TEMPORAL VARIATIONS OF SCOUR AND FILL PROCESSES AT SELECTED BRIDGE SITES IN ALASKA

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Abstract: Streambed-scour monitoring at selected sites in Alaska is being used to assess real-time hazards, but also illustrates the complexities of scour and the difficulty of predicting scour using existing methods. Pier-mounted sonar transducers and stage sensors installed on 16 bridges in Alaska measure the distance to the streambed and water stage every 30 minutes during the open-water season. Data have been collected for over 3 years at 5 of the bridges. Near real-time transmission of these data allow state engineers to monitor bed elevations during high flows at scour-critical bridges. A wide range of hydraulic and sediment regimes are represented by the monitoring network. Annual peak discharges range from approximately 1,000 ft^3/s to nearly 70,000 ft^3/s and median grain size diameter of bed material ranges from about 1 mm to over 50 mm. Measured local scour ranged from no change in bed elevation at some sites to nearly 20 ft of scour at 1 location. The sonar data together with hydraulic variables measured during high flows will be used to evaluate a range of predictive equations for scour. Initial results suggest that scour and fill conditions are generally site specific as well as being dependent upon timing and duration of high flows. Discharge peaks of similar magnitude did not always produce corresponding scour depths of similar magnitude at individual sites. Scour magnitude was more dependent on flow duration, seasonal timing, and source of the high flow. These factors all have an influence on the availability of sediment in the river. Four years of stage and bed elevation data at the Knik River near Palmer show an annual cycle of channel aggradation and degradation to an equilibrium level that is punctuated by shorter periods of scour and fill. The annual cycle of channel change at this site is an interplay of sediment supply, discharge, and the influence of instream hydraulic structures.

INTRODUCTION

Streambed scour followed by fill after a flood passage is a well documented process at locations where regular cross section measurements are made. Data describing the timing and duration of this process are limited by the frequency of field visits. To better understand this process and to monitor bed elevation at bridge piers, the U.S. Geological Survey and the Alaska Department of Transportation and Public Facilities operate a network of streambed scour-monitoring stations in Alaska. Currently 16 bridges are instrumented with sonars for measuring distance to the streambed and pressure transducers for measuring river stage (Figure 1). These stations provide state engineers with near real-time bed elevation data to remotely assess scour at bridge piers during high flows. The data also provide a nearly continuous record of bed elevation and responses to changes in discharge and sediment supply. Seasonal changes as well as shorter duration scour and fill have been recorded. The monitoring network covers a wide range of streamflow and sediment regimes across Alaska. Annual peak streamflow discharges range from less than 1,000 ft^3/s to near 70,000 ft^3/s and median grain-size diameter of the bed material ranges from 1 mm to over 50 mm. In addition to the near real-time data, channel bathymetry and velocity profiles are collected at each site several times per year. This paper focuses on 4 years of hydraulic and sonar data collected at the Knik River.

INSTRUMENTATION

Each bridge was instrumented with a retractable, pier-mounted 235 kHz echosounder. At locations with multiple scour-critical piers, sonar transducers were mounted on each pier. Sonar transducers were mounted either at an angle on the side of piers near the nose or on the pier nose in order to collect data just upstream of the pier footing. Data are collected every thirty minutes and transmitted every six hours via satellite. When bed elevation or stage thresholds are exceeded satellite transmissions increase in frequency. These near real-time data are available on the web at http://ak.water.usgs.gov/usgs_scour. Streambed elevation and stage data accuracies are ±0.5 ft and ±0.1 ft, respectively.

STREAMBED-SCOUR DATA

Changes in bed elevation at the monitored bridge piers and stage, represented by the maximum annual value less the minimum annual value, are presented in Table 1 for all stations. The network of pier scour-monitoring sites is dynamic, with locations being added and removed annually based on monitoring priority and installation of scour countermeasures. Instrumentation is subject to damage by high flows, debris, and ice and repairs at some sites can only be made during low-flow conditions.

Little to no change in bed elevation was observed at most sites. Streambed scour typically occurs during high flows and only one significant event affecting a single basin occurred during the period of data collection. Intense rainfall in July 2003 in the Tanana River Basin resulted in a rapid increase in stage at three sites. Discharge on the Chena River was near the 10-year recurrence interval and the 5-year recurrence interval was exceeded at both the Tanana and Salcha Rivers (Meyer and others, 2004). Despite the high streamflows, relatively little bed elevation change occurred at these sites. The Knik River near Palmer was the only site with large changes in bed elevation each year. Annual scour ranged from 17.2 ft to 20.0 ft.

Streambed Scour at the Knik River: The Knik River is a braided sand and gravel channel that transports large quantities of sediment from the Knik Glacier. It drains an area of approximately 1,200 mi^2, over half of which consists of glaciers. The braided channel narrows from approximately 3 mi wide at the glacier mouth to just over 400 ft at the Old Glenn Highway bridge where the channel is subject to a 4:1 contraction during summer high flows. Current morphological and alluvial characteristics of the river can be partially attributed to large glacial outburst floods that occurred nearly every year from 1914-1966. The maximum measured discharge from these events was 359,000 ft^3/s. At a discharge of 30,000 ft^3/s on July 12, 2003, suspended sediment concentration was measured at 711 mg/L and bedload discharge was 9,010 tons/d. Median grain size of the bedload was 1.5 mm.

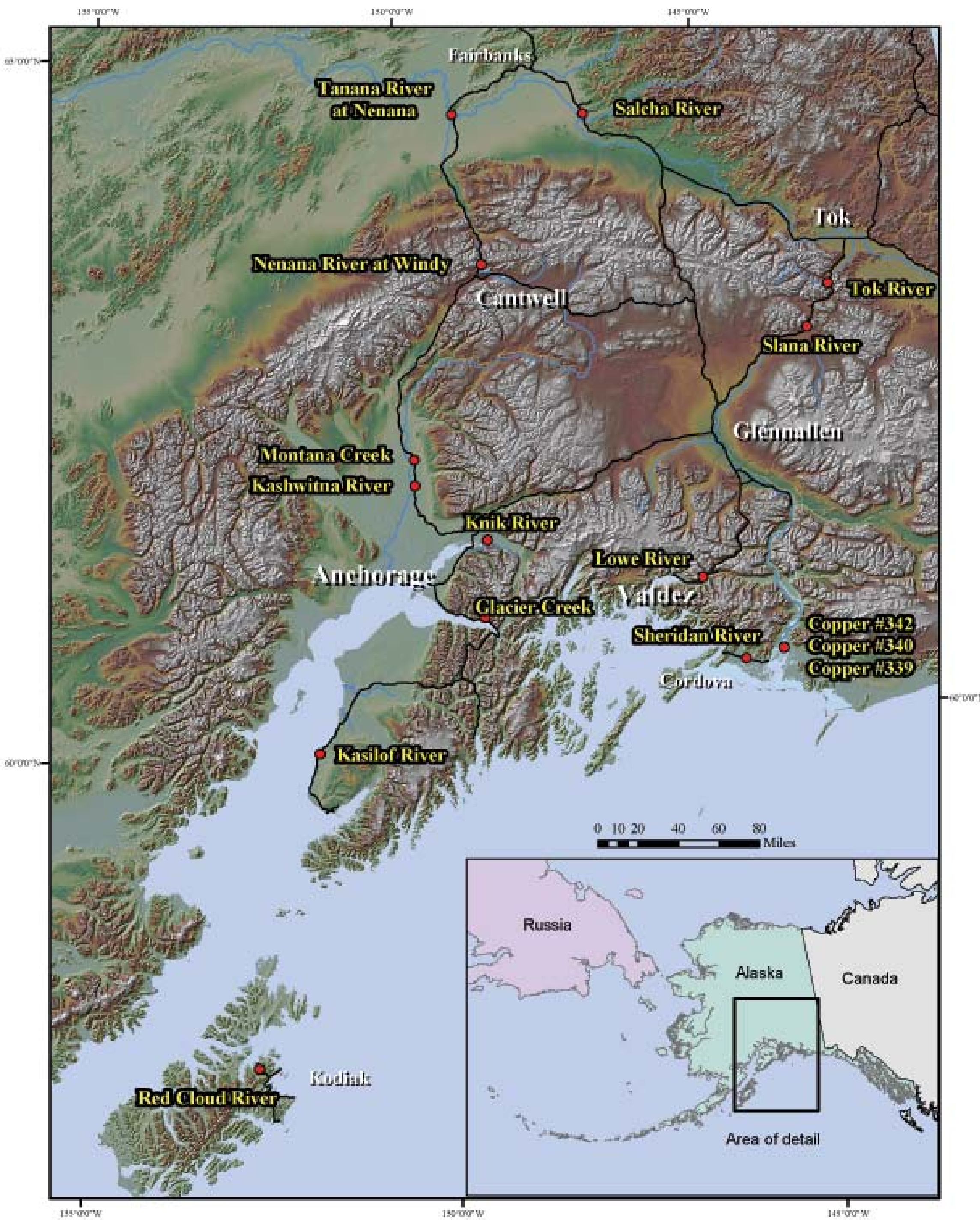

Figure 1 Active U.S. Geological Survey streambed-scour monitoring locations in Alaska.

Since the installation of the monitoring equipment, streamflows at the Knik River ranged from 600 ft^3/s to 60,400 ft^3/s for water years 2002-2005. During the winter months, the streambed at the monitored bridge pier aggraded to an elevation of between 29 and 31 ft (local datum) each year (Figure 2). From the beginning of data collection each year in early May until the latter part of June, the bed degraded at an average rate of 0.2 ft/day, about 8 ft each year. Over this same period of time, the stage increased at a rate of 0.07 ft/day, 0.09 ft/day, and 0.06 ft/day for 2003, 2004, and 2005, respectively. Following this period of seasonal channel degradation the bed elevation at the pier remains relatively stable, with brief periods of scour and fill. Stability in the bed elevation can be interpreted as an equilibrium in the sediment transport rather than a lack of sediment transport. The channel begins to aggrade in September as stage decreases.

Table 1 Changes in bed elevation at the monitored bridge piers and stage at streambed-scour monitoring stations. (All values are in feet and represent changes during open water, - indicates no data)

	2003		**2004**		**2005**	
Location	**Stage**	**Bed**	**Stage**	**Bed**	**Stage**	**Bed**
Tanana River at Nenana	9.9	3.5	-	-	-	-
Nenana River at Windy	5.5	2.0	2.1	3.0	-	0.5
Montana Creek	-	-	2.1	1.0	3.3	0
Kashwitna River	-	-	2.1	4.0	3.1	3.5
Red Cloud River	-	-	-	-	1.1	0.0
Salcha River	7.7	2.0	3.6	1.5	2.0	1.5
Tok River	0.7	0.0	0.9	0.0	1.5	4.0
Chena River	8.0	3.0	-	-	-	-
Slana River	-	-	-	-	2.8	1.5
Lowe River	-	-	-	-	4.2	2.0
Knik River	6.2	19.7	6.1	17.2	5.1	20.0
Kenai River	3.5	0.5	1.0	1.0	-	-
Kasilof River	2.4	1.0	2.3	1.5	4.6	1.0
Sheridan River	-	-	-	-	9.8	9.0
Copper River #339	-	-	-	-	3.5	7.5
Copper River #340	-	-	-	-	3.3	10.5
Copper River #342	-	-	-	-	5.4	8.0
Glacier Creek	-	-	2.5	0.0	2.7	0.0

The mean bed elevation at a river cross section is not only dependent upon discharge, but is also related to changes in width, depth, velocity, and sediment load during the passage of a flood (Leopold and others, 1964). Streambed scour in the bridge reach is an interplay of discharge, sediment transport and the flow hydraulics associated with the channel contraction, upstream guide banks, and piers. Although the sonar only measures the bed elevation in front of the right-bank pier, the measured changes in bed elevation represent channel change from all the above factors. The cross section defined by the upstream bridge opening was surveyed periodically to document changes in bed elevation across the channel (Figure 3). These cross sections and the sonar data show an annual cycle in channel change.

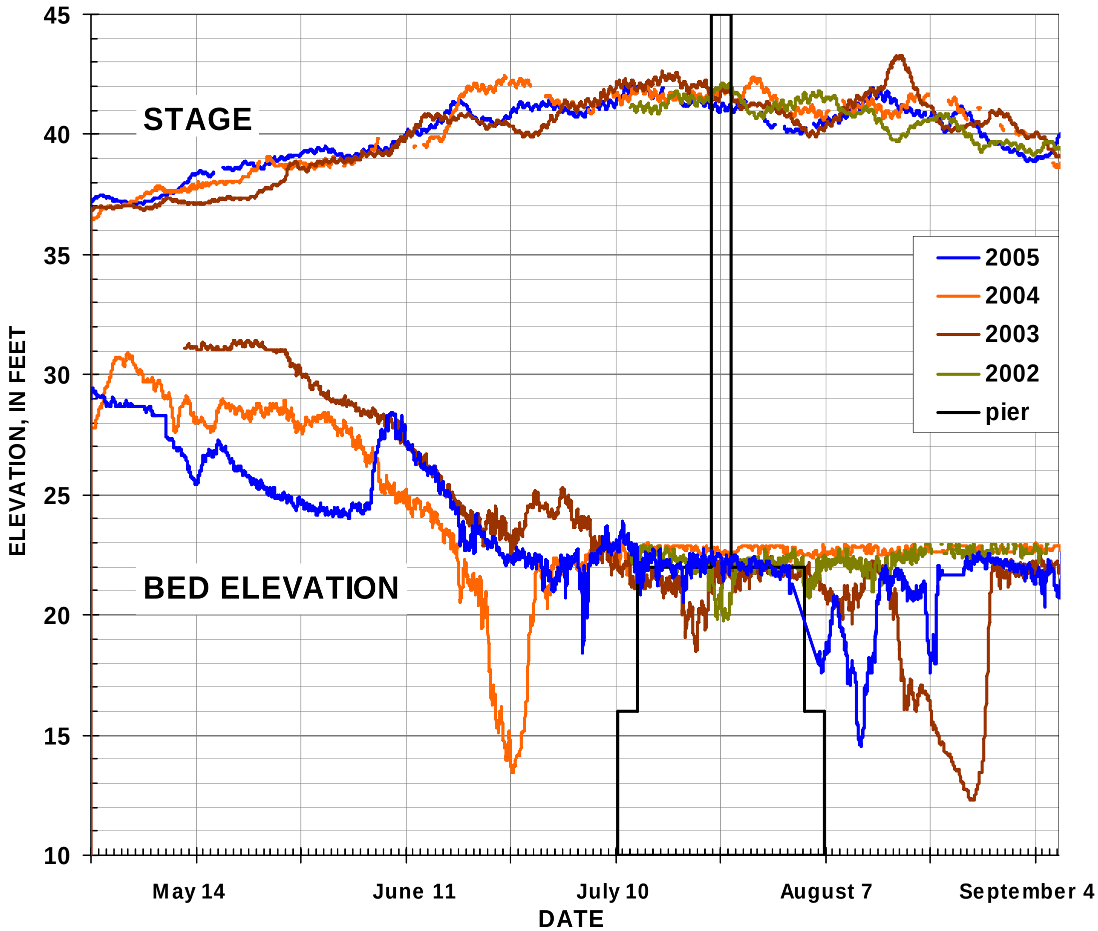

Figure 2 Stage and bed elevation at the monitored bridge pier for 2002-2005 at the Knik River near Palmer, Alaska. The bridge pier and footings are plotted for reference.

Flow vortices that develop as flow is routed around the guide banks erode the channel along the banks. Increases in stage result in larger flow vortices and progressive deepening of the channel from the banks towards the center of the channel. At higher stages this scour along the channel margins is thought to override the effects of local scour at the pier where the sonar is mounted. The pier is supported by a 24 ft wide footing and 30 ft wide sub footing. These footings appear to armor the local bed and bed elevation remained near the elevation of the top of the footing for extended periods (Figure 2). Parola and others (1996) found that rectangular pier footings protect the streambed from the scouring of vortex systems formed by the pier until the footing is above the streambed and then vortices from the footing induce scour. The channel scours vertically and laterally towards the center to accommodate increased summer streamflow. Vertical and lateral scour are concurrent until the footing of the pier is reached, at which point vertical scour is limited and increases in channel area are made by lateral scour. This process is illustrated in the successive cross sections plotted in Figure 3.

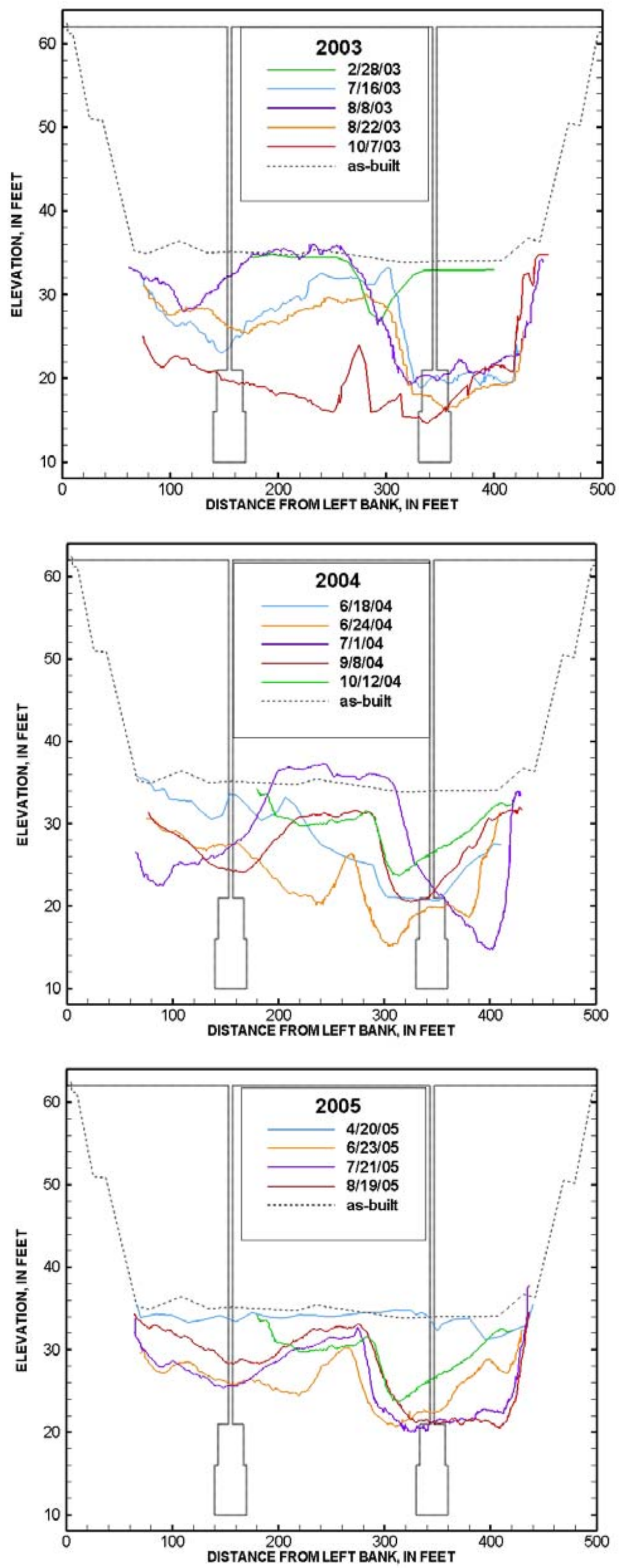

Figure 3 Upstream bridge cross sections at the Knik River for 2003-2005.

Two distinct scour and fill cycles from 2003 and 2004 highlight differences in timing and duration of scour (Figure 4). Both scour events were associated with a period of high temperatures and subsequent increased glacial melt, but in 2003 the warm weather was followed by 10 days of rainfall and cooler temperatures. The maximum scour occurred slightly after the peak in stage in 2003 and in 2004 maximum scour was concurrent with peak stage. The duration of scour, measured from when the bed elevation begins to decrease until fill begins, was 11.5 days in 2003 and 4 days in 2004. The scour in 2003 was of greater duration because the discharge and sediment supply from the glacier was reduced by the cooler temperatures. The channel filled 10 ft in two days after warmer temperatures resumed, likely accompanied by an increase in sediment load. In 2004, stage increased rapidly prior to scour and was then steady with diurnal fluctuations. The scour began after the bed had degraded to the elevation of the top of the pier footing. Filling of the channel began before the stage began to decrease. Bed elevation changes in alluvial systems are the response to changes in sediment supply and flow hydraulics. Since flow hydraulics were relatively constant, an increase in sediment supply is thought to have initiated the filling.

SUMMARY

Streambed-scour monitoring at bridges across Alaska provides state engineers with a tool to remotely evaluate the stability of these structures during high flows. The data sets also are providing a nearly continuous record of stage and bed elevation across a range of hydrologic regimes. Large changes in bed elevation were recorded each year at the Knik River. The bed elevation data recorded both a seasonal channel aggradation and degradation pattern and shorter duration cycles of scour and fill. The channel aggraded to the same relative elevation each winter and then degraded to an equilibrium elevation that is coincident with the elevation of the top of the pier footing. The bed scoured beyond this elevation for short periods as a result of prolonged high flow and possibly fluctuations in sediment supply. The onset of scour occurred on the falling limb of a hydrograph in 2003 and at the peak in 2004. Fill began after the recession in the hydrograph in 2003 and before it in 2004. The timing and duration of scour and fill at the Knik River is believed to be attributed more to sediment supply and the source of high flows rather than discharge alone.

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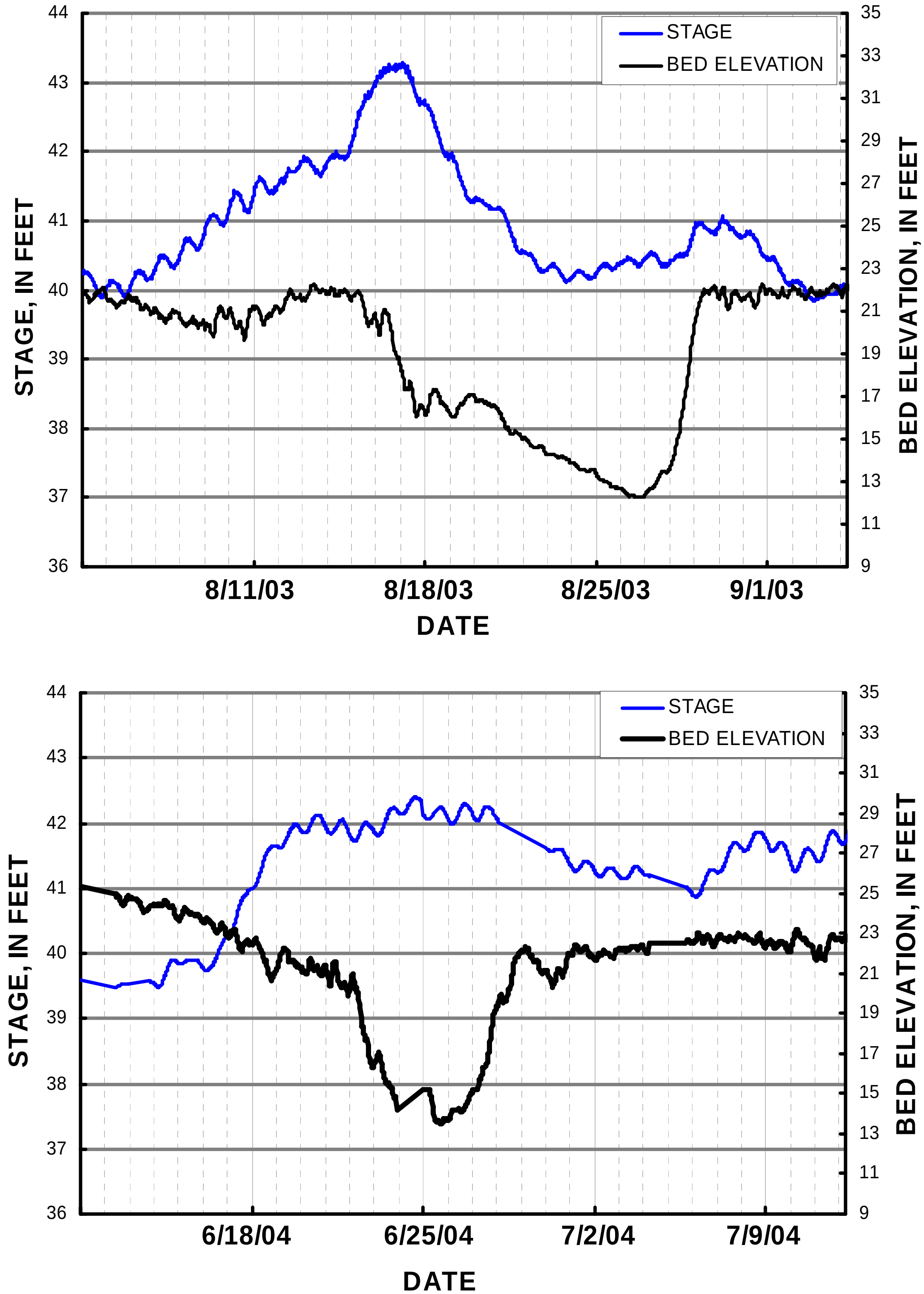

Figure 4 Stage and bed elevation at monitored bridge pier from two scour and fill events on the Knik River near Palmer, Alaska. Stage increases were the result of rainfall (2003, upper plot) and glacial melting from a prolonged period of warm weather (2004, lower plot).