Prepared in cooperation with the U.S. Army Corps of Engineers and the Oregon Department of State Lands

Preliminary Assessment of Channel Stability and Bed-Material Transport in the Rogue River Basin, Southwestern Oregon

Open-File Report 2011–1280

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

Cover: Gravel bars and bedrock outcrop on the Rogue River at its confluence with Lobster Creek. (Photograph by Krista L. Jones, U.S. Geological Survey, July 2010.)

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Conversion Factors and Datums

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
Volume		
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
Flow rate		
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per year (m^3/yr)	1.308	cubic yard per year (yd^3/yr)
meter per second (m/s)	3.281	foot per second (ft/s)
Mass		
kilogram (kg)	2.205	pound avoirdupois (lb)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
Elevation, as used in this report, refers to distance above the vertical datum.

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By Krista L. Jones, Jim E. O'Connor, Mackenzie K. Keith, Joseph F. Mangano, and J. Rose Wallick

Significant Findings

This report summarizes a preliminary assessment of bed-material transport, vertical and lateral channel changes, and existing datasets for the Rogue River basin, which encompasses 13,390 square kilometers (km^2) along the southwestern Oregon coast. This study, conducted to inform permitting decisions regarding instream gravel mining, revealed that:

- The Rogue River in its lowermost 178.5 kilometers (km) alternates between confined and unconfined segments, and is predominately alluvial along its lowermost 44 km. The study area on the mainstem Rogue River can be divided into five reaches based on topography, hydrology, and tidal influence. The largely confined, active channel flows over bedrock and coarse bed material composed chiefly of boulders and cobbles in the Grants Pass (river kilometers [RKM] 178.5–152.8), Merlin (RKM 152.8–132.7), and Galice Reaches (RKM 132.7–43.9). Within these confined reaches, the channel contains few bars and has stable planforms except for locally wider segments such as the Brushy Chutes area in the Merlin Reach. Conversely, the active channel flows over predominately alluvial material and contains nearly continuous gravel bars in the Lobster Creek Reach (RKM 43.9–6.7). The channel in the Tidal Reach (RKM 6.7–0) is also alluvial, but tidally affected and unconfined until RKM 2. The Lobster Creek and Tidal Reaches contain some of the most extensive bar deposits within the Rogue River study area.
- For the 56.6-km-long segment of the Applegate River included in this study, the river was divided into two reaches based on topography. In the Upper Applegate River Reach (RKM 56.6–41.6), the confined, active channel flows over alluvium and bedrock and has few bars. In the Lower Applegate River Reach (RKM 41.6–0), the active channel alternates between confined and unconfined segments, flows predominantly over alluvium, shifts laterally in unconfined sections, and contains more numerous and larger bars.
- The 6.5-km segment of the lower Illinois River included in this study was treated as one reach. This stretch of the Illinois River is fully alluvial, with nearly continuous gravel bars flanking the channel. The width of the active channel is confined by the narrow topography of the valley.
- The primary human activities that have likely influenced channel condition, bed-material transport, and the extent and area of bars are (1) historical gold mining throughout the basin, (2) historical and ongoing gravel mining from instream sites in the Tidal Reach and floodplain sites such as those in the Lower Applegate River Reach, (3) hydropower and flow control structures, (4) forest management and fires throughout the basin, and (5) dredging. These anthropogenic activities likely have varying effects on channel condition and the transport and deposition of sediment throughout the study area and over time.

- Several vertical (aspect) aerial photographs (including the complete coverages of the study area taken in 1995, 2000, 2005, and 2009 and the partial coverages taken in 1967, 1968, 1969, and 1990) are available for assessing long-term changes in attributes such as channel condition, bar area, and vegetation cover. A Light Detection And Ranging (LiDAR) survey performed in 2007–2008 provides 1-m resolution topographic data for sections of the Grants Pass (RKM 178.5–167.6) and Lobster Creek (RKM 17.8–12 and 10–6.7) Reaches and the entire Tidal Reach.
- Previous studies provide information for specific locations, including (1) an estimated average annual bed-material load of 76,000 m^3 at the former Savage Rapids Dam site (RKM 173.1, Grants Pass Reach), (2) over 490 m of channel shifting from 1965 to 1991 in the Brushy Chutes area (RKM 142–141, Merlin Reach), (3) active sediment transport and channel processes in the Lobster Creek Reach, (4) lateral channel migration in the Tidal Reach, and (5) up to 1.8 m of bar aggradation from the town of Agness (RKM 45.1) to the Rogue River mouth following the flood in water year 1997.
- Review of the repeat surveys conducted at the instream gravel-mining sites on Elephant and Wedderburn Bars tentatively indicated that these bars (1) experience some bed-material deposition in most years and more substantial deposition following high flows such as those in water years 1997 and 2006, and (2) are dynamic and subject to local scour and deposition.
- Results from the specific gage analyses completed for five long-term USGS streamflow-gaging stations showed that only the Grants Pass station on the Rogue River (RKM 164.4, Grants Pass Reach) experienced substantial changes in the stage–discharge relationship across a range of flows from 1938 to 2009. Observed changes indicate channel incision at this site.
- The Rogue and Applegate Rivers are dynamic and subject to channel shifting, aggradation, and incision, as indicated by channel cross sections surveyed during 2000–2010 on the Rogue River and 1933–2010 on the Applegate River. The elevation of the riverbed changed substantially (defined here as more than a net 0.5 m of incision or aggradation) at three locations on the Rogue River (near RKM 164.5, 139.2, and 1.3) and two on the Applegate River (near RKM 42 and 13.5).
- Systematic delineation of bar features from vertical photographs taken in 1967–69, 2005, and 2009 indicated that most of the repeat mapping sites had a net loss in bar area over the analysis period, ranging from 22 percent at the Oak Flat site (Illinois River Reach) to 69 percent at the Thompson Creek site (Upper Applegate River Reach). Bar area remained stable at the Williams Creek site (Lower Applegate River Reach), but increased 11 percent at the Elephant Rock site (Tidal Reach). The declines in bar area were associated primarily with the establishment of vegetation on upper bar surfaces lacking obvious vegetation in the 1960s. Some of the apparent changes in bar area may also owe to some differences in streamflow and tide levels between the vertical photographs.
- On the mainstem Rogue River, the median diameter of surface particles varied from 21 mm at the Wedderburn Bar in the Tidal Reach to more than 100 millimeters (mm) at some of the coarsest bars in the Galice Reach. Low armoring ratios tentatively indicated that sediment supply likely exceeds transport capacity at Orchard (Lobster Creek Reach) and Wedderburn (Tidal Reach) Bars. Conversely, relatively higher armoring ratios indicated that transport capacity likely is in balance with sediment supply at Roberston Bridge Bar (Merlin Reach) and exceeds sediment supply at Rogue River City (Grants Pass Reach), Solitude Riffle (Galice Reach), and Hooks Gulch (Galice Reach) Bars.

- Limited particle data were collected in the study areas on the Applegate and Illinois Rivers. Particle size measurements and armoring ratios tentatively show that sediment supply likely exceeds transport capacity at Bakery Bar in the Lower Applegate Reach. Also, the bed material exiting the Applegate River is likely finer than the bed material in the Rogue River, whereas bed material exiting the Illinois River is likely coarser than the bed material in the Rogue River.

- Together, these observations and findings indicate that (1) the size, area, and overall position of bars in the Rogue River study area are determined largely by valley physiography, such that unconfined alluvial sections have large channel-flanking bars, whereas confined sections have fewer and smaller bars, (2) segments within the Grants Pass, Merlin, Tidal, Upper Applegate River, and Lower Applegate River Reaches are prone to vertical and/or lateral channel adjustments, and (3) the balance between transport capacity and sediment supply varies throughout the study area.

- High winter flows and the steep, confined character of much of the Rogue River within the study area result in a river corridor with a high capacity to transport bed material. In the Grants Pass and Galice Reaches, the extensive in-channel bedrock as well as the sparse number and coarse texture of bars indicate that these reaches are likely supply-limited, meaning that the river's transport capacity exceeds the supply of bed material. In contrast, the Lobster Creek and Tidal Reaches and perhaps portions of the Merlin Reach receive bed-material inputs that more closely balance or even exceed the river's transport capacity.

- The lowermost reaches on the Illinois and Applegate Rivers are fully alluvial segments that are likely transport limited, meaning sediment supply likely exceeds the river's transport capacity. However, the steeper Upper Applegate River Reach is likely supply-limited as indicated by the sparse number and area of bars mapped in this reach and the intermittent bedrock outcrops in the channel. The sediment loads derived from these large tributaries draining the Klamath Mountains are probably important contributions to the overall transport of bed material in the Rogue River basin.

- Compared to the slightly smaller Umpqua River basin (drainage area 12,103 km^2) to the north, the Rogue River (13,390 km^2) likely transports more bed material. Although this conclusion of greater bed-material transport in the Rogue River is tentative in the absence of either actual transport measurements or transport capacity calculations, empirical evidence, including the much greater area and frequency of bars along most of the Rogue River as well as the much shorter tidal reach on the Rogue River (6.7 km) compared to the Umpqua River (40 km) supports this inference.

- More detailed investigations of bed-material transport rates and channel morphology would support assessments of channel condition, longitudinal trends in particle size, the relation between sediment supply and transport capacity, and the potential causes of bar area loss (such as vegetation establishment and potential changes in peak flow patterns). The reaches most practical for such assessments and relevant to several management and ecological issues are (1) the lower Rogue River basin, including the Lobster Creek and Tidal Reaches of the Rogue River as well as the Illinois River Reach and (2) the Lower Applegate River Reach.

Introduction

This report summarizes a reconnaissance-level study of channel condition and bed-material transport relevant to the permitting of instream gravel mining on the Rogue River and its largest tributaries, the Applegate and Illinois Rivers (fig. 1). The study reviewed existing datasets (such as bridge inspection surveys, watershed analyses, and instream gravel-mining records), delineated bar and channel features from aerial and orthophotographs taken in multiple years, and made field observations and particle size measurements in July and September 2010. Findings from these datasets and observations were used to (1) assess the vertical and lateral stability of river segments in the Rogue River basin and identify locations where the channels may be incising, aggrading, prone to migrations, or stable and (2) identify key datasets and issues that are relevant to understanding channel condition and bed-material transport as well as the potential effects of instream gravel mining on channel condition and bed-material transport in the basin.

This reconnaissance-level study was a “Phase I” investigation similar to studies on the Umpqua River (O’Connor and others, 2009) and on Hunter Creek (Jones and others, 2011), as outlined by the U.S. Army Corps of Engineers, and the Oregon Department of State Lands to inform the permitting of instream gravel mining in Oregon.

Locations and Reporting Units

Locations along the Rogue, Applegate, and Illinois Rivers are referenced to river kilometers (RKM). Measurements for the Rogue River begin about 650 m upstream of its mouth and continue upstream. To develop this reference system, centerlines were digitized through the wetted channels of the Rogue, Applegate, and Illinois Rivers within the study area using 2009 orthophotographs from the National Agriculture Imagery Program. Points were then distributed at 0.5-km intervals along these centerlines starting at the mouth of each river. Even after accounting for the conversion between river miles as shown on current (1987–1991) USGS quadrangle maps and river kilometers produced by this study, these reference systems differ slightly owing to factors such as channel migration and starting points of the reference systems.

Landmarks and locations in the study area along the mainstem Rogue River (from up- to downstream; fig. 1) include the confluence of the Rogue River and Evans Creek near the town of Rogue River (RKM 178.6), the upstream boundary of the Rogue River Wild and Scenic section at the confluence of the Rogue and Applegate Rivers (RKM 152.8), the confluence of the Rogue and Illinois Rivers (RKM 43.8), the downstream boundary of the Rogue River Wild and Scenic section at Lobster Creek Bridge (RKM 17.8), the head of tide (approximately RKM 6.7), and the mouth of the Rogue River near the city of Gold Beach (slightly downstream of RKM 0). Other towns and cities in the study area include Grants Pass (RKM 163.4), Galice (RKM 122.1), Marial (RKM 78.0), Agness (RKM 45.1), and Gold Beach (RKM 0). On the Applegate River, key locations include the town of Murphy (RKM 21.6), the town of Applegate (RKM 42.0), and the confluence of the Applegate and Little Applegate Rivers (RKM 56.7).

Where possible, names for the study reaches were assigned based on reach attributes, major tributaries, or nearby towns or cities. Names for the bed-material sampling sites were derived largely from USGS topographic maps and gravel mining permits, but in some cases were assigned informal names based on nearby places. Sites for which bar and channel features were mapped from vertical photographs taken in different years (hereinafter termed “repeat delineation”) were named after nearby features, such as parks and tributaries on the USGS topographic maps.

Data collected and analyzed in this study as well as most data reported by other sources are in metric (SI) units. The conversions to English units are provided in the report front matter.

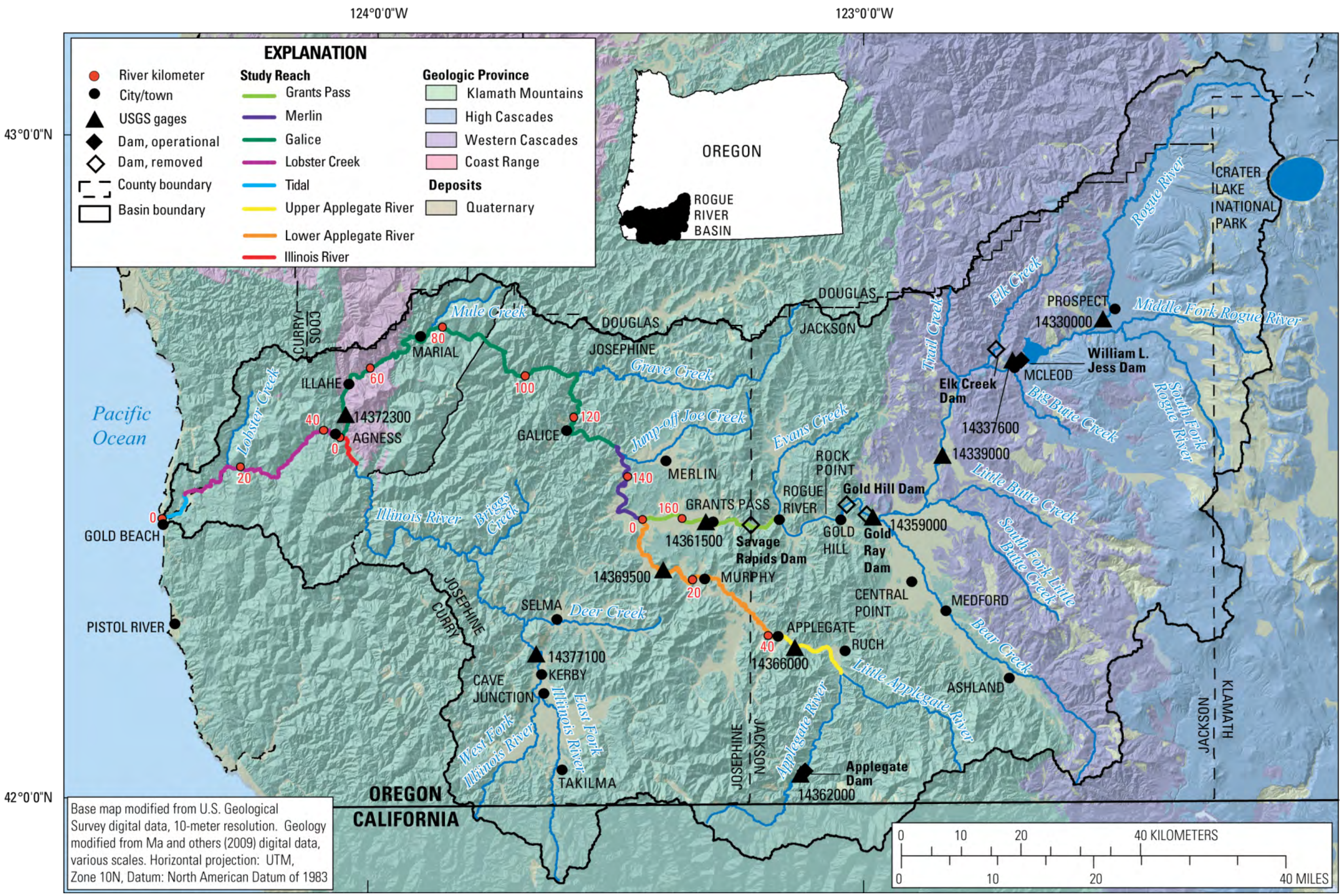

Figure 1. Map showing the stream network, basin and county boundaries, geologic provinces and deposits, study reaches, dams, and select U.S. Geological Survey streamflow-gages in the Rogue River basin, southwestern Oregon.

The Rogue River

The Rogue River drains 13,390 km^2 of southwestern Oregon before flowing into the Pacific Ocean near the town of Gold Beach (fig. 1). Over 8,500 km of mapped stream channel make up the Rogue River network (StreamStats, *http://water.usgs.gov/osw/streamstats*). The Rogue River begins in the Cascade Range and traverses the Klamath Mountains, where it gains its largest tributaries, the Applegate (1,994 km^2) and Illinois (2,564 km^2) Rivers, on its way to the coast. The Rogue River basin is flanked to the north by the Umpqua, Coquille, and Elk River basins and the Euchre Creek basin, to the east by the Williamson River basin, and to the south by the Klamath, Smith, Chetco, and Pistol River basins and the Hunter Creek basin. The Rogue River basin is located in Klamath, Jackson, Josephine, and Curry Counties in Oregon and Siskiyou and Del Norte Counties in California.

Along the Oregon coast, the Rogue River basin is the largest producer of Pacific salmon after the Columbia River basin (Middle Rogue Watershed Association, 2001). Recognizing the Rogue River's "outstanding remarkable scenic, recreational, geologic, fish and wildlife, historical, [and] cultural … values," Congress included the Rogue River as one of the original eight rivers in the Wild and Scenic Rivers Act of 1968 (Public Law 90–542; 16 U.S.C. 1271 et seq.; *http://www.rivers.gov/publications/act/90-542.pdf*). The 1968 Act designated 135 km of the Rogue River from its confluence with the Applegate River (RKM 152.8) to the Lobster Creek Bridge (RKM 17.8) as Wild and Scenic (Interagency Wild and Scenic Rivers Council, 2011). Subsequent amendments to the Act added Wild and Scenic sections in the basin, including an 81-km section along the Illinois River in 1984 and a 64-km section in the upper Rogue River basin in 1988. As of 2011, approximately 280 km of the over 8,500 km making up the mapped Rogue River network are designated as Wild and Scenic.

Geographic, Geologic, and Geomorphic Setting

The Rogue River basin encompasses parts of four geologic provinces (fig. 1): the High Cascades (14 percent), Western Cascades (16 percent), Klamath Mountains (56 percent), and Coast Range (1 percent). In addition, mapped Quaternary sedimentary deposits and landslides cover 13 percent of the basin. Its largest tributaries, the Applegate and Illinois Rivers, are predominantly within the Klamath Mountains geologic province (fig. 1). The four geologic provinces reflect unique geologic histories and conditions, resulting in distinct characteristics such as basin relief, drainage density, erosion processes, and water permeability that are relevant to sediment yield and transport.

The headwaters of the Rogue River basin (including most of the basin east of the confluences of the South Fork, Middle Fork, and mainstem Rogue River) are primarily within the High Cascades geologic province (fig. 1). The typically low-relief High Cascades geologic province is underlain by highly permeable Pliocene and Quaternary lava flows that have low rates of surface water runoff and sediment transport (Jefferson and others, 2010). The parts of the Rogue River basin within this province include the western slopes of Crater Lake, which is the remnant of a large Quaternary-age stratovolcano that erupted cataclysmically about 7,700 years ago and blanketed parts of the Rogue River's headwaters with thick tephra and pyroclastic flow deposits (Bacon, 2008).

An area of the Rogue River's headwaters also spans the Western Cascades geologic province (fig. 1). This portion is chiefly a 20-km-wide band running north-south between the upstream confluence of the mainstem and the South Fork Rogue River and the downstream confluence of the mainstem and Trail Creek. This geologic province is underlain by Tertiary volcanic and volcaniclastic rocks that are typically weathered and highly dissected and, thus, are susceptible to high rates of runoff and mass wasting processes.

Most (56 percent) of the Rogue River basin and study area (described below) is within the Klamath Mountains geologic province. The rugged Klamath Mountains are underlain by an amalgamation of Paleozoic and Mesozoic terranes that affixed to western North America during the late Mesozoic Era and early Tertiary Period. During and after accretion, the rocks have been metamorphosed and intruded by igneous plutons, dikes, and sills that are mainly of Cretaceous and Tertiary age. The degree of metamorphism decreases westward so that the oldest, hardest, and most highly deformed rocks are in the headwaters of the Applegate River with rocks then becoming progressively less deformed and softer toward the coast. The Klamath Mountains geologic province underlies many of the gravel-rich rivers in southwestern Oregon and northern California such as the Chetco (Wallick and others, 2010) and Smith Rivers (MFG, Inc., Graham Mathews and Associates, and Alice Berg and Associates, 2006).

The Rogue River transects a small swath of sedimentary rocks belonging to the Coast Range geologic province between RKM 70 and its confluence with the Illinois River at RKM 43.8 (fig. 1). These are mainly Eocene-age marine sedimentary rocks deposited on top of the thrust-faulted and metamorphosed rocks of the Klamath Mountains geologic province. The marine sedimentary rocks of the Coast Range are much weaker than the metamorphic and igneous rocks that otherwise flank the Rogue River for much of the Galice and Tidal Reaches, resulting in a wider valley bottom and reduction in river gradient at about RKM 70 (fig. 2B).

The Rogue River begins at Boundary Springs northwest of the Crater Lake National Park (fig. 1) in the High Cascades and then flows southward for 80 km primarily through the Western Cascades, draining 1,008 km^2 before its confluence with the South Fork Rogue River (653 km^2) near the transition between the Western Cascades and Klamath Mountains. Downstream of its confluence with the South Fork Rogue River, the Rogue River continues southwest for 54 km to its confluence with Trail Creek near the boundary of the Western Cascades and Klamath Mountains geologic provinces. The William L. Jess Dam, completed in 1977, regulates the flow of the Rogue River (see the “Hydrology” and “Dams” sections below) about 12.3 km downstream of the confluence of the mainstem and South Fork Rogue River. Below the dam site, Big Butte (642 km^2), Elk (347 km^2), Trail (143 km^2), Little Butte (974 km^2), Bear (938 km^2), and Evans (580 km^2) Creeks join the Rogue River.

The study area for this project begins at the confluence of the Rogue River and Evans Creek (RKM 178.6), where the mainstem transitions from a channel dominantly confined by and flowing on bedrock to a channel locally flanked by bars and its floodplain. At RKM 152.8, the Rogue River is joined by the northwest-flowing Applegate River, which drains 1,994 km^2 and has its headwaters in the Siskiyou Range of California and Oregon. From its confluence with the Applegate River, the Rogue River continues northwestward for about 35 km to China Bar, slightly northeast of the town of Marial. Jump-off Joe Creek (282 km^2), Grave Creek (422 km^2), and Mule Creek (79 km^2) are the main tributaries in this section (fig. 1). Downstream of China Bar, the Rogue River turns southwest for its final 48 km before reaching the Pacific Ocean. Within this section, the Rogue River gains its largest tributary, the Illinois River (2,564 km^2), at RKM 43.8. Like the Applegate River, the Illinois River heads in the Siskiyou Range of the Klamath Mountains and flows generally northwestward before joining the Rogue River. Lobster Creek (179 km^2) is the last major tributary to the Rogue River that joins the mainstem at RKM 17.8. The Rogue River is tidally affected in approximately its lowermost 6.7 km (Oregon Department of State Lands, 2007).

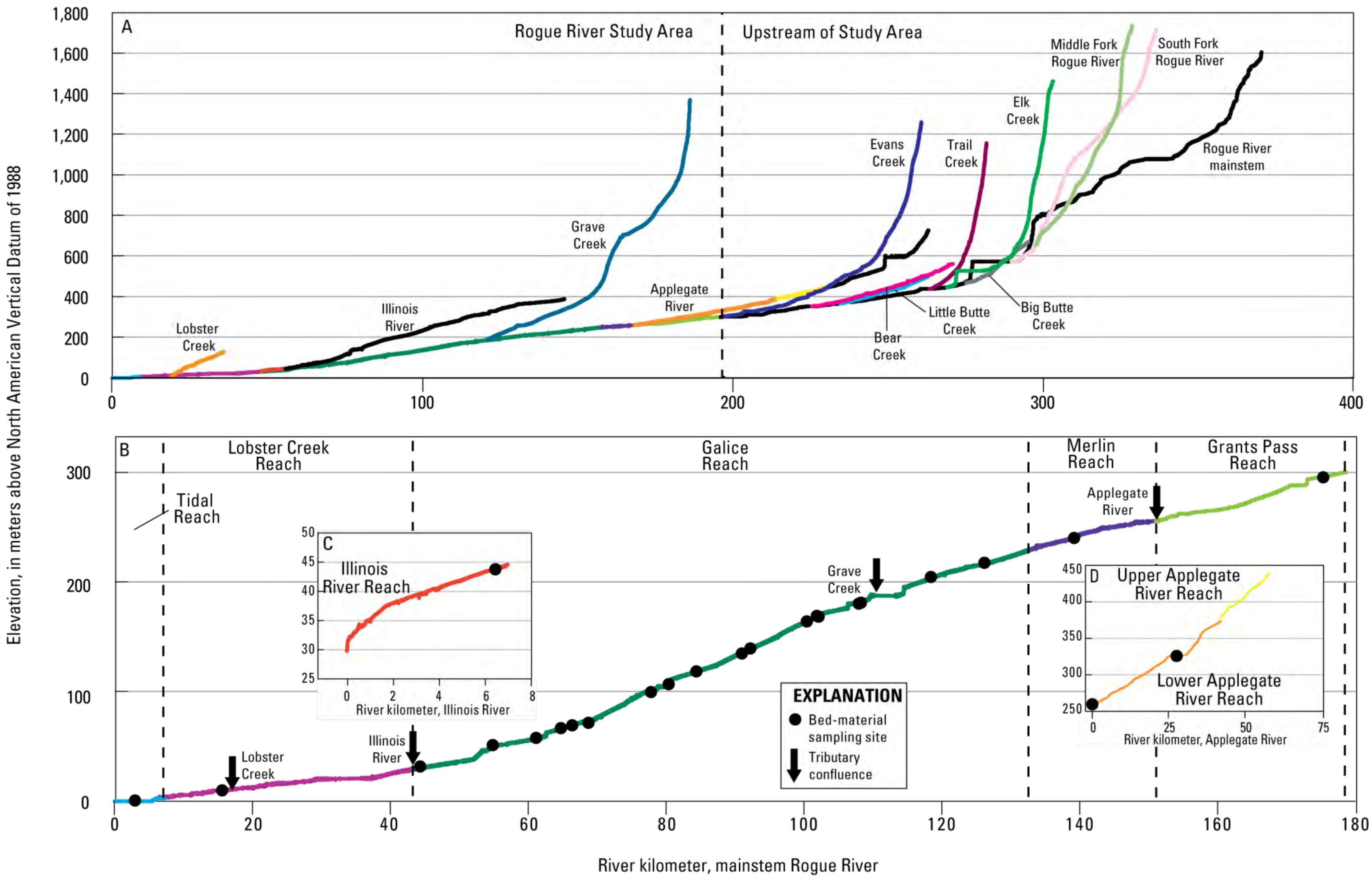

Figure 2. Diagrams showing longitudinal profiles for the Rogue River basin and study areas on the Rogue, Illinois, and Applegate Rivers, southwestern Oregon. Elevations derived from the U.S. Geological Survey 10-m Digital Elevation Model (DEM)

The longitudinal profile for the basin (fig. 2A) shows a smooth gradation in water surface slope along the Rogue River from its headwaters to its confluence with the Pacific Ocean. This profile, in conjunction with the abundant gravel bars observed to the mouth of the river and the relatively small tidal reach, indicates that the Rogue River has transported gravel to the Pacific Ocean at a rate that has exceeded the depositional accommodation space created by Holocene sea-level rise. Hence, the Rogue River basin differs from the many Coast Range drainages where bed-material deposition has not kept pace with sea-level rise, resulting in longer tidal reaches (Komar, 1997). The wide valley bottom in the lowest portion of the study area in part reflects Holocene filling of the Rogue River Valley.

Historical River Descriptions

Historical observations and accounts of the river channels in the Rogue River basin are useful counterpoints for comparing present channel conditions. The most thorough of several descriptions was an 1879 report by Philip Eastwick, an Assistant Engineer with the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1879). Eastwick completed a comprehensive survey of the Rogue River to identify opportunities for improving navigation between the inland towns of Medford and Grants Pass and the coast. In his report, Eastwick described low-water conditions along the Rogue River from Rock Point (a small town approximately 3.5 km west of Gold Hill; fig. 1) to the river's mouth. Between Rock Point and a place described by Eastwick as Green's Bend (likely near Matson Park, RKM 148), Eastwick noted:

> "… The river flow[s] in a nearly direct westerly course to Green's Bend, having cut a channel throughout this distance deep into a bed of cement-gravel. The banks of the river rise to a height of from 30 to 50 feet above the present low stage of water, and are surmounted on both sides by level or slightly undulating table or bench land, generally of narrow width, but occasionally extending a mile or more back from the river. … The banks of the river immediately adjoining the water are generally rocky, the rocks being frequently imbedded in the cement-gravel. … A remarkable feature of the river-bed is the entire absence of loose gravel or sand bars. This is no doubt due to the effect of the very strong current which prevails in the river at the time of the freshets, the volume of water and intensity of the current at such times being such as to carry before it all the gravel and sand as soon as it is detached from the cement, leaving the bottom and sides swept clean of all small, loose material, and frequently channeled out in the bed of the river in narrow and deep furrows running with the direction of the river."

Eastwick then continued approximately 90 km downstream from Green's Bend to Big Bend (slightly north of the town of Illahe near RKM 60; fig. 1). For this stretch of river, which is now wholly within the Wild and Scenic corridor, Eastwick reported:

> "The character of the [Rogue] river is that of a rapidly-falling mountain stream. It is with very few exceptions narrow, rarely exceeding 150 feet in width, and frequently narrowing down to a width of from 25 to 50 feet; the waters in the narrows pouring with great velocity and rapid fall through the gorges. The fall of the river is, as may be expected, very great, though occasional long and slackwater levels are met with, more especially in the close canons [canyons], where, in some cases, the river being very deep, the current was scarcely perceptible … This part of the river abounds in rapids and waterfalls, 72 of them occurring in the first 39 miles of this division. At a number of these the fall in a very short distance is as great as 10 feet. Entering this division of the river at Green's Bend, the cement-gravel of the river bed rapidly disappears, occasional and extensive gravel-bars are met with, and these in turn disappear, the mountains

> closing in upon the river, forming an almost continuous canon for the balance of the distance, the walls of the canon being very frequently of barren rocks rising in places perpendicularly to a height of several hundred feet, their summits surmounted by the steep mountain slopes. More generally, however, a narrow beach very much obstructed by large masses of rock is found between the river and the foot of the bluffs."

From Big Bend at RKM 56 to the mouth of the Rogue River, Eastwick documented the channel changes as the Rogue River enters its alluvial section:

> "…the river widens and its fall decreases; numerous gravel bars and shoals are met with, which become more frequent in the lower part of the river … the river from the mouth of the Illinois is very crooked, the bends being very numerous and abrupt, and the intermediate straight parts being with few exceptions very short. The river has a width over nearly the whole distance from Big Bend to the ocean varying from 200 to 400 feet, except at a few of the rapids and swifts, where it narrows, and at and near the mouth of the river, where it widens to a maximum of but little over one-third of a mile. On this division I noted 31 rapids and swifts, but few of them, however, offering much impediment to the free navigation of the river for a distance of 35 miles from its mouth. The foot-hills of the mountains are here cut through by the river, and the valley loses the canon-like character which has been characteristic of the river above. Though as a rule the steep hillsides terminate abruptly on the edge of the river, and in some cases in perpendicular rock-bluffs, yet frequent short and narrow benches of arable land are met with. This character the river valley maintains with great uniformity until the head of tide water is reached, at a point 4 miles above its mouth. The river has cut its way through beds of indurated clay-rock, interspersed with occasional beds of sandstone. At places it is shoaled or narrowed by extensive gravel-bars. The fall of the river will not exceed an average of more than 2 or 3 feet per mile, being greatest at the upper end of the division."

On the basis of his observations, Eastwick concluded that, "[t]he channel of Rogue River, by reason of its ruggedness and forbidding character, at once bars egress from the upper valley by the navigation of that river, the construction of works to admit of its navigation being utterly impracticable, if not impossible." Although Eastwick's account does not mention the Applegate River or any bar complexes at the confluence of the Rogue and Applegate Rivers and notes the absence of gravel and sand bars between Rock Point and Green's Bend (see fig. 7; fig. 8), his characterization of the Rogue River is otherwise comparable with river conditions today.

Hydrology

The USGS has measured streamflow at six gages on the mainstem Rogue River for periods ranging from 45 to 105 years (fig. 1; table 1; *http://waterdata.usgs.gov/or/nwis/; http://wdr.water.usgs.gov/* [U.S. Geological Survey, 2010]). Additional flow data have been collected at three gages on the Applegate River and one gage on the upper Illinois River that is approximately 74 km upstream of the Illinois River study area (table 1). Jones and others (1932) summarized key aspects of the hydrology of the Rogue River.

Mean annual streamflow is 162.4 m^3/s on the Rogue River near Agness (1961–2010), 19.9 m^3/s on the Applegate River near Wilderville (1939–1955; 1979–2010), and 35.5 m^3/s on the Illinois River near Kerby (1962–2010; table 1). Streamflow in the Rogue River basin is driven by seasonal precipitation that typically falls primarily in winter as snow in the upper basin near Crater Lake and as rainfall and snow in the lower basin (fig. 3A–F).

Table 1. Summary of U.S. Geological Survey (USGS) streamflow data for the Rogue River basin, southwestern Oregon.

[RKM, river kilometer; km^2, square kilometer; WY, water year; m^3/s, cubic meter per second; --, outside of the study area; km, kilometer; Mean annual streamflow values derived from U.S. Geological Survey (2010).]

Site Information						Streamflow information		
Station	ID	Study reach	Location	Drainage area (km^2)	Period of record (WY)	Mean annual streamflow (m^3/s)	Peak streamflow (m^3/s)	Date of peak event
Rogue River below Prospect	14330000	--	Approximately 134 km upstream of the study area	982	1914–1930; 1969–2010	36.5	708	12/22/1964
Rogue River near McLeod	14337600	--	Approximately 112 km upstream of the study area	2,429	1966–2010	58.7	2,104	12/22/1964
Rogue River at Dodge Bridge near Eagle Point	14339000	--	Approximately 64 km upstream of the study area	3,147	1939–2010	71.3	2,481	12/22/1964
Rogue River at Raygold near Central Point	14359000	--	Approximately 24 km upstream of the study area	5,317	1906–2010	82.9	3,710	12/23/1964
Rogue River at Grants Pass	14361500	Grants Pass	RKM 164.6	6,369	1940–2010	95.9	4,304	12/23/1964
Rogue River near Agness	14372300	Galice	RKM 47.6	10,202	1961–2010	162.4	8,212	12/23/1964
Applegate River near Copper	14362000	--	Approximately 19 km upstream of the study area	583	1939–2010	12.2	844	1/15/1974
Applegate River near Applegate	14366000	Upper Applegate River	RKM 45.2	1,251	1939–2010	14.5	1,053	1/15/1974
Applegate River near Wilderville	14369500	Lower Applegate River	RKM 12.7	1,808	1939–1955; 1979–2010	19.9	1,883	12/22/1955
Illinois River near Kerby	14377100	--	Approximately 74 km upstream of the study area	984	1962–2010	35.5	2,611	12/22/1964

On average, approximately 1.4 m of precipitation falls annually in the Rogue River basin, with the largest amounts occurring primarily in the Rogue River's headwaters, Illinois River basin, and near the coast. Less precipitation falls in the interior portions of the basin, such as near the city of Medford and in the Applegate River basin (Jones and others, 1932). Peak flows on the mainstem Rogue River typically derive from winter frontal systems, with the largest flows resulting from regional rain-on-snow events. For example, flows exceed 1,000, 200, and 400 m^3/s during typical winter storms on the Rogue, Applegate, and Illinois Rivers, respectively (as shown for the Agness, Applegate, and Kerby sites in figs. 3C, D, and F and in figs. 4C, D, F).

Suspension bridge over the Rogue River near Agness that was destroyed during the 1964 flood. (Historical postcard image used with permission of Roxann Gess Smith of Salem, Oregon.)

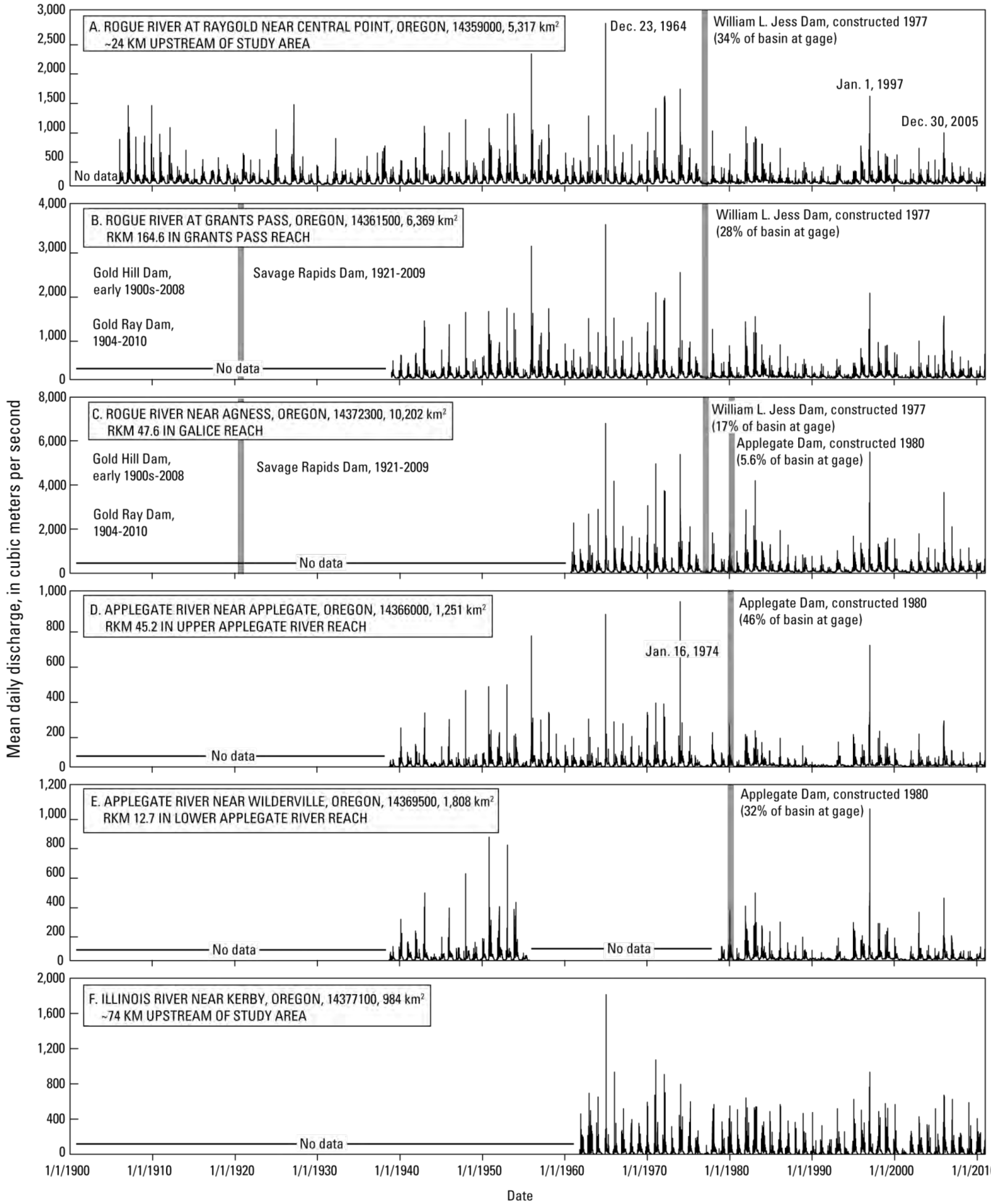

Figure 3. Graphs showing mean daily discharge for select U.S. Geological Survey (USGS) streamflow-gaging stations in the Rogue River basin, southwestern Oregon.

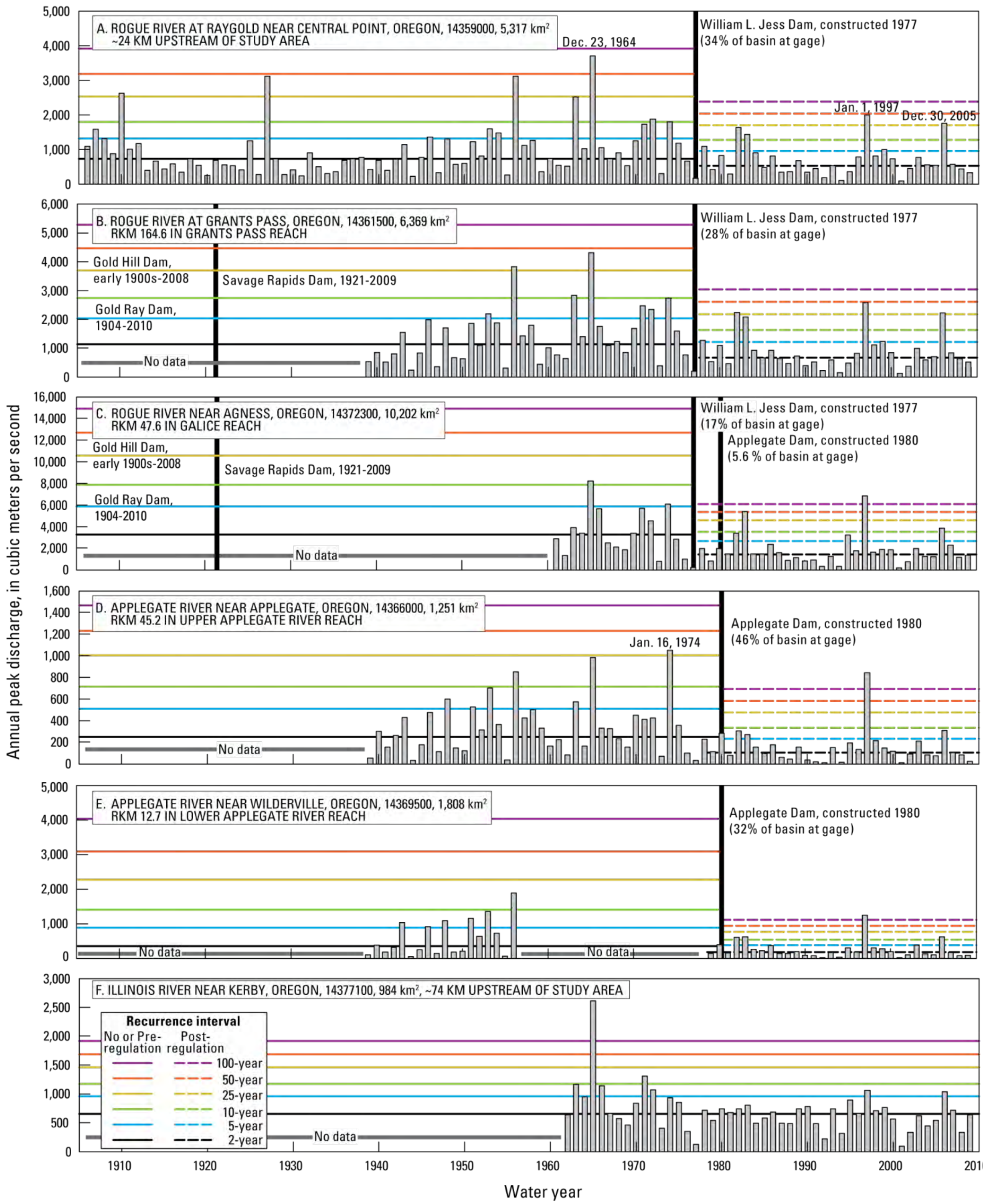

Figure 4. Graphs showing annual peak discharge for select U.S. Geological Survey (USGS) streamflow-gaging stations in the Rogue River basin, southwestern Oregon. Recurrence intervals were calculated for pre- and post-regulation by William L. Jess Dam in A–C and Applegate Dam in D–E and the entire period of record in F using methods from the Interagency Advisory Committee on Water Data (1982) and Flynn and others (2006).

From July to October, base flows are sustained by groundwater contributions from the upper Rogue River basin and occasional precipitation events (Jones and others, 1932). Base flow typically recedes to 51.6, 3.8, and 1.3 m^3/s on the Rogue, Applegate, and Illinois Rivers, respectively (based on data reported in U.S. Geological Survey, 2010). Sections of the Applegate River dewater during summer, such as on the Applegate River near the Wilderville gage in 1977 (U.S. Geological Survey, 2010). Likewise, summer flows on the Illinois River substantially decline because of the valley's steep topography and lack of groundwater storage (Jones and others, 1932).

Because the delivery and transport of bed material in the Rogue River basin are driven in part by high flow events, we identified high flow events from long-term streamflow records for select gages in the basin (fig. 4A–F; table 1; table 2). The peak of record for all the gages on the mainstem Rogue and Illinois Rivers was in December 1964, when peak flows on the Rogue River ranged from 708 m^3/s on December 22 at the Prospect gage to 8,212 m^3/s on December 23 at the Agness gage (RKM 47.6). Flow on the Illinois River peaked at 2,611 m^3/s on December 22 at the Kerby gage (approximately 80.8 km upstream from the confluence of the Illinois and Rogue Rivers). Other flow events on the Rogue River prior to its regulation by the William L. Jess Dam and comparable to or exceeding a 25-year recurrence interval event at the Raygold gage (2,536 m^3/s) occurred in 1910, 1927, 1956, and 1963 (table 2; fig. 4A).

Table 2. Streamflow at different recurrence intervals for select U.S. Geological Survey (USGS) streamflow-gaging stations in the Rogue River basin, southwestern Oregon.

[m^3/s, cubic meter per second; --, no mainstem dam regulation]

Recurrence interval	Station name and USGS identification number					
	Rogue River at Raygold near Central Point 14359000	Rogue River at Grants Pass 14361500	Rogue River near Agness 14372300	Applegate River near Applegate 14366000	Applegate River near Wilderville 14369500	Illinois River near Kerby 14377100
	Streamflow at recurrence interval (m^3/s) for pre-regulation period or no regulation					
2-year	739	1,137	3,265	249	350	651
5-year	1,314	2,039	5,882	509	880	958
10-year	1,798	2,732	7,859	715	1,402	1,174
25-year	2,536	3,696	10,561	1,003	2,272	1,462
50-year	3,186	4,469	12,690	1,230	3,081	1,685
100-year	3,922	5,285	14,899	1,465	4,036	1,916
	Streamflow at recurrence interval (m^3/s) for post-regulation period					
2-year	535	677	1,438	105	181	--
5-year	963	1,221	2,668	233	383	--
10-year	1,281	1,626	3,520	335	543	--
25-year	1,710	2,175	4,582	475	764	--
50-year	2,043	2,602	5,341	583	936	--
100-year	2,385	3,042	6,066	692	1,112	--

Although the 1964 flood is the largest measured event on the mainstem Rogue River, floods in 1861 and 1890 were larger (U.S. Geological Survey, 2010). In the 49-year period of record at the Kerby station on the Illinois River, the 1964 flood reached 2,611 m^3/s and exceeded a 100-year recurrence-interval event (1,916 m^3/s; fig. 4F; table 2).

The timing of peak flows on the Applegate River differs from that on the Rogue and Illinois Rivers (fig. 4; table 1). Peak streamflows on the Applegate River occurred on January 15, 1974, and reached 106 and 1,053 m^3/s, respectively, at the Copper and Applegate gages. For comparison, the 1964 peak flows were 74 and 982 m^3/s at the Copper and Applegate gages, respectively (table 1). Similar to the 1964 flood, but of smaller extent, the flooding in 1974 resulted from heavy rain and rapid snowmelt in the western Klamath Mountains (Beaulieu and Hughs, 1977). Prior to the streamflow period of record, flood marks indicate that a high-flow event occurred in February 1927 near the town of Applegate (U.S. Geological Survey, 2010).

Subsequent to the floods of 1964 on the mainstem Rogue and Illinois Rivers and 1974 on the Applegate River, more recent flooding occurred in water years 1997 and 2006 (fig. 4A–F). Flooding in water year 1997 exceeded a 100-year recurrence interval event at the Agness (6,066 m^3/s; fig. 4C; table 2), Applegate (692 m^3/s; fig. 4D; table 2), and Wilderville (1,112 m^3/s; fig. 4D; table 2) gages and a 5-year recurrence interval event at the Kerby gage (958 m^3/s; table 2; fig. 4F). Despite the occurrence of these recent high-flow events, overall flood magnitude has declined somewhat since the 1964 flood on the Rogue and Illinois Rivers and the 1974 flood on the Applegate River (fig. 4A–E). Peak flow reduction on the Rogue and Applegate Rivers is likely attributable to the 1977 completion of the William L. Jess Dam on the mainstem Rogue River near McLeod (fig. 1; fig. 4A–C) and the 1980 completion of the Applegate Dam on the Applegate River south of Ruch, respectively (fig. 1; fig. 4D–E; see the “Dams” section for more information). Additionally, as suggested by the peak flow record for the Kerby station (fig. 4F), decadal-scale climate changes may also result in diminished peak flow patterns in the Rogue River basin as observed in other coastal basins, such as the Chetco and Umpqua Rivers (Wallick and others, 2010; 2011).

Occupation, Land Use, and Landscape Disturbance

Several Native American tribes, such as the Takelma, Latgawa, and Tututi, inhabited the Rogue River basin prior to Euro-American settlement (Purdom, 1977; Ruby and Brown, 1992). Although reconnaissance surveys by fur traders and others started in the late 1700s and continued throughout the early 1800s, Euro-American settlement of the basin did not fully commence until the 1850s, when the discovery of gold fueled the development of towns, agriculture, and commerce (Schwartz, 1997). Today, 38 percent of the basin is privately owned, whereas the remaining 62 percent is publicly owned and managed by Federal and State agencies, such as the Bureau of Land Management, U.S. Forest Service, and Oregon Department of Fish and Wildlife (ownership determined using land management data from the Oregon Natural Heritage Program [1999]). The historical anthropogenic activities likely exerting the greatest influence on channel morphology are gold mining, gravel mining, construction and management of impoundments for hydropower and flood control, forestry activities, and navigation dredging.

Gold Mining

Oregonians from the Willamette Valley traveled through the Rogue River basin and into California during the California Gold Rush of 1849 (Kramer, 1999). Once the California Gold Rush lost its luster, returning prospectors searched the hills and rivers of southwestern Oregon for gold, finding it in Josephine and Canyon Creeks (tributaries to the Illinois River near Kerby) and at Sailor’s Diggings near the town of Takilma, in 1851 (Kramer, 1999).

Widespread placer mining over the next two decades and subsequent hydraulic mining from the 1880s and into the 1900s (Kramer, 1999) likely liberated large volumes of sediment from streamside terraces and substantially affected instream bed-material conditions in the Rogue, Applegate, and Illinois Rivers as well as in numerous smaller tributaries (fig. 5A–D). In particular, the Sterling mine (fig. 5C), the largest hydraulic mine operating in the western United States during the 1880s, moved an average of over 1,150 m^3 of spoils each day into Sterling Creek, a tributary in the Applegate River basin (Fowler and Roberts, 2004). Bucket-line dredge mining at the confluence of the Rogue River and Foots Creek near Gold Hill also likely loosened large amounts of gravel (fig. 5E). This operation ran year-round with 4.9 km^2 of dredging ground available and a daily dredge capacity of 2,300 to 3,000 m^3 at its peak (Mining World Company, 1910) with operations continuing at varying levels until the 1940s (Kramer, 1999). The Rogue River (near the towns of Gold Hill and Rogue River), Evans Creek, Pleasant Creek, the Applegate River (near the town of Ruch), and the Illinois River near Eight Dollar Mountain were also dredge mined (Libbey, 1976; Kramer, 1999). Gold mining efforts, however, were suspended to support the World War II efforts from 1942 to 1945; today, most mining is recreational, employing suction dredges (Kramer, 1999).

Gravel Mining

Instream gravel mining can potentially result in channel incision and bar armoring (Kondolf, 1994). Gravel bars in the Rogue River basin have been used as a local source of aggregate for road and construction projects and to make concrete since at least 1972 (Pratt, 2004). Although accounts of historical gravel mining are scarce, an inventory completed by the Curry County Department of Public Services provides some insight into instream gravel mining activities on the lower Rogue and Illinois Rivers from 1972 to 2004 (Pratt, 2004). In 1974, 14 permits, with a total removal limit of approximately 239,000 m^3 per year, were issued on the lower 53.3 km of the Rogue River for uses such as the maintenance of county roads, the construction and maintenance of logging roads, navigation purposes, and commercial aggregate (Pratt, 2004). Also, in 1974, an additional three permits issued for road maintenance were active on the lower 3.1 km of the Illinois River with a total removal limit of approximately 58,000 m^3 per year (Pratt, 2004). By 2004, no active permits were reported for the Illinois River, whereas seven permits were reported for the Rogue River between RKM 0 and 34.5 for commercial aggregate and navigation purposes and with a total permitted removal of approximately 103,000 m^3 per year (Pratt, 2004). Permitted and actual mined volumes on the Rogue and Illinois Rivers likely vary based on multiple factors such as interannual variation in gravel recruitment. The decline in removal permits for the Rogue River follows the trend for Curry County, where the number of instream gravel mining permits declined from 61 in 1972 to 19 in 2004 (Pratt, 2004).

As of 2008, two instream gravel mining permits that were active in 1972 (Pratt, 2004) were still active on the lower Rogue River. Freeman Rock, Inc. operates ongoing sites on the Elephant Bar (at RKM 2.8 to 4.5 on the Rogue River’s south bank), with a total annual removal limit of approximately 31,000 m^3 (Judy Linton, U.S. Army Corps of Engineers, written commun., 2010). On the north bank at RKM 2.8, Tidewater Industries, Inc., mined gravel at the Wedderburn Bar site until their permit, with a total removal limit of approximately 76,000 m^3, expired in November 2008 (Judy Linton, U.S. Army Corps of Engineers written commun., 2010; Robert Lobdell, Oregon Department of State Lands, written commun., 2011). Data available from these sites are presented in more detail below in “Review of Gravel-Operator Information and Surveys.”

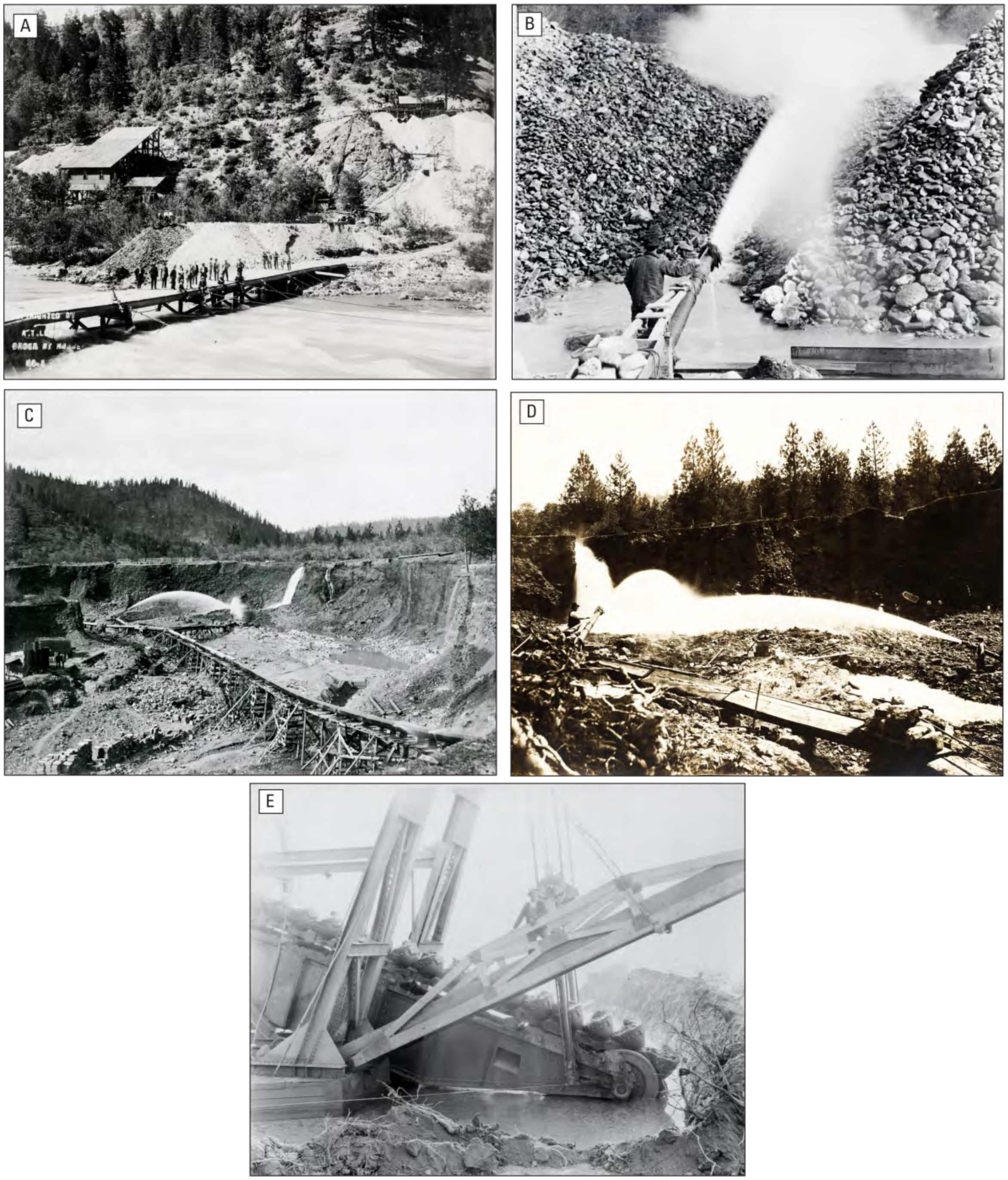

Figure 5. Photographs of historical mining activities in the Rogue River basin, southwestern Oregon. (A) Panoramic view of the Almeda Mine on the Rogue River at RKM 115.8 in the Galice Reach (Southern Oregon Historical Society [SOHS] 3367). (B) Hydraulic mining in Jackson County, ca. 1929 (SOHS 7897). (C) Hydraulic mining at the Sterling mine on a tributary to the Little Applegate River, ca. 1880s (SOHS 5086). (D) Hydraulic mining in the Applegate Area, ca. 1903 (SOHS 20761). (E) The Rogue River Gold Company's bucket-line dredge, ca. 1931 near the confluence of the Rogue River and Foot Creeks (SOHS 18208). (Photographs used by permission of the Southern Oregon Historical Society.)

Gravel is also mined from the floodplains of the Rogue and Applegate Rivers (Schlicker and Deacon, 1970a, b). Like instream mining, floodplain mining may affect channel condition and bed-material transport. The active channel near floodplain mining sites is often channelized, levied, and armored to increase site accessibility and prevent the active channel from avulsing into floodplain excavations and resulting pit captures (Kondolf and others, 2002). Once a river captures a floodplain pit, channel incision can occur up- and downstream of the pit owing to knickpoint regression and sediment trapping at the pit, respectively (Kondolf and others, 2002). Floodplain pit captures have occurred on the Rogue River near Table Rock and at several locations in the Applegate River study area (for example, near RKM 5.3, 25, 29.8, and 32.2; Frank Schnitzer, Oregon Department of Geology and Mineral Industries, written commun., 2010). A compilation of the locations of floodplain mining sites would be needed to support assessments of the possible effects of floodplain gravel mining on channel condition and bed-material transport in the Rogue River basin.

Dams

Streamflows have been regulated by dams on the mainstem Rogue River since the early 1900s and on the Applegate River since 1980. As of 2011, the William L. Jess Dam is the last remaining dam on the mainstem Rogue River. Built by the U.S. Army Corps of Engineers in 1977 and about 12.3 km downstream from the confluence of the mainstem and South Fork Rogue River (fig. 1), the Jess Dam and its Lost Creek Reservoir store over 388,000,000 m^3 when full and regulate flow for flood protection, hydropower, recreation, and irrigation (Willingham, 1983). The upstream area draining to this dam is 1,782 km^2, or 13 percent of the Rogue River basin at its mouth.

On the Applegate River, the Applegate Dam was completed in 1980 by the U.S. Army Corps of Engineers for flood protection, fish and wildlife enhancement, and irrigation uses (fig. 1). This project creates Applegate Lake, which can store over 101,000,000 m^3 of water (Willingham, 1983), and has a contributing basin area of 575 km^2, or approximately 29 percent of the Applegate River basin at its mouth. Both Applegate and William L. Jess Dams probably trap most bed material delivered from their contributing drainage basins and contribute to some extent to diminished peak flow events and alterations in summer flows on the Rogue and Applegate Rivers since their closure (fig. 4A–E).

Since 2008, three small dams have been removed from the mainstem Rogue River, leaving it free-flowing except for the Jess Dam. The Gold Ray, Gold Hill, and Savage Rapids Dams were removed in part because of outdated infrastructure that did not meet the National Marine Fisheries Service’s passage requirements for migratory fishes. The Gold Ray (1904–2010; contributing basin area of 5,309 km^2, 39.7 percent of Rogue River basin) and Gold Hill (early 1900s–2008; contributing basin area of 5,387 km^2, 40.2 percent of Rogue River basin) Dams were upstream of the study area and on the mainstem between its confluences with Bear and Evans Creeks (fig. 1). Within the study area at RKM 173.1, Savage Rapids Dam was built in 1921 and removed in 2009. The Gold Ray, Gold Hill, and Savage Rapids Dams were small (less than 12 m high), filled with sediment, and probably did not substantially affect peak flows and rates of bed-material transport on the mainstem after filling with sediment within a few years of closure (Bureau of Reclamation, 2001a). While the removal of these dams has likely contributed bed material to the Rogue River, assessing the effects of these dam removals on downstream bed-material transport was outside the scope of this study. Combined, the Gold Hill and Savage Rapids Dams stored about 450,000 m^3 of mainly sand and gravel (Bureau of Reclamation, 2001a; HDR, 2009), which is about 6 years of sediment flux at the mean annual bed-material transport rate of nearly 76,000 m^3/yr at Savage Rapids Dam (Bureau of Reclamation, 2001a; determined using transport capacity calculations).

Other historical dams in the basin include the Elk Creek Dam (1982–2008) on Elk Creek, a tributary joining the Rogue River downstream of the Jess Dam (fig. 1)

Forest Management and Fire

Although a substantial percentage of the Rogue River basin is managed by Federal and State agencies for uses including timber harvesting, we found little data summarizing historical logging volumes and practices in the basin. Peck and Park (2006) estimated that 89.6 km^2 of forests were harvested from 1950 to 1990 in the coastal districts of the Rogue River–Siskiyou National Forest. Although Peck and Park (2006) reported high harvest rates in the 1970s and 1980s, forests throughout the Rogue River basin have been harvested since the 1850s to support diverse construction and development efforts, including gold mining (particularly hydraulic mining and flume construction), dam construction, and agriculture.

Fires ignited by lightning strikes or by people, historically and today, shape the forests and landscape of the Rogue River basin (Bureau of Land Management, 2000). More recently, fire suppression efforts have reduced the number of fires and the extent of burned forests (Bureau of Land Management, 2000). During the earliest recorded major fire season in 1910, several fires burned over 204 km^2 in the Rogue River basin, including its headwaters in the Western Cascades and the Bear Creek basin (U.S. Forest Service, 2008). In the next major fire season of 1987, several fires burned in the Klamath Mountains including the Silver Creek Fire (389.8 km^2) along Silver Creek and the Wild and Scenic section of the Illinois River, the Longwood Fire (39.9 km^2) in the headwaters of the East Fork Illinois River, and the Galice Fire (23.4 km^2) along tributaries to the Wild and Scenic section of the Rogue River (U.S. Forest Service, 2008). The largest fire in the Rogue River basin was the 2002 Biscuit Fire, which burned over 2,000 km^2 of the Klamath Mountains, including the entire Wild and Scenic section of the Illinois River and large portions of neighboring watersheds (U.S. Forest Service, 2008). The U.S. General Accounting Office (2004) reported that the Biscuit Fire lasted 120 days in the summer and fall of 2002, with over 7,000 firefighters and support personnel working at the fire's peak. Additionally, many smaller fires have burned areas throughout the basin, particularly in the Klamath Mountains and the headwaters of the Applegate River. While Peck and Park (2006) state that fires in the lower Rogue River basin have not substantially impacted hydrology, additional assessments would be needed to determine if these fires and subsequent reductions in forest cover have led to increased erosion and inputs of sediment to the Illinois and Rogue Rivers. Such information may be beneficial since the current and projected risks for fires in the basin are high owing to factors such as increased vegetation density and fuel buildup (Bureau of Land Management, 2000), the growing abundance of less fire-resistant plant species because of fire suppression (Middle Rogue Watershed Association, 2001), and the longer fire seasons predicted with climate change (Doppelt and others, 2008).

Navigation Improvements and Dredging

As noted by the U.S. Army Corps of Engineers (1879), the Rogue River from RKM 148 to 56 "possesses all the features of a mountain stream, steep slopes, swift in its currents, and filled with rapids and falls, choked with detached masses of rocks and boulders, which discourage any attempts at improvement," and downstream, from Big Bend near RKM 56 to the mouth of the Rogue River, "bends [that] are very abrupt, and the connecting straight reaches short and cut up into frequent shoals and swifts, making navigation impossible for vessels having any commercial importance." Given this character of the Rogue River, channel improvements have predominately focused on the mouth. Following the enactment of the River and Harbor Act of 1954, the U.S. Army Corps of Engineers completed the construction of the south and north jetties in 1959 and 1960, respectively, as well as a navigation channel and boat turning basin in 1961 at the mouth of the Rogue River to support timber and fishing industries (Willingham, 1983). The U.S. Army Corps of Engineers dredges the navigation channel and boat turning basin to maintain a stable channel elevation. At least 1.9 million m^3 of sediment were removed from the lower kilometer of the Rogue River from 1974 to 2010 and averaged over 51,000 m^3/yr (fig. 6; Judy Linton and Katharine Groth, U.S. Army Corps of Engineers, written commun., 2011; U.S. Army Corps of Engineers, 2010).

In addition to the navigation improvements at the mouth, smaller-scale modifications of the Rogue River have been made upstream. Glen Wooldridge, a pioneering river guide on the Rogue River, dynamited several rapids from Dunn Riffle (RKM 131.2) to slightly upstream of the town of Agness (near RKM 45.1) in the 1930s and 1940s to expedite river passage by recreational boaters (Bureau of Land Management and U.S. Forest Service, 2004; Leidecker, 2008). The jet and mail boat companies running the lower Rogue River from Gold Beach to Blossom Bar (RKM 73) and the upper Rogue River from Grave Creek (RKM 110.2) to Grants Pass also displace some gravel, generally less than 7,600 m^3 over several kilometers (based on 2004 permit data provided by Pratt, 2004), to maintain adequate channel elevations for boat passage.

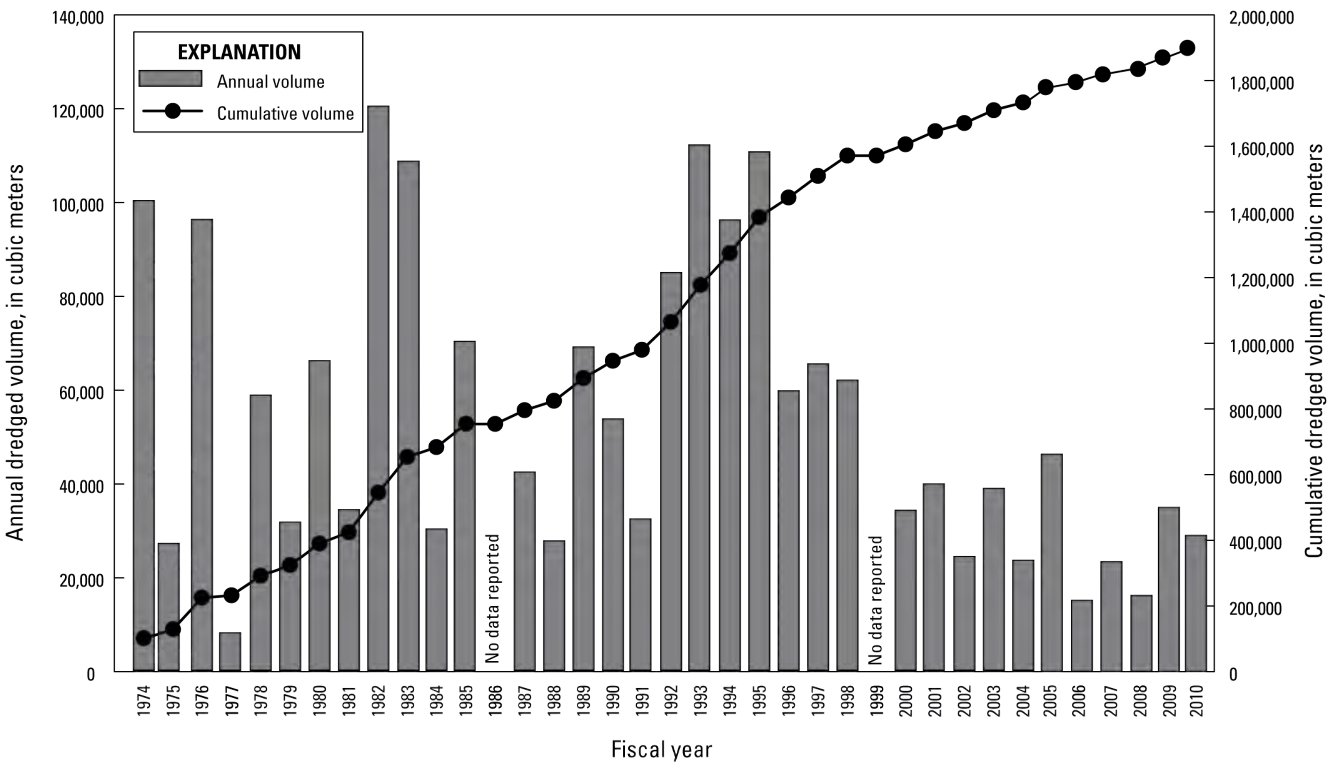

Figure 6. Graph showing annual volume of sediment removed from 1974 to 2010 near the mouth of the Rogue River, southwestern Oregon. Data were provided by Judy Linton and Katharine Groth (U.S. Army Corps of Engineers, written commun., 2011) and U.S. Army Corps of Engineers (2010). Fiscal year refers to the Federal fiscal year of October 1 to September 30.

Study Area

For this assessment, the overall geography, geomorphology, and land-use history of the Rogue River basin lead to delineation of a focused study area including (1) the mainstem Rogue River from approximately its confluence with Evans Creek to its mouth (Rogue RKM 178.6–0), (2) the Applegate River from its confluence with the Little Applegate River to its mouth (Applegate RKM 56.7–0), and (3) the lower 6.5 km of the Illinois River (Illinois RKM 6.5–0; fig. 1). These mainstem and tributary corridors contain the majority of the alluvial sections within the basin and have had the most active and historical instream gravel mining. The study area is entirely within the Klamath Mountains geologic province except for a 20 km stretch between the towns of Marial and Agness, where the Rogue River transects the southern extent of the Coast Range geologic province (fig. 1). This study area, encompassing 214.6 km of river channel in total, was further subdivided into eight study reaches based on topography, hydrology, and tidal influence (fig. 1; table 3; table 4).

Table 3. Summary of characteristics for study reaches on the Rogue River, southwestern Oregon

[RKM, river kilometer; km^2, square kilometers; m, meter]

Attribute	Study reaches on the mainstem Rogue River				
	Grants Pass	Merlin	Galice	Lobster Creek	Tidal
River kilometer	178.5–152.8	152.8–132.7	132.7–43.9	43.9–6.7	6.7–0
Reach and channel description	Confined channel with few bars until the Rogue River approaches its confluence with the Applegate River	Channel with confined and unconfined segments; narrows near the Robertson Bridge (RKM 139) and remains confined to Hellgate Canyon; bars throughout reach	Bedrock-controlled channel with several rapids; confined by canyons and gorges; bars numerous from RKM 127.25 to 126, 57 to 54, and 47 to 43.9	Bedrock-controlled channel from RKM 43.9 to 32; confined by valley until RKM 8 then widens as it enters coastal plain; nearly continuous bars from RKM 43.5 to 40.25 and 29 to 6.7	Tidally affected; unconfined channel until RKM 2; position of mouth fixed by jetties; larger bars present from RKM 6.7 to 2
Drainage area at end of reach (km^2)[a]	6,475	8,910	10,308	13,338	13,390
Drainage area at beginning of reach (km^2)[a]	6,242	8,469	8,910	12,872	13,338
Reach gradient (m/m)[b]	0.0014	0.0014	0.0020	0.0007	0.0005
Flow modifications	Regulated by the Jess Dam on the Rogue River; withdrawals for multiple uses	Same as the Tidal Reach	Same as the Tidal Reach	Same as the Tidal Reach	Regulated by the Jess Dam (Rogue River) and the Applegate Dam (Applegate River); withdrawals for multiple uses

Table 3. Summary of characteristics for study reaches on the Rogue River, southwestern Oregon—continued

[RKM, river kilometer; km^2, square kilometers; m, meter]

Attribute	Study reaches on the mainstem Rogue River				
	Grants Pass	Merlin	Galice	Lobster Creek	Tidal
Background sedimentation drivers	Sediment releases from decommissioned dams and inputs from upstream sources	Inputs from the Applegate River	Inputs from Grave Creek and other tributaries	Low-gradient promotes deposition of bed and suspended loads; inputs from the Illinois River and tributaries	Low gradient promotes deposition of bed and suspended loads
Channel disturbance factors	Same as the Merlin Reach plus dam building and removal; urban development; levees; historical bucket-line dredging	Same as the Galice Reach plus historical and ongoing navigation dredging	Placer and hydraulic mining; recreational suction dredging; upland fires and forest harvests	Same as the Tidal Reach	Historical, ongoing navigation dredging; sand, gravel mining and placer mining; fires and upland forests
General channel trends	Flows on alluvium, cement-gravels, and bedrock; lateral channel position historically stable likely owing to bedrock and cement-gravels in banks	Flows on alluvium, cemented gravels, and bedrock; lateral channel position historically stable except near Brushy Chutes and the Robertson Bridge Bar	Flows on bedrock, which promotes lateral and vertical channel stability	Flows on bedrock and alluvium; valley topography confines the width of the active channel	Flows on alluvium; topography and jetties confine the width of the active channel from RKM 2 to 0

[a] Drainage area at reach boundaries was determined using StreamStats, *http://water.usgs.gov/osw/streamstats/oregon.html.*

[b] Water-surface gradient for the reach was determined from 10-m USGS Digital Elevation Model (DEM).

Left: Gravel bar and bedrock outcrops on the Rogue River upstream of the former Savage Rapids Dam site in the Grants Pass Reach.

Table 4. Summary of characteristics for study reaches on the Applegate and Illinois Rivers, southwestern Oregon

[RKM, river kilometer; km^2, square kilometers; m, meter]

Attribute	Study reaches on tributary rivers		
	Upper Applegate River	Lower Applegate River	Illinois River
River kilometer	56.6–41.6	41.6–0	6.5–0
Reach and channel description	Channel flows on alluvium with several sections confined and controlled by bedrock throughout the reach; valley is less confined in RKM 52–56.5; reach contains relatively few gravel bars	Channel flows on alluvium and alternates between unconfined and confined segments; large, dynamic bars in unconfined segments	Channel flows on alluvium; narrow valley confines active channel width; large, alternating bars throughout reach
Drainage area at end of reach (km^2)[a]	1,370	1,994	2,564
Drainage area at beginning of reach (km^2)[a]	1,080	1,370	2,437
Reach gradient (m/m)[b]	0.0036	0.0028	0.0019
Flow modifications	Regulated by the Applegate Dam; withdrawals for multiple uses	Regulated by the Applegate Dam; withdrawals for multiple uses	Unregulated by any upstream mainstem dams
Background sedimentation factors	Same as the Illinois River Reach	Same as the Illinois River Reach	Inputs from tributaries and upstream sources
Channel disturbance factors	Placer, hydraulic, and dredge mining; ongoing floodplain gravel mining; fire	Placer and hydraulic mining; ongoing floodplain gravel mining; fire	Placer and hydraulic mining; historical sand and gravel mining; fire and upland forest harvest
General channel trends	Flows on alluvium and bedrock; channel has shifted laterally in a few locations, but bedrock limits lateral movement	Flows on alluvium and exhibits substantial lateral channel shifting and avulsions in unconfined sections	Flows on alluvium; lateral movement limited by narrow valley topography

[a] Drainage area at reach boundaries was determined using StreamStats, *http://water.usgs.gov/osw/streamstats/oregon.html.*

[b] Water-surface gradient for the reach was determined from 10-m USGS Digital Elevation Model (DEM).

Grants Pass Reach

The Grants Pass Reach is the uppermost study reach on the mainstem Rogue River, beginning slightly downstream of the Rogue River and Evans Creek confluence and ending at the Rogue and Applegate River confluence (RKM 178.5–152.8; fig. 7; table 3). This reach passes through the city of Grants Pass and has a drainage area of 6,242 km^2 at its upstream boundary and 6,475 km^2 at its downstream boundary. This reach has a water surface gradient of 0.0014 m/m (as determined from the 10-m USGS Digital Elevation Model [DEM] for this slope and all slopes reported in this section). The active channel, defined as the channel area typically inundated during annual high flows as determined by the presence of water and flow-modified surfaces (Church, 1988), ranges from 75 m wide at the upstream boundary (from 2009 orthophotographs for this width and all other widths reported in this section) to 100 m wide slightly upstream of the Rogue and Applegate Rivers confluence (fig. 7; table 3). The streambed is composed of alluvial deposits as well as cemented gravels and volcanic rocks that form extensive outcrops in locations such as near the former Savage Rapids Dam site (fig. 1). The Grants Pass reach contains sparse lateral, point, and medial bars that have moderate vegetative cover.

Key locations in this reach include a bed-material sampling site at the Rogue River City Bar (RKM 176.6), three public bridges with inspection data (RKM 164.5, 163.5, 163.4), and the long-term USGS streamflow-gaging station at Grants Pass (RKM 164.4, 14361500, table 1). Repeat bar and channel feature delineation was completed for the Riverside Park site (RKM 172.5–160.5; fig. 7).

Gravel bars and bedrock outcrops on the Rogue River at the former Savage Rapids Dam site in the Grants Pass Reach.

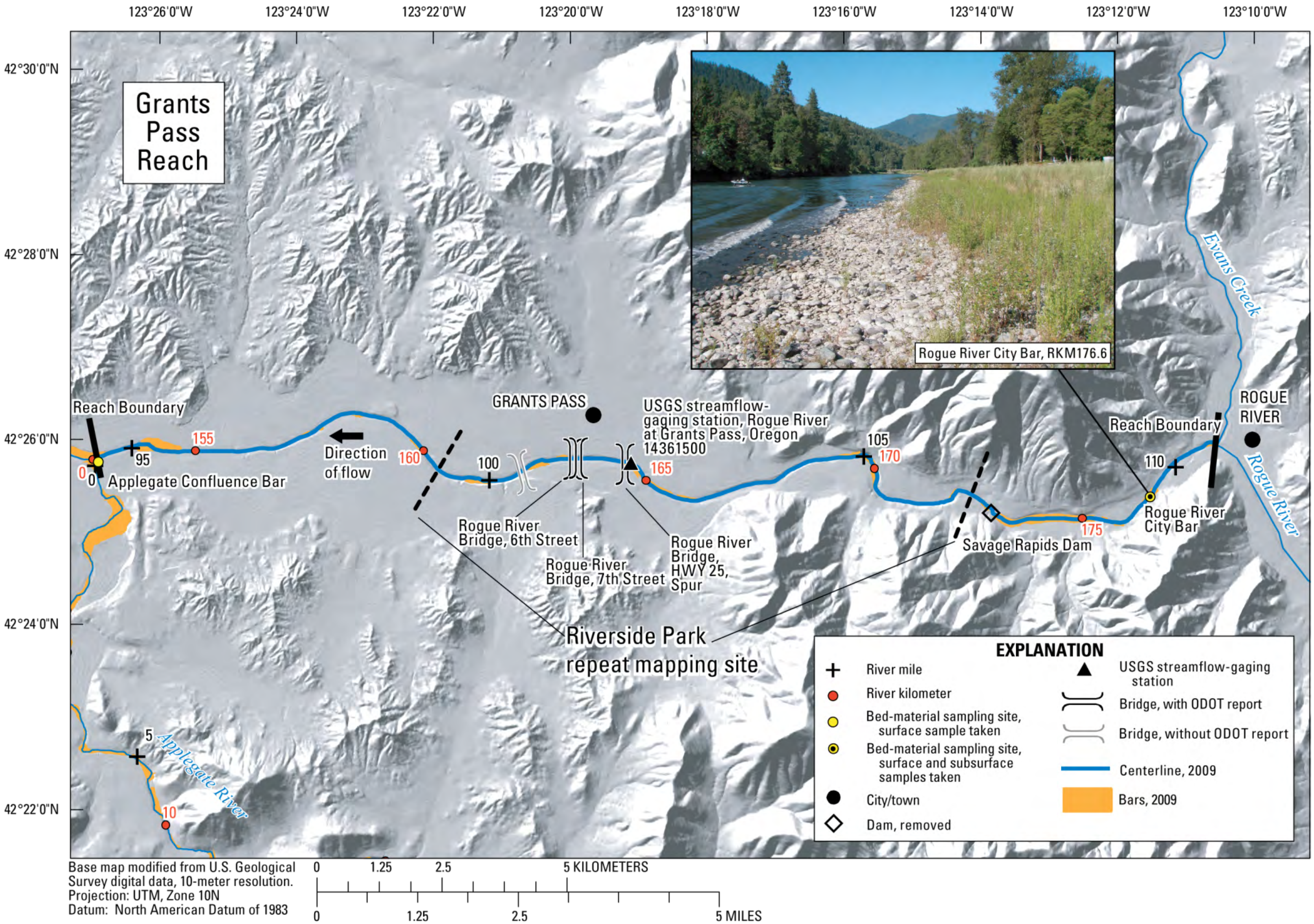

Figure 7. Map showing bars and channel centerline in the upstream section of the Grants Pass Reach of the Rogue River, southwestern Oregon, delineated from 2009 orthophotographs, and photographs showing field reconnaissance sites.

Merlin Reach

Downstream of the Grants Pass Reach, the Merlin Reach stretches from the confluence of the Rogue and Applegate Rivers to slightly upstream of Hellgate Canyon (RKM 152.8–132.7; fig. 8; table 3), and includes both confined and unconfined segments. At the reach's upstream boundary, the combined contributing area of the Rogue and Applegate Rivers is 8,469 km^2. In this reach, the channel has a gradient similar to the Grants Pass Reach (0.0014 m/m; table 3) and a cobble and gravel bed with cemented gravels, boulders, and bedrock outcrops. Below the Applegate-Rogue River confluence, the active channel typically exceeds 170 m in width and contains several medial and lateral gravel bars that have relatively stable locations and some vegetative cover. Near RKM 151, the channel narrows to 80 m and accommodates only smaller lateral and point bars. From RKM 149–139.5, the channel alternates between valley walls and has larger bars in wider sections, such as near Brushy Chutes (RKM 142–141) where the width of the active channel exceeds 630 m. Valley topography constricts the width of the active channel to 65 m from RKM 139.5 to 139 near the Robertson Bridge. Downstream of the Robertson Bridge, the channel contains few gravel bars and remains mostly confined and only 40-m wide at Hellgate Canyon.

Prominent locations in this reach include the bed-material sampling site at Robertson Bridge Bar (RKM 140.1), Robertson Bridge (RKM 139.2), and the Matson Park site (RKM 149.5–138.4; fig. 8) used for repeat bar and channel feature delineation.

Gravel bar along the Rogue River at RKM 146 in the Merlin Reach.

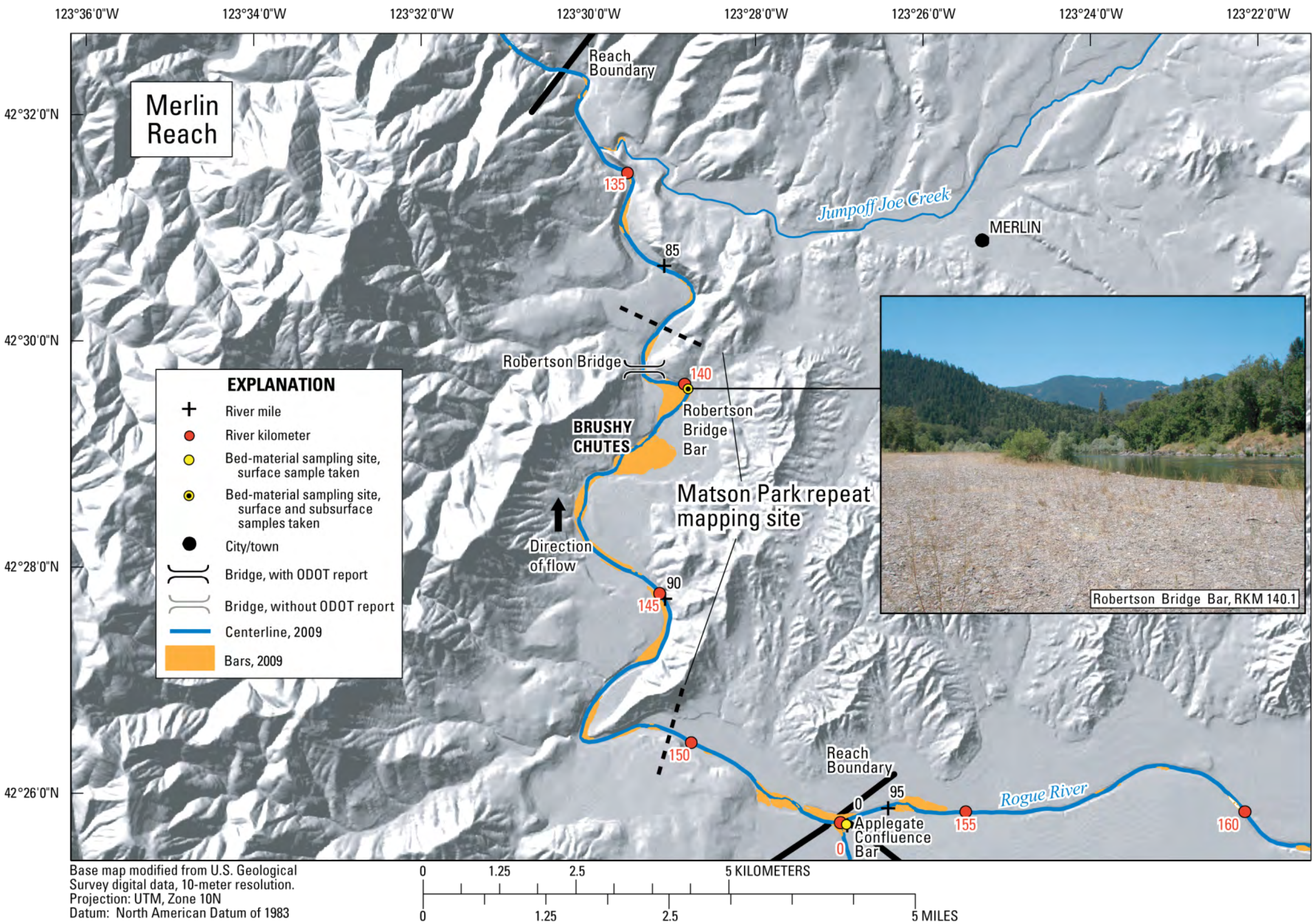

Figure 8. Map showing bars and channel centerline in the upstream section of the Merlin Reach of the Rogue River, southwestern Oregon, delineated from 2009 orthophotographs, and photographs showing field reconnaissance sites.

Galice Reach

The Galice Reach is the largely confined section of the Rogue River stretching from the entrance to Hellgate Canyon to the confluence of the Rogue and Illinois Rivers (RKM 132.7–43.9; fig. 9; fig. 10; table 3). Wholly within the Wild and Scenic corridor, this 89-km-long stretch of the Rogue River flows over several bedrock rapids and attains the river's highest gradient (0.0020 m/m; table 3) within the study area. The channel is predominately bedrock controlled, with bars forming in eddies, deposited as thin layers over bedrock, and as larger, boulder deposits in the canyon expanses. In the three unconfined sections (RKM 127.25–126, 57–54, and 47–43.9), the channel accommodates large point and medial bars.

The Galice Reach has a USGS streamflow-gaging station near Agness (RKM 47.6, Rogue River near Agness, OR, 14372300, table 1) and 16 bed-material sampling sites. Repeat bar and channel delineation was done for the Foster Bar site (RKM 66.5–53.9; fig. 10).

Hellgate Canyon on the Rogue River near the upstream boundary of the Galice Reach.

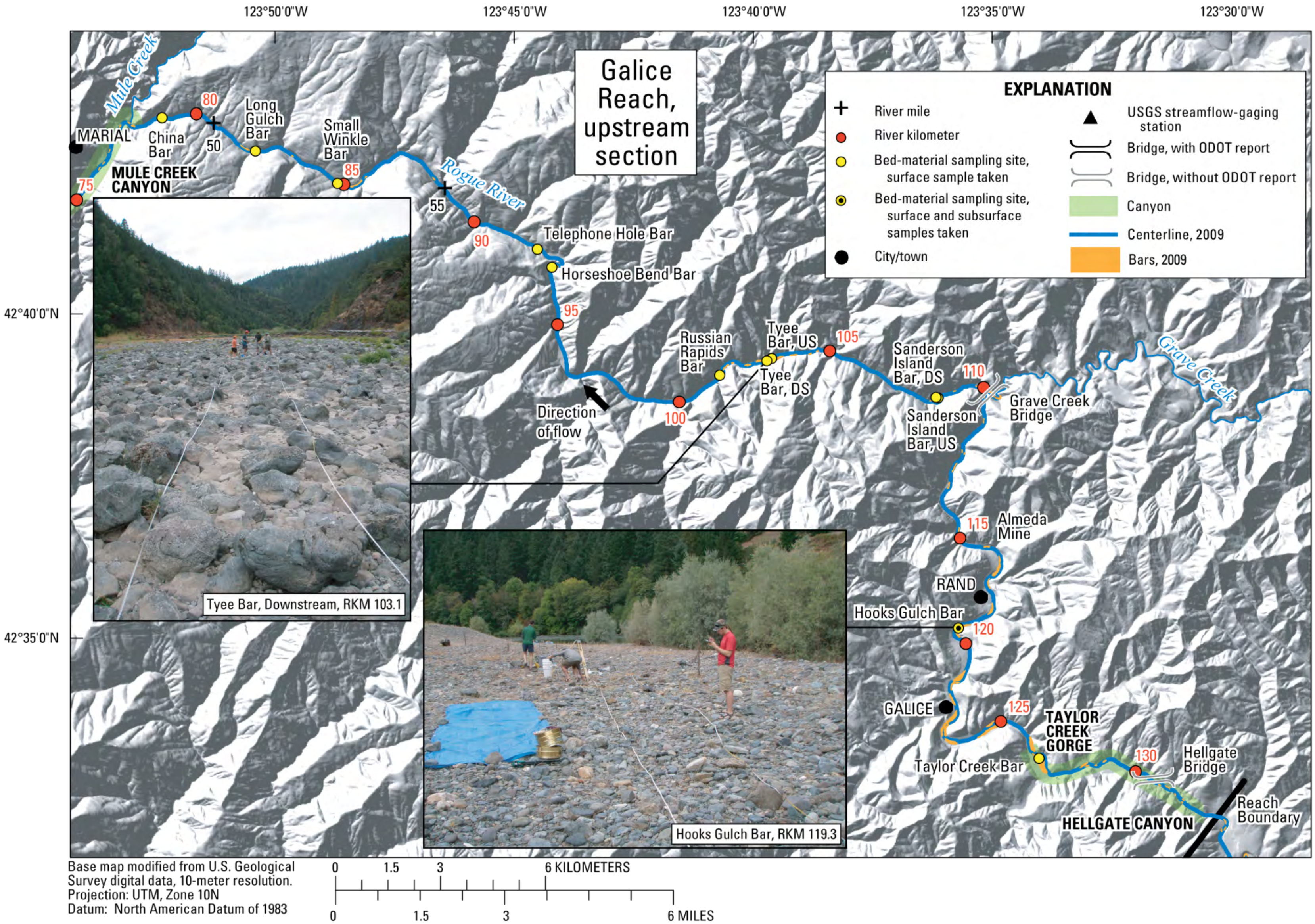

Figure 9. Map showing bars and channel centerline in the upstream section of the Galice Reach of the Rogue River, southwestern Oregon, delineated from 2009 orthophotographs, and photographs showing field reconnaissance sites.

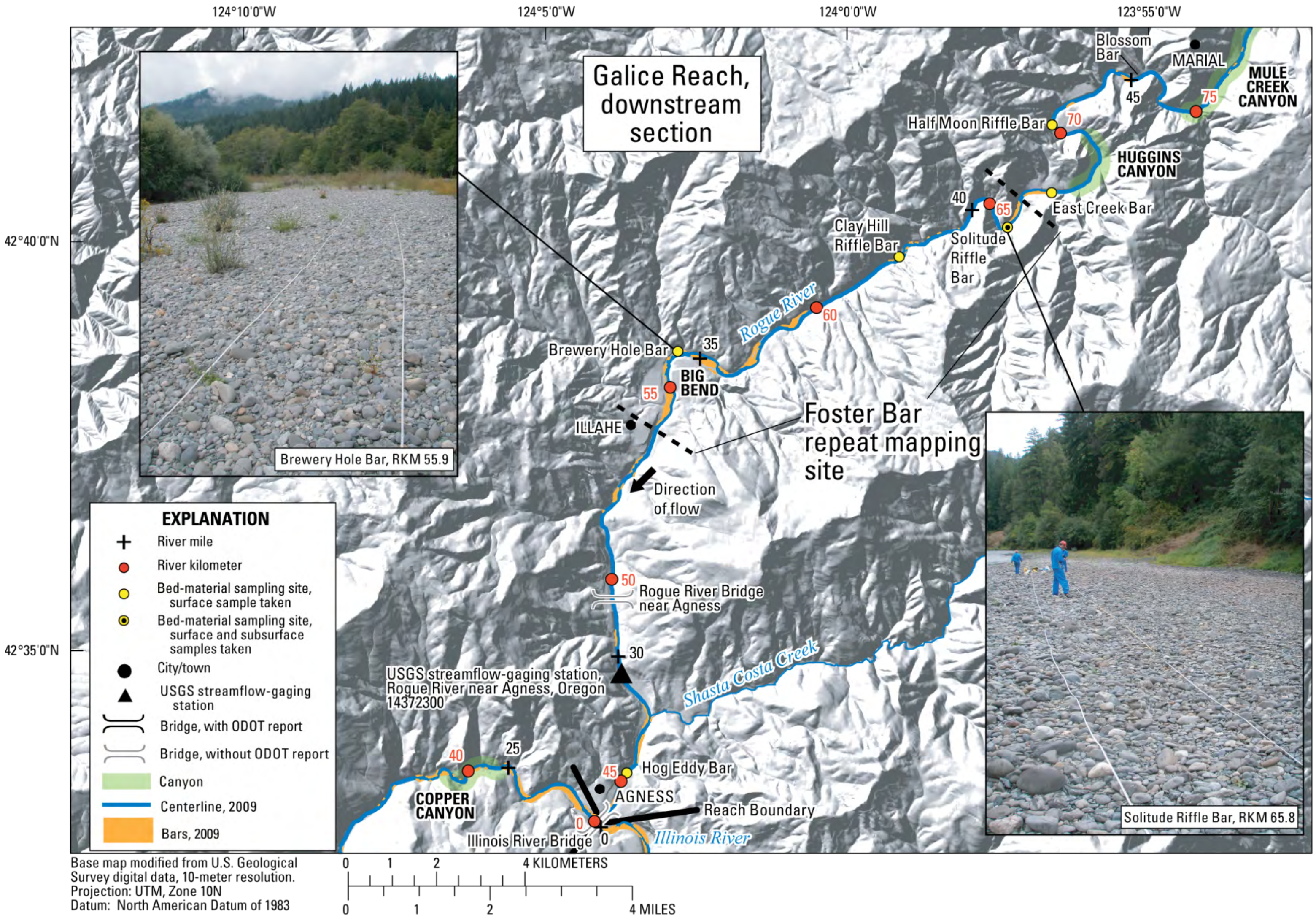

Figure 10. Map showing bars and channel centerline in the downstream section of the Galice Reach of the Rogue River, southwestern Oregon, delineated from 2009 orthophotographs, and photographs showing field reconnaissance sites.

Measurement transect at the Telephone Hole Bar in the Galice Reach.

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Lobster Creek Reach

The Lobster Creek Reach begins at the confluence of the Rogue and Illinois Rivers and ends at approximately the head of tide (RKM 43.9–6.7; fig. 11; table 3). The channel in this reach has a gradient of 0.0007 m/m and is confined by Copper (RKM 40.5–39.5; fig. 11) and Bear (RKM 38–32; fig. 11) Canyons. Downstream of RKM 32, the width of the active channel increases to more than 150 m near RKM 32 and more than 1,000 m near RKM 7 as the Rogue River enters the coastal plain. The channel flows over bedrock from RKM 43.9 to 32 as well as alluvial deposits contributed from upstream and tributary sources. Lobster and Quosatana Creeks are larger tributaries, with bar and delta complexes at their mouths, indicating active sediment delivery to the mainstem.

For this study, bed material at Orchard Bar (RKM 16.1) was sampled, and the Jennings Riffle site was the focus for repeat bar and channel feature delineation in this reach (RKM 26.5–15.2; fig. 11).

Expansive gravel bars on the Rogue River in the Lobster Creek Reach.

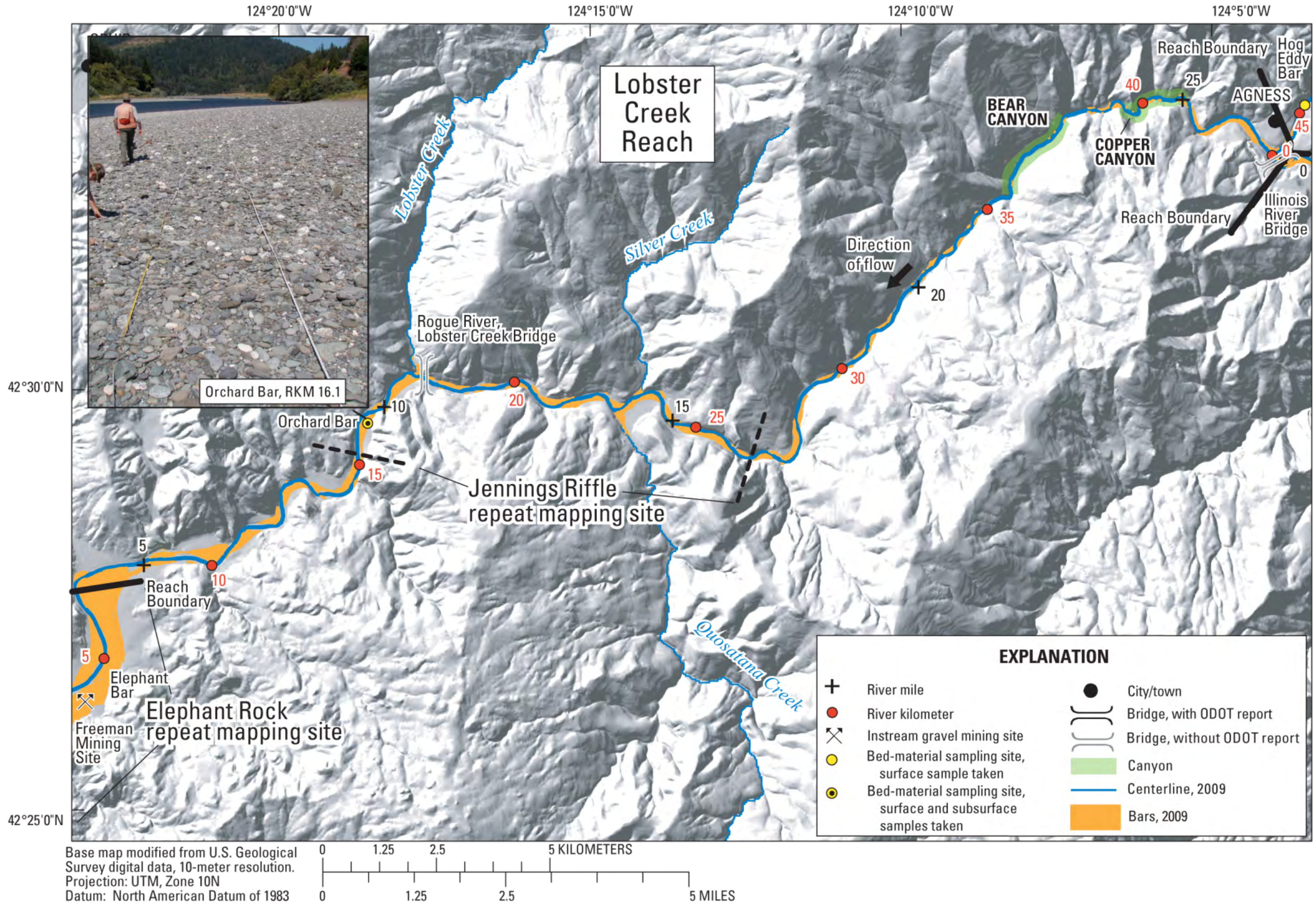


Figure 11. Map showing bars and channel centerline in the downstream section of the Lobster Creek Reach of the Rogue River, southwestern Oregon, delineated from 2009 orthophotographs, and photograph showing field reconnaissance site.

Tidal Reach

The downstream-most reach on the mainstem Rogue River is the Tidal Reach, which extends from the head of tide to slightly upstream of the river's mouth (RKM 6.7–0; fig. 12; table 3). In this tidally affected reach, the low-gradient (0.0005 m/m) channel flows over an unconsolidated gravel and sand bed and locally exceeds 1,000 m in active channel width. The width of the active channel narrows to 400 m near RKM 2 and further narrows to 300 m between the jetties. The drainage area of the Rogue River at its mouth is 13,390 km^2.

Key sites include the instream mining sites at Elephant and Wedderburn Bars, the bed-material sampling site on Wedderburn Bar, and Patterson Bridge (Highway [Hwy] 101) at RKM 1.3. Channel modifications in this reach include the construction and maintenance of jetties at the river's mouth and historical and ongoing dredging to maintain the navigation channel. Repeat bar and channel delineation for the Elephant Rock site encompassed the entire Tidal Reach.

Gravel bar on the Rogue River near Patterson Bridge (Highway 101) in the Tidal Reach.

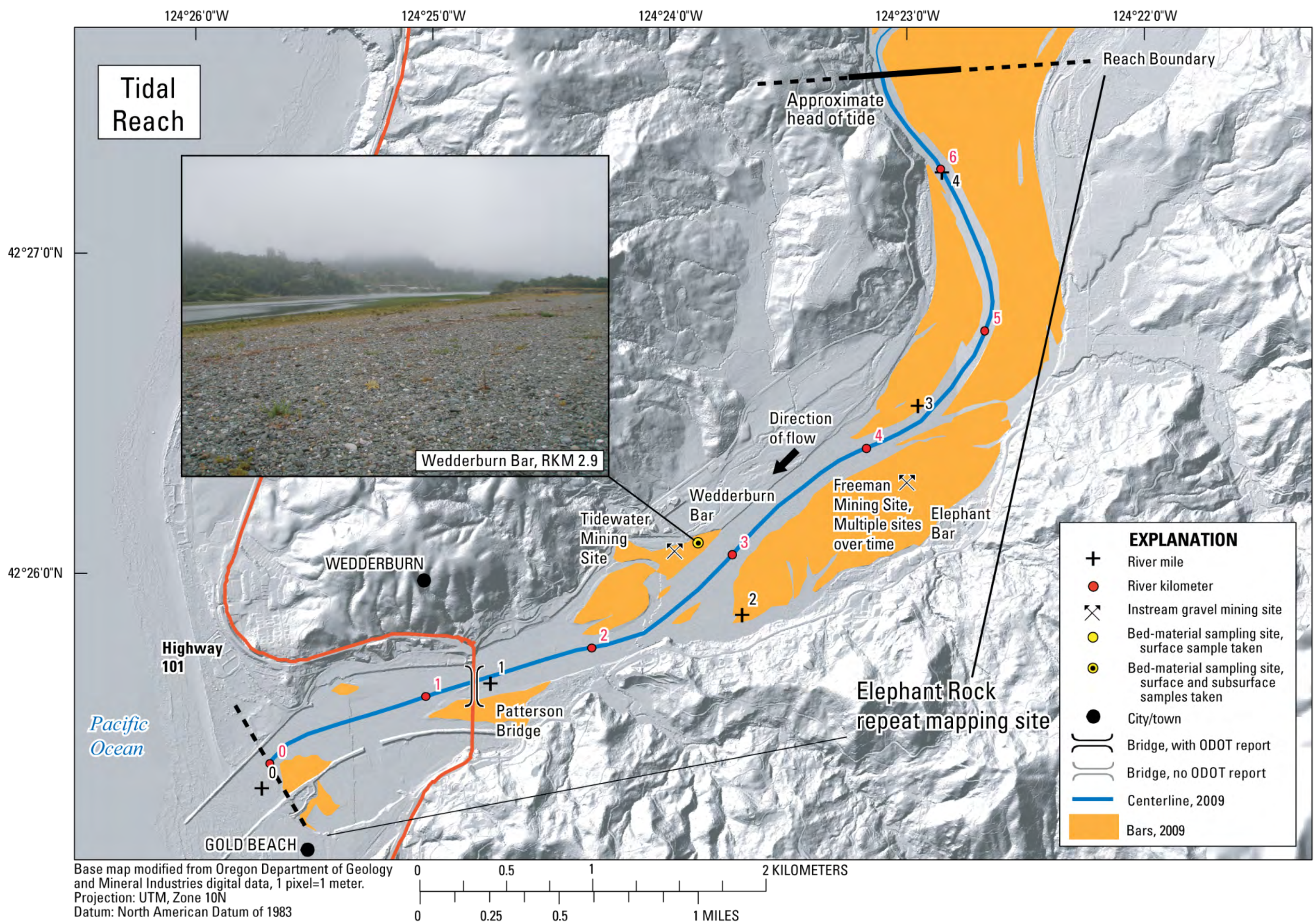


Figure 12. Map showing bars and channel centerline in the Tidal Reach of the Rogue River, southwestern Oregon, delineated from 2009 orthophotographs and photograph showing field reconnaissance site.

Upper Applegate River Reach

In addition to the five reaches on the Rogue River, we defined two reaches on the Applegate River. The Upper Applegate River Reach begins slightly downstream of the Applegate-Little Applegate River confluence, and ends downstream of the Applegate River-Thompson Creek confluence (RKM 56.6–41.6; fig. 13; table 4). The Applegate River has a drainage area of 1,080 km^2 downstream of its confluence with the Little Applegate River. In this high-gradient (0.0036 m/m) reach, the Applegate River flows through alternating confined and unconfined valley sections and over a cobble and gravel bed that is interspersed with bedrock outcrops. The active channel is generally less than 30-m wide and contains few bars between the reach's upstream boundary and RKM 52 where it runs along the valley wall. Downstream of RKM 52, the channel is flanked by small lateral and point bars and has several short, wide sections where the active channel is nearly 80 m wide. Near RKM 41.6, the valley constrains the Applegate River, reducing the active channel width to 23 m. The drainage area of the Applegate River at the downstream boundary is 1,370 km^2. Larger tributaries in this reach include Forest (RKM 52.5, 91 km^2) and Thompson (RKM 42, 82 km^2) Creeks.

This reach includes one long-term USGS streamflow-gaging station (RKM 45.2, Applegate River near the city of Applegate, 14366000, table 1) and one public bridge with inspection data near the town of Applegate (RKM 42). The Thompson Creek site was the focus for repeat bar and channel feature delineation in this reach (RKM 49.5–41.6; fig. 13). No bed-material samples were collected in this reach.

Gravel bar on the Applegate River near its confluence with the Little Applegate River.

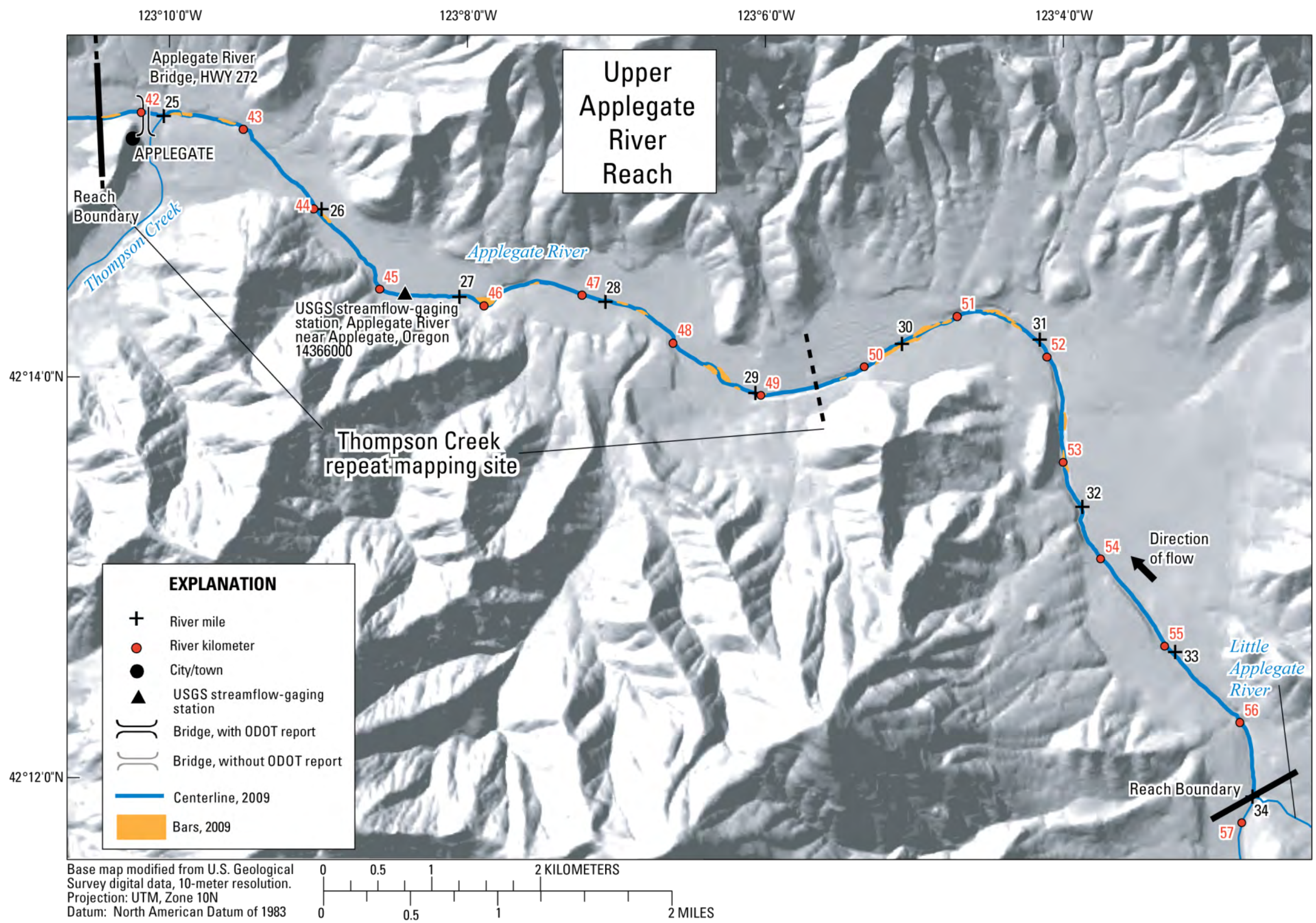


Figure 13. Map showing bars and channel centerline in the Upper Applegate Reach of the Applegate River, southwestern Oregon, delineated from 2009 orthophotographs.

Lower Applegate River Reach

The Lower Applegate River Reach begins downstream of the Applegate River-Thompson Creek confluence and ends at the Applegate-Rogue River confluence, where the cumulative drainage area of the Applegate River is 1,994 km^2 (RKM 41.6–0; fig. 14; table 4). The gradient in this reach is 0.0028 m/m. At the upstream end of this reach, the Applegate River channel enters a wide alluvial floodplain, where the width of the active channel increases from 200 to 560 m. The channel contains large, active bars from the reach's upstream boundary to RKM 23.5. From RKM 23.5–6.5, the channel is confined by valley walls, and has an active channel less than 190 m wide and fewer channel-flanking bars. The Applegate River then increases in width, accommodating large, dynamic bar sections between RKM 6.5–4.5 and RKM 2.5–1 with alternating narrower sections near RKM 4.5 and 1. The Applegate River flows in a straight channel between roads as it approaches its mouth. In this reach, larger tributaries to the Applegate River include the Williams (RKM 33, 229 km^2) and Slate Creeks (RKM 4.5, 116 km^2).

This reach has two bed-material sampling sites located at the Bakery Bar (RKM 29.1) and the mouth of the Applegate River (RKM 0), one streamflow-gaging station (RKM 12.7, Applegate River near Wilderville, OR, 14369500, table 1), and three bridges with inspection data (RKM 21.6, 13.5, and 4.6). Bar and channel features were delineated for the portion of this reach near Williams Creek (RKM 41.6–28.5; fig. 14).

Gravel riffle downstream of Fish Hatchery Road Bridge in the Lower Applegate River Reach.

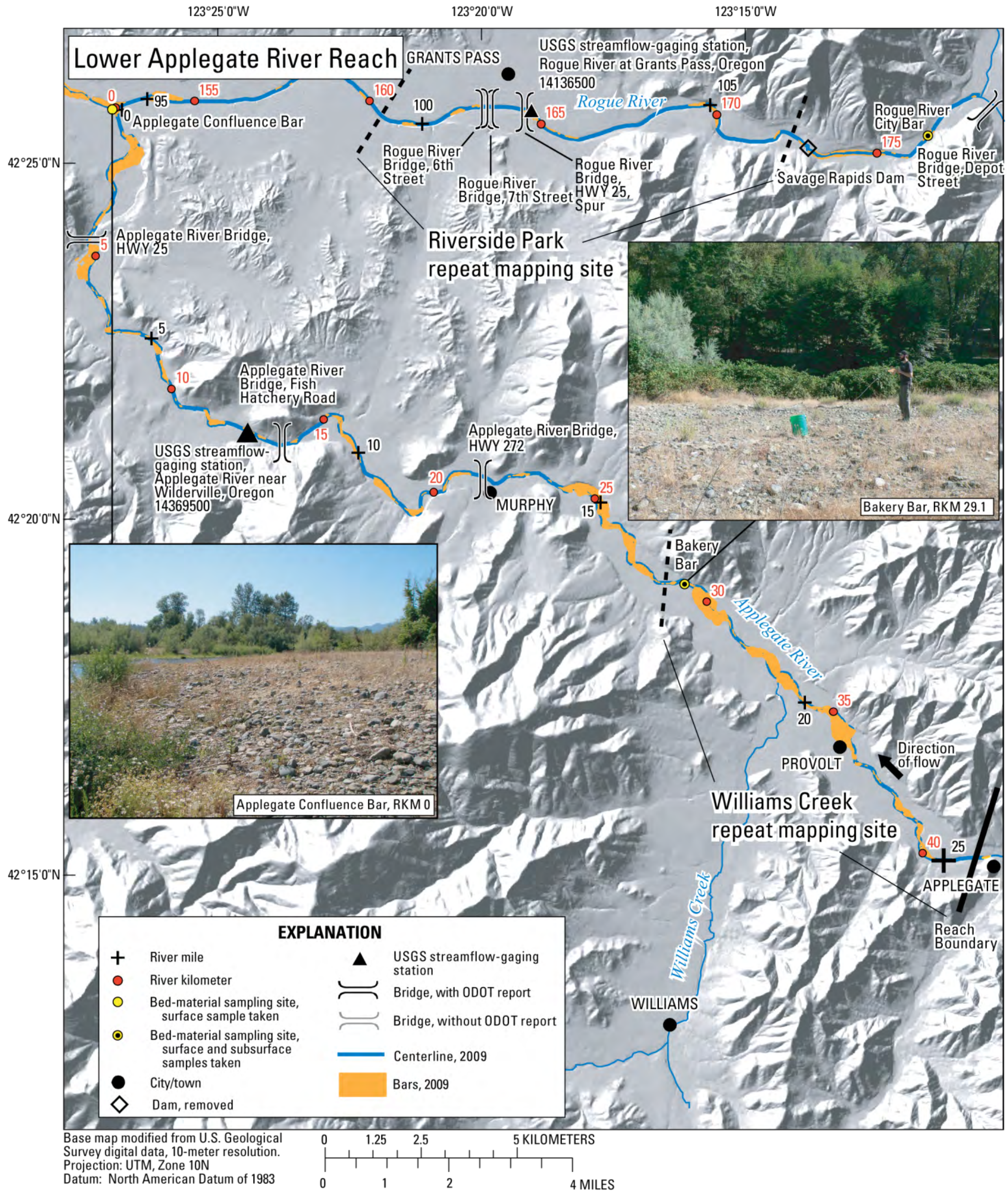


Figure 14. Map showing bars and channel centerline in the lower Applegate Reach of the Applegate River, southwestern Oregon, delineated from 2009 orthophotographs, and photographs showing field reconnaissance sites.

Illinois River Reach

The Illinois River Reach, the only study reach on the lower Illinois River, runs from the Oak Flat campground, managed by the Rogue River–Siskiyou National Forest, to the confluence of the Illinois and Rogue Rivers (RKM 6.5–0; fig. 15; table 4). In this reach, the Illinois River has a wide, active, alluvial channel (ranging from 85 to 360 m wide) that is flanked by nearly continuous gravel bars that are most extensive near RKM 3.4, where the active channel is over 360 m wide. The active channel is confined by its narrow valley topography. The gradient of the reach is 0.0019 m/m. The bed is made up of alluvium and marine sedimentary rocks. At its mouth, the Illinois River has a drainage area of 2,564 km^2.

Surface bed material at the Nancy Creek Bar (RKM 6.3) was sampled for this project. Repeat bar and channel delineation was completed for the Oak Flat site, encompassing the entire study reach.

Expansive alternating gravel bars on the Illinois River Reach.

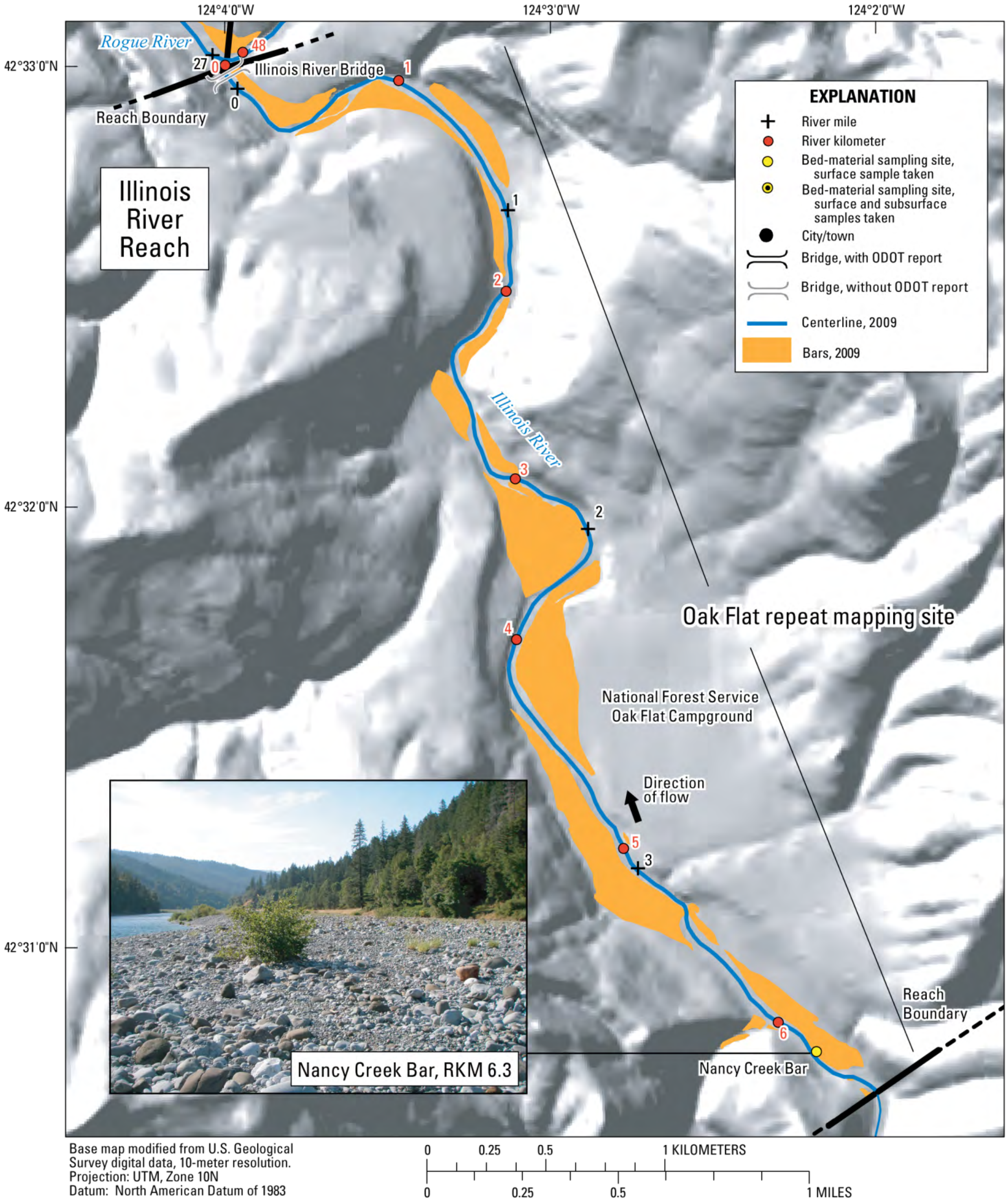


Figure 15. Map showing bars and channel centerline of the Illinois River Reach of the Applegate River, southwestern Oregon, delineated from 2009 orthophotographs, and photograph showing field reconnaissance site.

Approach and Key Findings

For this study, we reviewed existing datasets and studies regarding channel condition and bed-material transport in the Rogue River basin, applied reconnaissance-level GIS analyses, and collected field observations and particle size measurements in July and September 2010. The objectives of these efforts were to (1) identify existing datasets that would support more detailed analyses of bed-material transport and channel condition, (2) summarize instream gravel mining activities, (3) characterize broad-scale patterns in bar and channel features using vertical photographs spanning 1967/69–2009, (4) determine general bar characteristics, (5) identify locations where the channel bed may be aggrading, incising, prone to lateral channel migrations, or stable, and (6) assess the relationship between transport capacity and sediment supply for each study reach. Additionally, this study provides a preliminary review of channel condition and bed-material transport in the Rogue, Applegate, and Illinois Rivers and identifies outstanding issues relevant to the permitting of instream gravel mining that may be addressed by future studies. The following sections summarize each of the major activities and key findings.

Assessment of Aerial and Orthophotographs

We assessed the availability of spatial datasets in the Rogue River basin that could be used to evaluate channel condition and bed-material transport. This search focused primarily on aerial and orthophotographs, but also evaluated geospatial datasets, such as Light Detection And Ranging (LiDAR) data, geologic maps, General Land Office Surveys, and navigation surveys.

This study reviewed aerial photograph collections of the Rogue River basin available from the U.S. Army Corps of Engineers' aerial photograph collection (Portland, Oregon) and the University of Oregon Map and Aerial Photograph Library (Eugene, Oregon) as well as digital orthophotographs available from online sources (table 5). Other potential sources of aerial photographs not investigated for this review include the Bureau of Land Management, National Archives, county governments, and private timber companies.

Table 5. List of aerial and orthophotographs with full coverage of the Rogue River study area, southwestern Oregon.

[Aerial photographs shown in bold were used to delineate bar and channel features for this study. USACE, U.S. Army Corps of Engineers; USACE, PD, U.S. Army Corps of Engineers, Portland District; NA, not available; BLM, Bureau of Land Management; UO Library, University of Oregon Map Library; OSDF, Oregon State Department of Forestry; USGS, U.S. Geological Survey; USDA, U.S. Department of Agriculture; CH2MH, CH2M Hill; m, meter; ~, approximately]

Area covered	Year	Collection month/day	Scale	Collection entity	Repository
Entire Rogue River study area	1965	2/7	1:24,000	USACE	USACE, PD
	1971	NA	1:80,000	BLM	UO Library
	1972	NA	1:64,000	OSDF	UO Library
	1994	5/24–8/28	1:24,000	USGS	UO Library, USGS
	1995	6/27–28; 7/14	1:24,000	USGS	UO Library, USGS
	2000	7/24–8/21	1:24,000	USGS	USGS
	2001	7/13–14	1:24,000	USGS	USGS

Table 5. List of aerial and orthophotographs with full coverage of the Rogue River study area, southwestern Oregon—continued

[Aerial photographs shown in bold were used to delineate bar and channel features for this study. USACE, U.S. Army Corps of Engineers; USACE, PD, U.S. Army Corps of Engineers, Portland District; NA, not available; BLM, Bureau of Land Management; UO Library, University of Oregon Map Library; OSDF, Oregon State Department of Forestry; USGS, U.S. Geological Survey; USDA, U.S. Department of Agriculture; CH2MH, CH2M Hill; m, meter; ~, approximately]

Area covered	Year	Collection month/day	Scale	Collection entity	Repository
Entire Rogue River study area (continued)	**2005**	7/17–8/5	**1 pixel = 0.5 m**	**USDA**	**USGS**
	2009	6/7–7/15	**1 pixel = 1 m**	**USDA**	**USGS**
Rogue and Applegate River study reaches	1973	4/30	1:24,000	USACE	USACE, PD
	1982	5/24	1:48,000	USACE	USACE, PD
Applegate River study reaches	1939	May	~1:10,200	USACE	USACE, PD
	1957	2/17	1:9,600	USACE	USACE, PD
	1957	4/26	1:10,000; 1:24,000	USACE	USACE, PD
	1968	9/16	1:24,000	USACE	USACE, PD
	1973	4/30	1:24,000	USACE	USACE, PD
	1974	2/7	1:27,400	USACE	USACE, PD
	1975	11/18	1:24,000	CH2MH	USACE, PD
	1982	5/24	1:48,000	USACE	USACE, PD
	1990	8/6	1:24,000	USACE	USACE, PD
	1997	1/14	1:12,000	USACE	USACE, PD
Illinois River Reach	1956	11/3	1:12,000; 1:24,000	USACE	USACE, PD
	1965	2/12	1:12,000	USACE	USACE, PD

On the basis of this photograph review, at least four sets of vertical photographs, taken in 1994–95, 2000–01, 2005, and 2009, provide complete coverage of the Rogue River study area. These photographs were taken at appropriate scales (1:24,000 or greater) for bar and channel feature delineation and between July and October, when the Rogue River is typically at baseflow and bar exposure is maximized. At least 12 sets of photographs taken at scales of 1:24,000 or greater and during July to October are available for the Applegate River study reaches and portions of the Rogue and Applegate Rivers (table 6). Within these 12 sets of photographs, the Tidal, Lower Applegate River, and Upper Applegate River Reaches were frequently captured, whereas the Galice Reach was covered only once. In addition to the photographs listed in tables 5 and 6, at least 37 sets of photographs of the Rogue River mouth were collected by the U.S. Army Corp of Engineers for navigation and jetty maintenance purposes between 1962 and 2002.

Table 6. List of aerial and orthophotographs with partial coverage of the Rogue River study area, southwestern Oregon

[Aerial photographs shown in bold were used to delineate bar and channel features for this study. USACE, U.S. Army Corps of Engineers; USACE, PD, U.S. Army Corps of Engineers, Portland District; NA, not available; BLM, Bureau of Land Management; UO Library, University of Oregon Map and Aerial Photograph Library; OSDF, Oregon State Department of Forestry; USGS, U.S. Geological Survey; USDA, U.S. Department of Agriculture; CH2MH, CH2M Hill; m, meter; ~, approximately]

Area covered	Year	Collection month/day	Scale	Collection entity	Repository
Rogue River (RKM 178.5–132.5)	1939	May	~1:10,200	USACE	USACE, PD
Applegate River (RKM 16–0)	1949	7/11	1:6,200	NA	USACE, PD
Rogue River (RKM 173- 96, RKM 110.2–0)	1952	NA	1:47,200	USGS	UO Library
Rogue River (RKM 77.5–17)	1956	NA	1:12,000	USFS	UO Library
Rogue River (RKM 54.5–0)	1956	11/3	1:12,000; 1:24,000	USACE	USACE, PD
Rogue River (RKM 178.5–148)	1957	2/17	1:9,600	USACE	USACE, PD
Rogue River near Grants Pass (RKM 163.4)	1957	4/26	1:10,000; 1:24,000	USACE	USACE, PD
Rogue River (RKM 178.5–132.5)	1957	4/26	1:24,000	USACE	USACE, PD
Rogue River (RKM 178.5–77.5, RKM 17–13)	1960	NA	1:20,000	USDA	UO Library
Rogue River (RKM 11.5–0)	1962	2/1	1:16,800	USACE	USACE, PD
Rogue River (RKM 10.5–0)	1964	4/13	1:12,000	USACE	USACE, PD
Rogue River (RKM 53.5–0)	1965	2/12	1:12,000	USACE	USACE, PD
Rogue River (RKM 178.5–110.2); full coverage of Applegate River study area	**1967**	**7/22–27**	**1:20,000**	**USDA**	**UO Library**
Rogue River (RKM 178.5–132.5)	1968	9/16	1:24,000	USACE	USACE, PD
Rogue River (RKM 163.5–115, RKM 87–0); full coverage of Illinois River study area	**1969**	**8/25–9/10**	**1:15,840**	**USFS**	**UO Library**
Rogue River (RKM 19–0)	1972	6/4	1:12,000	USACE	USACE, PD
Rogue River (RKM 163.4–13)	1976/77	NA	1:15,840	USFS	UO Library
Confluence of the Rogue and Applegate Rivers, the confluence of the Applegate and Little Applegate Rivers, the USGS gaging stations in Grants Pass and at Applegate, and Applegate River south of Ruch, near Wilderville, and at RKM 21.5	1977	8/15	1:4,800	CH2MH	USACE, PD
Rogue River (RKM 16.5–0)	1978	5/19	1:12,000	USACE	USACE, PD

Table 6. List of aerial and orthophotographs with partial coverage of the Rogue River study area, southwestern Oregon—continued

[Aerial photographs shown in bold were used to delineate bar and channel features for this study. USACE, U.S. Army Corps of Engineers; USACE, PD, U.S. Army Corps of Engineers, Portland District; NA, not available; BLM, Bureau of Land Management; UO Library, University of Oregon Map and Aerial Photograph Library; OSDF, Oregon State Department of Forestry; USGS, U.S. Geological Survey; USDA, U.S. Department of Agriculture; CH2MH, CH2M Hill; m, meter; ~, approximately]

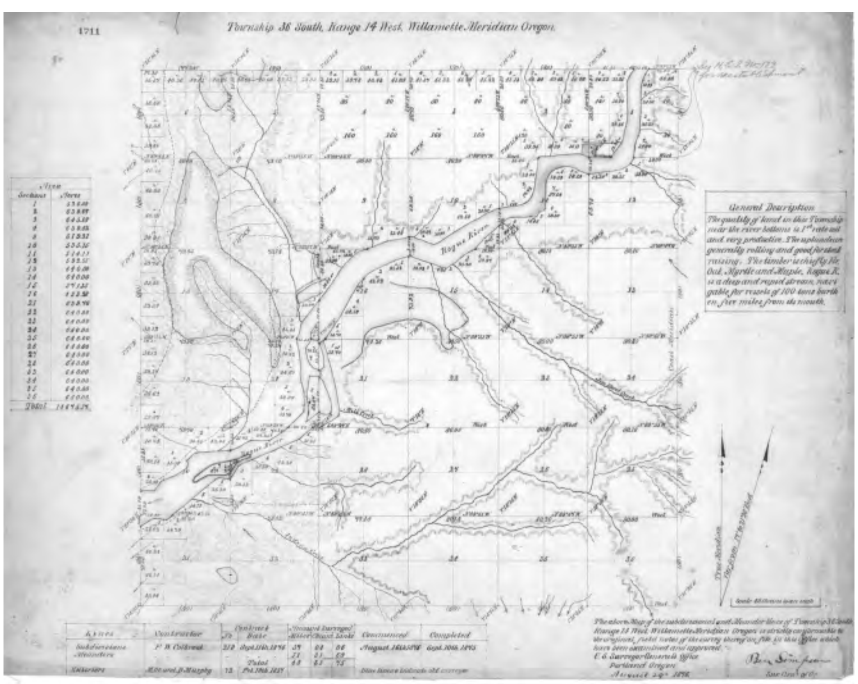
Area covered	Year	Collection month/day	Scale	Collection entity	Repository
Rogue River (RKM 20.5–0)	1978	9/23	1:24,000	USACE	USACE, PD
Rogue River (RKM 20.5–1.3)	1978	10/18	1:24,000	USACE	USACE, PD
Rogue River (RKM 19.5–0)	1980	6/30	1:12,000	USACE	USACE, PD
Rogue River (RKM 18–15)	1982	3/23	1:48,000	USACE	USACE, PD
Rogue River (RKM 24.5–0)	1982	5/24	1:48,000	USACE	USACE, PD
Rogue River (RKM 110.2–29.5)	1982	5/24	1:48,000	USACE	USACE, PD
Rogue River (RKM 19.5–0)	1986	7/6	1:24,000	USACE	USACE, PD
Rogue River (RKM 110.2–108.5)	1988	6/11	1:4,800	USACE	USACE, PD
Confluence of the Rogue and Applegate Rivers, USGS gaging station at Grants Pass, the city of Rogue River, Gold Hill Dam, and Military Slough	1988	6/11	1:4,800	USACE	USACE, PD
Rogue River (RKM 110.2–108.5)	1989	1/11	1:4,800	USACE	USACE, PD
Confluence of the Rogue and Applegate Rivers, confluence of the Applegate and Little Applegate Rivers, and USGS gaging station at Grants Pass	1989	1/11	1:4,800	USACE	USACE, PD
Rogue River (RKM 24.5–0)	1989	11/14	1:24,000	USACE	USACE, PD
Rogue River (RKM 178.5–110.2)	1990	8/6	1:24,000	USACE	USACE, PD
Rogue River (RKM 178.5–163.4)	1991	5/23	1:24,000	USACE	USACE, PD
Rogue River (RKM 11.5–0)	1998	9/15	1:16,200	USACE	USACE, PD
Rogue River (RKM 178.5–132.5); Applegate River (RKM 56.6–0)	2002	5/8–12	1:24,000	USACE	USACE, PD

This vertical photograph assessment for the entire Rogue River study area documented that several photograph sets (such as the complete collections taken in 1994, 2000, 2005, and 2009 and partial coverages taken in 1967, 1968, 1969, and 1990) are suitable for assessing long-term changes in attributes such as channel condition, gravel bar area, and vegetation cover because they were taken at sufficient spatial scales and during baseflow periods. Other photographs useful for repeat bar mapping may be identified by determining the acquisition dates and then assessing flow conditions for the nine photograph sets taken in June and November that have partial coverage and adequate resolution (table 6). Additionally, a supplemental inventory of other aerial photograph sources might reveal aerial photographs taken prior to the 1960s; such photographs would be particularly informative for assessments of long-term changes in channel condition and sediment transport.

Compilation of Historical Maps and Survey Data

We reviewed historical maps and survey data for the Rogue River study area from several sources (table 7). The objectives in reviewing these datasets were to determine whether they might provide information regarding bar and channel features and bed elevations and to identify maps that could be digitized and analyzed to support future studies of channel change.

The earliest available surveys of the reaches on the 49tem Rogue and Illinois Rivers were conducted by the General Land Office (GLO) and produced as meandered (surveyed) maps from 1857 to 1919 (table 7). The townships containing the two Applegate River reaches were surveyed (but not meandered) starting in 1857 (table 7). As summarized by Atwood (2008), the main purpose of the GLO surveys was to establish the Township, Range, and Section lines of the Public Land Survey System. The location of the river was approximated for nonmeandered maps, but surveyed for meandered maps. Further review of the GLO maps and notes would help determine whether the surveyors recorded any applicable descriptions of channel and vegetation features.



Left: General Land Office map of the lower Lobster Creek and Tidal Reaches, circa 1876. (Courtesy of the Bureau of Land Management).

Table 7. List of existing datasets reviewed for this study of the Rogue River basin, southwestern Oregon

[NA, Not available; ~, approximately; GLO, General Land Office; USCGS, U.S. Coast and Geodetic Survey; USGS, U.S. Geological Survey; NOAA, National Oceanic and Atmospheric Administration; SEF, Stuntzner Engineering and Forestry; LRWC, Lower Rogue Watershed Council; DOGAMI, Department of Geology and Mineral Industries; RVCOG, Rogue Valley Council of Governments; LiDAR, Light Detection and Ranging; RKM, river kilometer]

Title	Scale	Date(s)	Source	Depository	Description
General Land Office Surveys	~1:31,680	1857–1919	GLO	BLM[1]	Meandered maps for the Tidal, Lobster Creek, and Illinois River Reaches (1857–1881), Galice Reach (1881–1919), Merlin and Grants Pass Reaches (1855–56); non-meandered maps for two Applegate reaches (1857); maps show plan view of river channel and surrounding lands, limited details on river features
Topography and hydrography of the lower Rogue River	NA	1888, 1889	USCGS	USGS; NOAA	Survey of the Rogue River (~RKM 5.5–0)-
Plan and profile of the Rogue River, Oregon	1:31,680	1925	USGS	USGS	Contour map of entire study areas on the Rogue and Illinois Rivers; includes profiles
Plan and profile of the Applegate River, Oregon	1:31,680	1940	USGS	USGS	Contour map of the Applegate River (RKM 33–16); includes profiles
Flood profiles in the Rogue River basin (two parts)	Varies	1970	USGS	USGS	Provides cross sections and flood profiles for the Grants Pass and Upper Applegate River Reaches, RKM 41.6–33 in the Lower Applegate River Reach; elevation data from orthophotographs and soundings
Habitat map of the Rogue River estuary	NA	1978	ODFW	OSU[2]	Map of the estuary categorized by tidal inundation, habitat type, vegetation, and sediment
Bathymetric survey near Savage Rapids Dam	NA	1999	BLM	BLM	Survey of the Rogue River (~RKM 172.3–152.8)
Thalweg survey	NA	2006	SEF	USGS, LRWC	Survey of the Rogue River thalweg (~RKM 8.5–2.5)
Geologic map	1:12,000–1:500,000	2009	DOGAMI	DOGAMI	Compilation of the Oregon geologic maps (Ma and others, 2009)
LiDAR	~1 m	Multiple dates[3]	DOGAMI; RVCOG	DOGAMI; RVCOG	High resolution topographic data of the Rogue River; RKM 178.5–167.6 (RVCOG); RKM 17.8–12 and 10–0 (DOGAMI)
Bathymetric surveys of the Rogue River mouth	NA	Multiple dates[4]	USACE	USACE	Repeat bathymetric surveys of the navigation channel in the lower RKM of the Rogue River

[1] BLM website: *http://www.blm.gov/or/landrecords/survey/ySrvy1.php*
[2] OSU website: *http://digitalcollections.library.oregonstate.edu/miscmaps/full/Rogue_Estuary.tif*
[3] LiDAR collection dates: 5/30–31/2007 for RKM 178.5–167.6; 5/11–6/14/2008 for RKM 17.8–12 and 10–0
[4] Bathymetric surveys: 8/1984, 5/1986, 6/1987, 10/1992, 6/1996, 5/1997, 5/1998, 6/1999, 7/2000, 9/2001, 5/2002, 5/2003, 6/2005, 5/2006, 4/2007, 5/2008, and 5/2009

The USGS surveyed parts of the Rogue, Applegate, and Illinois Rivers as well as some smaller tributaries and potential reservoir sites from 1925 to 1940. The USGS flood studies published in 1970 provide longitudinal profiles and cross sections for select reaches of the Rogue and Applegate Rivers (Harris, 1970; Harris and Alexander, 1970). These USGS data were originally collected to describe flood elevations, water surface profiles, and channel characteristics (geometry and slope), and would provide useful baseline topographic information for evaluating system-wide changes in channel geometry from 1970 to present.

Major geologic units and geomorphic divisions of the river basin are depicted in the geologic map of Oregon (Ma and others, 2009). A LiDAR survey collected in 2007–2008 provides 1-m-resolution topographic data for RKM 178.5–167.6 in the Grants Pass Reach, RKM 17.8–12 and 10–6.7 in the Lobster Creek Reach, and the entire Tidal Reach (table 7).

The Tidal Reach has several additional datasets that may provide useful topographic and bathymetric data for future studies of the lower Rogue River. For example, the National Ocean Survey (formerly the U.S. Coast and Geodetic Survey) surveyed the mouth of the Rogue River for topography in 1888 and water depth in 1889 (table 7). Compilation and review of these data and several late 19th and early 20th century surveys of the lower Rogue River such as those by McCray (1878), Schofield (1892), and Garrison (1916) may help identify useful datasets for assessing long-term changes in channel condition in the Tidal Reach. A 2006 survey shows the elevation of the river's thalweg from approximately RKM 8.2 to 2.5 in the Lobster Creek and Tidal Reaches (table 7). The more recent bathymetric surveys of the Rogue River mouth by the U.S. Army Corps of Engineers are limited to the navigation channel and boat basin (table 7).

Review of Previous Hydrologic and Geomorphic Studies

Our search for previous hydrologic and geomorphic studies in the Rogue River basin found few studies that directly addressed hydrology, channel geomorphology, and sediment dynamics. Here, we summarize (1) studies that provide information on sediment storage behind four dams on the mainstem Rogue River, (2) studies assessing bank and channel conditions in the Grants Pass and Merlin Reaches, and (3) a review of watershed analyses describing bed-material and channel-condition observations in the lower 56 km of the Rogue River.

Studies conducted at the Lost Creek Reservoir and Gold Ray, Gold Hill, and Savage Rapids Dams provide data on sediment trapped by these structures and particle sizes. Dykaar and Taylor (2009) reported that the Lost Creek Reservoir behind the Jess Dam (fig. 1) stores over 584,000 m^3 of coarse sediment and accumulates on average 17,700 m^3/yr (when averaged over a 33-year time period between the original surveys in 1976–77 and a resurvey in fall 2009). Downstream, at the Gold Ray Dam (constructed in 1904 near the town of Gold Hill; fig. 1), up to 300,000 m^3 of sediment were stored until the dam's removal in 2010 (HDR, 2009). Sediment samples collected in the Gold Ray reservoir were 63.4 percent sand, 9.2 percent gravel, and 19.4 percent silt and clay (HDR, 2009).

Farther downstream, at the Savage Rapids Dam (constructed in the 1921 in the Grants Pass Reach at RKM 173.1; fig. 1), the Bureau of Reclamation (2001a) estimated that the pool behind the dam was filled with about 150,000 m^3 of chiefly sand and gravel. Additionally, the Bureau of Reclamation (2001a) estimated that the annual flux of bedload at Savage Rapids Dam was about 76,000 m^3/yr on the basis of transport capacity calculations and the further assumption that the Rogue River transported bed material at about 70 percent of its capacity (thereby accounting for the sediment trapped in the Lost Creek Reservoir behind Jess Dam). Ongoing studies by Oregon State University are examining changes in bar area and volumes and channel elevation following the removal of Savage Rapids Dam. Unlike the Savage Rapids and Gold Ray Dams, however, the Gold Hill Diversion Dam stored little sediment owing to an upstream bedrock constriction of the river channel that prevented sediment deposition (Bureau of Reclamation, 2001b).

Although these previous studies provide some estimates of the sediment supplied to the study area from the upper basin (as much as 76,000 m^3/yr at the Savage Rapids Dam) and ongoing sediment accumulation of 17,700 m^3/yr at the Lost Creek Reservoir, we did not find any studies that estimated or measured bed-material flux in the lower Rogue River or in the Applegate and Illinois River basins. In particular, a better understanding of the volumes of bed-material transported on an annual basis by the Applegate and Illinois Rivers draining the gravel-rich Klamath Mountains would be important component for quantifying bed-material transport in the Rogue River basin.

Klingeman and others (1993) assessed the effects of motorized tour boats on river bank erosion and channel bed conditions on the Rogue River between its confluences with the Applegate River and Grave Creek (fig. 1), an area known as the Hellgate Recreation Section. Their report describes bank conditions in the Hellgate Recreation Section and for the Rogue River between Grants Pass and the mouth of the Applegate River as well as changes in channel position near Brushy Chutes (fig. 8). In the Hellgate Recreation Section, 5 percent of the total 86.4 km of stream banks showed signs of erosion, whereas the remaining 95 percent of the bank length was considered stable, with bedrock outcrops and stable alluvium lining the banks for 36.5 and 44.4 km, respectively (Klingeman and others, 1993). For Rogue River banks from Grants Pass to Applegate River, they noted that bank material was composed of bedrock in several locations, the channel was narrower with higher banks in the upstream portion of this segment, and bank undercutting and erosion was occurring beneath large trees and adjacent to boat ramps (Klingeman and others, 1993). Klingeman and others (1993) also reported that the channel in the Brushy Chutes area (fig. 8) had shifted more than 490 m in some locations from 1965 to 1991 and had ongoing bank erosion.

Klingeman (2003) builds upon the previous study and examines beach erosion at five sites in the Galice Reach between Blossom Bar (RKM 73) and Foster Bar (RKM 54.3) and one site in the Lobster Creek Reach within Copper Canyon (RKM 41 to 39) as well as bank conditions between Grave Creek (RKM 110.2) and Foster Bar. Klingeman reports that the shoreline between Grave Creek and Foster Bar consists primarily of bedrock and boulders with some gravel and sand near the water’s edge. Topographic surveys taken in summer 2001 and May 2002 showed that sand beaches near high-amplitude river bends experienced the most change (locally more than 0.9 m of lateral deposition). Substantial sediment deposition and reworking of the beach topography occurred at the sand beaches, indicating the strong influence of winter flows on beach topography. In contrast, the one coarse-gravel beach downstream of Brewery Hole Bar (RKM 55.9) remained relatively stable, likely owing to its coarse grain size, the over 100-m wide mainstem channel that permits flow dispersion, and the steep channel gradient. Overall, Klingeman (2003) concluded that winter flows are the primary control on erosion with boat operations, foot traffic, and wind being secondary factors.

As summarized by Peck and Park (2006), general watershed analyses by the U.S. Forest Service and others describe bed-material characteristics and channel conditions along the Rogue River from Brewery Hole near RKM 55.7 to its mouth and for several tributaries, including Shasta Cove, Quosatana, and Lobster Creeks. Upstream of Copper Canyon (RKM 41–39), approximately 0.8-km-wide alluvial sediment terraces have formed likely owing to Copper Canyon backing up flows from the Rogue and

Illinois Rivers during extreme flood events (fig. 11; Peck and Park, 2006). On the Rogue River between Agness (RKM 45.1) and its mouth, medial and channel flanking bars aggraded approximately 1.8 m as a result of the January 1997 flood (Peck and Park, 2006). Peck and Park also note interactions between sediment transport in the mainstem and tributaries. For instance, alluvial fans apparent at several tributary confluences (such as Tom East, Bill Moore, Silver, Kimball, Jim Hunt, and Quosatana Creeks) indicate that many of the high-gradient (4- to over 50-percent slope) tributaries in this section actively deliver sediment to the lower Rogue River (fig. 11; Peck and Park, 2006). On the basis of the summary provided by Peck and Park (2006), landslides and other slump-earthflows in these steep tributaries are likely substantial sediment sources to the Rogue River and may be enhanced by past timber harvesting and road construction practices in addition to the overarching geologic and climate controls. Lastly, a previous comparison of repeat aerial photographs from 1940, 1969, and 1997 indicates that the Rogue River has shifted position laterally from RKM 6 to 4.5, but has become increasingly stable and vegetated with large willows along its margin from RKM 2.5 to its mouth (Peck and Park, 2006).

Review of Gravel-Operator Information and Surveys

Reports including data on deposited and mined gravel volumes were provided for the Elephant Bar site by State agencies (Christy Leas, Oregon Department of State Lands, written commun., 2011; Alex Liverman, Oregon Department of Environmental Quality, written commun., 2011) and the Wedderburn Bar site by Tidewater Contractors, Inc. (Robert Elayer, Tidewater Contractors, Inc., written commun., 2010). Although these reports span the periods of 1985 to 2009 for Elephant Bar and 1994 to 2006 for Wedderburn Bar, our review of the reports yielded few estimates of deposited and mined volumes at these two sites (fig. 16). For instances where data are available, actual mined volumes were much less than permitted volumes. Annual mined volumes ranged from more than 4,000 to nearly 18,000 m^3 at Elephant Bar, for which the permitted volume was 31,000 m^3 (fig. 16). Likewise, at the Wedderburn site, mined volumes ranged from nearly 18,000 to more than 55,000 m^3, whereas the permitted volume was 76,000 m^3 (fig. 16). No deposition estimates were available for these sites except for the estimated deposition of 57,000 m^3/yr at Elephant Bar in 2005 and 2006 (Christy Leas, Oregon Department of State Lands, written commun., 2011).

Left: Gravel bar at the confluence of Lobster Creek and the Rogue River.

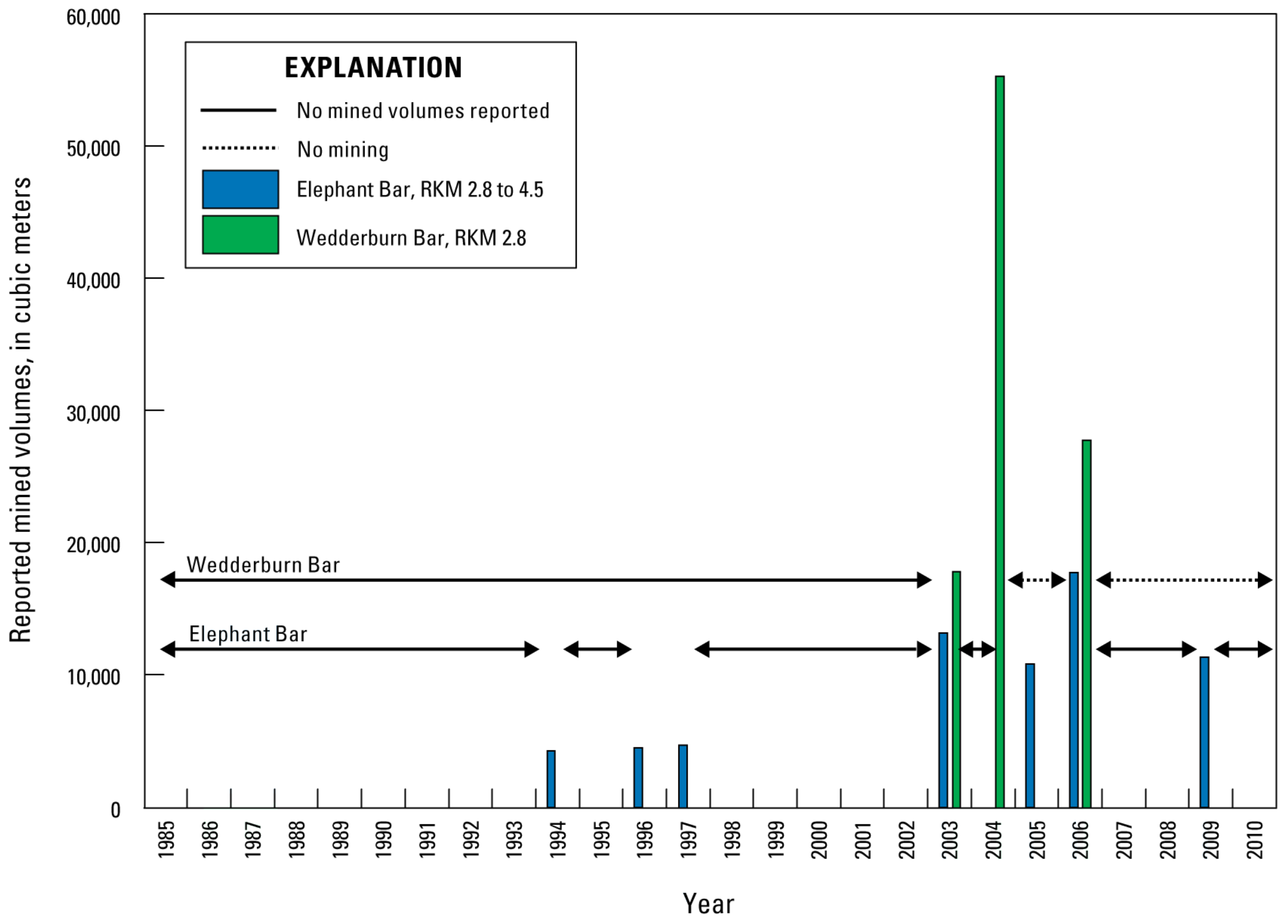


Figure 16. Graph showing partial volumes of gravel mined from 1985 to 2010 along the lower Rogue River, southwestern Oregon. Data for Wedderburn Bar were provided by Robert Elayer (Tidewater Contractors, Inc., written commun., 2010) and Elephant Bar by Christy Leas (Oregon Department of State Lands, written commun., 2011) and Alex Liverman (Oregon Department of Environmental Quality written commun., 2011).

Regulatory agencies permitting instream gravel mining in Oregon require the collection of topographic surveys before and after gravel removal at mining sites to document bar conditions and total removal volumes. A review of the surveys and site photographs taken from 1985 to 2009 at Elephant Bar and 1994 to 2006 at Wedderburn Bar tentatively indicate that the mining sites were subject to modest deposition in most years, with the deposition of bed-material rebuilding the bars substantially after higher flow events such as those in water years 1997 and 2006 (fig. 4C). These surveys, however, also indicate that the sites are dynamic and subject to local scour and deposition. Furthermore, repeat aerial photographs of the sites show that these bars have changed in size and shape since 1967 (see the “Delineation of Bar and Channel Features, 1967/69–2009” section). A more detailed analysis of the survey data would enable a more quantitative assessment of bar replenishment and changes in bar morphology at the Elephant and Wedderburn Bars.

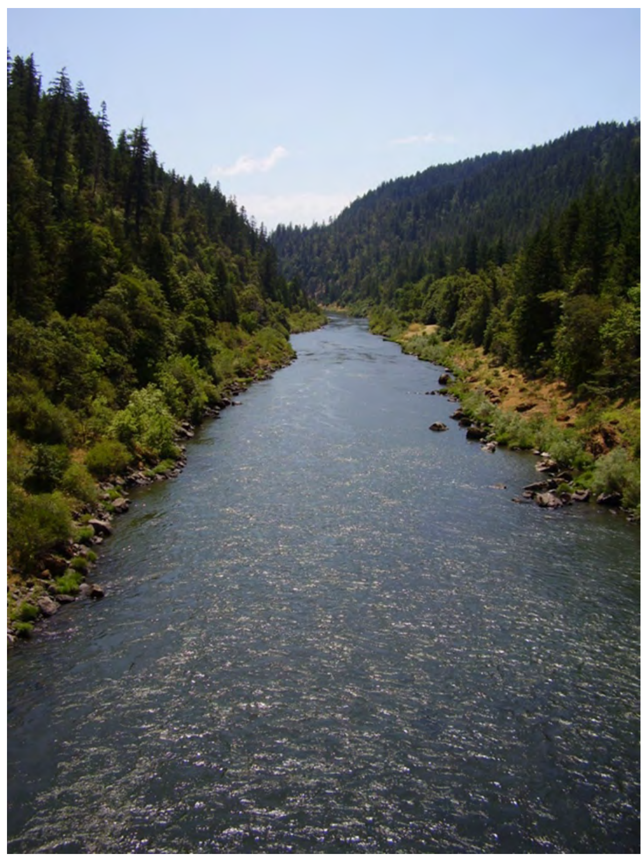
Specific Gage Analysis

Following the approach of Klingeman (1973), specific gage analyses were conducted for five USGS streamflow-gaging stations within or in close proximity to the Rogue River study area (fig. 1; table 1). Gages included the mainstem Rogue River at Raygold near Central Point (approximately 24 km upstream of the study area, 14359000), the Rogue River at Grants Pass (RKM 164.5, 14361500), the Rogue River at Agness (RKM 47.6, 14372300), the Applegate River near Applegate (RKM 45.2, 14366000), and the Applegate River near Wilderville (RKM 12.7, 14369500).

The specific gage analysis enables detection of changes in streambed elevation by assessing changes in water elevation (stage) over time for specific discharge values. At USGS streamflow-gaging stations, discharge is related to stage by a stage–discharge rating curve, which is based on multiple, coupled stage and discharge measurements taken at a range of streamflows. New rating curves are developed if channel conditions change substantially (as shown by consistent offsets of newer measurements from established rating curves) or if a station is relocated. The specific gage analysis evaluates trends in downstream hydraulic control as indicated by the sequence of rating curves; hydraulic control, is in turn a function of bed elevation.

Because the purpose of this analysis was to detect potentially small changes in bed elevation, we assessed changes in stage for low to moderate flows (28.3–509.6 m^3/s on the Rogue River and 0.71–65.1 m^3/s on the Applegate River), which are more sensitive to minor adjustments in bed elevation and are less likely to be influenced by temporal changes in bank vegetation or bank shape. Gaging stations on the Rogue River at Raygold and at Grants Pass, as well as on the Applegate River near Wilderville, were moved at least once, requiring multiple datum shifts.

The specific gage analysis shows that stage has remained relatively stable, with fluctuations generally less than +/- 0.20 m, over the analysis period at the Raygold (fig. 17A), Agness (fig. 17C), and two Applegate gaging stations (fig. 17D–E). At the Raygold station (fig. 17A), initial decreases of about 0.10 m in low-flow stage from 1905 to 1907 were offset by subsequent increases from 1907 to 1927, resulting in net stage increases up to 0.10 m for each discharge from 1905 to 1927. In subsequent years, stage had a net decrease of less than 0.07 m from 1929 to 1956 and then a net increase of up to 0.14 m from 1956 to 2009, with most of that increase occurring from 1963 to 1965. At the Agness station, the downstream-most site on the Rogue River, stage had a net increase of at least 0.12 m for all evaluated discharges from 1960 to 2000.



Rogue River upstream of the USGS streamflow-gaging station at Agness, Oregon.

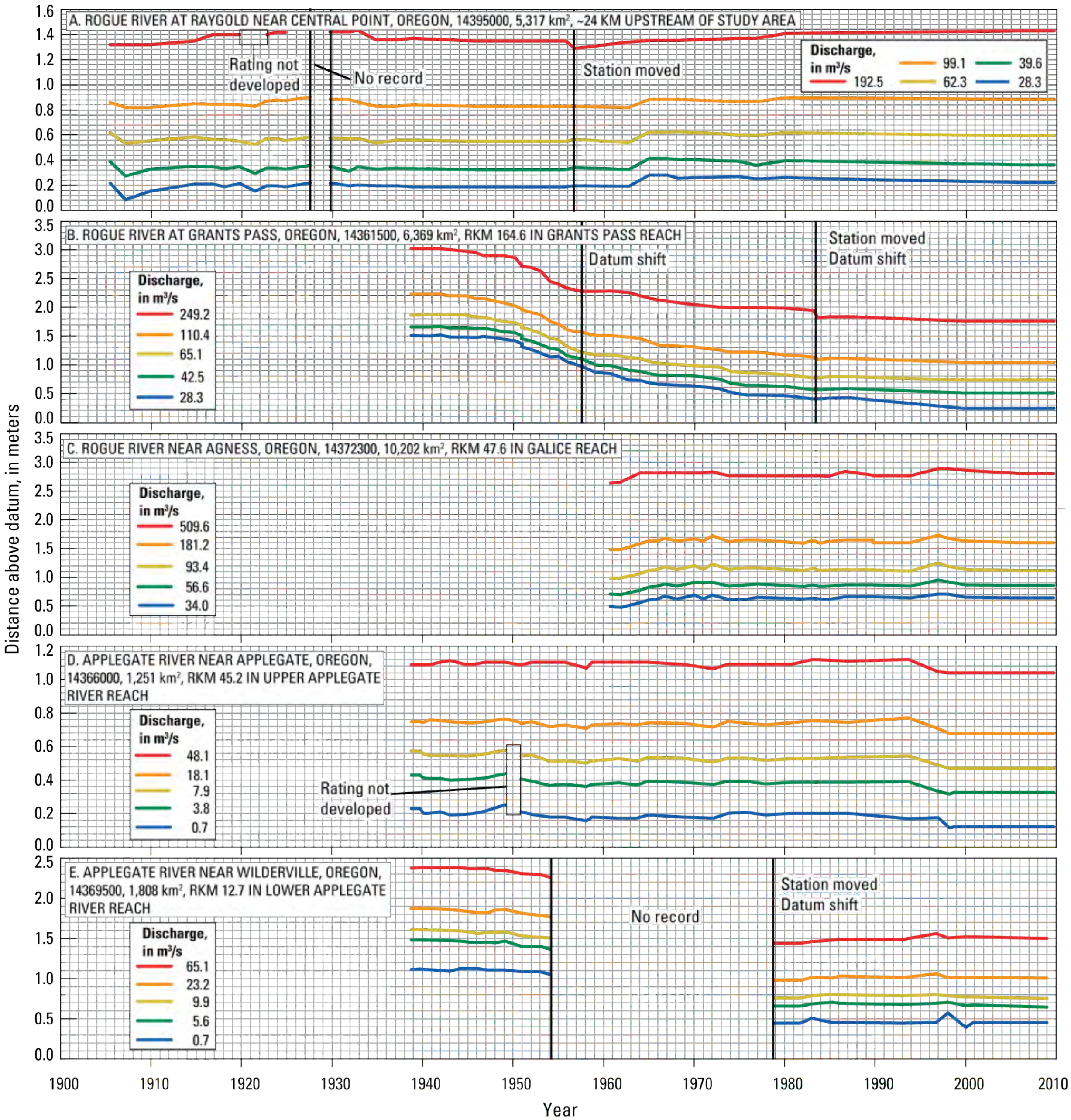


Figure 17. Graphs showing the stage-discharge rating-curve elements for specific discharges for select streamflow-gaging stations in the Rogue River basin, southwestern Oregon. The source data are station records housed at the U.S. Geological Survey, Portland, Oregon. Datum shifts have been accounted for in the plots. Discontinuities in the stage-discharge relationship between station moves are not related to channel change. Refer to figure 3 for dam closure dates.

Near the Applegate gage on the Applegate River (fig. 17D), stage increased as much as 0.07 m and declined as much as 0.11 m during the analysis period. Stage declined during the 1990s, resulting in a net lowering of water surface elevations of at least 0.05 m for the four higher flows from 1993 to 1998, and 0.06 m for the lowest flow from 1997 to 1998. Since 1998, stage has been stable for all flows in this analysis. Downstream on the Applegate River near the Wilderville gage, stage fluctuated less than 0.07 m between ratings while steadily lowering, resulting in net declines for all flows of at least 0.06 m from 1938 and 1955. From 1978 to 2009, stage varied by less than 0.18 m between ratings, resulting in a net decrease (approximately 0.01 m) in stage for flows of 5.6 and 9.9 m^3/s and a net increase (as much as 0.06 m) for the low and high flows of 0.71 and 65.1 m^3/s, respectively. From 1998 and 2000, stage fluctuated for all flows, with the maximum decrease (0.18 m) occurring at the lowest (0.71 m^3/s) flow.

Unlike the specific gage analyses for the other four USGS streamflow-gaging stations, the Grants Pass gaging station (14359000; RKM 164.4; Grants Pass Reach) on the Rogue River has exhibited a substantial reduction in stage for all five discharges and over the entire analysis period (fig. 17B). From 1939 to 1957, the stage of the river declined 0.46 m at low (28.3 m^3/s) flows and up to 0.69 m for relatively higher (249.2 m^3/s) flows, resulting in a datum shift in 1957. Since 1957, stage has continued to decline, as most evident for low (28.3 m^3/s) flows, during which stage declined 0.56 m from 1957 to 1983 (resulting in a station move and second datum shift) and then 0.17 m from 1983 to 2009.

Systematic stage reductions across all flows tend to result from either channel widening or incision (Klingeman, 1973). At the Grants Pass gaging station, the main factor inducing stage reductions is probably channel incision. A review of the repeat delineations of wetted channel width from 1967, 2005, and 2009 vertical photographs show that the wetted channel has narrowed more than 30 m at the Grants Pass site (fig. 18). This incision may have been caused by multiple factors, including historical and ongoing reductions in flow and sediment inputs by the upstream dams and the historical mining of the mainstem Rogue River and tributaries above the gaging station. As of the end of water year 2010, the sediment released in conjunction with the removal of the Gold Hill, Gold Ray, and Savage Rapids Dams has had no evident effect on the ratings for this station.

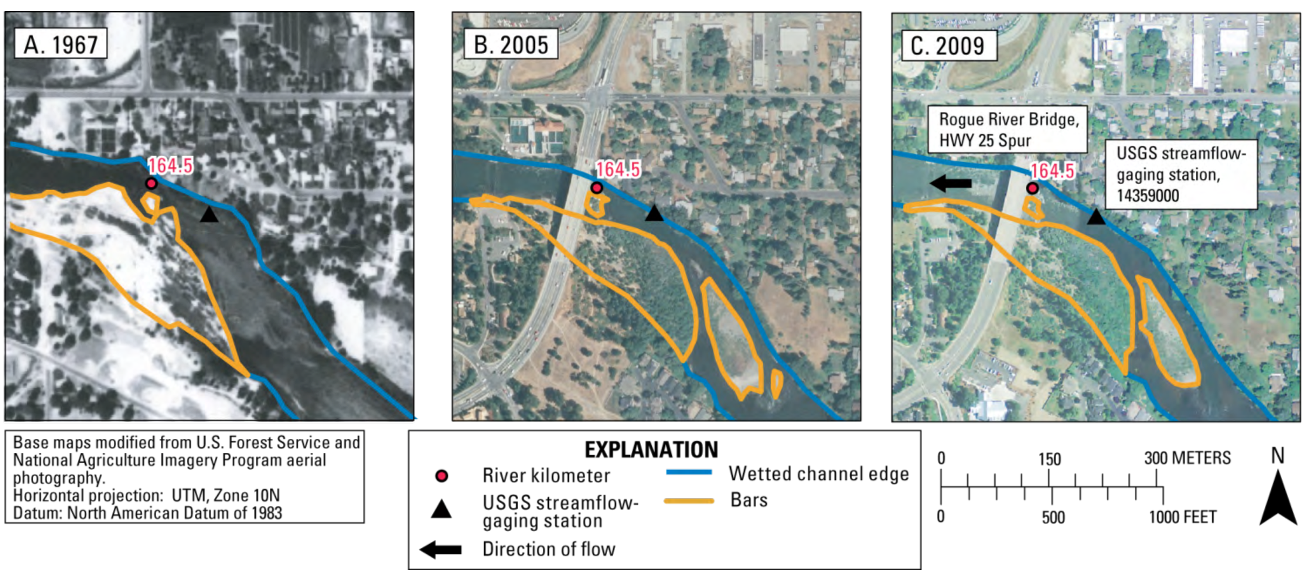


Figure 18. Images of the bars and wetted channel width as mapped from aerial and orthophotographs taken in 1967, 2005, and 2009 and near the U.S. Geological Survey streamflow-gaging station at Grants Pass, southwestern Oregon.

Compilation and Review of Bridge-Inspection Reports

The Oregon Department of Transportation (ODOT) conducts routine bridge inspections to assess overall bridge condition, footing stability, and scour. Information from these assessments can be useful for evaluating channel condition. Our assessment of the inspection reports for bridges within the study area focused primarily on comparing repeat channel cross sections and secondarily on reviewing supplemental data, including underwater reports, photographs, and scour assessments that are also helpful for assessing channel condition.

Fifteen public bridges cross the mainstem Rogue, Applegate, and Illinois Rivers within the study area. The ODOT bridge inspection database contains reports for the following 9 bridges, including 5 bridges on the Rogue River and 4 bridges on the Applegate River (Oregon Department of Transportation, written commun., 2010):

1. Rogue River at the Highway (Hwy) 25 Spur (RKM 164.5, fig. 7)
2. Rogue River at 7th Street (RKM 163.5, fig. 7)
3. Rogue River at 6th Street (RKM 163.4, fig. 7)
4. Rogue River at the Robertson Bridge (RKM 139.2, fig. 8)
5. Rogue River at the Patterson/Hwy 101 Bridge (RKM 1.3, fig. 12)
6. Applegate River at Hwy 272 in the town of Applegate (RKM 42.0, fig. 13)
7. Applegate River at Hwy 272 in the town of Murphy (RKM 21.6, fig. 14), and
8. Applegate River at Fish Hatchery Road (RKM 13.5, fig. 14)
9. Applegate River at Hwy 25 (RKM 4.6, fig. 14).

The ODOT database did not contain records for five additional bridges over the mainstem Rogue River, including the pedestrian bridge in Grants Pass (RKM 162.1; fig. 7) and the bridges at Hellgate Canyon (RKM 130.4; fig. 9), Grave Creek (RKM 110.1; fig. 9), Agness (RKM 49.3; fig. 9), and Lobster Creek (RKM 17.8; fig. 11) as well as the one bridge crossing the Illinois River (RKM 0.1; fig. 15).

Repeat channel cross sections are available for three bridges on the mainstem Rogue River. Using an estimate of thalweg elevation for the 2006 cross section and numerical values of thalweg elevation for the 2008 and 2010 cross sections, the thalweg of the Rogue River near the Hwy 25 Spur Bridge (RKM 164.5, Grants Pass Reach) incised 2.7 m from 2006 to 2008 and then aggraded 2 m from 2008 to 2010 (fig. 19A). From 2008 to 2010, the thalweg of the secondary channel also aggraded 0.6 m (fig. 19A). The estimated net lowering of the mainstem thalweg at this location was approximately 0.7 m from 2006 to 2010. Downstream at the Robertson Bridge in the Merlin Reach (RKM 139.2), the thalweg remained at approximately the same elevation but shifted its position slightly from 2006 to 2010 (fig. 19B). Additionally, the elevation of both banks aggraded approximately 0.8 m. On the Rogue River at the Patterson Bridge (Hwy 101) in the Tidal Reach (RKM 1.3), the thalweg aggraded a net 1.1 m and slightly shifted its position from 2000 to 2009 (fig. 19C). Overall, these cross-section surveys illustrate that the elevation of the Rogue River's thalweg is dynamic and subject to both aggradation and incision near these bridge crossings.

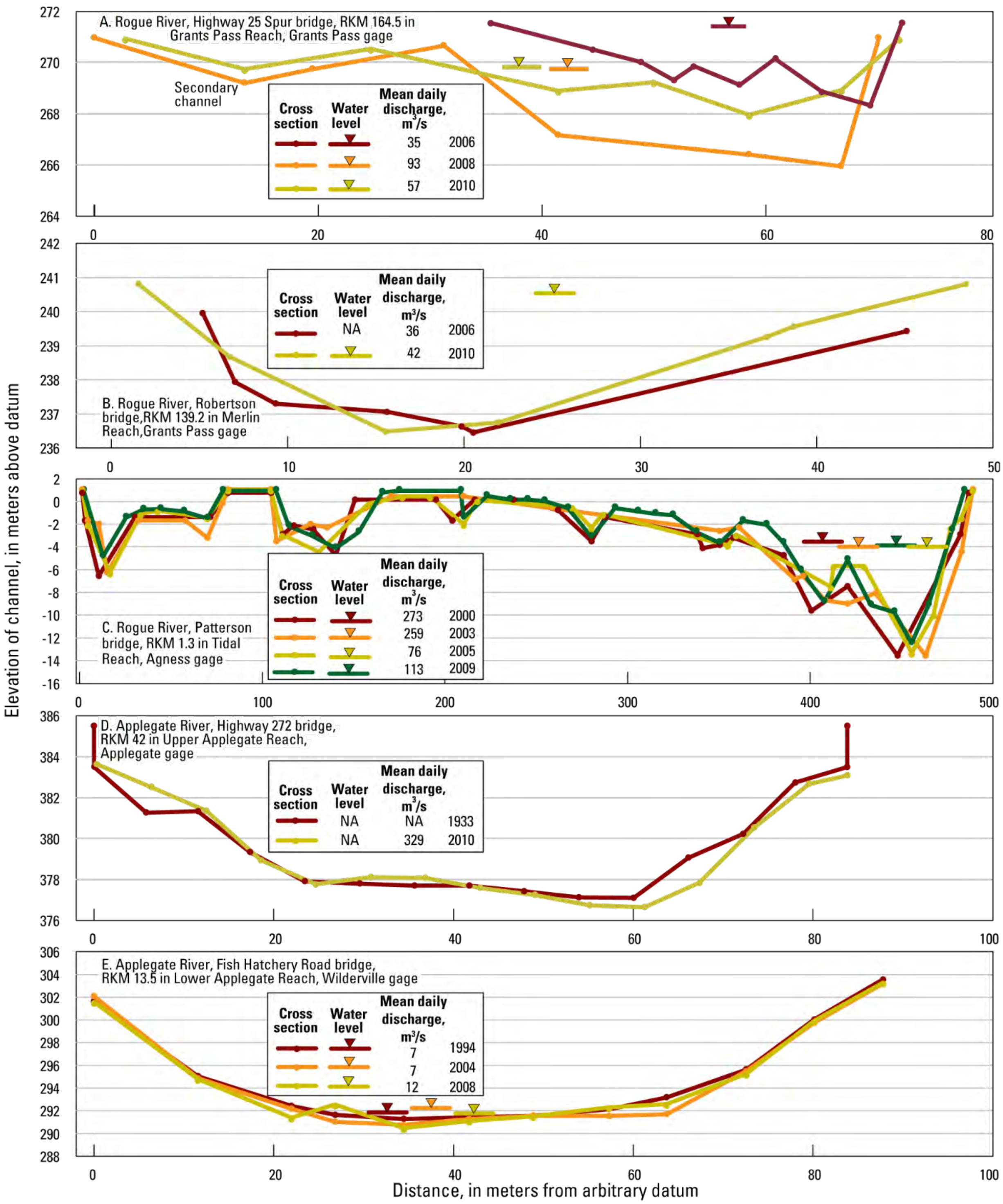


Figure 19. Graphs showing repeat channel cross sections (oriented downstream) of the Rogue River near the Highway 25 Spur, Robertson, and Patterson Bridges and the Applegate River near the Highway 272 and Fish Hatchery Road Bridges. The 2006 cross section in (A) was approximated from Oregon Department of Transportation cross-section diagrams. The 1939 cross section in (D) was derived from bridge plans. Mean daily discharge was derived from the Grants Pass gage for (A) and (B), Agness gage for (C), Applegate gage for (D), and Wilderville gage for (E).

In addition to the Rogue River bridge surveys, ODOT has measured channel cross sections at two bridge crossings along the Applegate River. The upstream cross section, located in the Upper Applegate River Reach at the Hwy 272 crossing (RKM 42), was surveyed in 1933 and 2010 (fig. 19D). Between the surveys, the low-flow channel widened and deepened by cutting 1.2 m into the toe of the right bank and 0.4 m into the thalweg while also aggrading 0.4 and 1.2 m near the toe and top, respectively, of the left bank. Downstream, near the Fish Hatchery Road bridge over the Applegate River (RKM 13.5), the channel incised (from 0.2 to 1.5 m) along the transect from 1994 to 2004 (fig. 19E). From 2004 to 2008, the channel aggraded up to 1.5 m in several locations but continued to downcut along the thalweg and on the left bank. The net reduction in thalweg elevation was 0.8 m from 1994 to 2008. Further investigation would be necessary to determine whether the bed lowering from 2004 to 2008 at this location is related to the winter 2005 capture of a floodplain gravel pit at RKM 5.3 (Frank Schnitzer, Oregon Department of Geology and Mineral Industries, written commun., 2010) or is simply representative of channel dynamism.

The bridge inspection reports also indicate some bank erosion, such as bank slumping and eroded bank protection, for all five Rogue River bridges with available assessments. Additionally, the inspections document the scour of the channel and bridge infrastructure at three Rogue River bridges. The Applegate River is also prone to scour as well as bank slumping, or "minor channel damage" (as stated in ODOT reports), at three of the four bridges with inspection reports. The report for the Robertson Bridge on the Rogue River (Merlin Reach) is the only report noting exposed bedrock and cemented gravel in the channel, whereas reports for the other bridges describe the channel bed material as primarily sand and gravel or note sand and gravel deposition near the structures.

In summary, the bridge inspection reports show that channels near the bridge crossings on the Rogue and Applegate Rivers are dynamic and subject to channel shifting, aggradation, and incision. The limited cross-section data reviewed in this study indicate that bed elevations changed substantially (defined here as more than 0.5 m of incision or aggradation) at the Hwy 25 Spur, Robertson, and Patterson Bridges over the Rogue River and the Murphy Hwy 272 and Fish Hatchery Road Bridges over the Applegate River.

Delineation of Bar and Channel Features, 1967/69–2009

For this reconnaissance-level study, we delineated:

- Bars and the channel centerlines for the study areas along the Rogue, Applegate, and Illinois Rivers from orthophotographs taken in 2009 (table 5) to develop a linear reference system for this study and to provide a baseline inventory of bar features, and
- Bars, channel centerlines, and wetted channel edges for sites within each study reach from vertical photographs taken in 1967 or 1969 (depending on availability; table 6), and 2005 (table 5) as well as wetted channel edges for these sites from vertical photographs taken in 2009 to assess temporal changes in the location and areal coverage of bars and length and wetted width of the channel. This mapping is referred to herein as "repeat delineation." The 1967 and 1969 photographs are hereinafter referred to as 1967/69 because they cover different parts of the basin and were used to assess bar and channel conditions in approximately the same timeframe.

For both efforts, bars greater than 300 m^2 in area were delineated from vertical photographs at a scale of 1:3,000 for all fluvial reaches and 1:10,000 for the Tidal Reach using the Geographic Information System (GIS) program ESRI ArcMap 9.3.1.

Scanned copies of black and white photographs taken in 1967 and 1969 were acquired from the University of Oregon Map Library and georectified using techniques similar to Wallick and others (2011). The quality of underlying photographs and error introduced by georectifying and digitizing processes are three of many potential sources of uncertainty in digital channel maps (Gurnell, 1997; Mount and Louis, 2005; Hughes and others, 2006; Walter and Tullos, 2009). Vertical photographs of the Rogue River study area were of sufficient resolution and generally free of glare and shadow to enable precise mapping. Each of the 1967 and 1969 photographs were georectified with a minimum of nine ground control points concentrated near the mainstem channel and a second order polynomial transformation. The total root mean square error (RMSE) values for each of the rectified photographs from 1967 and 1969 indicated that horizontal position uncertainties associated with the georectification process ranged from 1.08 to 5.90 m, but averaged 3.50 m for the 1967 photographs and 3.24 m for the 1969 photographs. Because control points were concentrated near the channel, error associated with mapped features along channel corridor is probably lower than the total RMSE for the entire photograph. Delineation of bars, channel centerlines, and wetted channel edges was repeatedly verified to ensure consistent delineation of features among years and throughout the study area following the protocol of Wallick and others (2011).

For the temporal assessment (1967/69–2009) of bar and channel changes, we identified eight sites for repeat bar and channel delineations:

1. Riverside Park (RKM 172.5–160.5, Grants Pass Reach; fig. 7)
2. Matson Park (RKM 149.5–138.4, Merlin Reach; fig. 8)
3. Foster Bar (RKM 66.5–53.9, Galice Reach; fig. 10)
4. Jennings Riffle (RKM 26.5–15.2, Lobster Creek Reach; fig. 11)
5. Elephant Rock (RKM 6.7–0, Tidal Reach; fig. 12)
6. Thompson Creek (RKM 49.5–41.6, Upper Applegate River Reach; fig. 13)
7. Williams Creek (RKM 41.6–28.5, Lower Applegate River Reach; fig. 14) and
8. Oak Flat (RKM 6.5–0, Illinois River Reach; fig. 15).

Streamflows varied among the years when the select photographs were taken (table 8). Generally, streamflows were highest when the 2009 photographs were taken and lowest when the 1967/69 photographs were taken on the Rogue and Illinois Rivers. For the two Applegate reaches, streamflows were generally highest in the 2005 photographs and lowest in the 1967 photographs.

Table 8. Stream discharge for the aerial photographs used for repeat bar and channel delineations in the Rogue River study area, southwestern Oregon.

[m^3/s, cubic meter per second]

Year	Repeat mapping site	Reach	Flight dates	Minimum discharge (m^3/s)	Maximum discharge (m^3/s)	Main discharge[1] (m^3/s)	USGS station used to determine discharge at time of collection
1967	Riverside Park	Grants Pass	7/22	35.4	35.4	35.4	Grants Pass (14361500)
	Matson Park	Merlin	7/27	32.0	32.0	32.0	Grants Pass (14361500)
	Thompson Creek	Upper Applegate River	7/22	2.5	2.5	2.5	Applegate (14366000)
	Williams Creek	Lower Applegate River	7/22	2.5	2.5	2.5	Applegate (14366000)[2]

Table 8. Stream discharge for the aerial photographs used for repeat bar and channel delineations in the Rogue River study area, southwestern Oregon—continued

[m^3/s, cubic meter per second]

Year	Repeat mapping site	Reach	Flight dates	Minimum discharge (m^3/s)	Maximum discharge (m^3/s)	Main discharge[1] (m^3/s)	USGS station used to determine discharge at time of collection
1969	Foster Bar	Galice	9/2, 3,	30.9	32.0	32.0	Agness (14372300)
	Jennings Riffle	Lobster Creek	8/25, 8/26; 9/3, 9/10	30.9	34.5	30.9–32.0	Agness (14372300)
	Elephant Rock	Tidal	8/25, 9/10	32.8	34.5	34.5	Agness (14372300)
	Oak Flat	Illinois River	9/2	0.9	0.9	0.9	Kerby (14377100)
2005	Riverside Park	Grants Pass	8/5	46.4	46.4	46.4	Grants Pass (14361500)
	Matson Park	Merlin	8/5	46.4	46.4	46.4	Grants Pass (14361500)
	Foster Bar	Galice	7/19, 8/5	57.5	68.2	57.5, 68.2	Agness (14372300)
	Jennings Riffle	Lobster Creek	7/17, 8/5	57.5	70.5	70.5	Agness (14372300)
	Elephant Rock	Tidal	7/17	70.5	70.5	70.5	Agness (14372300)
	Thompson Creek	Upper Applegate River	8/5	7.6	7.6	7.6	Applegate (14366000)
	Williams Creek	Lower Applegate River	8/5	7.8	7.8	7.8	Wilderville (143695000)
	Oak Flat	Illinois River	7/19, 8/5	1.1	2.8	1.1	Kerby (14377100)
2009	Riverside Park	Grants Pass	6/8	92.9	92.9	92.9	Grants Pass (14361500)
	Matson Park	Merlin	6/8	92.9	92.9	92.9	Grants Pass (14361500)
	Foster Bar	Galice	6/18	99.9	99.9	99.9	Agness (14372300)
	Jennings Riffle	Lobster Creek	6/17	102.8	102.8	102.8	Agness (14372300)
	Elephant Rock	Tidal	6/17	102.8	102.8	102.8	Agness (14372300)
	Thompson Creek	Upper Applegate River	6/7, 6/8	5.8	6.7	6.7	Applegate (14366000)
	Williams Creek	Lower Applegate River	6/8	7.3	7.3	7.3	Wilderville (143695000)
	Oak Flat	Illinois River	6/18	5.1	5.1	5.1	Kerby (14377100)

[1] Main discharge is the streamflow when the majority of the reach was photographed. Two discharge values are providedwhen areal coverages were approximately equal for photograph collection dates.

[2] Wilderville gage not operational.

Owing to the diversity of bar types in the entire Rogue River study area and the need for consistent and systematic mapping, we delineated all bar features within the active channel that the river has the potential to mobilize during high flows. Therefore, bars delineated by this study include a variety of geomorphic features such as (1) active and apparently unvegetated bars flanking the river channel, (2) more rarely inundated and mobilized flood bars with large boulders, and (3) apparently stable bars that have erosional and depositional feature as well as mature vegetation that appears similar to that on nearby floodplain surfaces.

Large, active, and apparently unvegetated gravel bars occur predominantly in the Lobster Creek, Tidal, and Illinois River Reaches (fig. 11, 12, and 15), whereas smaller flood bars consisting of gravel and sand are more common in the

Galice Reach (fig. 9). Floodplain bars form mostly in the Grants Pass (fig. 7), Merlin (fig. 8), Galice (fig. 9), and two Applegate River reaches (fig. 13 and 14). The delineation of bar features in the Lower Applegate River Reach (fig. 14) was especially challenging because of substantial lateral channel migrations (for instance, up to 480 m near RKM 35.8 from 1967 to 2009), resulting in large vegetated bars that are likely remnant floodplain surfaces contained within the active channel. Although field observations and particle measurements indicate that particle texture varies between bars within the study area (see the “Analyses of Bed-material Particle Sizes” section), bars delineated for each set of vertical photographs were not classified by particle size for this reconnaissance-level study.

The bar area measurements and the resulting discussion of trends presented in this report are preliminary. Throughout the study area, the identification and delineation of bar features was difficult owing to a variety of issues, such as distinguishing between gravel bars and bedrock outcrops that are covered by a thin veneer of fluvial sediments, remnant floodplain surfaces located within the active channel and within active deposition areas (such as on the Applegate River), and bar features that are mosaics of features such as active deposition zones, mature vegetation, scour swales, and rocky or floodplain areas (see “Outstanding Issues and Possible Approaches” for further discussion). Because the bars delineated for this reconnaissance-level study include recently deposited bars and more vegetated and relatively stable bar surfaces, these results likely overestimate the area of active gravel bar surfaces in the Rogue River study area. The wider mosaic of bar types delineated in this study, however, may better reflect the area of stored sediment that is available for future erosion and transport in the Rogue River study area across a range of flow events.

Distribution and Area of Bars

In 2009, the total area of bars delineated in the approximately 242-km-long study area encompassing portions of the Rogue, Applegate, and Illinois Rivers was 10,563,000 m^2. Unit bar area in 2009, or the area of bars per meter of channel (square meters per meter, m^2/m), was 43.8 m^2/m for the entire study area and 35.0 m^2/m for the combined fluvial reaches upstream from the head of tide. The Tidal Reach contained the greatest unit bar area for an individual reach (348.7 m^2/m; fig. 20; table 9). In the fluvial reaches, unit bar area ranged from 4.3 m^2/m in the Upper Applegate River Reach to 91.8 m^2/m in the Illinois River Reach (table 9).

Particles covering Nancy Creek Bar on the Illinois River.

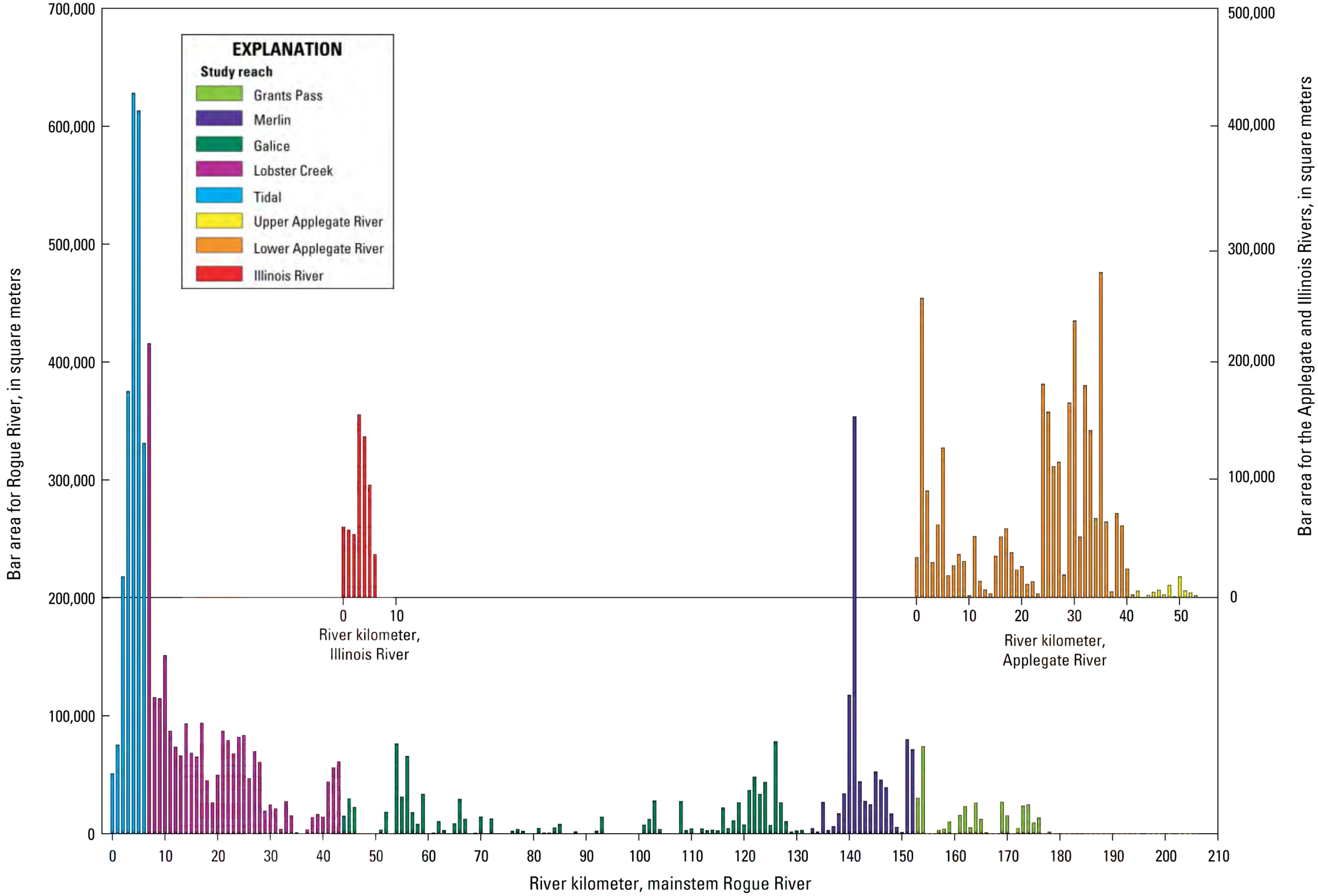


Figure 20. Graph showing bar area by river kilometer, as delineated from the 2009 orthophotographs for the study reaches on the Rogue, Applegate, and Illinois Rivers, southwestern Oregon.

Table 9. Bar area, channel centerline, and unit bar area by reach as delineated from 2009 orthophotographs for reaches in the Rogue River study area, southwestern Oregon.

[m^2, square meter, m, meter; m^2/m, square meter of bar per meter of channel]

Reach	Bar area (m^2)	Centerline length (m)	Unit bar area (m^2/m)
Grants Pass	325,000	25,400	12.8
Merlin	980,000	20,300	48.3
Galice	937,000	88,800	10.6
Lobster Creek	2,348,000	37,200	63.1
Tidal	2,336,000	6,700	348.7
Upper Applegate River	65,000	15,000	4.3
Lower Applegate River	2,974,000	41,600	71.5
Illinois River	597,000	6,500	91.8
Entire study area	10,563,000	241,400	43.8
Fluvial reaches	8,226,000	234,800	35.0

Values for reach-specific unit bar area in the Rogue River study area generally exceeded the 5.0–17.6 m^2/m reported for fluvial reaches in the similar-sized but bedrock-dominated Umpqua River basin (Wallick and others, 2011; mapped from 2005 photographs). The range of unit bar area values for some fluvial reaches in the Rogue River study area, however, were comparable to the range (9.3 to 77.5 m^2/m) reported for the Chetco River (Wallick and others, 2010; mapped from 2005 photographs). Differences in unit bar area between the Chetco and Rogue Rivers would likely be greater if only unvegetated and active gravel bars were mapped on the Rogue River, as was done for the Chetco River.

An examination of the distribution of bars delineated from the 2009 photographs shows that the location, abundance, and size of bars in the Rogue River study area are mainly dictated by interrelated factors such as the locations of gravel-rich tributaries, channel slope (fig. 2A–D), valley physiography, and the associated increase in valley width as the river approaches its mouth (fig. 20). As shown in table 9 and fig. 20, the areal coverage of bars is less in the confined Grants Pass (fig. 7), Galice (fig. 9), and Upper Applegate (fig. 13) Reaches as well as confined segments such as RKM 149–150 and RKM 135–132.7 in the Merlin Reach (fig. 8), and in Copper Canyon from RKM 35 to 37 in the Lobster Creek Reach (fig. 11). Conversely, the largest bars are located in the Lobster Creek (fig. 11), Tidal (fig. 12), Lower Applegate River (fig. 14), and Illinois River (fig. 15) Reaches, as well as in short, unconfined segments in the other reaches, such as the Brushy Chutes area in the Merlin Reach (fig. 8).

The distribution of bars also indicates key sources of gravel to the Rogue River. The high frequencies of bars along the Lower Applegate River Reach and in the several kilometers downstream of the Applegate River in the mainstem Merlin Reach are evidence of substantial gravel inputs entering the Rogue River from the Applegate River. Likewise, the Illinois River is a substantial source of bed material to the Rogue River, based on the numerous and extensive bar areas along the lower Illinois River and downstream Lobster Creek Reach on the Rogue River. Extensive gravel production from the Applegate and Illinois Rivers is consistent with their situation as high-relief basins draining the Klamath Mountains geologic province (fig. 1).

The Tidal Reach has by far the greatest areal coverage of bars. Extensive bar formations within this reach (and perhaps to some extent in the Lobster Creek Reach) reflect Holocene aggradation of the Rogue River valley bottom as a consequence of sea-level rise and concomitant reduction in channel slope (table 2). The lower slope reduces transport capacity and, thereby, induces the deposition of bed material that has been transported from the steeper, confined reaches upstream and promotes channel aggradation. Nonetheless, the absence of an extensive tidal reach indicates that the bed-material transported by the Rogue River has been sufficient to keep up with Holocene sea-level rise. In this respect, the Rogue River is similar to the Chetco River (Wallick and others, 2010), but contrasts markedly with the Umpqua River, which is tidally affected for 40 km upstream from its mouth (Wallick and others, 2011).

Results for Repeat Bar Delineation, 1967/69–2009

From 1967/69 to 2009, the mapped sites (representing about 32 percent of the total study area) had an overall loss in bar area of about 16 percent (table 10). For the fluvial reaches, the loss over this period was 27 percent. Bar loss resulted in part from a decrease in the number of bars but chiefly from bars becoming smaller (fig. 21A–fig. 29; table 10 and 11). The sites with the greatest bar loss (in terms of percent area) were the Thompson Creek (Upper Applegate River Reach; fig. 27) and the Riverside Park (Grants Pass Reach; fig. 22) sites. Bar area remained stable in the Williams Creek site (Lower Applegate River Reach; fig. 28) and increased 11 percent in the tidal Elephant Rock site (Tidal Reach; fig. 26).

Rogue River at Hog Eddy in the Galice Reach.

Table 10. Repeat bar attribute data as delineated from vertical photographs taken in 1967/69, 2005, and 2009 for repeat mapping sites in the Rogue River study area, southwestern Oregon

[RKM, river kilometer; m^2, square meter; %, percent]

Site information			Total bar area (m^2)				Number of bars				Average bar area (m^2)			
River	Site (Reach)	RKM	1967/69	2005	2009	Net change (%)	1967/69	2005	2009	Net change (%)	1967/69	2005	2009	Net change (%)
Rogue	Riverside Park (Grants Pass)	172–160	250,920	127,920	125,850	-50	26	20	16	-38	9,650	6,550	8,220	-15
	Matson Park (Merlin)	149.5–138.4	1,234,020	810,320	778,100	-37	20	33	28	40	61,700	24,570	27,790	-55
	Foster Bar (Galice)	66.5–53.9	433,980	291,880	272,110	-37	39	41	33	-15	11,130	7,780	8,990	-19
	Jennings Riffle (Lobster Creek)	26.5–15.2	1,191,830	767,400	754,260	-37	41	50	40	-2	34,050	21,320	27,980	-18
	Elephant Rock (Tidal)	6.7– 0	2,100,470	2,222,770	2,336,570	11	6	15	13	117	350,080	149,510	168,310	-52
Applegate	Thompson Creek (Upper Applegate River)	49.5–41.6	111,640	41,950	34,590	-69	27	18	14	-48	4,130	2,370	2,470	-40
	Williams Creek (Lower Applegate River)	41.6–28.5	1,352,590	1,325,580	1,348,040	0	41	54	56	37	32,990	23,680	24,510	-26
Illinois	Oak Flat (Illinois River)	6.5–0	760,920	621,040	595,600	-22	23	17	19	-17	33,080	36,530	31,350	-5
Total from all repeat mapping sites			7,436,380	6,208,850	6,245,110	-16	223	248	219	-2	33,350	25,040	28,520	-14
Total from repeat mapping sites in the fluvial reaches			5,335,900	3,986,080	3,908,540	-27	217	233	206	-5	24,590	17,110	18,970	-23

Table 11. Repeat unit bar area as delineated from vertical photographs taken in 1967/69, 2005, and 2009 for the repeat mapping sites in the Rogue River study area, southwestern Oregon.

[RKM, river kilometer; m^2, square meter; %, percent]

Site information				Unit bar area (m^2/m)			
River	Site	Reach	RKM	1967/69	2005	2009	Net change (%)
Rogue	Riverside Park	Grants Pass	172–160	20.8	10.6	10.4	-50
	Matson Park	Merlin	149.5–138.4	111.2	72.2	69.5	-38
	Foster Bar	Galice	66.5–53.9	34.6	23.2	21.6	-37
	Jennings Riffle	Lobster Creek	26.5–15.2	105.5	67.7	67.1	-36
	Elephant Rock	Tidal	6.7–0	319.3	334.3	350.8	10
Applegate	Thompson Creek	Upper Applegate River	49.5–41.6	14.2	5.3	4.4	-69
	Williams Creek	Lower Applegate River	41.6–28.5	102.1	101.0	102.6	1
Illinois	Oak Flat	Illinois River	6.5–0	114.8	95.8	91.2	-20
	Total from all repeat mapping sites			822.4	710.1	717.7	-13
	Total from repeat mapping sites in fluvial reaches			503.1	375.8	366.9	-27

Ferry Hole Bar on the Rogue River near the boundary of the Lobster Creek and Tidal Reaches.

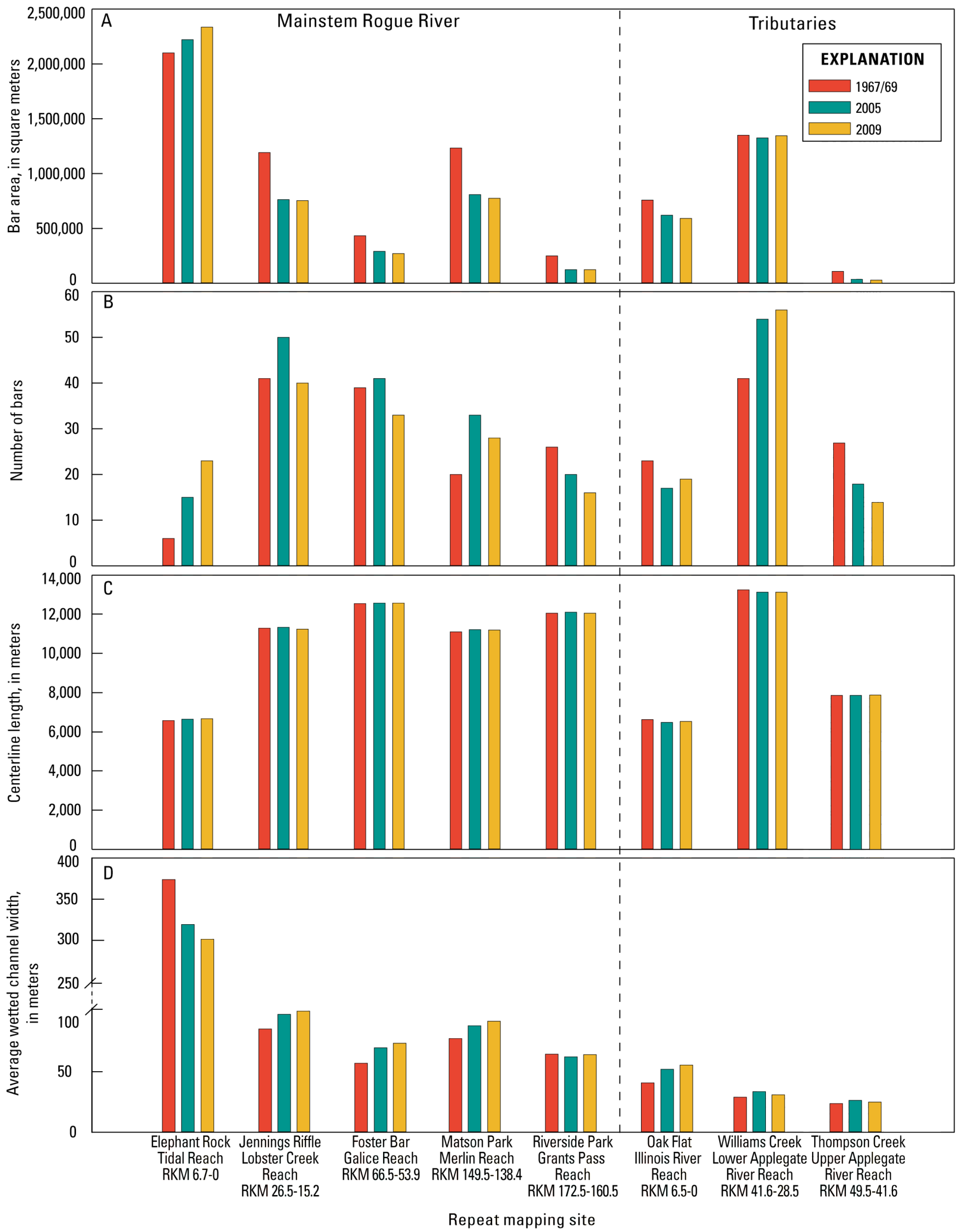


Figure 21. Graphs showing the results for bar area, bar number, channel centerline length, and average wetted channel width as delineated from photographs taken in 1967/69, 2005, and 2009 for repeat mapping sites in the Rogue River study area, southwestern Oregon.

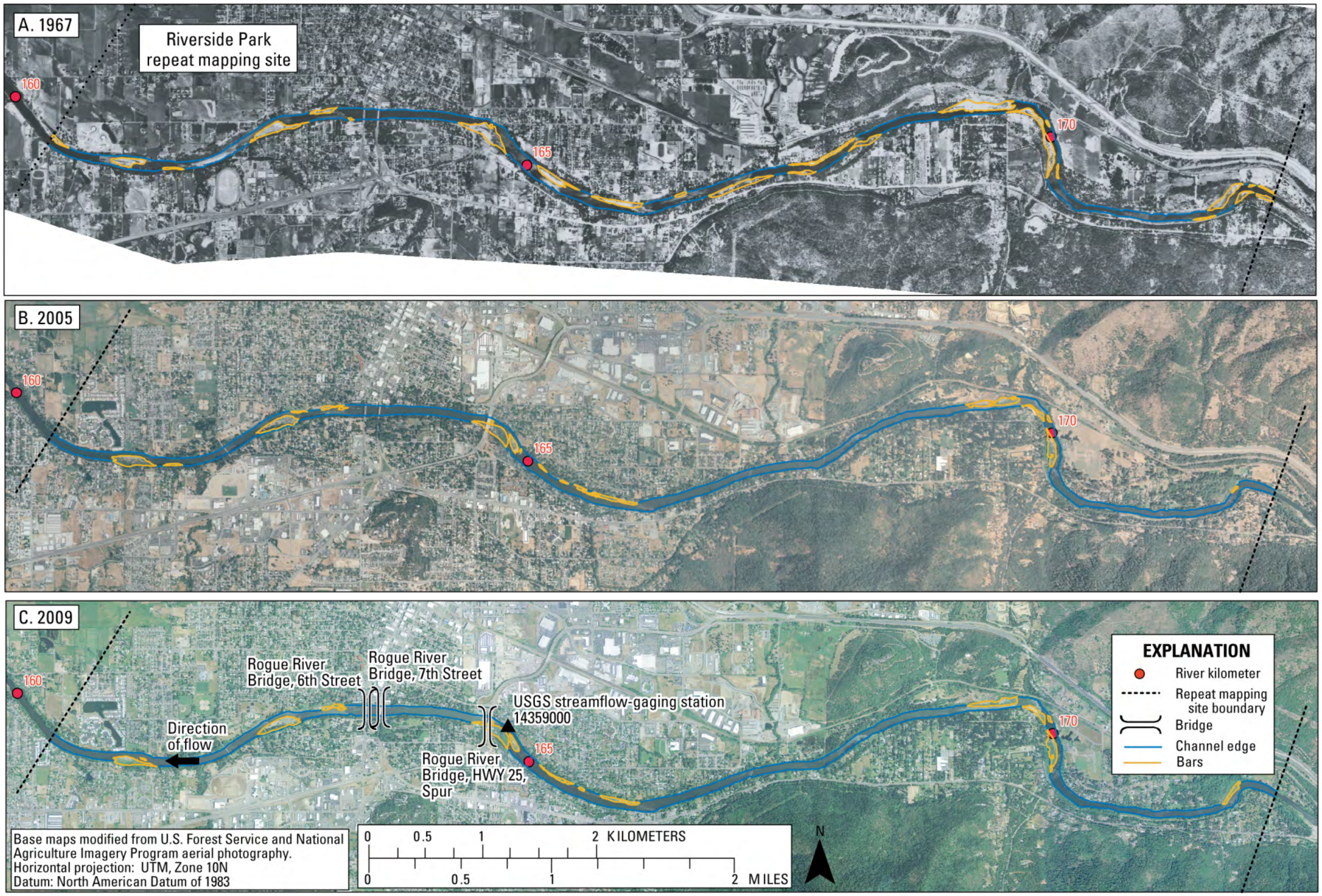


Figure 22. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1967, 2005, and 2009 for the Riverside Park site in the Grants Pass Reach on the Rogue River, southwestern Oregon.

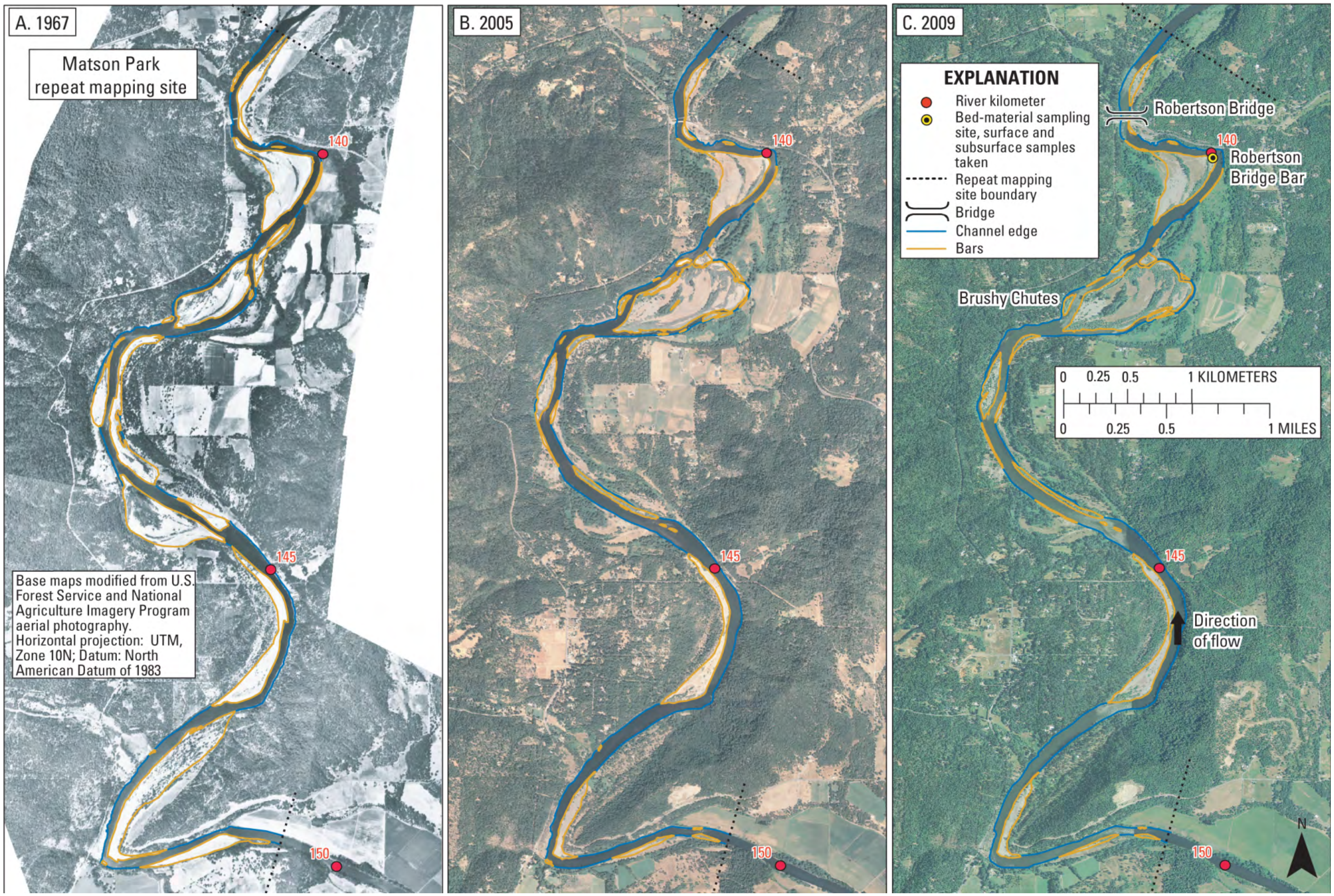


Figure 23. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1967, 2005, and 2009 for the Matson Park site in the Merlin Reach on the Rogue River, southwestern Oregon.

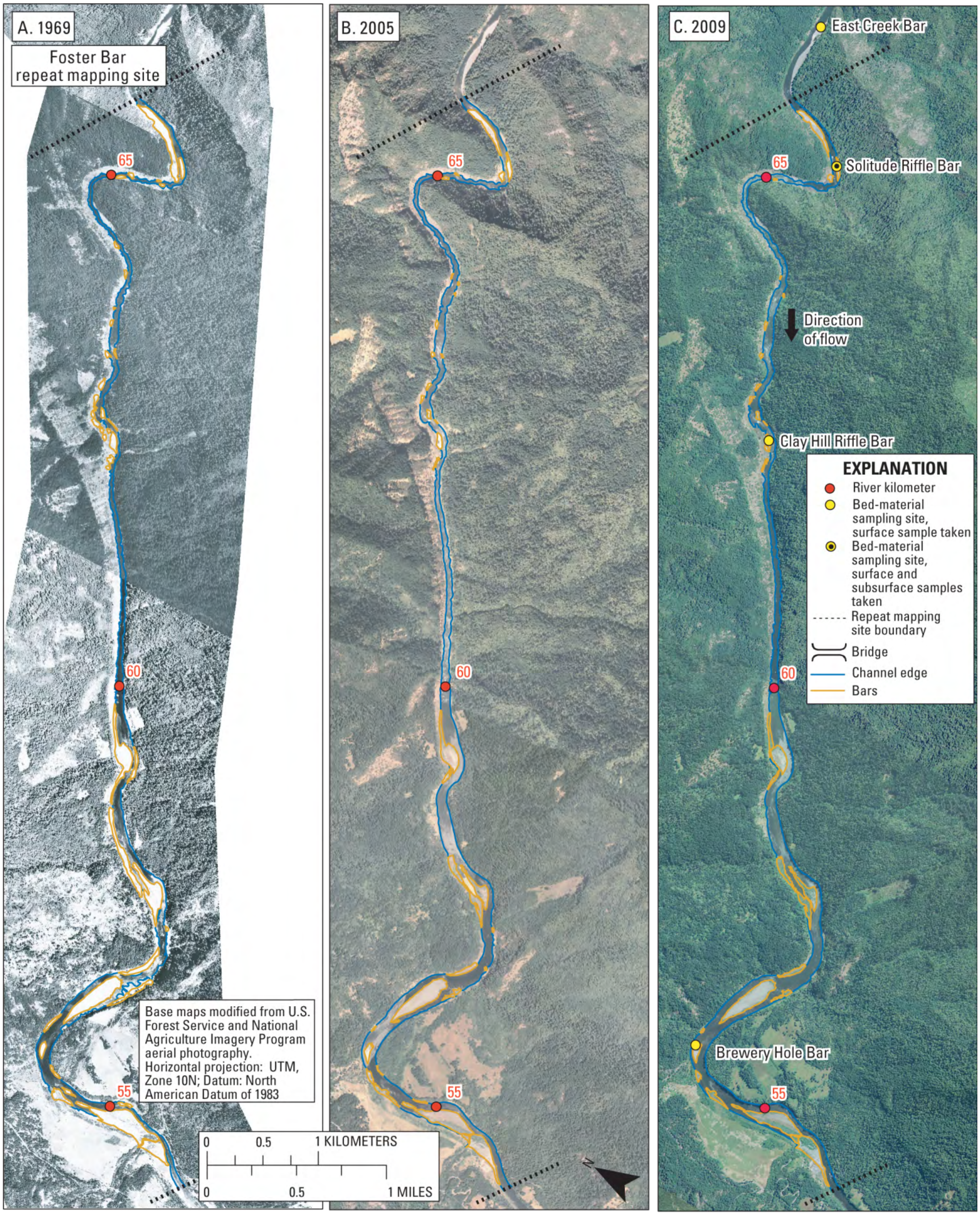


Figure 24. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1969, 2005, and 2009 for the Foster Bar site in the Galice Reach on the Rogue River, southwestern Oregon.

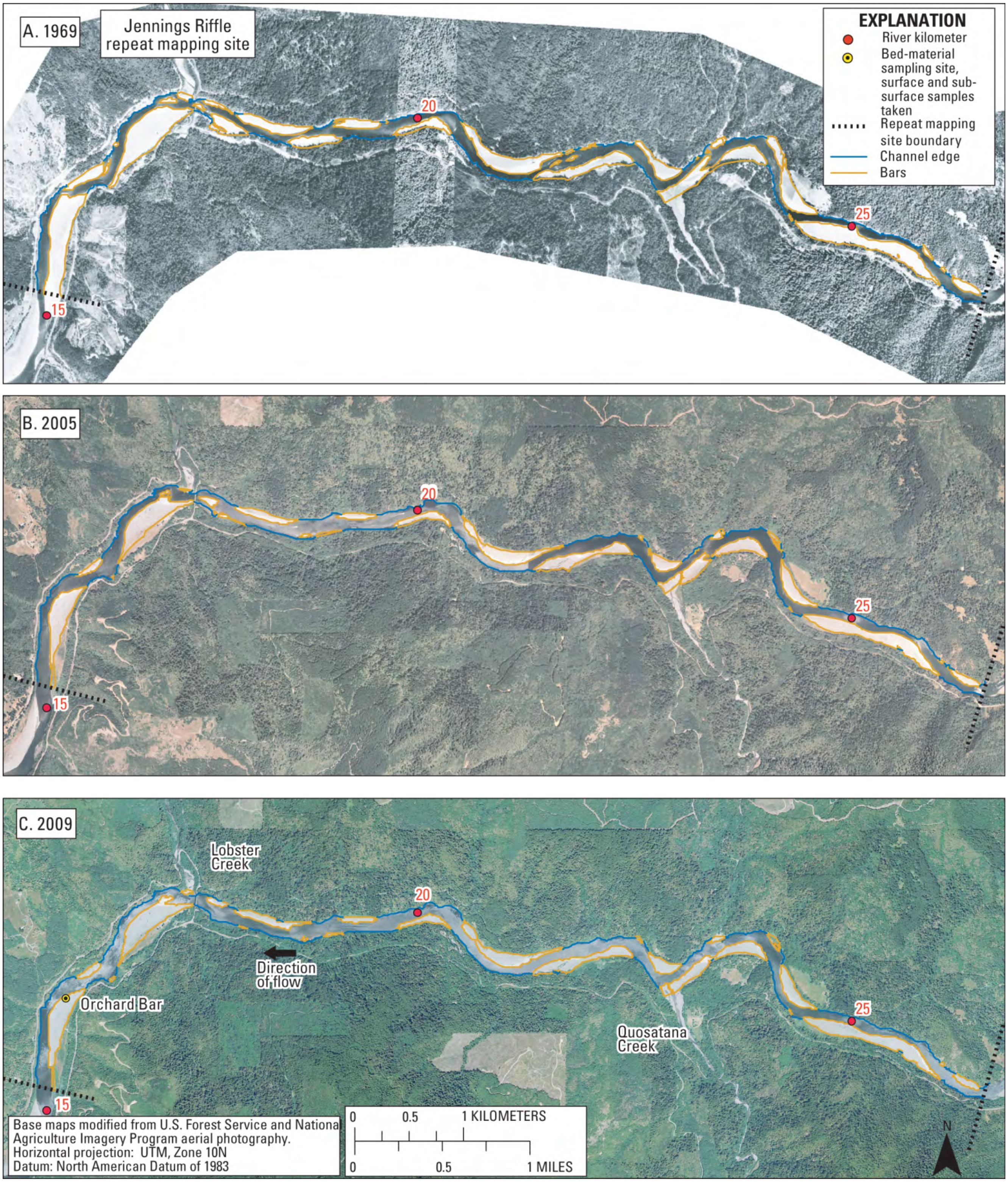


Figure 25. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1969, 2005, and 2009 for the Jennings Riffle site in the Lobster Creek Reach on the Rogue River, southwestern Oregon.

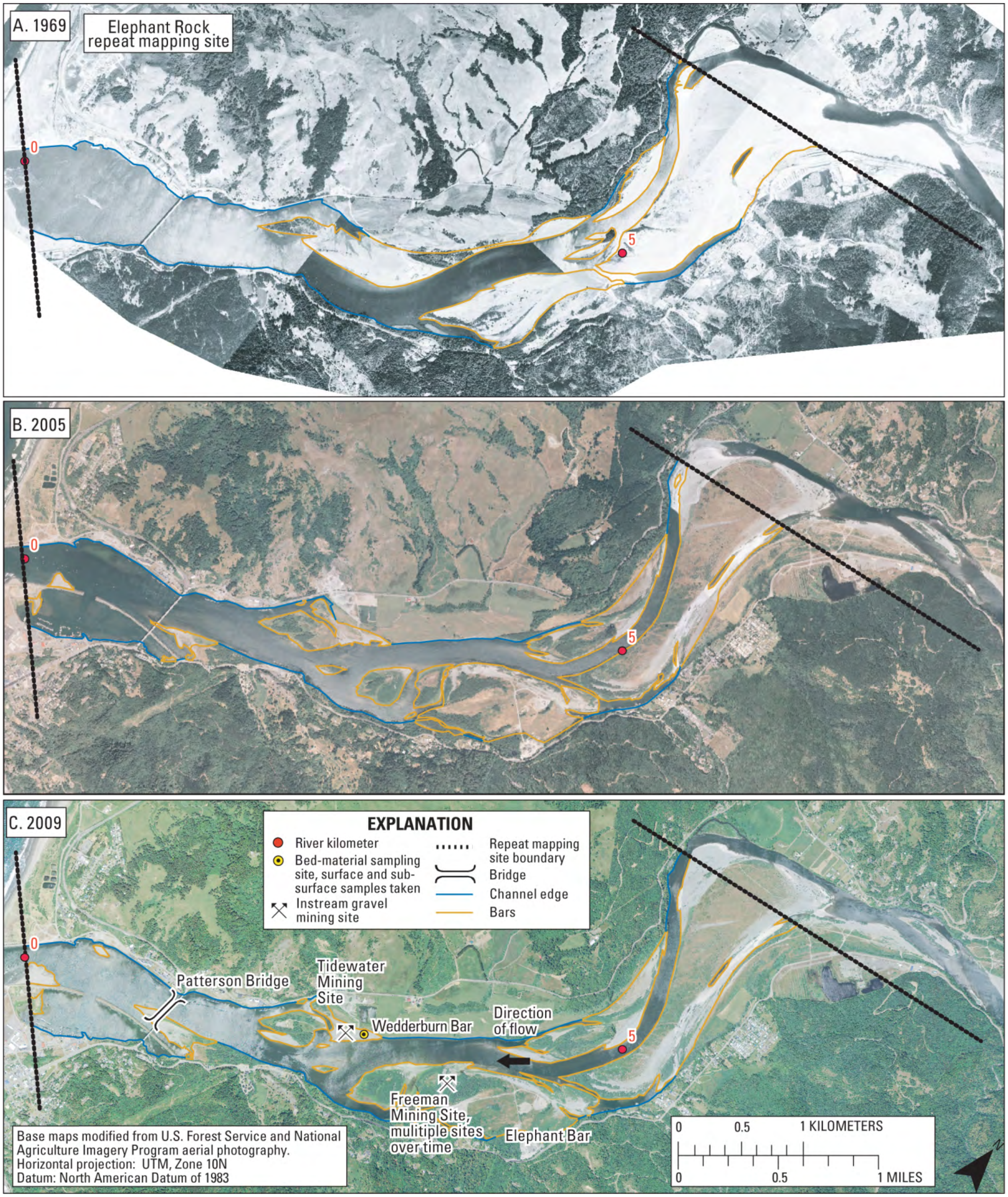


Figure 26. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1969, 2005, and 2009 for the Elephant Rock site in Tidal Reach on the Rogue River, southwestern Oregon.

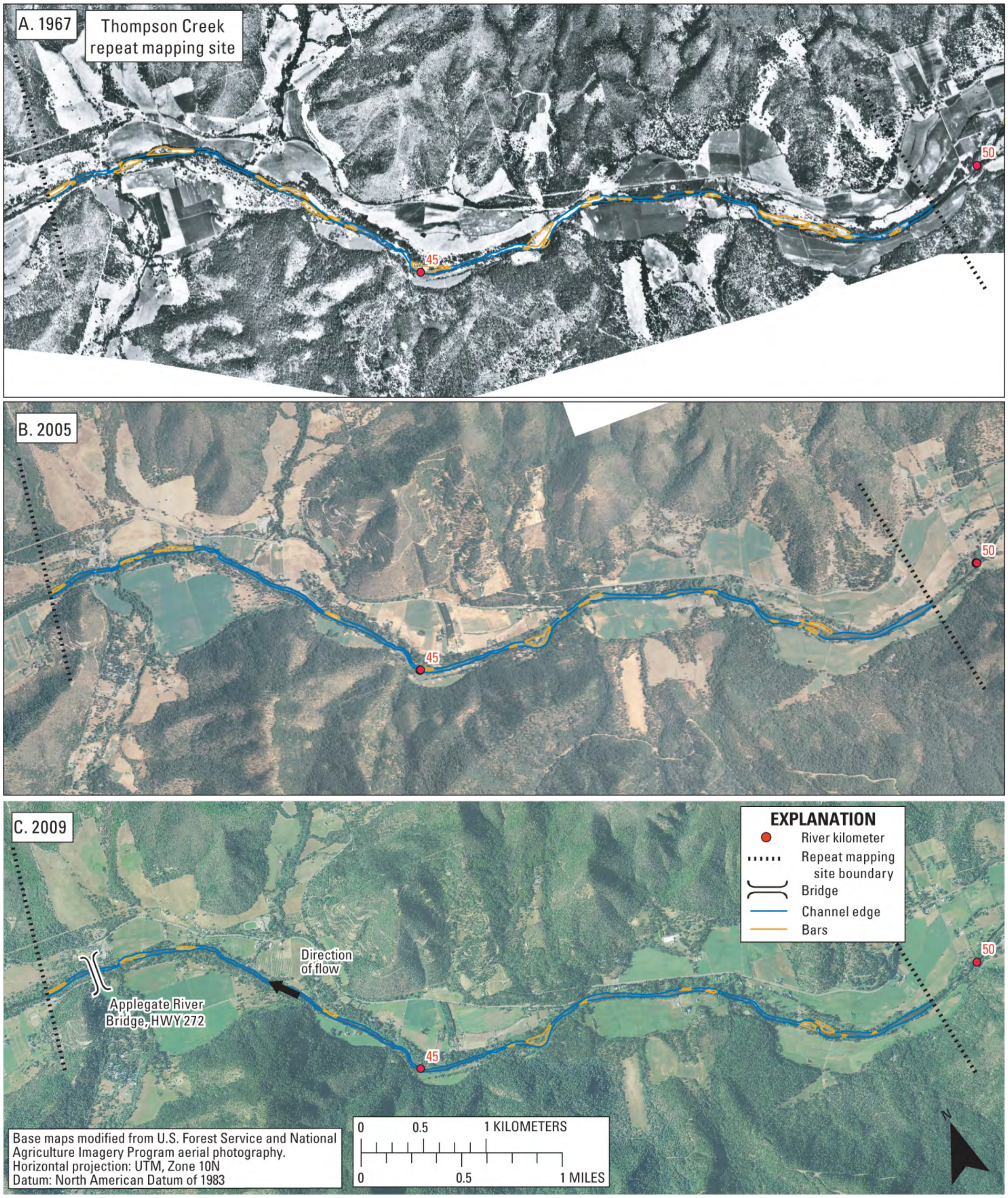


Figure 27. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1967, 2005, and 2009 for the Thompson Creek site in the Upper Applegate River Reach on the Applegate River, southwestern Oregon.

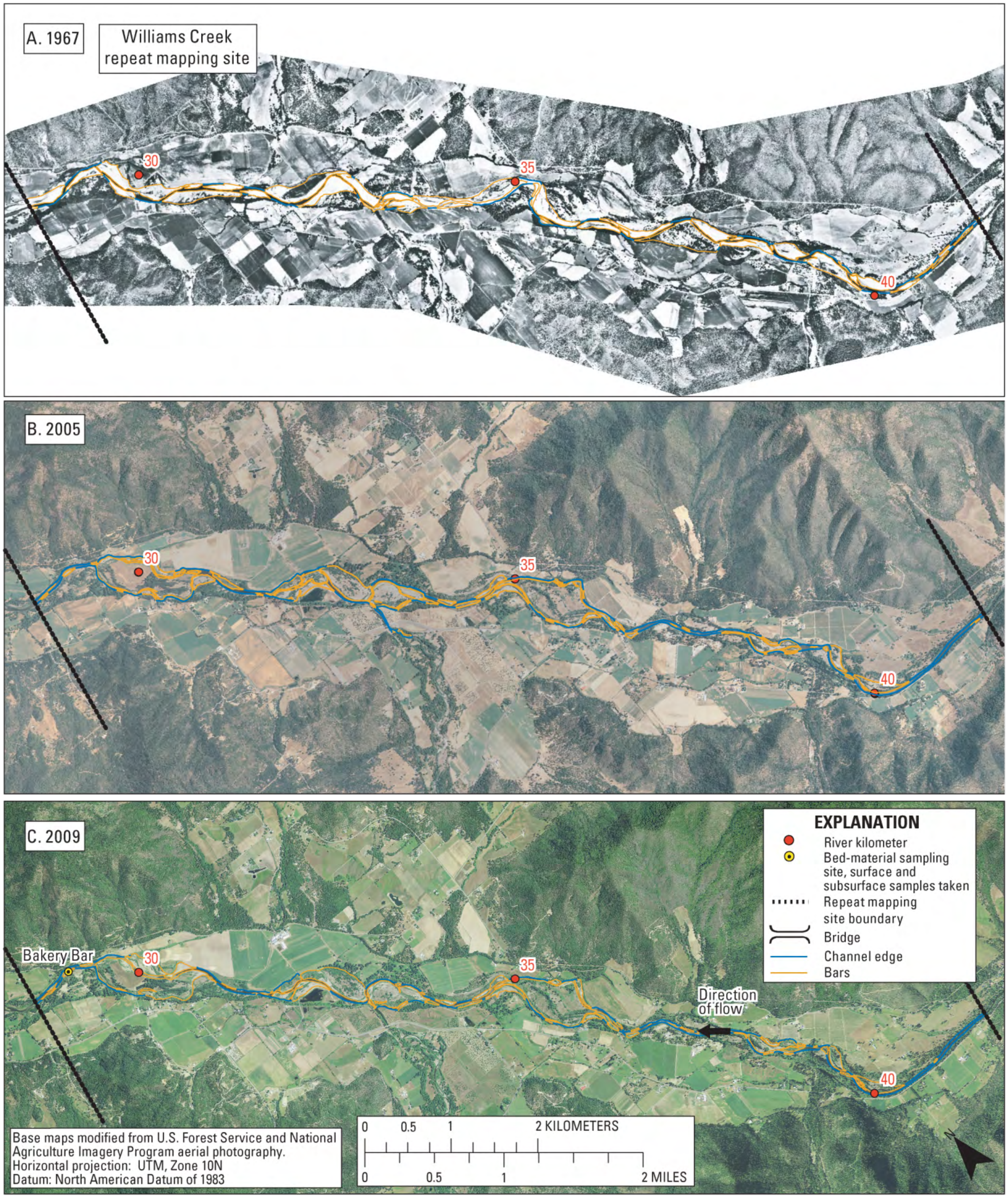


Figure 28. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1967, 2005, and 2009 for the Williams Creek site in the Lower Applegate River Reach on the Applegate River, southwestern Oregon.

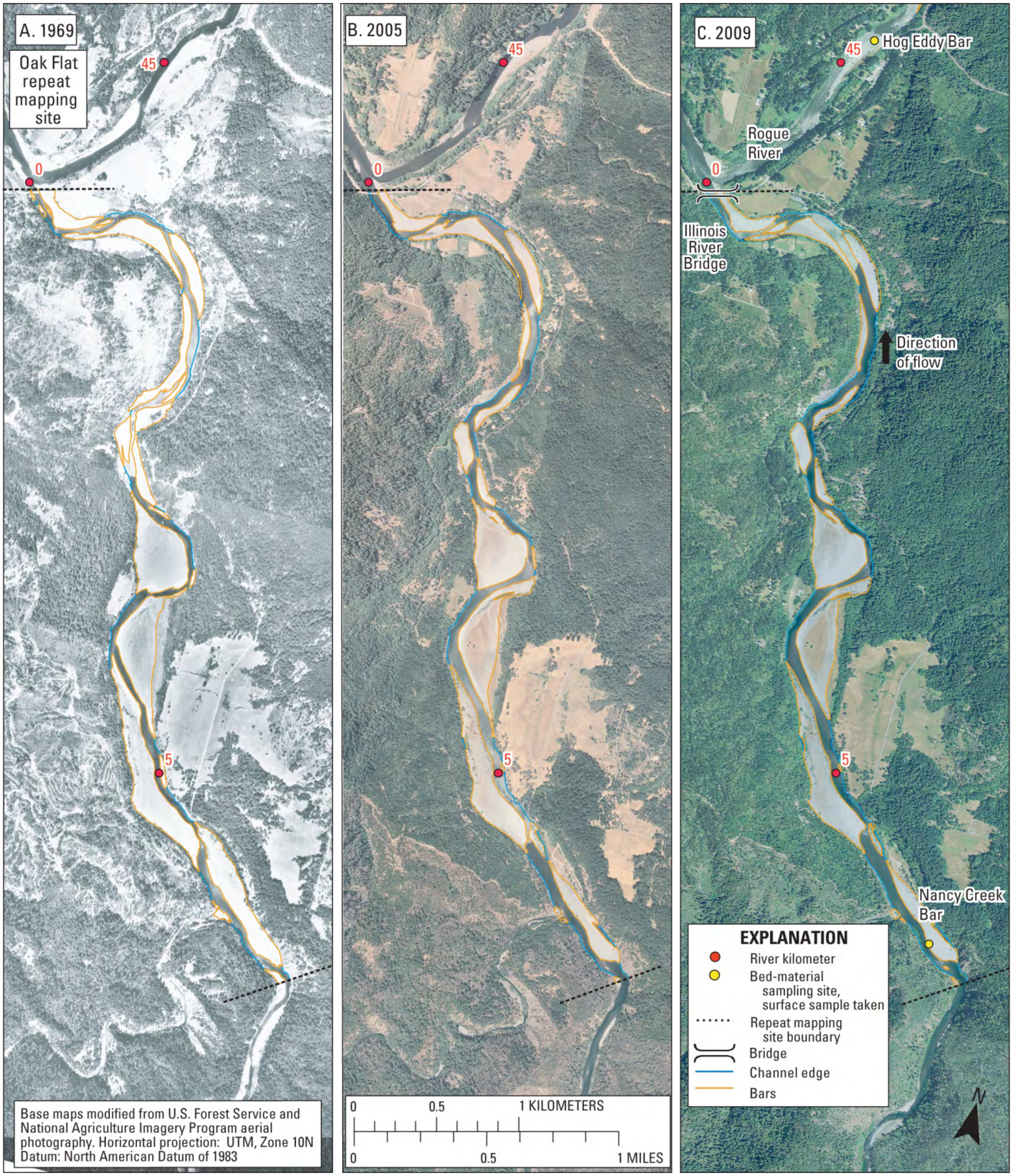


Figure 29. Images showing bars and wetted channel edges as delineated from vertical photographs taken in 1969, 2005, and 2009 for the Oak Flat site in the Illinois River Reach on the Illinois River, southwestern Oregon.

The number of bars generally decreased in the fluvial repeat mapping sites (fig. 21B; table 10). An exception is the Matson Park site in the Merlin Reach, where the number of bar features increased primarily in the Brushy Chutes area as the secondary channel shifted east (fig. 23). Also at the Williams Creek site in the Lower Applegate Reach, where bar area remained relatively stable during the analysis period, the number of bars increased by 37 percent in conjunction with substantial channel migrations between RKM 36.5 and 28.5 (fig. 28). In the tidal Elephant Rock mapping site, the number of bars also increased (fig. 26) in conjunction with a total increase in bar area.

As discussed above, we delineated a variety of bar types, ranging from apparently unvegetated bar surfaces to bars with relatively denser vegetation, in order to consistently map bars throughout the study area. This delineation method likely results in estimates of bar area that exceed the area of active bar surfaces that is subject to bed-material transport in most years. Nonetheless, results indicate that net reductions in bar area from 1967/69 to 2009 for the fluvial repeat mapping sites on the mainstem Rogue River (-37 to -50 percent; fig. 21A; table 10).

Comparison of the vertical photographs from 1967/69 and 2009 revels that bar surfaces that were apparently unvegetated in 1967/69 became increasingly vegetated in 2009 at the Riverside Park (Grants Pass Reach; fig. 22), Matson Park (Merlin Reach; fig. 23) and Jennings Riffle (Lobster Creek Reach; fig. 25) sites. Similar patterns of bar loss owing to vegetation establishment have been documented in the nearby Chetco (Wallick and others, 2010) and Umpqua (Wallick and others, 2011) Rivers where vegetation has established upper bar surfaces since the December 1964 flood. Subsequently, vegetated bar surfaces on the Chetco and Umpqua Rivers have not been remobilized as consequence of diminished peak flows. For the Foster Bar repeat site in the confined Galice Reach, comparison of the vertical photographs indicates that the net reduction in bar area from 1969 to 2009 is likely attributable to a combination of factors such as vegetation establishment on bar surfaces and discharge differences associated with the vertical photographs (fig. 24).

Results for the two repeat mapping sites on the Applegate River varied considerably. Like several of the repeat mapping sites on the Rogue River, the Thompson Creek site had substantial bar loss over the analysis period (Upper Applegate River Reach; fig. 21A; table 10). For this site, which has a relatively confined channel, comparison of the repeat images indicates that bar loss is attributable primarily to vegetation establishment on formerly unvegetated bar surfaces and to a lesser extent the higher streamflows during the collection of the 2009 photographs (table 8; fig. 27). Conversely, the Williams Creek site in the Lower Applegate River Reach showed no noticeable net change in bar area despite the substantial lateral movement of the channel (fig. 21A; table 10). For this site, however, distinguishing the boundary between bar surfaces and the floodplain was particularly challenging because of some glare and lack of contrast in the 1967 photographs and several lateral migrations and channel avulsions into floodplain material between RKM 40 and 28.5 (fig. 28); these challenges consequently reduce some confidence in the apparent temporal trends for this site.

At the Oak Flat site on the Illinois River, nearly continuous gravel bars flank the channel in 1969, 2005, and 2009 (fig. 29). Bar area decreased 22 percent from 1969 to 2009. Most of this loss in bar area occurred from 1969 to 2005, when bar area declined 18 percent. In the vertical photographs (fig. 29), it is apparent that some of the loss of bar area from 1969 to 2005 owes to (1) vegetation establishment on upper bar surfaces near RKM 6.5 to 5.5 and (2) erosion of bar edges in the lower section of the reach. The bar area apparently lost from 2005 to 2009 may primarily reflect the submersion of gravel surfaces visible in 2005 by the higher discharge during the collection of the 2009 photographs (table 8).

The repeat mapping of bar features for the Elephant Rock site is influenced by streamflow and tide levels during the collection of the photographs. From 1969 to 2009, the areal coverage of bar features increased as bars became smaller in area but more numerous in this repeat mapping site (fig. 20; fig. 26; table 10). Tide differences, channel migration and local aggradation likely explain the net increase in bar area within the Elephant Rock site.

Results for Repeat Channel Centerline and Width Delineations, 1967/69–2009

Comparison of channel centerline length over time reveals that channel length changed little for all repeat mapping sites from 1967/69 to 2009 (fig. 21C; table 12). Despite this overall stability in channel length, the channel shifted in position substantially in several locations including RKM 87–90 of the Matson Park site (Brushy Chutes area in Merlin Reach; fig. 23), RKM 2–6 in the Elephant Rock site (Tidal Reach; fig. 26), and RKM 28.5–40.5 of the Williams Creek site (Lower Applegate River Reach; fig. 28).

Table 12. Repeat channel attribute data as delineated from vertical photographs collected in 1967/69, 2005, and 2009 for the Rogue River study area, southwestern Oregon.

[m, meter; RKM, river kilometer; %, percent]

Site information			Centerline length (m)				Average wetted channel width (m)			
River	Site (Reach)	RKM	1967/1969	2005	2009	Net change (%)	1967/1969	2005	2009	Net change (%)
Rogue	Riverside Park (Grants Pass)	172 to 160	12,050	12,110	12,060	0.1	63	61	63	0
	Matson Park (Merlin)	149.5 to 138.4	11,100	11,230	11,200	0.9	76	86	90	18
	Foster Bar (Galice)	66.5 to 53.9	12,550	12,560	12,570	0.2	56	68	72	29
	Jennings Riffle (Lobster Creek)	26.5 to 15.2	11,300	11,330	11,240	-0.5	84	96	98	17
	Elephant Rock (Tidal)	6.7 to 0	6,580	6,650	6,660	1.2	374	318	301	-19
Applegate	Thompson Creek (Upper Applegate River)	49.5 to 41.6	7,870	7,880	7,920	0.5	24	26	24	4
	Williams Creek (Lower Applegate River)	41.6 to 28.5	13,250	13,130	13,130	-0.9	29	33	30	6
Illinois	Oak Flat (Illinois River)	6.5 to 0	6,630	6,480	6,530	-1.6	40	51	55	36
Total from all repeat mapping sites			81,320	81,370	81,310	0				
Total from repeat mapping sites in the fluvial reaches			74,740	74,720	74,650	-0.1				

For fluvial repeat mapping sites, the average wetted channel width remained relatively stable for the Riverside Park (Grants Pass Reach; fig. 22) and two Applegate sites (fig. 27; fig. 28), but increased 14–36 percent in the other fluvial reaches (fig. 21D; table 12). In the tidal Elephant Rock site, the average wetted width of the channel decreased 19 percent. For most reaches, these width changes are consistent with the streamflow differences between the vertical photographs (table 8). Quantitatively accounting for these discharge differences would be needed to determine if the apparent changes in average wetted channel width reflect actual geomorphic changes. Overall channel narrowing, however, is evident near the Grants Pass gage as discussed above in the “Specific Gage Analysis” section (fig. 17B). Additionally, a more detailed delineation of the active channel width (instead of the wetted channel width, which can be influenced by small differences in streamflow or tide) may help better quantify possible changes in channel width and condition for the repeat mapping sites.

Near the two instream gravel mining sites on Elephant and Wedderburn Bars in the Tidal Reach, the position of the channel shifted between RKM 2 and 7.5 since the 1969 photographs (fig. 26). Shifts include the channel moving north near RKM 7.5, east between RKM 5.5 and 4, and north between RKM 4.5 and 2.5. Associated with this channel shifting that Peck and Park (2006) attributed to the 1996 flood (water year 1997), bar area has decreased at Wedderburn Bar and increased at Elephant Bar. These changes are not obviously attributable to local gravel mining activities. Future analyses of temporal changes in channel width, sinuosity, and bar morphology using a combination of vertical photographs and LiDAR would be helpful in discerning the drivers of channel migration in this area.

Analyses of Bed-material Particle Sizes

During the July and September 2010 reconnaissance trips, we measured surface particle sizes at 25 bars and collected subsurface bulk samples at a subset of 7 bars in the study area. Of these 25 sites, 1 was located in the Grants Pass Reach, 2 in the Merlin Reach, 18 in the Galice Reach, 1 in the Lobster Creek Reach, 1 in the Tidal Reach, 1 in the Lower Applegate River Reach, and 1 in the Illinois River Reach. All reaches, except for the Upper Applegate River Reach, had at least one sampling site. The sampling sites were selected on the basis of bar size, accessibility, and condition (such as little to no vehicle disturbance). Where possible, particle data were collected at point or lateral bars that were likely formed by recent deposition events, as indicated by the absence or minimal coverage of vegetation. Sampling in the Galice Reach included these bar types as well as medial bars and flood bars consisting of boulder-sized particles.

At each site, 200 surface particles were measured using a modified grid technique (Kondolf and others, 2003) and a gravelometer measurement template (Federal Interagency Sediment Project US SAH–97 Gravelometer), which standardizes the measurement of sediment clasts greater than 2 mm in diameter. Depending on the coarseness of the bed material, particles were measured at 0.15-m increments along two parallel 15-m tapes or 0.30-m increments along two parallel 30-m tapes. Tapes were spaced 1–2 m apart and aligned parallel to the long axis of the bar. To support consistent intersite comparisons, the measurement transects were located at the bar apex (defined as the topographic high point along the upstream end of the bar) when possible. At some bars, the apex was not clearly defined because of bedrock outcrops, vegetation, and irregular bar topography. In such instances, the measurement transects were located in a section of the bar that appeared active and representative of the overall bar texture.

Subsurface bed material was sampled at seven sites to evaluate particle size differences between the surface and subsurface bed material (a measure of bar “armoring”). Bulk samples of subsurface material were collected at the same locations as the surface-measurement sites by removing approximately 0.5–1 m^2 of bar surface material, and then collecting 76–114 kg of bar substrate material, with larger bulk samples collected at sites with coarser surface particle texture. The bulk samples were then dried and analyzed for ½ phi particle sizes by the U.S. Geological Survey Sediment Laboratory in Vancouver, Washington. The subsurface sample at Hooks Gulch was sieved in the field and a well-mixed subsample of the particles less than 2 mm were taken and later analyzed by the USGS Sediment Laboratory.

On the mainstem Rogue River, the median diameter (D_{50}) of the surface particles varied from more than 100 mm at some of the coarsest bars in the Galice Reach to 21 mm at the Wedderburn Bar in the Tidal Reach (fig. 30; table 13). Surface D_{50} values varied considerably between the Grants Pass and Tidal Reaches in conjunction with the reach characteristics. The coarsest bars were in the steep, confined Galice Reach, where surface D_{50} exceeded 100 mm at four bars: the upstream Tyee (RKM 103.3), Russian Rapids (RKM 101.5), Half Moon Riffle (RKM 70.2), and East Creek (RKM 67.3) Bars. These boulder bars form up- and downstream of substantial valley constrictions of the active Rogue River channel. For instance, the active channel is more than 145 m wide at Tyee Bar but narrows to less than 50 m as it enters Wildcat Rapids about 1 km downstream. Then, about 0.75 km below Wildcat Rapids, the active channel widens again to more than 150 m at Russian Rapids Bar, where coarse bed material has been deposited on top of a bedrock shelf. Likewise, the narrow (less than 50 m wide) Huggins Canyon constricts the active channel between Half Moon Riffle Bar and East Creek Bar.

Gravelometer template used to measure the diameter of surface particles.

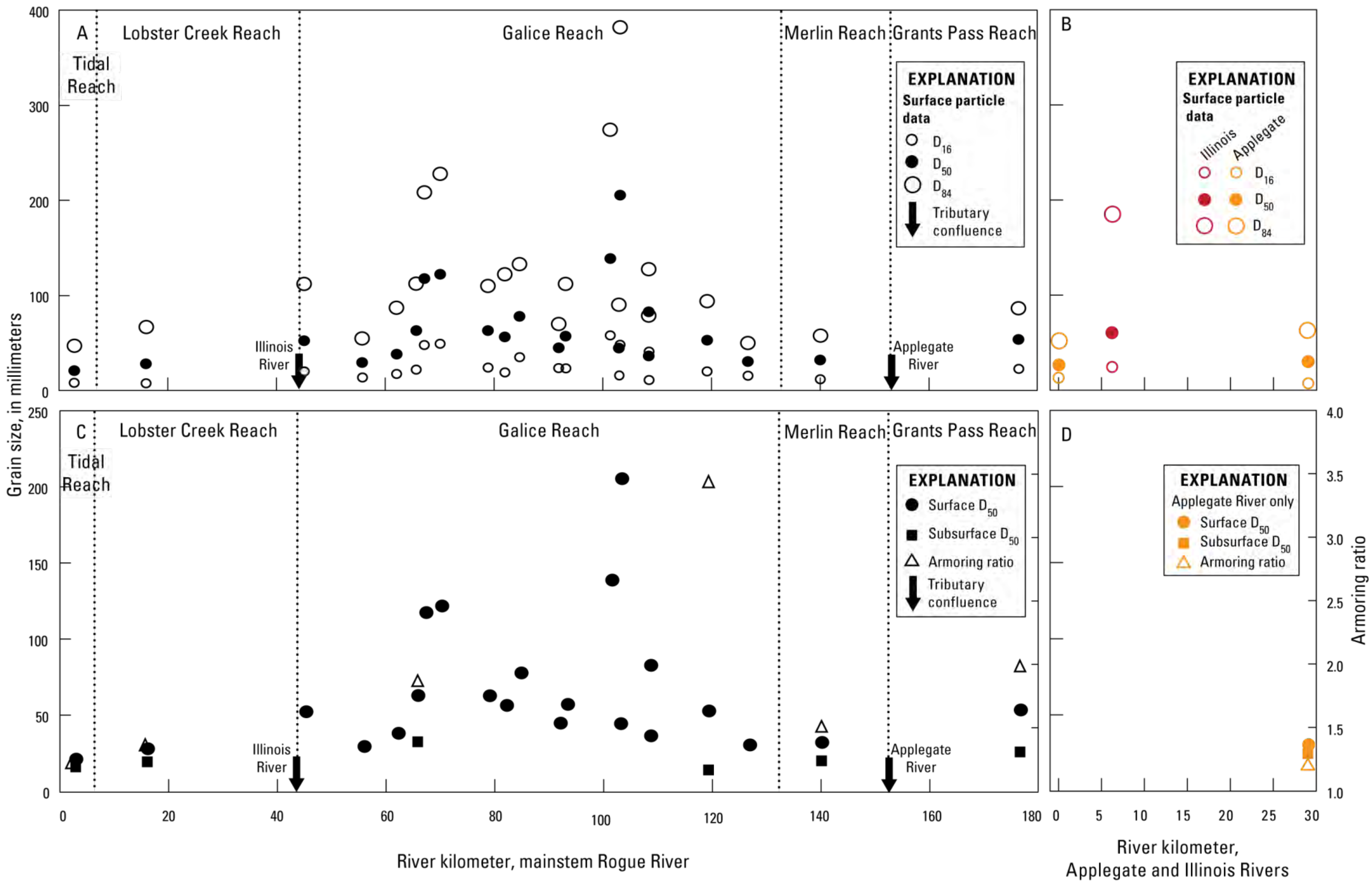


Figure 30. Graphs showing the size distributions of surface and subsurface particles measured at 25 sites along the Rogue, Applegate, and Illinois Rivers, southwestern Oregon. The surface size distributions were determined by measuring 200 clasts; subsurface size distributions were determined from a bulk sample taken below the armor layer. Surface particle data for the (A) mainstem Rogue River and (B) Applegate and Illinois Rivers. Comparison of median D_{50} values for surface and subsurface particles and armoring ratios for (C) mainstem Rogue River and (D) Applegate River.

Table 13. Bed-material data collected in the Rogue River study area, southwestern Oregon

[RKM, river kilometer; D_{16}, 16th percentile diameter in mm; D_{50}, median diameter in mm; D_{84}, 84th percentile diameter in mm; DS, downstream; US, upstream]

Site information						Surface particles			Subsurface particles			Armoring ratio
River	Bar name[1]	Reach	RKM	Northing (m)	Easting (m)	D_{16}	D_{50}	D_{84}	D_{16}	D_{50}	D_{84}	
Rogue	Rogue River City	Grants Pass	176.6	484200	4696879	23	53	86	4	27	104	2.0
	Robertson Bridge	Merlin	140.1	460545	4704709	12	32	57	2	21	67	1.5
	Taylor Creek	Galice	126.8	453642	4711512	15	30	50				
	Hooks Gulch	Galice	119.3	451327	4715252	20	53	94	2	15	44	3.4
	Sanderson Island, US	Galice	108.6	450760	4721810	41	83	127				
	Sanderson Island, DS	Galice	108.6	450707	4721822	11	36	79				
	Tyee, US	Galice	103.3	446008	4722923	48	205	382				
	Tyee, DS	Galice	103.1	445874	4722852	16	44	90				
	Russian Rapids	Galice	101.5	444521	4722440	58	139	274				
	Horseshoe Bend	Galice	93.3	439728	4725524	23	57	112				
	Telephone Hole	Galice	92.0	439325	4726035	23	45	70				
	Small Winkle	Galice	84.8	433622	4727925	35	78	133				
	Long Gulch Creek	Galice	82.1	431279	4728839	19	56	122				
	China	Galice	79.0	428626	4729799	24	63	110				
	Half Moon Riffle	Galice	70.2	422791	4727136	49	122	228				
	East Creek	Galice	67.3	422777	4725607	48	117	208				
	Solitude Riffle	Galice	65.8	421765	4724864	22	63	112	4	34	82	1.9
	Clay Hill Riffle	Galice	62.2	419337	4724160	17	38	87				
	Brewery Hole	Galice	55.9	414317	4722022	14	29	55				
	Hog Eddy	Galice	45.2	413177	4712488	20	52	112				
	Orchard	Lobster Creek	16.1	392512	4705606	7	28	66	3	21	61	1.4
	Wedderburn	Tidal	2.9	385065	4699073	8	21	47	1	17	57	1.2
Applegate	Bakery	Lower Applegate River	29.1	477842	4685256	6	29	62	1	25	62	1.2
	Applegate Confluence	Lower Applegate River	0.0	463041	4697537	12	26	51				
Illinois	Nancy Creek	Illinois River	6.3	414923	4707264	24	59	184				

[1] Bar names were assigned on the basis of features on USGS quadrangle maps or nearby locations.

At all six sites where subsurface bed-material samples were taken on the mainstem Rogue River, the median size of subsurface particles was finer than the median size of surface particles (fig. 30; table 13). Subsurface D_{50} declined from the Rogue River City Bar (RKM 176.6) to the Hooks Gulch Bar (RKM 119.3), but then increased at the Solitude Riffle Bar (RKM 65.8), which is located upstream from a sharp bend in the river and a channel constriction in the Galice Reach. Downstream of Solitude Riffle Bar, the median size of subsurface particles continued to diminish to the Wedderburn Bar in the Tidal Reach. The differences between the surface and subsurface D_{50} values were less than 11 mm at the Robertson Bridge, Orchard, and Wedderburn Bars and greater than 25 mm at the Rogue River City, Hooks Gulch, and Solitude Riffle Bars (table 13).

Differences in surface and subsurface particle sizes can be related to the balance between sediment supply and transport capacity, with the surface layer coarsening when the river's transport capacity exceeds its supply of fine sediments (Dietrich and others, 1989; Buffington and Montgomery, 1999). The armoring ratio, or the ratio of the median grain sizes (D_{50}) of the surface to subsurface layers, provides an indication of the degree of armoring. The armoring ratio is typically close to 1 for rivers with a high sediment supply and approaches or exceeds 2 for supply-limited rivers (Bunte and Abt, 2001). Measured armoring ratios were 1.5 or less at Robertson Bridge, Orchard, and Wedderburn Bars, approached 2 at Rogue River City and Solitude Riffle Bars, and exceeded 3 at the Hooks Gulch Bar (fig. 30; table 13). These armoring ratios indicate that transport capacity exceeds sediment supply at the Hooks Gulch Bar and to a lesser extent at Rogue River City and Solitude Riffle Bars. For comparison, armoring ratios ranged from 0.99 to 4.73 in the Umpqua River basin (30 sites; Wallick and others, 2011), 1.38 to 2.09 in the Chetco River basin (3 sites; Wallick and others, 2010), and 0.97 to 1.5 in the Hunter Creek basin (2 sites; Jones and others, 2011).

On the Applegate River, surface and subsurface particle data were taken at Bakery Bar while only surface particles were measured at the Applegate Confluence Bar. Only surface particles were measured at Nancy Creek Bar on the Illinois River because of the large (D_{84} = 184 mm) particles covering the bar surface that precluded excavation into the bar's subsurface (fig. 30; table 13). This limited sampling indicates that bed material exiting the Applegate River is finer than bed material sampled at the upstream Rogue River City Bar and downstream Robertson Bridge Bar. Conversely, bed material measured at Nancy Creek Bar on the Illinois River is coarser than bed material at Hog Eddy Bar located approximately 1.4 km upstream of the confluence of the Rogue and Illinois Rivers. The armoring ratio calculated for the Applegate River's Bakery Bar is 1.2, indicating that sediment supply exceeds the river's transport capacity at this site.

As shown by the variability in samples collected in the Galice Reach (fig. 30), bar texture can vary greatly between sites on gravel-bed rivers. Thus, additional measurements at sites on the Rogue, Applegate, and Illinois Rivers would help refine assessments of the relation between transport and sediment supply and longitudinal trends in bed material.

Discussion and Synthesis of Study Results

Our review of existing studies and historical observations in conjunction with our bar and channel mapping and bed-material measurements provide a framework for deriving general conclusions regarding the overall river characteristics and historical channel changes for portions of the Rogue, Applegate, and Illinois Rivers. These observations support inferences regarding bed-material transport and how conditions may vary spatially and temporally in the Rogue River basin.

Reach Characteristics

On the basis of our field observations, bar and channel mapping from vertical photographs, and review of existing datasets and studies, the 178.5-km-long study area on the mainstem Rogue River has confined and unconfined segments and is predominately alluvial in its lowermost 44 km. Within the study area, the Rogue River can be divided into five reaches based on topography, hydrology, and tidal influence. The active channel is largely confined and flows over a mixed bed of bedrock, boulders, and smaller grain sizes in the Grants Pass (RKM 178.5–152.8), Merlin (RKM 152.8–132.7), and Galice Reaches (RKM 132.7–43.9). These confined reaches tend to have fewer bars and stable channel planforms. Conversely, the active channel flows over predominately alluvial material and is flanked by nearly continuous gravel bars in the Lobster Creek Reach (RKM 43.9–6.7). The tidally affected alluvial channel in the Tidal Reach (RKM 6.7–0) is unconfined until RKM 2, where it becomes confined until its mouth at the Pacific Ocean. The Lobster Creek and Tidal Reaches contain some of the most extensive bar deposits on the mainstem Rogue River.

Likewise, the study areas on the Applegate and Illinois Rivers were also divided into distinct reaches. The 56.6-km-long study area on the Applegate River was divided into two reaches based on topography; the confined channel in the Upper Applegate River Reach (RKM 56.6–41.6) flows over alluvium and bedrock and has few bars, whereas the active channel in the Lower Applegate River Reach (RKM 41.6–0) alternates between confined and unconfined segments, flows predominantly over alluvium, shifts position laterally in unconfined sections, and contains more numerous and extensive bar features. We assessed a single, 6.5-km-long study area on the Illinois River. This fully alluvial section flows through a narrow valley and has nearly continuous, channel-flanking gravel bars.

Bed-Material Transport Conditions

As summarized in table 14 for reaches on the mainstem Rogue River and in table 15 for reaches on the Applegate and Illinois Rivers, the study area within the Rogue River basin contains a mix of fluvial environments. Overall, the steep and confined character of much of the Rogue River within the study area, in conjunction with its high winter flows, results in a river corridor with high bed-material transport capacity, a condition noted by some of the earliest surveys of the river corridor. The extensive in-channel bedrock and sparse number and coarse texture of bars indicate that the mainstem Grants Pass and Galice Reaches are likely supply-limited, meaning that the river's transport capacity exceeds its supply of bed material. In contrast, the Lobster Creek and Tidal Reaches and perhaps parts of the Merlin Reach have bed-material supplies that more closely balance or even exceed transport capacity, as indicated by their greater bar areas (fig. 20) and lower armoring ratios (fig. 30). These reaches are downstream of the apparently more gravel-rich Illinois and Applegate Rivers. The lowermost reaches of these two tributaries are fully alluvial, likely with transport-limited conditions. Sediment inputs from these tributaries draining steep portions of the Klamath Mountains are probably important contributions to the overall transport of bed-material in the Rogue River. The Upper Applegate River Reach, however, likely has high transport capacity (and thus is sediment supply limited) as indicated by its steep gradient (table 4), intermittent bedrock outcrops in the channel, and the relatively sparse area of bars mapped in this reach (tables 10 and 11, fig. 21A).

Table 14. Summary of findings by dataset for study reaches on the mainstem Rogue River, southwestern Oregon.

[RKM, river kilometer; ~, approximately; m, meter; %, percent; D_{50}, median particle diameter; NA, Not available]

Reach (Repeat mapping site)	Review of previous studies	Repeat channel cross sections collected near bridge crossings	Net changes for repeat mapping site, 1967/69–2009	Bed-material data	Results from specific gage analysis or surveys at instream gravel mining sites	Summary
Grants Pass (Riverside Park)	Bank undercutting and erosion[1]; annual sediment load of 76,000 m^3 at Savage Rapids Dam[2]	At RKM 164.5, the thalweg incised an estimated 2.7 m (2006–08) and then aggraded ~2 m (2008–10), resulting in an estimated net loss of 0.7 m (2006–10)	50% net decline in total bar area; no detectable changes in wetted channel width	Surface D_{50}=53; armoring ratio=2.0	Specific gage analysis for the gage at RKM 164.4 shows a net reduction in stage across a range of flows, indicating possible channel incision	Channels flows over alluvium and bedrock; repeat cross sections, specific gage analysis, and repeat delineation indicate potential for lateral and vertical adjustments; cement-gravel and bedrock in banks likely limit lateral movement; armoring ratio, sparse area of mapped bars, and in-channel bedrock tentatively indicate reach is supply limited
Merlin (Matson Park)	Lateral position of channel shifted up to 490 m in Brushy Chutes area (1965–91)[1]	At RKM 139.2, channel shifted laterally and maintained a stable thalweg elevation while banks aggraded ~0.75 m (2006–10)	37% net decline in total bar area; 18% net increase in wetted channel width; active channel widened ~290 m in Brushy Chutes area (1967–2009)	Surface D_{50}=32; armoring ratio=1.5	NA	Channels flows over alluvium (primarily near confluence with Applegate River) and bedrock; some potential for lateral adjustments based on repeat delineation; some plan and profile stability owing to bedrock outcrops; sparse area of mapped bars and in-channel bedrock tentatively indicate reach is overall supply limited; however, armoring ratio tentatively indicates a relative balance between transport capacity and sediment supply at Robertson Bridge Bar

Table 14. Summary of findings by dataset for study reaches on the mainstem Rogue River, southwestern Oregon—continued

[RKM, river kilometer; ~, approximately; m, meter; %, percent; D_{50}, median particle diameter; NA, Not available]

Reach (Repeat mapping site)	Review of previous studies	Repeat channel cross sections collected near bridge crossings	Net changes for repeat mapping site, 1967/69–2009	Bed-material data	Results from specific gage analysis or surveys at instream gravel mining sites	Summary
Galice (Foster Bar)	Substantial deposition and reworking of sand beaches by winter flows; beach erosion also influenced by boats, foot traffic, and wind.[3]	NA	37% net decline in total bar area; 29% net increase in wetted channel width	Surface D_{50}=29–205; armoring ratio=1.9–3.4	Specific gage analyses did not indicate any substantial changes in channel condition near RKM 47.6	Channel flows mostly on bedrock; coarse, rarely activated, bars in valley expanses; bedrock-controlled channel limits lateral adjustments or incision; armoring ratios, sparse area of mapped bars, and in-channel bedrock tentatively indicate that reach is supply limited.
Lobster Creek (Jennings Riffle)	Sediment inputs from tributaries[4]; deposition of ~1.8 m on bars after 1996 flood[4]	NA	37% net decline in total bar area; 17% net increase in wetted channel width	Surface D_{50}= 28; armoring ratio=1.4	NA	Channel flows on alluvium; lateral channel position controlled by valley; armoring ratio and large area of mapped bars tentatively indicate that reach is transport limited.
Tidal (Elephant Rock)	From 1940 to 97, Rogue River shifted between its banks[4]; deposition of ~1.8 m on bars after 1996 flood[4]	At RKM 1.3, the thalweg has aggraded about 1.1 m and slightly shifted its position (2000–09)	11% net increase in bar area; 19% net decline in wetted channel width	Surface D_{50}=21; armoring ratio=1.2	Surveys tentatively show that Elephant and Wedderburn Bars are: (1) dynamic with modest annual deposition and erosion, and (2) rebuilt by deposition after large floods	Tidally affected channel flows on alluvium; dynamic with potential for lateral and vertical adjustments as indicated by repeat cross sections and delineation; tidal influence, armoring ratio, and large area of mapped bars tentatively indicate that reach is transport limited.

[1] Klingeman and others (1993)

[2] BLM (2001a)

[3] Klingeman (2003)

[4] Peck and Park (2006)

Table 15. Summary of findings by dataset for study reaches on the Applegate and Illinois Rivers, southwestern Oregon.

[RKM, river kilometer; m, meter; %, percent; D_{50}, median particle diameter; NA, Not available]

Reach (Repeat mapping site)	Review of previous studies	Repeat channel cross sections collected near bridge crossings	Net changes for repeat mapping site, 1967/69–2009	Bed-material data	Results from specific gage analysis or surveys at in-stream gravel mining sites	Summary
Upper Applegate River (Thompson Creek)	NA	At RKM 42, the channel cut 1.2 m into the toe of the right bank and 0.4 m into the thalweg but aggraded 0.4–1.2 m on the left bank (1933–2010)	69% net decline in total bar area; 4% net increase in wetted channel width	NA	Specific gage analyses did not indicate substantial changes in channel condition near RKM 45.2 where the channel is narrow and confined before entering a bedrock rapid	Bedrock-controlled channel limits likelihood of substantial lateral shifting or incision; some potential for vertical channel adjustments based on repeat cross sections; steep gradient, bedrock outcrops, and sparse area of mapped bars tentatively indicate that reach is supply limited.
Lower Applegate River (Williams Creek)	Known floodplain pit-captures at several locations in this reach (DOGAMI, written commun., 2010)	At RKM 13.5, channel incised up to 1.5 m throughout transect (1994–2004); channel then aggraded up to 1.5 m in several locations but continued to incise through bed-material in the thalweg and on the left bank (2004–08); net reduction in thalweg elevation was 0.8 m	No detectable net change in bar area; 6% net increase in wetted channel width; the mainstem channel shifted (~40–480 m) in several locations (1967–2009)	Surface D_{50}=26 and 29; armoring ratio=1.2	Specific gage analyses did not indicate any substantial changes in channel condition at RKM 12.7 where the channel is narrow and confined by its valley	Dynamic channel with considerable potential for lateral and vertical adjustments in unconfined sections based on repeat cross sections and delineation; armoring ratio and large area of mapped bars tentatively indicate that reach is fully alluvial and transport limited.
Illinois River (Oak Flat)	NA	NA	22% net decline in bar area; 36% net increase in wetted channel width	Surface D_{50}=59; armoring ratio, NA	NA	Alluvial channel with lateral channel position controlled by valley; large area of mapped bars tentatively indicates that reach is fully alluvial and transport limited.

The difference among reaches in terms of the balance between sediment supply and transport capacity leads to distinct patterns in the distribution and texture of gravel bars. This balance is in part affected by points of sediment input, including the Applegate River, Illinois River, and the several steep tributaries joining the Rogue River, particularly in the Lobster Creek Reach. The other aspect affecting the balance between transport capacity and bed-material supply is the variation in the river's transport capacity; the steeper slope and confined valley in the Galice Reach, in particular, probably result in transport capacity that likely exceeds that of the other reaches. Consequently, most of the bed material entering the Galice Reach is likely transported through the reach and deposited downstream in the flatter and wider Lobster Creek and Tidal Reaches.

Compared to the slightly smaller Umpqua River basin (12,103 km^2) to the north, the Rogue River basin (13,390 km^2) likely has greater overall bed-material transport. Wallick and others (2011) estimated that the Umpqua River transports on average 20,000 to 82,000 metric tons/yr of bed material (approximately equivalent to 10,000 to 39,000 m^3 assuming a density of 2.1 tons/m^3). While the conclusion of greater bed-material transport in the Rogue River is tentative in the absence of either actual transport measurements or transport capacity calculations (aside from the average of 17,700 m^3/yr of sand and gravel that has accumulated in the Lost Creek Reservoir; Dykaar and Taylor, 2009), it is supported by the observations of greater bar area and frequency along most of the Rogue River as well as the much shorter tidal reach on the Rogue (6.7 km) compared to that on the Umpqua River (40 km). Greater bed-material transport in the Rogue River relative to the Umpqua River is also consistent with the overall geologic and geomorphic settings of the two basins, especially the large area (56 percent) of the Rogue River basin that drains the Klamath Mountain geologic province.

Historical Changes in River Morphology

While the overall patterns of bed-material accumulation logically relate to channel and valley physiography, hydrology, and geology, temporal trends in bed material and their interpretation are more ambiguous. Six of the eight repeat mapping sites had a net reduction in bar area from 1967/69 to 2009 (table 10) that ranged from 22 percent loss at the Oak Flat site (Illinois River Reach; fig. 29) to 69 percent loss at the Thompson Creek (Upper Applegate River Reach; fig. 27). The loss in bar area appears to have resulted chiefly from the establishment of vegetation on upper bar surfaces and subsequent stabilization of formerly active surfaces in most reaches as well as modifications of bar surfaces along the channel margins in the lower section of the Oak Flat site. Vegetation establishment is likely a consequence of vegetation growth on surfaces formed or eroded by the high flows of 1964, and further promoted by the diminishment of peak flows since the flood events in 1964 and 1974, in part owing to dams in the upper Rogue and Applegate River basins. These vegetated and stabilized bar features, however, store large quantities of bed-material sediment that may be subject to erosion and transport during high flow events in the future. Some of the temporal changes in bar area may also owe to differences in streamflow and tide levels during the acquisition of the vertical photographs.

For the remaining two repeat mapping sites, bar area changed little at the Williams Creek site (Lower Applegate River Reach) but increased 11 percent at the Elephant Rock site (Tidal Reach). The increase in bar area for the Elephant Rock site is likely associated with possible tide differences between the vertical photographs as well as increases in the area of Elephant Bar resulting from the Rogue River channel migrating toward the right bank near RKM 4–2.5 from 1969 to 2005 (fig. 26).

From 1967/69 to 2009, channel centerline lengths showed little net change for repeat mapping sites on the Rogue, Applegate, and Illinois Rivers (table 12). While the confined channels and valleys throughout most of the study area limit lateral movement of the channel, channel planform has changed substantially over the analysis period in unconfined sections such as the Brushy Chutes area of the Merlin Reach (fig. 23), RKM 40 to 28.5 in the Lower Applegate River Reach (fig. 28), and RKM 6.7 to 2 in the Tidal Reach (fig. 26). This historical evidence of channel change indicates that bed-material transport and deposition are important processes maintaining channel form in the more alluvial reaches. Additionally, these dynamic alluvial reaches are those most likely to be sensitive to changes in bed-material supply and transport capacity.

The repeat channel cross sections and specific gage analyses show that channels locally have the potential for vertical adjustments. Our analyses using existing datasets indicate channel incision and narrowing on the Rogue River near the Grants Pass gage (Grants Pass Reach; fig. 17B; fig. 19A) and on the Applegate River near RKM 42 and 13.5 (Upper and Lower Applegate River Reaches; fig. 19D,E) as well as aggradation near the Patterson Bridge at RKM 1.3 (Tidal Reach; fig. 19C). As expected, most of the evidence of vertical changes is from reaches, or sections within reaches, with more extensive alluvial deposits. From these limited data, we cannot determine if the evidence of local incision on the Rogue River is also related to other temporal changes such as vegetation establishment and the reduction in bar area. Bar growth and local aggradation at Patterson Bridge may indicate overall aggradation in the Tidal Reach, consistent with the long-term filling of the river valley in response to Holocene sea-level rise. In the absence of repeat channel cross sections, other types of channel surveys, or stage-discharge information, we cannot make conclusions regarding the vertical stability of the Lobster Creek and Illinois River Reaches.

Outstanding Issues and Possible Approaches

This reconnaissance-level study provides a framework and baseline information for understanding bed-material transport in the Rogue River basin. Future efforts addressing specific issues and reaches could greatly refine the understanding of historical and ongoing bed-material transport processes and their effects on channel morphology. Additionally, such information would provide a solid basis for evaluating future hydrologic and geomorphic changes in the Rogue River basin.

High-resolution Topographic Data

High-resolution topographic data are critical baseline information for assessing channel conditions and supporting hydraulic analysis. As of 2011, modern, high-resolution topographic surveys for the Rogue River study area are limited to the LiDAR coverage of the mainstem Rogue River from RKM 178.5 to 167.5, 17.8 to 12, and 10 to 0 (table 7). Acquiring LiDAR surveys or similar high-resolution topographic data for other sections of interest would be critical for any quantitative analysis of channel morphology and bed-material transport (as described in subsequent sections). Additionally, these detailed surveys would be valuable baseline data for long-term, reach-scale monitoring of channel and floodplain conditions and support other hydrologic, geomorphic, and ecological research needs.

Streamflow Data

Modeling and predicting bed-material transport require high-quality streamflow information, particularly for peak flows. As of 2011, no streamflow-gaging station is operated that measures the streamflow contributions of the Illinois River to the Rogue River or flows in the Lobster Creek and Tidal Reaches. Such hydrologic data would be required by most approaches to quantify sediment supplied to the alluvial Lobster Creek and Tidal Reaches of the Rogue River.

The most accurate approach for obtaining such information would be to expand the USGS streamflow-gaging station network; possible locations include Lobster Creek Bridge on the mainstem Rogue River near RKM 17.8 and Illinois River Bridge near RKM 0.1. Mean daily flow data measured for the lower Rogue and Illinois Rivers could then be used to estimate annual sediment fluxes for the period of record and shorter time periods (such as water years) using methods outlined in Wallick and others (2010) and employed in Wallick and O'Connor (2011). An alternative approach, with lower costs but greater uncertainties, would be to apply regional regression equations to estimate discharge for a range of flow events at specific locations. Additionally, the collection of streamflow data for the Little Applegate River would be useful to quantify the flow and bed material contributions from this tributary to the mainstem Applegate River.

Bed-Material Transport Rates and Sediment Budget

Understanding the possible effects of instream gravel mining on channel condition and longitudinal and temporal changes in bed material requires a thorough accounting of sediment inputs from upstream and lateral sources as well as sediment losses associated with particle attrition, transport, and storage. Such information would support a comparison of the volumes of gravel removed by ongoing mining activities relative to the volume of gravel delivered to the study area. An approach for expediently developing this sediment budget might include the following components:

1. Sediment flux estimates using published bedload transport equations as was done for the Chetco and Umpqua Rivers by Wallick and others (2010, 2011). This approach could be used with most confidence in the reaches of the entire Rogue River study area where bed-material transport is capacity-limited. Reaches conducive to this type of analysis include the Lobster Creek and Tidal Reaches and possibly the Merlin, Lower Applegate River, and Illinois River Reaches. Similar to the Chetco River analysis by Wallick and others (2010), such analyses would be best performed by the development of a hydraulic model in conjunction with the collection of systematic of bed-material measurements for a reach of interest. These analyses will require high-resolution topographic data and additional bed material sampling sites for the area(s) of analysis. Additionally, such work would require flow estimates (as described above in the "Streamflow Data" section) if conducted for the Illinois River, Lobster Creek, and/or Tidal Reaches.
2. Empirical GIS-based sediment yield analyses, factoring in sediment production, delivery to the channels, and in-channel attrition. This approach would be similar to that applied in the Umpqua River basin (Wallick and others, 2011). Such an analysis could focus on specific reaches regardless of their alluvial or bedrock character, but would require an analysis of their entire contributing area. Such analyses would be bolstered by assessments of bed-material composition, thereby confirming the source areas of bed material delivered to the Rogue River.
3. Direct measurements of bedload transport to verify bedload transport equations and estimate actual bedload fluxes. Ideally, such measurements would be collected near operational USGS streamflow-gaging stations. Possible locations for bedload measurements near USGS streamflow-gaging stations include the Rogue River near the Grants Pass (RKM 164.6) and Agness (RKM 47.6) gages. Other locations not near USGS gages include the Rogue River at Robertson Bridge (RKM 139.2), Rogue River at Agness Bridge (RKM 49.3), Applegate River at Fish Hatchery Road Bridge (RKM 13.5), and Illinois River Bridge (RKM 0.1). A measurement program using established techniques, however, would be challenging on the Rogue and Illinois Rivers because of their high flows and coarse bed material, but may be more tractable on

the Applegate River. In addition, recent developments in proxy approaches for bedload transport measurements (Hsu and others, 2010; Turowski and Rickenmann, 2011) may offer avenues for more efficiently measuring transport conditions in larger rivers such as the Rogue and Illinois Rivers.

4. Sediment flux estimates based on mapped changes in bar area over specific temporal intervals, in a manner similar to the morphological approach used on the Chetco River by Wallick and others (2010). Ideally, this approach would use LiDAR or other high-resolution topographic data from two time periods to directly calculate volumetric change in sediment storage. This method, however, can also be implemented using sequential aerial photographs along with a single LiDAR survey. Like an analysis of bed-material transport using transport capacity relationships, this approach is best applied in alluvial reaches that are transport-capacity limited. Despite the uncertainties associated with this type of analysis (Wallick and others, 2010), such data and analyses can also serve as a basis for efficient monitoring of long-term changes in channel and floodplain conditions. With the existing LiDAR coverage, this analysis could be completed for the Tidal Reach and portions of the Lobster Creek Reach. A LiDAR survey for reaches on the Applegate and Illinois Rivers and the remaining portions of the Lobster Creek Reach would support additional analyses.
5. Review of pre- and post-gravel-mining surveys. In-depth and comprehensive review of all mining surveys on the Rogue River may provide insight into estimates of coarse gravel recruitment. While these surveys are subject to uncertainties and limitations and may be missing data for some locations and years, all available data on gravel replenishment would help reduce uncertainty in sediment-flux estimates at instream gravel mining sites.

Detailed Channel Morphology Assessment

In this study, we delineated bar surfaces from vertical photographs spanning 1967/69 to 2009, and found that the areal coverage of bars declined for most repeat mapping sites (table 10). These datasets and measurements could serve as the starting point for more comprehensive temporal analyses of morphological trends on the Rogue, Applegate, and Illinois Rivers. On the basis of the findings reported here, more detailed analyses would ideally document changes in bar area owing to erosion and deposition, as well as those owing to the establishment of vegetation and the associated transformations of active, unvegetated bars to floodplain surfaces. These analyses will require accounting for the uncertainties associated with the mapping protocols and differences in discharge between the vertical photographs. An approach that would meet these objectives would include the following elements:

1. Detailed mapping of land cover for multiple time periods. This effort would involve delineating the active channel and floodplain features based on vegetation density, which would reduce uncertainty and ambiguity in determining the bar-floodplain boundary (such as on the Lower Applegate River Reach). Examining temporal changes in apparently unvegetated and vegetated bar surfaces would allow a more quantitative assessment of erosion, deposition, and vegetation establishment during different time periods and enable a more complete description of the processes and trends related to bar changes. An assessment of overall bar status and trends would benefit from supplemental bar delineations from vertical photographs taken in the 1940s, 1960s, 1970s, 1990s, and 2000.
2. Comprehensive mapping of channel features before and after major floods to assess the response of the channel to different flood magnitudes and, ultimately, sediment flux and channel evolution in the Rogue, Applegate, and Illinois Rivers. Possible floods for

focusing this effort include the events of December 1964, January 1974, and January 1997.

3. Assessment of the relation between vegetation establishment and peak flow patterns. In the Umpqua and Chetco River basins, historical declines in bar area are associated with long-term decreases in flood magnitude (Wallick and others 2010; 2011). Determining possible linkages between peak flows in the Rogue, Illinois, and Applegate Rivers and climate factors related to flood peaks, such as the Pacific Decadal Oscillation, could support inferences of likely future changes in floodplain vegetation and channel conditions.
4. Investigation of planform changes and possible bed-level changes. Modern channel surveys could be compared to historical surveys, such as the USGS plan and profile maps and the flood profile surveys and bathymetric surveys in the Tidal Reach (table 7), to more systematically document spatial and temporal changes in bed elevation such as near the Grants Pass gaging station. Other data sources likely applicable for assessing planform changes include the historical cross sections at USGS cable ways. These analyses would complement a comprehensive mapping of channel and floodplain characteristics and help provide insight into the factors controlling observed changes. Properly conducted and archived, such modern surveys could also serve as a basis for long-term monitoring of channel conditions.
5. A more detailed review of the data available for bridges within the study area or reaches of interest. A review of the as-built surveys and construction plans for publicly owned bridges may provide information sufficient to assess sediment thickness and changes in bed elevation. Construction plans, permits, and investigations of additional bridges owned by private landowners, the counties, or National Forest Service also may yield useful information.

Legacy and Ongoing Effects of Land Use Activities

Anthropogenic activities such as gold mining, gravel mining from instream and floodplain areas, flow regulation, dam construction and removal, forest practices, and dredging likely affect sediment transport and deposition in the Rogue River study area to varying degrees over time and throughout the river network. Quantitatively assessing the effects of these factors on sediment dynamics would be challenging owing to interactions between these factors as well as their interactions with the background, physical controls on sediment dynamics such as basin topography, channel slope, geology, and hydrology. Further investigations of fine- and coarse-sediment inputs associated with land use activities may provide information on the relative fluxes of different clast sizes to and within the study area. An approach for investigating the relative importance of past activities on overall sediment dynamics would be to:

1. Determine the distribution of areas of active gravel transport and deposition and analyze temporal trends in channel and floodplain morphology relative to land-use disturbances.
2. Assess changes in bar area and channel planform near historical and ongoing instream and floodplain gravel mining sites.
3. Identify historical dredge spoils and mine tailings along the river corridor and determine their likely availability for future erosion and deposition. Possible locations include the Little Applegate River, a tributary that was intensively mined historically (fig. 5C) and potentially a source of sediment to the mainstem Applegate River, the Applegate River reaches, Illinois River Reach, and the mainstem Rogue River.
4. Coordinate with an ongoing study by Oregon State University to assess bed elevation changes within the Grants Pass Reach and at the gaging station following the removal of the Gold Hill, Gold Ray, and Savage Rapids Dams.

Priority Reaches for Future Analysis

Given the large drainage area of the Rogue River basin and area included in this study, addressing all the data gaps and conducting all the analyses outlined above are probably not practical in the near future. Some reaches, however, might be more amenable to analysis than others; some of these reaches coincide with active or proposed instream gravel mining.

Analysis of the lower Rogue River system, encompassing the Lobster Creek, Tidal, and Illinois River Reaches, would provide information on sediment flux and channel dynamics in this ecologically important section of the Rogue River basin. Additionally, this section of the river has been subject to multiple anthropogenic disturbances (including instream gravel mining), and its low-gradient and downstream position in the basin make it responsive to overall basin conditions. As these reaches are alluvial, many of the analyses outlined above would have high likelihoods for success. While the Illinois River Reach has limited ongoing disturbance and management issues within the study area, assessment of this reach would be important because of its apparent contributions of sediment and streamflow to the lower Rogue River. As described above, detailed analysis of the lower Rogue River basin would require acquisition of continuous high-resolution topographic data and the development of supplementary hydrologic information.

The Lower Applegate River Reach would also be a logical area for detailed analysis. Like the lower Rogue River basin, this section of the Applegate River has been affected by multiple disturbances, including historical in-channel and historical and ongoing floodplain gravel mining (some leading to channel avulsions), upstream damming, and locally intense disturbances from historical gold mining. Since this reach is alluvial, many of the analysis approaches described above would be applicable. Additionally, direct measurement of bedload transport is probably more feasible in the Lower Applegate River Reach than the other reaches, and would provide information relevant to understanding downstream channel and floodplain processes as well as support the development of regional empirical estimates of bed-material flux from the Klamath Mountains geologic province. In-depth analysis of the Lower Applegate River Reach could be combined with the analyses of the Grants Pass and Merlin Reaches on the Rogue River to provide an overall assessment of key channel and floodplain processes for the Rogue River in the most densely occupied portion of the basin.

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