³/sec)
1641	Nataga Creek	1-percent AEP flood	Yes	WW	3,820	125.9	30.3	4,010	48.0	83.5
		0.2-percent AEP flood			4,487	125.9	35.6	5,100	48.0	106.2
1457	Newlunberry Creek	1-percent AEP flood	No	WW	308	16.0	19.3	330	26.7	12.4
		0.2-percent AEP flood			411	16.0	25.7	450	27.8	16.2
1018	North Fork Anchor River	1-percent AEP flood	No	WW	1,425	44.0	32.4	1,790	30.0	59.7
		0.2-percent AEP flood			1,821	44.0	41.4	2,370	30.0	79.0
1409	Pats Creek	1-percent AEP flood	No	WW	1,526	29.1	52.4	1,700	65.5	26.0
		0.2-percent AEP flood			1,898	29.1	65.2	2,190	69.9	31.3
1501	Peters Creek	1-percent AEP flood	Yes	ST	4,712	50.5	93.3	4,870	53.4	91.1
		0.2-percent AEP flood			6,756	50.5	133.8	7,130	55.8	127.8
		1995 flood			4,830	50.5	95.7	5,000	53.6	93.4
432	Sawmill Creek	1-percent AEP flood	Yes	ST	15,355	69.9	219.7	15,440	135.2	114.2
		0.2-percent AEP flood			15,632	69.9	223.8	15,720	135.2	116.3
		2005 flood			11,479	69.9	164.3	1,1500	132.8	86.6

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
1641	Nataga Creek	1-percent AEP flood	2.75	0.0	7.4	7.4	1.1	8.1	0.7
		0.2-percent AEP flood	2.98	0.0	8.7	8.7	1.1	9.6	0.9
1457	Newlunberry Creek	1-percent AEP flood	0.64	0.0	2.7	2.7	1.1	2.9	0.3
		0.2-percent AEP flood	0.63	0.0	3.2	3.2	1.1	3.5	0.3
1018	North Fork Anchor River	1-percent AEP flood	1.84	2.4	5.1	7.5	1.3	9.7	4.7
		0.2-percent AEP flood	1.91	3.7	5.8	9.5	1.3	12.1	6.3
1409	Pats Creek	1-percent AEP flood	0.50	0.0	4.5	4.5	1.1	4.9	0.4
		0.2-percent AEP flood	0.48	0.0	5.4	5.4	1.1	5.9	0.5
1501	Peters Creek	1-percent AEP flood	0.98	0.8	8.7	9.5	1.1	10.4	1.8
		0.2-percent AEP flood	0.95	0.9	11.3	12.2	1.1	13.5	2.1
		1995 flood	0.98	0.8	8.9	9.7	1.1	10.6	1.8
432	Sawmill Creek	1-percent AEP flood	0.52	3.1	19.6	22.7	1.1	25.0	5.4
		0.2-percent AEP flood	0.52	3.0	19.6	22.6	1.1	24.9	5.3
		2005 flood	0.53	1.2	19.6	20.8	1.1	22.9	3.3

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft²/s)	Discharge at bridge (ft³/s)	Bridge opening	
					Discharge (ft³/s)	Width (ft)			Width (ft)	Unit discharge (ft³/sec)
1098	Smith Creek	1-percent AEP flood	Yes	ST	748	172.8	4.3	780	85.1	9.2
		0.2-percent AEP flood			1,026	172.8	5.9	1,080	88.7	12.2
1199	South Fork Anchor River	1-percent AEP flood	Yes	WW	4,007	157.1	25.5	5,230	68.7	76.2
		0.2-percent AEP flood			4,541	157.1	28.9	7,310	68.8	106.3
2138	Swiftwater Creek	1-percent AEP flood	Yes	ST	403	16.0	25.2	520	25.4	20.5
		0.2-percent AEP flood			448	16.0	28.0	700	26.0	27.0
309	Taiya River	1-percent AEP flood	Yes	WW	21,103	193.9	108.8	22,000	205.0	107.3
		0.2-percent AEP flood			26,670	193.9	137.5	28,100	205.0	137.1
		1967 flood			23,820	193.9	122.8	25,000	205.0	122.0
463	Takotna River	1-percent AEP flood	No	ST	6,013	324.7	18.5	6,020	225.2	26.7
		0.2-percent AEP flood			7,677	324.7	23.6	7,800	226.9	34.4
462	Tatalina River	1-percent AEP flood	No	WW	1,137	28.9	39.3	1,170	56.7	20.6
		0.2-percent AEP flood			1,176	28.9	40.7	1,210	56.9	21.3
584	Trims Creek	1-percent AEP flood	Yes	WW	628	26.8	23.5	760	32.4	23.5
		0.2-percent AEP flood			792	26.8	29.6	1,010	32.8	30.8

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
1098	Smith Creek	1-percent AEP flood	2.12	0.0	3.2	3.2	1.2	3.6	0.5
		0.2-percent AEP flood	2.05	0.0	3.7	3.7	1.2	4.3	0.6
1199	South Fork Anchor River	1-percent AEP flood	2.99	0.6	7.8	8.4	1.1	9.2	1.4
		0.2-percent AEP flood	3.68	5.9	8.1	14.0	1.1	15.4	7.3
2138	Swiftwater Creek	1-percent AEP flood	0.81	0.2	2.5	2.7	1.1	2.9	0.4
		0.2-percent AEP flood	0.96	0.4	2.9	3.3	1.1	3.6	0.7
309	Taiya River	1-percent AEP flood	0.99	0.6	11.3	11.9	1.1	13.0	1.8
		0.2-percent AEP flood	1.00	6.2	13.9	20.1	1.1	22.1	8.2
		1967 flood	0.99	4.0	10.8	14.8	1.1	16.3	5.5
463	Takotna River	1-percent AEP flood	1.44	0.0	7.6	7.6	1.5	11.6	4.1
		0.2-percent AEP flood	1.45	0.0	8.7	8.7	1.5	13.4	4.7
462	Tatalina River	1-percent AEP flood	0.52	0.4	4.2	4.6	1.1	5.0	0.8
		0.2-percent AEP flood	0.52	0.3	4.3	4.6	1.1	5.1	0.8
584	Trims Creek	1-percent AEP flood	1.00	0.0	4.5	4.5	1.2	5.4	0.9
		0.2-percent AEP flood	1.04	0.0	5.1	5.1	1.5	7.5	2.4

Table 8. Estimated abutment scour and variables for selected bridge sites in Alaska.—Continued

Bridge No. (fig. 2)	Stream name	Event	Adequate riprap?	Abutment type	Channel approach		Approach unit discharge (ft^2/s)	Discharge at bridge (ft^3/s)	Bridge opening	
					Discharge (ft^3/s)	Width (ft)			Width (ft)	Unit discharge (ft^3/sec)
1731	Trocodero Creek	1-percent AEP fFlood	Yes	ST	1,535	40.4	38.0	1,680	52.5	32.0
		0.2-percent AEP flood			1,862	40.4	46.1	2,150	55.1	39.0
2281	Trumpeter Creek	1-percent AEP flood	Yes	ST	2,311	87.1	26.5	3,090	65.8	46.9
		0.2-percent AEP flood			2,552	87.1	29.3	3,930	70.1	56.1
607	Victor Creek	1-percent AEP flood	No	WW	2,256	47.5	47.5	2,550	47.2	54.0
		0.2-percent AEP flood			2,592	47.5	54.6	3,260	57.8	56.4
1490	West Creek	1-percent AEP flood	Yes	WW	7,466	123.8	60.3	7,500	144.6	51.9
		0.2-percent AEP flood			9,611	123.8	77.6	9,670	149.7	64.6
		1967 flood			9,740	123.8	78.7	9,800	149.9	65.4
587	Whistler Creek	1-percent AEP flood	Fair	WW	389	46.0	8.5	390	27.1	14.4
		0.2-percent AEP flood			527	46.0	11.5	530	27.4	19.3
464	Yankee Creek	1-percent AEP flood	No	WW	406	27.2	14.9	1110	45.0	24.7
		0.2-percent AEP flood			466	27.2	17.1	1500	45.0	33.3

Bridge No. (fig. 2)	Stream name	Event	Relative contraction (q_2/q_1)	Contraction scour (ft)	Hydraulic depth at bridge (ft)	Flow depth including contraction scour (ft)	Live bed amplification factor (α)	Flow depth at bridge including contraction and abutment scour (ft)	Maximum scour depth at abutment (ft)
1731	Trocodero Creek	1-percent AEP flood	0.84	0.0	5.3	5.3	1.1	5.8	0.5
		0.2-percent AEP flood	0.85	0.0	5.6	5.6	1.1	6.2	0.6
2281	Trumpeter Creek	1-percent AEP Fflood	1.77	1.2	5.4	6.6	1.2	8.2	2.7
		0.2-percent AEP flood	1.91	1.7	6.2	7.9	1.2	9.4	3.2
607	Victor Creek	1-percent AEP flood	1.14	0.7	5.7	6.3	1.7	10.7	5.0
		0.2-percent AEP flood	1.03	1.4	5.5	7.0	1.4	9.6	4.1
1490	West Creek	1-percent AEP flood	0.86	0.3	5.2	5.5	1.1	6.1	0.9
		0.2-percent AEP flood	0.83	0.0	6.2	6.2	1.1	6.9	0.7
		1967 flood	0.83	0.0	6.3	6.3	1.1	6.9	0.6
587	Whistler Creek	1-percent AEP flood	1.70	0.0	1.9	1.9	1.4	2.6	0.7
		0.2-percent AEP flood	1.68	0.0	2.3	2.3	1.4	3.2	0.9
464	Yankee Creek	1-percent AEP flood	1.65	1.1	4.3	5.4	1.4	7.8	3.5
		0.2-percent AEP flood	1.95	2.3	4.3	6.6	1.3	8.2	3.9

Table 9. Hydraulic variables and estimated pier scour at selected bridge sites in Alaska with simple piers.

[**Abbreviations and symbol:** AEP, annual exceedance probability; ft, foot; –, debris was not considered in the pier scour estimate]

Bridge No. (fig. 2)	Stream name	Events	Debris			Debris shape coefficient	Mean velocity upstream of pier (ft³/s)	Calculated Froude	Pier nose shape	Pier nose shape coefficient	Depth upstream of pier (ft)
			Width (ft)	Height (ft)	Shape						
445	Good River[1]	1-percent AEP flood	–	–	–	–	9.0	0.48	Group of cylinders	1	10.9
		0.2-percent AEP flood	–	–	–	–	10.0	0.50	Group of cylinders	1	12.3
1409	Pats Creek	1-percent AEP flood	–	–	–	–	6.0	0.40	Square	1.1	6.9
		0.2-percent AEP flood	–	–	–	–	6.5	0.41	Square	1.1	7.9
1098	Smith Creek	1-percent AEP flood	–	–	–	–	2.4	0.21	Group of cylinders	1	4.0
		0.2-percent AEP flood	–	–	–	–	2.8	0.23	Group of cylinders	1	4.7
395	Alaganik Slough	1-percent AEP flood	12	6	Rectangular	0.79	5.0	0.22	Group of cylinders	1	16.2
		0.2-percent AEP flood	12	6	Rectangular	0.79	5.5	0.23	Group of cylinders	1	17.6
645	Campbell at Old Seward	1-percent AEP flood	12	3	Triangular	0.21	6.0	0.36	Group of cylinders	1	8.3
		0.2-percent AEP flood	12	3	Triangular	0.21	6.7	0.39	Group of cylinders	1	9.5
1685	Jordan Creek	1-percent AEP flood	3	1	Triangular	0.21	5.3	0.52	Group of cylinders	1	3.3
		0.2-percent AEP flood	3	1	Triangular	0.21	5.8	0.54	Group of cylinders	1	3.6
1490	West Creek	1-percent AEP flood	10	2.5	Triangular	0.21	9.7	0.70	Group of cylinders	1	6.0
		0.2-percent AEP flood	10	2.5	Triangular	0.21	10.6	0.70	Group of cylinders	1	7.1
		1967 flood	10	2.5	Triangular	0.21	10.7	0.70	Group of cylinders	1	7.1

Bridge No. (fig. 2)	Stream name	Events	Pier width (ft)	Pier scour depth (ft)	Effective pier width with debris (ft)	Pier scour depth with debris (ft)	Final scour depth (ft)	Scour depth increase from debris (ft)
445	Good River[1]	1-percent AEP flood	1	3.7	–	–	2.4	–
		0.2-percent AEP flood	1	3.9	–	–	2.4	–
1409	Pats Creek	1-percent AEP flood	2	4.6	–	–	4.6	–
		0.2-percent AEP flood	2	4.8	–	–	4.8	–
1098	Smith Creek	1-percent AEP flood	1	1.8	–	–	1.8	–
		0.2-percent AEP flood	1	2.0	–	–	2.0	–
395	Alaganik Slough	1-percent AEP flood	1.5	4.0	4.6	8.2	8.2	4.2
		0.2-percent AEP flood	1.5	4.2	4.3	8.3	8.3	4.1
645	Campbell at Old Seward	1-percent AEP flood	1	3.0	1.8	4.4	4.4	1.4
		0.2-percent AEP flood	1	3.2	1.7	4.6	4.6	1.4
1685	Jordan Creek	1-percent AEP flood	1.5	3.3	1.6	3.4	3.4	0.1
		0.2-percent AEP flood	1.5	3.4	1.6	3.6	3.6	0.1
1490	West Creek	1-percent AEP flood	1.5	4.6	2.2	6.0	6.0	1.4
		0.2-percent AEP flood	1.5	4.9	2.1	6.1	6.1	1.2
		1967 flood	1.5	4.9	2.1	6.1	6.1	1.2

Table 9. Hydraulic variables and estimated pier scour at selected bridge sites in Alaska with simple piers.—Continued

Bridge No. (fig. 2)	Stream name	Events	Debris			Debris shape coefficient	Mean velocity upstream of pier (ft^3/s)	Calculated Froude	Pier nose shape	Pier nose shape coefficient	Depth upstream of pier (ft)
			Width (ft)	Height (ft)	Shape						
2213	Barney Creek	See table 11									
1021	Crescent Creek	See table 11									
432	Sawmill Creek	See table 10									
607	Victor Creek	See tables 10 and 11									

Bridge No. (fig. 2)	Stream name	Events	Pier width (ft)	Pier scour depth (ft)	Effective pier width with debris (ft)	Pier scour depth with debris (ft)	Final scour depth (ft)	Scour depth increase from debris (ft)
2213	Barney Creek	See table 11						
1021	Crescent Creek	See table 11						
432	Sawmill Creek	See table 10						
607	Victor Creek	See tables 10 and 11						

[1] Calculated scour depth was greater than 2.4 times the pier width. The maximum value of 2.4 times the pier width was used instead.

Table 10. Hydraulic variables and estimated pier scour at selected bridge sites in Alaska with complex piers.

[D_{50}: Median grain diameter. D_{84}: Grain diameter that is greater than 84 percent of the population. **Abbreviations and symbol:** AEP, annual exceedance probability; ft, foot; ft/s, foot per second; –, indicates that a scour component was not calculated because scour was not expected to reach that pier component]

Bridge No. (fig. 2)	Bridge name	Event	Approach flow depth (ft)	Pile cap in front of pier stem (ft)	Pier stem width (ft)	Pile cap elevation		Pile cap thickness (ft)	Low stream bed elevation (ft)	Approach velocity (ft/s)	Pier stem shape
						Bottom (ft)	Top (ft)				
432	Sawmill Creek[1]	1-percent AEP flood	22.7	2	3	1.7	4.2	2.5	4.3	11.0	Square
		0.2-percent AEP flood	22.7	2	3	1.7	4.2	2.5	4.3	10.2	Square
		2005 flood	20.4	2	3	1.7	4.2	2.5	4.3	9.2	Square
607	Victor Creek	1-percent AEP flood	8.5	1	6	463.0	466.5	3.5	467.0	8.3	Round
		0.2-percent AEP flood	9.6	1	6	463.0	466.5	3.5	467.0	9.2	Round

Bridge No. (fig. 2)	Bridge name	Event	Pile cap		Angle of attack (degrees)	Pile cap length (ft)	D_{84} (ft)	D_{50} (ft)	Pier stem scour (ft)	Pile cap scour (ft)	Pile group scour (ft)	Total scour (ft)
			Shape	Width (ft)								
432	Sawmill Creek[1]	1-percent AEP flood	Square	7	0	7	0.66	0.24	3.8	4.4	–	2.8
		0.2-percent AEP flood	Square	7	0	7	0.66	0.24	3.9	4.5	–	2.8
		2005 flood	Square	7	0	7	0.66	0.24	3.5	4.0	–	2.8
607	Victor Creek	1-percent AEP flood	Square	8	0	32	0.53	0.16	0.4	8.3	0.2	8.9
		0.2-percent AEP flood	Square	8	0	32	0.53	0.16	0.4	8.2	0.2	8.8

[1] Sawmill Creek piers are founded on bedrock at a depth of 2.8 feet. Total complex pier scour exceeds this, but scour would not progress below the bedrock.

Table 11. Hydraulic variables and estimated pier scour at selected bridges in Alaska with coarse beds and clear-water scour conditions.

[D_{50}: Median grain diameter. D_{84}: Grain diameter that is greater than 84 percent of the population. **Abbreviations and symbol:** AEP, annual exceedance probability; ft, foot; ft/s foot per second; mm, millimeter; – indicates variables that are not used because debris accumulation is not likely to be a problem]

Bridge No. (fig. 2)	Stream name	Event	Debris				Pier nose shape coefficient	Depth upstream of pier (ft)	Pier width (ft)	Effective pier width with debris
			Width (ft)	Height (ft)	Shape	Debris shape coefficient				
2213	Barney Creek	1-percent AEP flood	–	–	–	–	1	3.01	1.5	–
		0.2-percent AEP flood	–	–	–	–	1	4	1.5	–
607	Victor Creek	1-percent AEP flood	–	–	–	–	1.1	8.5	7.0	–
		0.2-percent AEP flood	–	–	–	–	1.1	9.6	7.0	–
1021	Crescent Creek	1-percent AEP flood	18	3	Rectangular	0.79	1	5.6	1.0	8.2
		0.2-percent AEP flood	18	3	Rectangular	0.79	1	7.2	1.0	6.6
		1969 Flood	18	3	Rectangular	0.79	1	5.2	1.0	8.7

Bridge No. (fig. 2)	Stream name	Event	D_{50} (mm)	D_{84} (mm)	Mean velocity upstream of pier (ft/s)	Depth of scour (ft)	Depth of scour with debris (ft)
2213	Barney Creek	1-percent AEP flood	42	83	6.04	1.6	–
		0.2-percent AEP flood	42	83	5.85	1.7	–
607	Victor Creek	1-percent AEP flood	49	362	8.31	1.8	–
		0.2-percent AEP fFlood	49	362	9.23	2.4	–
1021	Crescent Creek	1-percent AEP flood	21	44	4.78	1.7	6.1
		0.2-percent AEP flood	21	44	5.88	2.1	6.9
		1969 flood	21	44	4.68	1.6	6.0

Table 12. Summary of estimated scour for selected bridge sites in Alaska, 2013–15.

[All values are in feet. Estimated scour depths greater than 5 feet are shaded. **Abbreviation and symbol:** AEP, annual exceedance probability; –, no piers]

Bridge No. (fig. 2)	Stream name	Event	Contraction scour depth	Abutment scour depth	Total scour depth at pier	Scour greater than 5 feet	Notes
395	Aliganik Slough	1-percent AEP flood	3.2	4.5	11.4	Yes	Debris removal would mitigate pier scour issues.
		0.2-percent AEP flood	3.0	4.4	11.3		
433	Barabara Creek	1-percent AEP flood	0.0	3.9	–	No	
		0.2-percent AEP flood	0.0	3.2	–		
		1983 flood	0.0	3.4	–		
2213	Barney Creek	1-percent AEP flood	0.2	1.7	1.8	No	Coarse pier scour equation used
		0.2-percent AEP flood	0.0	1.9	1.7		
1935	Bodenburg Creek	1-percent AEP flood	0.0	0.4	–	Yes	Pressure flow
		0.2-percent AEP flood	0.0	0.4	–		
		Max pressure flow	3.9	8.8	–		
588	Boulder Creek	1-percent AEP flood	0.0	1.1	–	No	
		0.2-percent AEP flood	0.0	1.5	–		
645	Campbell at Old Seward	1-percent AEP flood	0.0	0.6	4.4	No	
		0.2-percent AEP flood	0.0	0.7	4.6		
1140	Chicken Creek	1-percent AEP flood	0.6	1.0	–	No	
		0.2-percent AEP flood	0.0	0.5	–		
424	Chisana River	1-percent AEP flood	1.9	6.4	–	Yes	
		0.2-percent AEP flood	2.5	7.5	–		
		1997 flood	2.4	7.2	–		
2282	Coffman Creek	1-percent AEP flood	0.0	0.5	–	No	
		0.2-percent AEP flood	0.1	0.7	–		
674	Cooper Creek	1-percent AEP flood	0.1	3.2	–	No	
		0.2-percent AEP flood	0.3	4.3	–		
		2003 flood	0.1	2.9	–		
1021	Crescent Creek	1-percent AEP flood	2.5	3.1	8.6	Y	Coarse pier scour equation used
		0.2-percent AEP flood	1.9	2.8	8.8		
		1969 flood	2.3	2.9	8.3		
2283	Dog Creek	1-percent AEP flood	0.0	2.5	–	No	
		0.2-percent AEP flood	0.0	2.8	–		
2279	Dog Creek Tidal	1-percent AEP flood	0.0	0.3	–	No	
		0.2-percent AEP flood	0.0	0.4	–		
1463	Falls Creek	1-percent AEP flood	0.3	0.7	–	No	
		0.2-percent AEP flood	0.0	0.5	–		

Table 12. Summary of estimated scour for selected bridge sites in Alaska, 2013–15.—Continued

Bridge No. (fig. 2)	Stream name	Event	Contraction scour depth	Abutment scour depth	Total scour depth at pier	Scour greater than 5 feet	Notes
586	Flood Creek	1-percent AEP flood	0.0	1.8	–	No	
		0.2-percent AEP flood	0.0	1.9	–		
1900	Georges Creek	1-percent AEP flood	0.3	0.3	–	No	
		0.2-percent AEP flood	0.3	0.4	–		
1899	Georges Creek	1-percent AEP flood	0.1	0.4	–	No	
		0.2-percent AEP flood	0.2	0.5	–		
445	Good River	1-percent AEP flood	0.0	0.8	2.4	No	
		0.2-percent AEP flood	0.0	0.9	2.4		
1821	Grouse Creek	1-percent AEP flood	4.8	7.4	–	Yes	
		0.2-percent AEP flood	8.0	9.8	–		
		2012 flood	2.2	4.3	–		
578	Gunn Creek	1-percent AEP flood	1.1	1.7	–	No	
		0.2-percent AEP flood	2.1	2.8	–		
590	Gunny Sack Creek	1-percent AEP flood	0.0	1.0	–	No	
		0.2-percent AEP flood	0.0	1.2	–		
2264	Harriet Hunt Creek	1-percent AEP flood	0.0	0.8	–	No	
		0.2-percent AEP flood	0.0	0.9	–		
3000	Hatchery Creek	1-percent AEP flood	0.0	3.7	–	No	
		0.2-percent AEP flood	0.0	2.3	–		
2129	Hatchery Creek Tributary	1-percent AEP flood	0.0	1.9	–	No	
		0.2-percent AEP flood	0.0	2.1	–		
844	Heney Creek	1-percent AEP flood	0.0	0.3	–	No	
		0.2-percent AEP flood	0.0	0.4	–		
1253	Hunter Creek	1-percent AEP flood	2.7	3.7	–	No	
		0.2-percent AEP flood	2.9	4.2	–		
1685	Jordan Creek	1-percent AEP flood	0.5	2.8	3.9	No	
		0.2-percent AEP flood	1.0	3.0	4.6		
893	Kougarok River	1-percent AEP flood	0.0	0.4	–	No	
		0.2-percent AEP flood	0.0	0.4	–		
1713	Little Susitna River Braid	Max pressure flow	5.8	13.1	–	Yes	Pressure flow
1717	Log Jam Creek	1-percent AEP flood	0.0	4.8	–	Yes	
		0.2-percent AEP flood	0.0	5.0	–		

Table 12. Summary of estimated scour for selected bridge sites in Alaska, 2013–15.—Continued

Bridge No. (fig. 2)	Stream name	Event	Contraction scour depth	Abutment scour depth	Total scour depth at pier	Scour greater than 5 feet	Notes
580	McCallum Creek	1-percent AEP flood	0.5	3.4	–	No	Pressure flow
		0.2-percent AEP flood	1.0	4.6	–		
		1967 flood	0.2	2.6	–		
585	Michael Creek	1-percent AEP flood	0.0	1.6	–	No	
		0.2-percent AEP flood	0.0	2.5	–		
1669	Montana Creek	1-percent AEP flood	0.0	1.6	–	N	Pressure flow
		0.2-percent AEP flood	2.3	1.5	–		
		1987 flood	0.0	1.6	–		
1641	Nataga Creek	1-percent AEP flood	0.0	0.7	–	N	Pressure flow
		0.2-percent AEP flood	0.0	0.9	–		
1457	Newlunberry Creek	1-percent AEP flood	0.0	0.3	–	N	On bedrock
		0.2-percent AEP flood	0.0	0.3	–		
1018	North Fork Anchor River	1-percent AEP flood	2.4	4.7	–	Y	
		0.2-percent AEP flood	3.7	6.3	–		
1409	Pats Creek	1-percent AEP flood	0.0	0.4	4.6	N	Pier and abutment scour would only occur if channel moved to one side.
		0.2-percent AEP flood	0.0	0.5	4.8		
1501	Peters Creek	1-percent AEP flood	0.8	1.8	–	N	
		0.2-percent AEP flood	0.9	2.1	–		
		1995 flood	0.8	1.8	–		
432	Sawmill Creek	1-percent AEP flood	3.1	5.4	2.8	Y	Bedrock below pier and left abutment. Scour depth of 2.8 ft maximum except right side of channel and right abutment.
		0.2-percent AEP flood	3.0	5.3	2.8		
		2005 flood	1.2	3.3	2.8		
1098	Smith Creek	1-percent AEP flood	0.0	0.5	1.8	N	
		0.2-percent AEP flood	0.0	0.6	2		
1199	South Fork Anchor River	1-percent AEP flood	0.6	1.4	–	Y	Pressure flow
		0.2-percent AEP flood	5.9	7.3	–		
2138	Swiftwater Creek	1-percent AEP flood	0.2	0.4	–	N	
		0.2-percent AEP flood	0.4	0.7	–		
309	Taiya River	1-percent AEP flood	0.6	1.8	–	Y	
		0.2-percent AEP flood	6.2	8.2	–		
		1967 flood	4.0	5.5	–		
463	Takotna River	1-percent AEP flood	0.0	4.1	–	N	
		0.2-percent AEP flood	0.0	4.7	–		
462	Tatalina River	1-percent AEP flood/ 1998 Flood	0.4	0.8	–	N	
		0.2-percent AEP flood	0.3	0.8	–		
584	Trims Creek	1-percent AEP flood	0.0	0.9	–	N	
		0.2-percent AEP flood	0.0	2.4	–		

Table 12. Summary of estimated scour for selected bridge sites in Alaska, 2013–15.—Continued

Bridge No. (fig. 2)	Stream name	Event	Contraction scour depth	Abutment scour depth	Total scour depth at pier	Scour greater than 5 feet	Notes
1731	Trocodero Creek	1-percent AEP flood	0.0	0.5	–	N	
		0.2-percent AEP flood	0.0	0.6	–		
2281	Trumpeter Creek	1-percent AEP flood	1.2	2.7	–	N	
		0.2-percent AEP flood	1.7	3.2	–		
607	Victor Creek	1-percent AEP flood	0.7	5.0	9.6	Y	Complex pier equation does not account for armoring.
		0.2-percent AEP flood	1.4	4.1	10.2		
1490	West Creek	1-percent AEP flood	0.3	0.9	6.3	Y	
		0.2-percent AEP flood	0.0	0.7	6.1		
		1967 flood	0.0	0.6	6.1		
587	Whistler Creek	1-percent AEP flood	0.0	0.7	–	N	
		0.2-percent AEP flood	0.0	0.9	–		
464	Yankee Creek	1-percent AEP flood	1.1	3.5	–	N	Pressure flow
		0.2-percent AEP flood	2.3	3.9	–		

Bridges with High Scour Estimates

Five feet is considered the threshold for “substantial scour”, although the influence of scour on the bridge structure ultimately depends on the depth of the bridge foundations. Those bridges coded as U in table 1 are founded on piles of unknown depth; thus, these numbers may be used to prioritize bridge for pile-depth testing. Only 9 of the 52 sites have substantial scour estimates at the design flood or largest measured flood, and four additional sites have substantial scour estimates for the check flood. These and other bridges of concern are described individually.

Alaganik Slough Bridge 395

Pier scour of 11.3–11.4 ft is the primary concern at Alaganik Slough Bridge 395. A 2002 underwater inspection noted scour holes 1.5–4 ft deep around the pilings, and scour near the left abutment. Debris accumulations, noted in every inspection report, increase estimated pier scour by more than 4 ft. Photographs show debris on the upstream pile and wedged between piles, as well as on the streambed near the bridge. The sounding record shows a change in low streambed elevation of 3.5 ft between 1998 and 2008, indicating that the streambed is readily scoured.

Bodenburg Creek Bridge 1935

The check flood for Bodenburg Creek is based on overflow from the Matanuska River filling the channel to capacity at Bridge 1935. This flow of 1,500 ft^3/s would scour the channel an estimated 3.9 ft, with 8.8 ft of scour at the abutments. The 1-and 0.2-percent AEP floods derived from the surface drainage basin of Bodenburg Creek are estimated to cause very minor scour.

Chisana River Bridge 424

Chisana River at Bridge 424 is a low-gradient meandering river with a mobile sand and fine gravel bed. The 252-ft bridge easily accommodates the estimated 1- and 0.2-percent AEP floods, and had a 14,500 ft^3/s flood in 1997 (similar to the 0.2-percent AEP flood of 15,000 ft^3/s). Soundings show a change in low bed elevation of 3.1 ft. Estimated abutment scour of 6.4–7.5 ft during floods does not seem excessive for this large of a channel; however, the modeled water surface does not extend all the way across the bridge opening, so only one abutment is likely to be scoured in a given flood.

Crescent Creek Bridge 1021

Crescent Creek has an estimated pier scour of 6.0–6.9 ft, with an accumulation of debris and accounting for channel armoring with the coarse bed equation. With contraction scour, this increases to 8.3–8.6 ft. This seems excessive for a small stream with no evidence of pier or contraction scour in soundings or post-flood reports. The bridge survived a flood in 1969 that was greater than the 1-percent AEP flood, with a predicted scour of 8.3 ft at piers. One-dimensional modeling may not adequately capture the flow distribution at Crescent Creek, which is perched on an inactive alluvial fan with one side of the floodplain sloping away from the channel for several miles. The fluvial geomorphology of this reach suggests some flood flow would be expected to escape the channel and cross the approach road. Crescent Creek Bridge 1021 may be a good candidate for pile-depth testing, more frequent monitoring, or two-dimensional modeling.

Grouse Creek Bridge 1821

Grouse Creek Bridge 1821 is a small bridge with vertical sheet pile cell abutments spanning a mobile-bedded stream. Bridge 1821 is undersized, and has vertical contraction at the 1- and 0.2-percent AEP flows, and weir flow at the 0.2-percent AEP flow. Contraction scour of 4.8 ft and abutment scour of 7.4 ft are estimated for the 1-percent AEP flood. Even at low flow, the water surface is against both abutments, and inspection reports note that the abutments are not protected by riprap.

Little Susitna River Braid Bridge 1713

Bridge 1713, built in 2011, spans a sub-channel of the Little Susitna River in a braided reach. An indefinite proportion of the estimated 1- and 0.2-percent AEP floods would enter this channel, so a “maximum pressure flow” was determined that would fill the channel to capacity without losing substantial flow to the road approach. This flow is 5,450 ft^3/s, compared to 7,740 ft^3/s measured in 2012 at an upstream streamgage, with estimates of 7,290 and 10,300 ft^3/s for the 1- and 0.2-percent AEP floods, respectively. Estimated vertical contraction and abutment scour for a 5,450 ft^3/s flow are 5.8 and 13.1 ft, respectively. Low water measurements in 2013 showed that the streambed below the bridge was about 3.5 ft lower than the uncontracted channel upstream and downstream, indicating that significant scour had already occurred. Because the bridge is new and 20 ft longer than the original bridge, the sounding record is too short to derive any conclusions about stability.

Logjam Creek Bridge 1717

Estimated abutment scour is high at Logjam Creek (4.8–5 ft), but other evidence suggests that the actual risk of scour is low. The channel is mixed bedrock and alluvial, with bedrock underneath the right abutment. The channel is moderately contracted and the approach flow is deep, two factors that greatly increase the live-bed amplification factor in the abutment scour equation, but do not necessarily increase scour, especially in a coarse-bedded, relatively low-gradient channel.

North Fork Anchor River Bridge 1018

Estimated abutment scour at North Fork Anchor River also is high, at 4.7–6.3 ft, although in this case it may be an underestimate. Hydraulic conditions (including a contracted bridge opening with vertical abutments and a sharp bend in the river approaching the bridge) are conducive to scour. A 5-ft-deep scour hole was noted in a 2005 inspection at the right abutment toe, and inspection reports consistently note failure of the embankments and gabions placed to protect the abutments. A 90-degree bend in the channel approaching the bridge exposes the right abutment to increased hydraulic forces and flow separation unaccounted for in the one-dimensional model.

Sawmill Creek Bridge 432

Sawmill Creek Bridge 432 is located in a complicated setting. The bridge is highly skewed to the flow direction, reducing its capacity. The channel immediately upstream of the bridge has been extensively modified to accommodate a powerplant outfall. The 1- and 0.2-percent AEP floods and the largest flood on record in 2005 all reach the bridge superstructure. Estimated abutment scour ranges from 3.3 to 5.4 ft. Pier-scour estimates exceed 8 ft for the complex piers with exposed footings; however, the footings are founded on bedrock 2.8 ft below the current streambed so that pier scour is limited to 2.8 ft. Additionally, the left abutment is founded on bedrock, so only the channel to the right of the pier and the right abutment are subject to scour. A design engineer working on the powerplant observed aggradation of several feet following floods from tributary debris flows down the steep valley walls upstream (Dean Orbison, City of Sitka [retired], oral commun., August 27, 2015).

South Fork Anchor River Bridge 1199

The 0.2-percent AEP flood at South Fork Anchor River reaches the superstructure of the bridge and creates vertical contraction scour of 5.9 ft and abutment scour of 7.3 ft. The 1-percent AEP flood is estimated to produce minor scour. The channel underneath Bridge 1199 was 2.5 ft lower than the upstream cross section and 2 ft lower than the downstream cross section during the field visit, indicating that contraction scour has occurred; thus, the 1-percent AEP flood estimate of 0.6 ft probably is too low. This could be because live-bed or mixed conditions are present at lower flows rather than the clear-water conditions calculated. Live-bed scour for the 1-percent AEP flood was 5.5 ft compared to 0.6 ft for clear-water.

Taiya River Bridge 309

Taiya River Bridge 309 fills to the low chord at the check flood, and nearly so at the design flood. The 4.0–6.2 ft of contraction scour and 5.5–8.2 ft of abutment scour predicted for the 1967 flood and 1-percent AEP flows are reasonable given the contraction caused by the bridge and the historical elevation changes of 6 ft in the channel bed noted in the sounding record. Taiya River is a relatively large river with a mobile bed.

Victor Creek Bridge 607

Pier scour at Victor Creek was calculated with the complex pier-scour equation and the coarse bed pier-scour equation. The complex pier-scour equation accounts for increased flow resistance caused by the exposure of the wide footing, but does not account for armoring. The coarse bed pier-scour equation accounts for armoring, and accounts for the width of the footing by using the full width of the footing as the pier width. Scour computed using the complex pier-scour equation was nearly 9 ft (with contraction scour, 9.6–10.2 ft), whereas scour computed coarse bed pier-scour equation with a footing-width pier was 1.8–2.4 ft. Theresults from the complex pier-scour equation are considered conservative, especially given the transition to firmer soils around the footing noted in the as-builts, but the results from the coarse-bed pier-scour equation seem like an underestimate given the exposure of the footing. The channel at Bridge 607 has been degrading incrementally according to soundings, despite the very coarse bed sediment surrounding the pier, so the more conservative results are reported.

West Creek Bridge 1490

Total scour at West Creek Bridge 1490 piers ranges from 6.1 to 6.3 ft. There is a persistent debris accumulation, which increases estimated scour by about 2 ft, and little evidence of channel armoring. No scour holes have been noted in inspections or are present in the sounding record; however, live-bed scour is expected at this site and scour holes would fill in quickly. Bridge 1490 was not in place during the 1967 flood of record.

Summary and Conclusions

Fifty-two bridge sites in Alaska were evaluated for streambed scour, including reach-scale stream stability, contraction scour, and local scour at piers and abutments. Most of the sites with unstable streambeds were on active alluvial fan landforms or were destabilized by in-stream mining. In these cases, reach-scale instability is not expected to increase contraction scour, although changing attack angles and aggradation may increase abutment scour, bank erosion, or approach road loss. One unstable site, Victor Creek Bridge 607, is entrenched in an inactive alluvial fan, and seems to be degrading slightly. Scour estimates are less reliable for unstable sites because the equations assume static channel geometry.

Design and check floods were determined for 52 sites that were modeled with HEC-RAS. The design floods used to calculate scour for most bridges were the estimated 1-percent AEP floods, but for two distributary sites where standard flood frequency techniques were not applicable, alternative design flood values (maximum pressure flow) were used to calculate conservative scour numbers. For two regulated streams, flood frequency estimation methods were adapted to the dam operation plans in place. Scour also was calculated for the 0.2-percent AEP flood at all but the two maximum pressure flow sites to show the effects of the check flood. Scour was calculated for large observed floods at 12 sites.

Contraction scour and abutment scour were calculated for all 52 bridges, and pier scour was calculated for the 11 bridges with piers. Vertical contraction occurred during the design flood or historical floods at four sites and during the check flood at eight sites, including the two distributary sites. Only four sites, all of which experienced vertical contraction, had estimated contraction scour of more than 5 feet (ft), and these only at the check flood. Sites with contraction scour concerns include Grouse Creek Bridge 1821, Little Susitna Braid Bridge 1713, South Fork Anchor River Bridge 1199, and Taiya River Bridge 309. Estimated total pier scour (pier scour plus contraction scour) exceeded 5 ft at the design and check floods at four sites. In one case, Crescent Creek Bridge 1021, the pier-scour estimates appeared to be excessively conservative. Sites with the greatest pier-scour concerns include Alaganik Slough Bridge 395 (where scour holes have been noted in dive reports), Victor Creek Bridge 607 (where the footing has been exposed), and West Creek Bridge 1490.

Total scour at abutments exceeded 5 ft during the design or historical floods at five sites, and during only the check flood at an additional five sites. Abutment scour is overestimated where embankment failure would widen channels, decreasing hydraulic forces on the abutment, and where low velocity and channel armoring would reduce the risk. Embankment erosion is common among study sites, with inspections noting it at 35 of the 52 sites. Riprap typically is used to protect abutments, but it is noted as missing or inadequate at 18 of the bridge sites.

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Glossary

Annual Exceedance Probability (AEP) Flood Annual exceedance probability of a peak flow is the probability of that flow being equaled or exceeded in a 1-year period and is expressed as a decimal fraction less than 1.0. The recurrence interval of a peak flow is the number of years, on average, in which the specified flow is expected to be equaled or exceeded one time. Exceedance probability and recurrence interval are mathematically inverse of each other; thus, an exceedance probability of 0.01 is equivalent to a recurrence interval of 100 years.

Aggradation General and progressive buildup of the longitudinal profile of a channel bed resulting from sediment deposition.

Check Flood A theoretical flood larger than the design flood used by engineers to evaluate hydraulic conditions at a structure. For bridges over waterways, this usually is a 0.2-percent AEP flood (also known as a 500-year flood).

Design Flood A theoretical flood used by engineers to design a structure. Most bridges are designed to safely withstand the hydraulics created by a 1-percent AEP flood (also known as a 100-year flood).

Low Chord The lowest elevation of the superstructure of a bridge, usually the bottom of the girder supporting the deck or the lowest element of the deck if there is no girder. Also called “low steel.”.

Superstructure The elements of a bridge, including deck, railing, and girder, that sit on top of the piers and abutments

Appendix 1. Stream Stability Cross Sections

Repeat cross sections at each bridge as measured by Alaska Department of Transportation and Public Facilities and the U.S. Geological Survey are Microsoft® Excel files and are available for download at https://doi.org/10.3133/sir20175149.

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