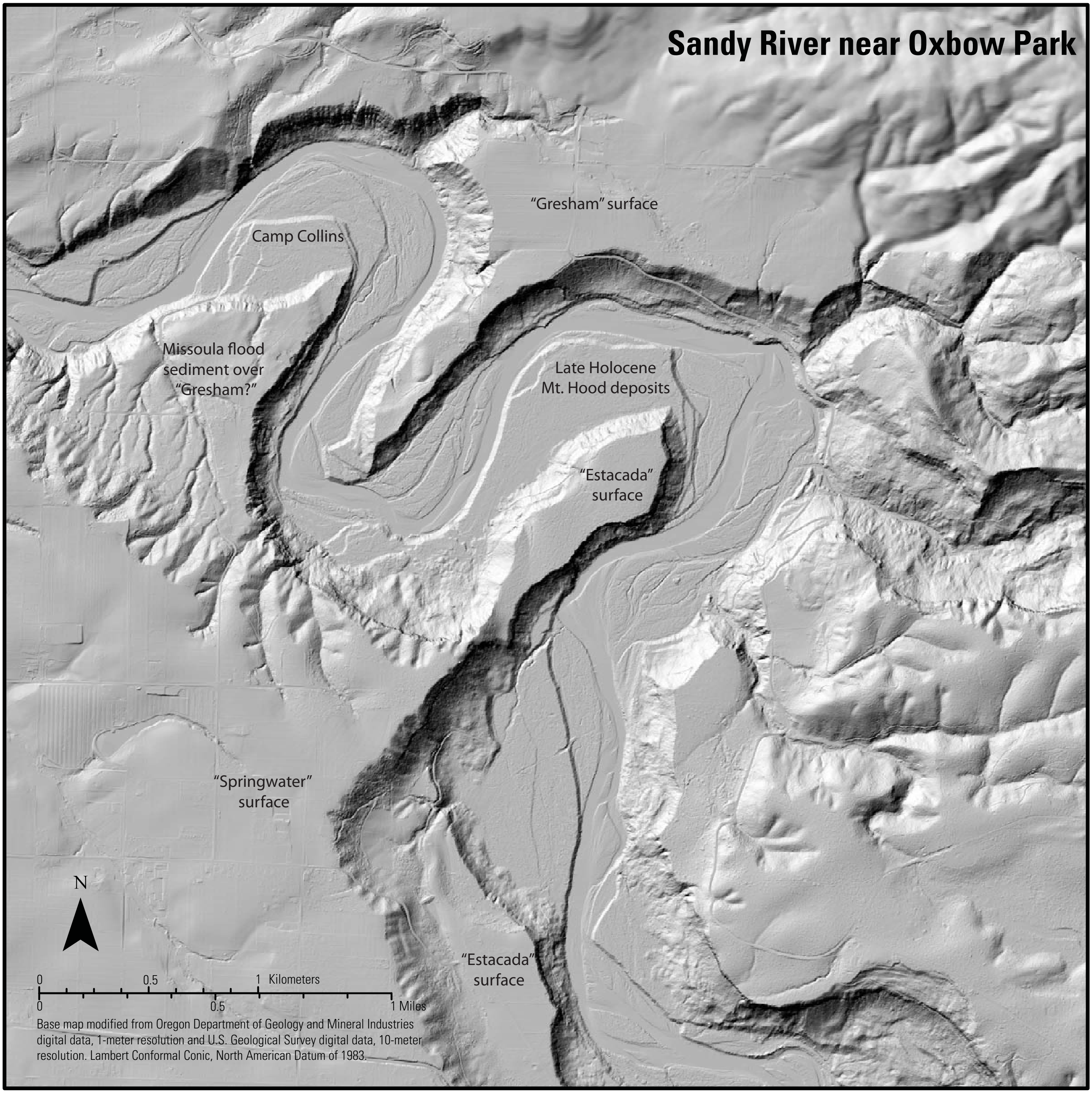


2014 Bretz Club Field Trip Materials

Sandy River, Oregon

April 10-12, 2014

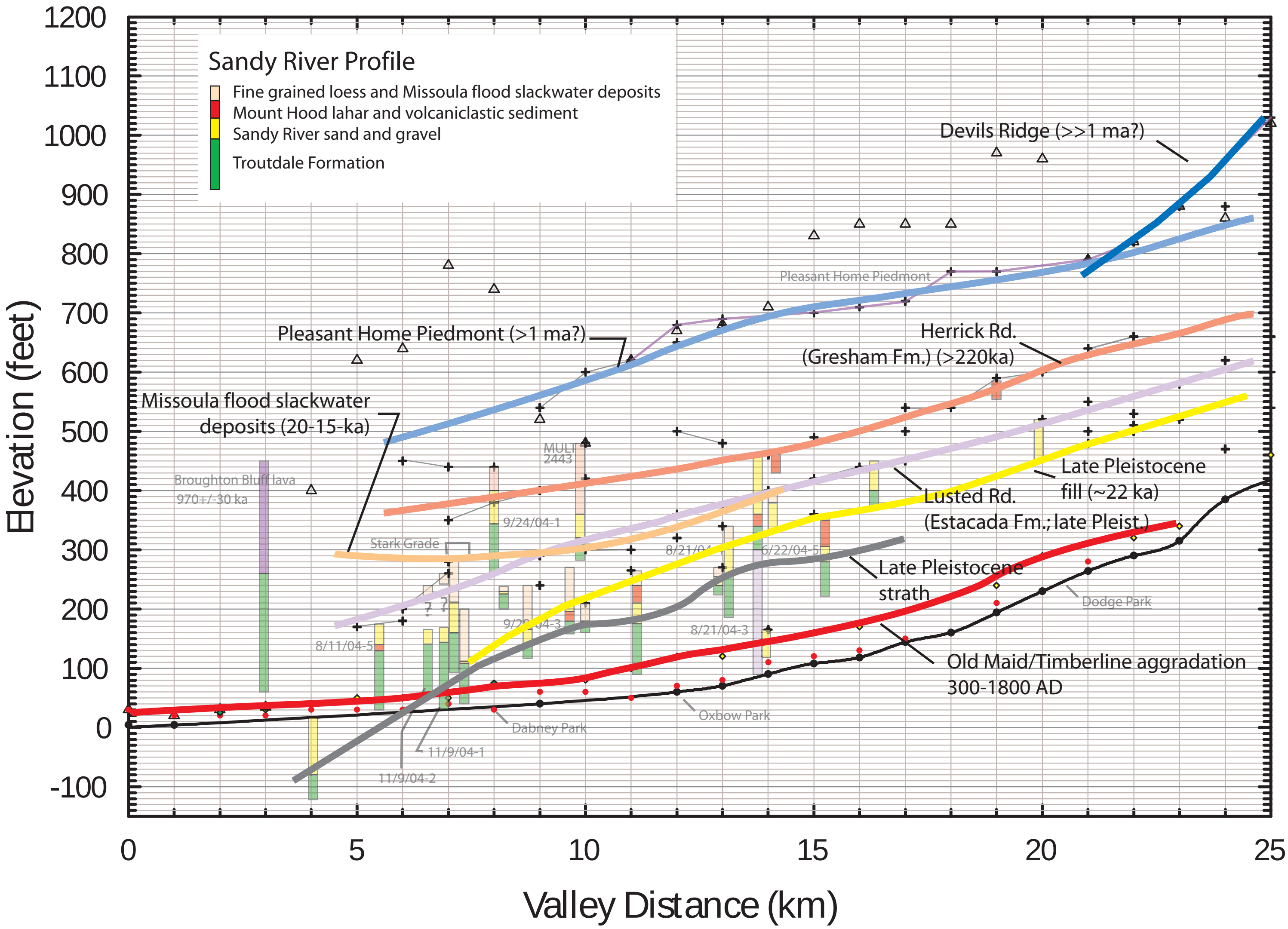
Multiple Parts

Multiple Authors

Not a citable document

Working river profile diagram
(Jim O'Connor, in slow progress)

Revised 9/26/06; 4/9/2014



Geological thumbnail, Sandy River Basin and Oxbow Park

(Jim O'Connor, Rose Wallick, Tom Pierson, USGS)

~50 ma **Birth of the Cascade Range Volcanic Arc**

12–2 ma **Cascade Range volcanism** produces broad aprons of volcaniclastic sediment (Rhododendron Formation, visible at Marmot Dam site). Later, rivers draining the young Cascades create large fans, locally overlying old Columbia River sand and gravels of the Troutdale Formation. Locally, this high surface is preserved as the Springwater Formation.

2 ma **Beginning of Pleistocene glacial ages**

1 ma **Early construction of Mt. Hood**, and other High Cascade volcanism.

1 ma **Birth of the 'modern' Sandy River.** The Sandy and Clackamas river basins separate. Episodic Quaternary incision results in the high terraces flanking the Sandy and Clackamas Rivers, some now ~700 ft above modern Sandy River.

100 ka **Mt. Hood partly collapses**, leaving scooped out north side, sending large debris flow down the Hood River. Subsequent volcanism and mountain building results in the Mt. Hood that we recognize today.

100–10ka **Multiple glacial episodes** build ice caps on Mount Hood and send valley glaciers down Sandy River. Largest extend to town of Brightwood. Glacial outwash preserved as terraces. At Oxbow Park, glacial terraces are as high as 300 ft above modern river.

20ka **Pollalie eruptive episode –** Mt. Hood eruptions send lahars to the Columbia River, covering outwash terraces now nearly 300 ft above present river elevation

12–15 ka **Missoula Floods –** dozens of mega-floods sweep down Columbia River, and *up* the lower Sandy River. Slackening backwater currents drop fine-grained sediment atop Sandy River glacial outwash. At Oxbow Park, Missoula Flood sediments cover the glacial terraces with several meters of fine sand and silt.

1.5 ka **Timberline eruptive period –** large eruptions send lahars down Sandy River to its confluence with the Columbia River. At Oxbow Park, Timberline deposits preserved as terraces as high as 85 ft above the modern river.

1781–93 **Old Maid Eruptive period –**Mount Hood dome-building eruptions send at least one lahar to Oxbow Park and beyond, and choke the lower river with huge volumes of fluvial sediment. These loose gray sandy deposits form fill terraces and bury Timberline deposits as high as 65 ft above the modern river.

1805–06 **Lewis & Clark** and crew enter the mouth of Sandy River. They call it the 'Quicksand River' because the loose sands from the Old Maid eruption formed wide sandy channels at the Columbia confluence. Their visit approximately coincides with maximum aggradation following the Old Maid eruption.

~1850: **Culmination of Little Ice Age** builds tall moraines rimming greatly expanded versions of the Sandy, Reid and Zigzag Glaciers in the Sandy River headwaters. Subsequent glacier retreat and thinning has left much of this sediment vulnerable to landsliding and downstream river transport.

1861-2011 **Large historic floods and debris flows** result in bank erosion, channel change & redistribute volcanic sediments throughout the river corridor, resulting in local aggradation. Notable floods in 1861, 1964, 1996, and 2011.

1913 **Marmot Dam constructed** near Brightwood– the pool behind the 15-m high dam quickly fills with sediment.

2007 **Marmot Dam removed**, resulting in the release of ~730,000 m^3 of stored sands and gravels. Sandy River quickly redistributes sediment.

Episodes of Extreme Syneruption Sedimentation in the Lower Sandy River

Information adapted from Pierson et al. 2009, 2011

Bretz Club, April 12, 2014 Field Trip to Oxbow Park

Overview—

Late Holocene dome-building eruptions at Mount Hood during the Timberline and Old Maid eruptive periods resulted in numerous dome-collapse pyroclastic flows and lahars that moved large volumes of volcaniclastic sediment into temporary storage in headwater canyons of the Sandy River. During each eruptive period, accelerated sediment loading to the river through erosion and remobilization of volcanic fragmental debris resulted in very high sediment-transport rates in the Sandy River during rain- and snowmelt-induced floods. Large sediment loads in excess of the river's transport capacity led to channel aggradation, channel widening, and change to a braided channel form in the lowermost reach of the river, between 61 and 87 km downstream from the volcano. The post-eruption sediment load moved as a broad bed-material wave, which in the case of the Old Maid eruption took about 2 decades to crest 83 km downstream at the Sandy delta. Maximum post-eruption aggradation levels of at least 28 and 23 m (above preexisting bed levels) were achieved in response to Timberline and Old Maid eruptions. In each case, downstream aggradation cycles were initiated by lahars, but the bulk of the aggradation was achieved by fluvial sediment transport and deposition. When the high rates of sediment supply began to diminish, the river degraded, incising the channel fills and forming progressively lower sets of degradational terraces. A variety of debris-flow, hyperconcentrated-flow, and fluvial (upper and lower flow regime) deposits record the downstream passage of the sediment waves that were initiated by these eruptions.

Figure 1. Source area for sediment on flank of Mount Hood. This debris fan accumulated sediment from numerous small lahars and pyroclastic flows.

Setting at Oxbow Park—

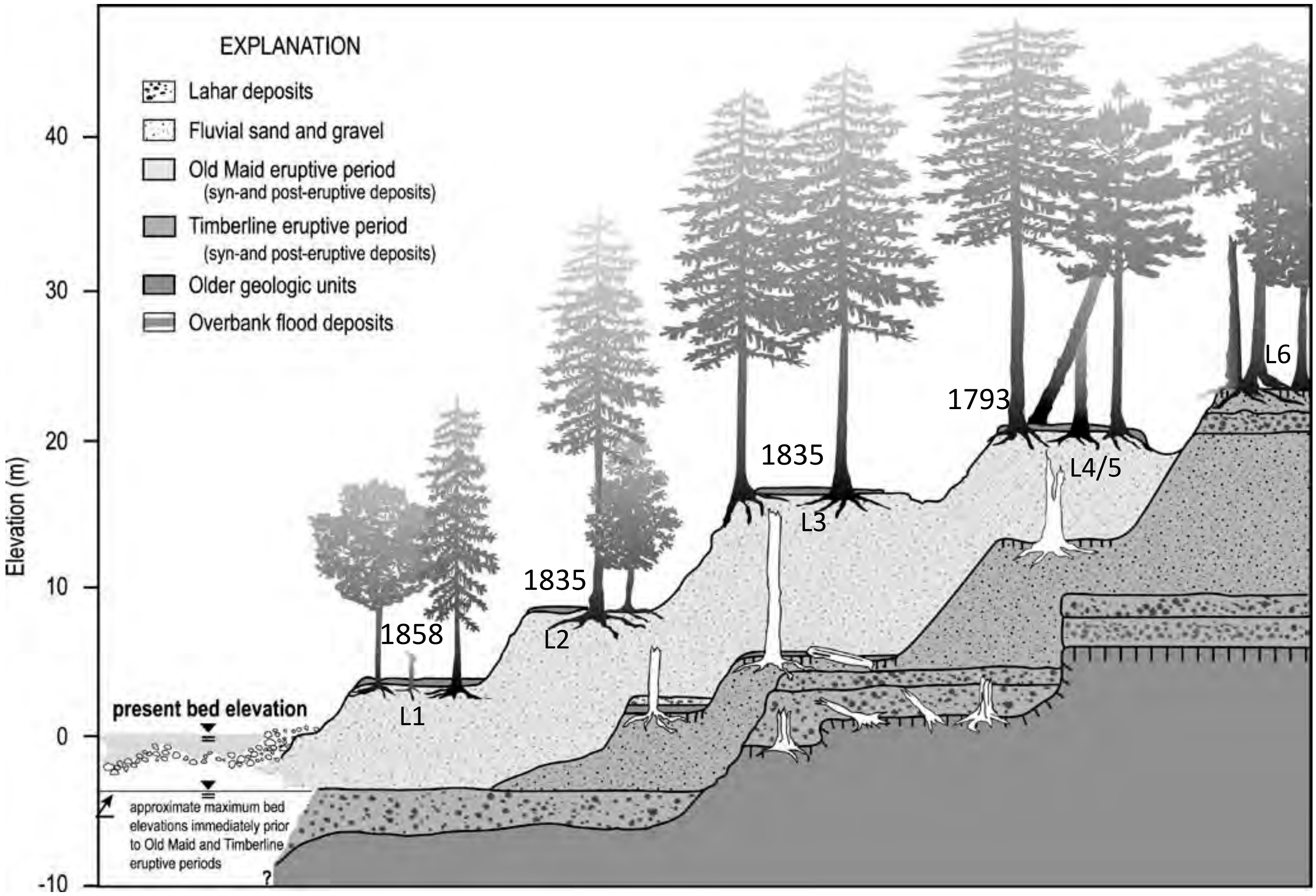


Figure 2. Dates of terrace formation (i.e., year the surface was abandoned as an active floodplain) are inferred from tree-ring dating of oldest trees growing on those surfaces (see Pierson, 2007 for methodology).

There are at least three age categories of terraces here at Oxbow Park:

- Terraces formed during and after the Old Maid eruption, now colonized by living trees (levels 1, 2, 3, 4/5).
- Terraces formed during and after the Timberline eruptive period, which had trees growing on them in AD 1781, all but the highest of which were buried in sediment within a few years of that date. Level 6 is the surviving Timberline surface.
- Terraces formed prior to the Timberline eruptive period, which had mature forest growing on them; these trees were buried and killed by Timberline activity between about AD 300–600 (stumps in river).

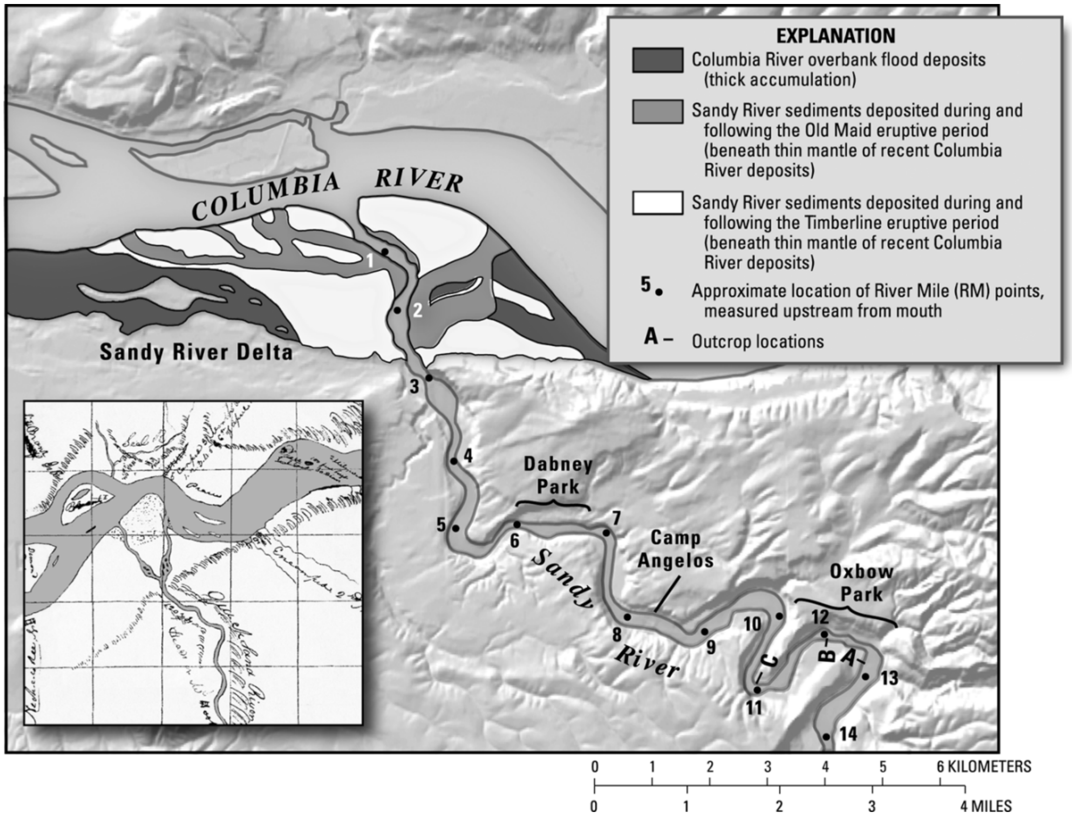


Figure 3. Location of Oxbow Park in depositional reach of the Sandy River.

Dating—

Dendrochronological dating of the Old Maid eruption reveals that the dome-building eruption lasted from AD 1781 to 1793, based on major element content of individual rings (Sheppard et al., 2010). Injuries to still-living trees allowed dating of major lahars (Pringle et al., 2010).

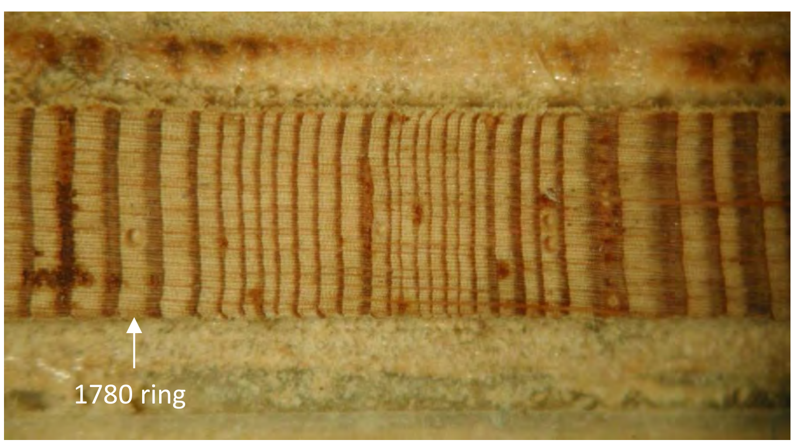


Figure 4. Tree coring showing evidence of injury to tree by the 1781 lahar.

Deposits—

The sediments composing the channel fill deposits in the response reach are dark gray, immature volcanic sands and gravels. Most of the rock types making up the sediment are the types that were erupted during the Timberline and Old Maid eruptions, although some of the volcanic sediment was remobilized from older reworked volcaniclastics and a small fraction are epiclastics. The sediments composing the highest alluvial terraces in the response reach, i.e., sediments deposited during aggradation, are dominantly cross-bedded, medium to coarse fluvial sands with minor gravel lenses. The sediments in the top few meters of the lower degradation terraces appear more gravelly and more crudely bedded. Preliminary sedimentologic data define three dominant lithofacies: The in-channel lithofacies (B and C) are.

A. Moderately to well-sorted medium to very fine sand—ripple-cross-laminated, trough-cross-bedded, and massive, commonly capped by a < 1 cm layer of silt—interpreted as overbank flood deposits.

B. Poorly to moderately sorted medium to coarse sand, locally including fine gravel—trough-cross-bedded, planar-cross-bedded, and ripple-cross-laminated—interpreted as in-channel deposits typical of shallow, braided rivers with moderate rates of sediment transport.

C. Poorly sorted coarse to very coarse sand, gravelly sand, and sandy gravel—horizontally bedded (with coarse gravel lenses), low-angle cross-bedded, and massive—interpreted as in-channel deposits typical of shallow, braided rivers with high sediment transport rates.

A

B

C

D

Figure 4. Old Maid deposits on Timberline terrace surfaces: (A) Lithofacies B; (B) Lithofacies A; (C) Lahar at base of section (even with man's midsection); (D) Lithofacies C.

A B

Figure 5. Old Maid lahar deposit sitting on lowest post-Timberline terrace (A) and reexposed forest litter on higher surface of post-Timberline terrace, which the lahar did not reach (B). Note twigs and hemlock needles (and pen) resting on this buried forest floor, engulfed by overbank flood deposits at the beginning of aggradation.

A B

Figure 6. Variation in fluvial deposits—major component of aggradational sequence: (A) Lithofacies C; (B) Lithofacies B

Timing--

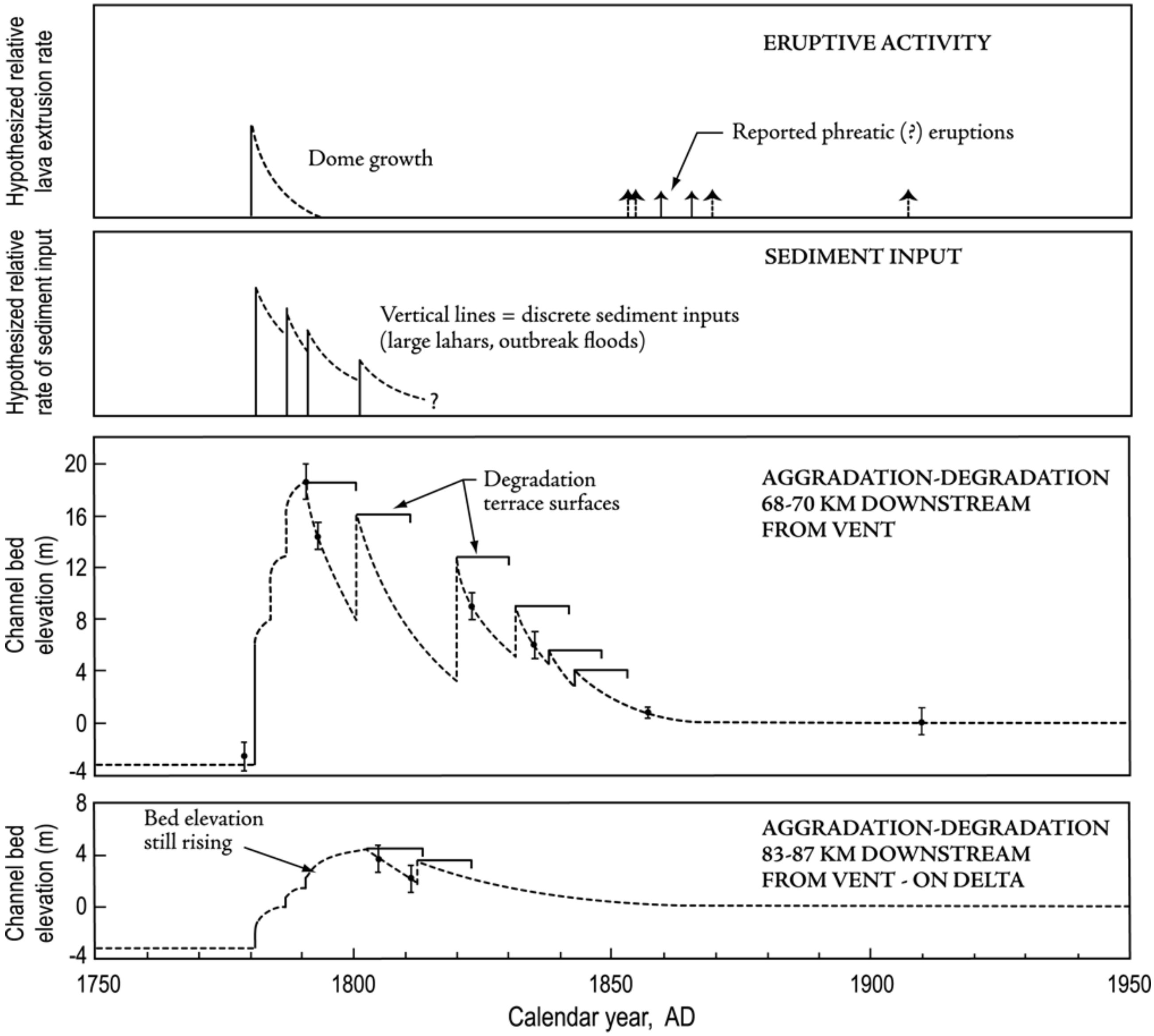


Figure 7. Timing of aggradation/degradation cycle in Sandy River.

References—

Pierson, T.C., 2007, Dating young geomorphic surfaces using age of colonizing Douglas-fir in southwestern Washington and northwestern Oregon, USA: Earth Surface Processes and Landforms, v. 32, p. 811-831.

Pierson, T.C., Scott, W.E., Vallance, J.W., and Pringle, P.T., 2009, Eruption-related lahars and sedimentation response downstream of Mount Hood: Field guide to volcaniclastic deposits along the Sandy River, Oregon, *in* O'Connor, J.E., Dorsey, R.J., and Madin, I.P., eds., Volcanoes to Vineyards: Geologic Field Trips through the Dynamic Landscape of the Pacific Northwest: Geological Society of America Field Guide 15, p. 229-244.

Pierson, T.C., Pringle, P.T., and Cameron, K.C., 2011, Magnitude and timing of downstream channel aggradation in response to a dome-building eruption at Mount Hood, Oregon: Geological Society of America Bulletin, v. 123, p. 3-20.

Pringle, P.T., Pierson, T.C., Cameron, K.A., and Sheppard, P.R., 2010, Late eighteenth century Old Maid eruption and lahars at Mount Hood, Oregon (USA) dated with tree rings and historical observations, *in* Stoffel, M., Bollschweiler, M., Butler, D.R., and Luckman, B.H., eds., Tree-Rings and Natural Hazards– A State of the Art: Berlin, Springer-Verlag, p. 487-491.

Sheppard, P.R., Weaver, R., Pringle, P.T., and Kent, A.J.R., 2010, Dendrochemical evidence of the 1781 eruption of Mount Hood, Oregon, *in* Stoffel, M., Bollschweiler, M., Butler, D.R., and Luckman, B.H., eds., Tree Rings and Natural Hazards–A State of the Art: Berlin, Springer-Verlag, p. 465–467.

Fluvial response to removal of Marmot Dam, Sandy River, Oregon

Mackenzie Keith and Jim O'Connor, adapted from Major and others, 2012

Led by Jim O'Connor, Mackenzie Keith, Gordon Grant, Lisa Ely

Bretz Club

April 12, 2014

Introduction

On 19 October 2007, a temporary cofferdam standing in place of the 15-meter (m)-tall, 50-m-wide Marmot Dam was breached, allowing the 80-kilometer (km)-long Sandy River to flow freely from Mount Hood, Oregon, to the Columbia River for the first time in nearly 100 years. At the time it was breached, it was one of the largest dam removals (in terms of dam height and stored sediment) in the United States in the past 45 years. Because the Sandy River is a sediment-rich, high-gradient mountain stream, the Marmot Dam removal provides a unique case study from which to examine a wide range of issues pertaining to sediment transport and channel evolution. This field trip will examine the fate of the former reservoir and downstream sedimentologic and geomorphic changes following dam removal.

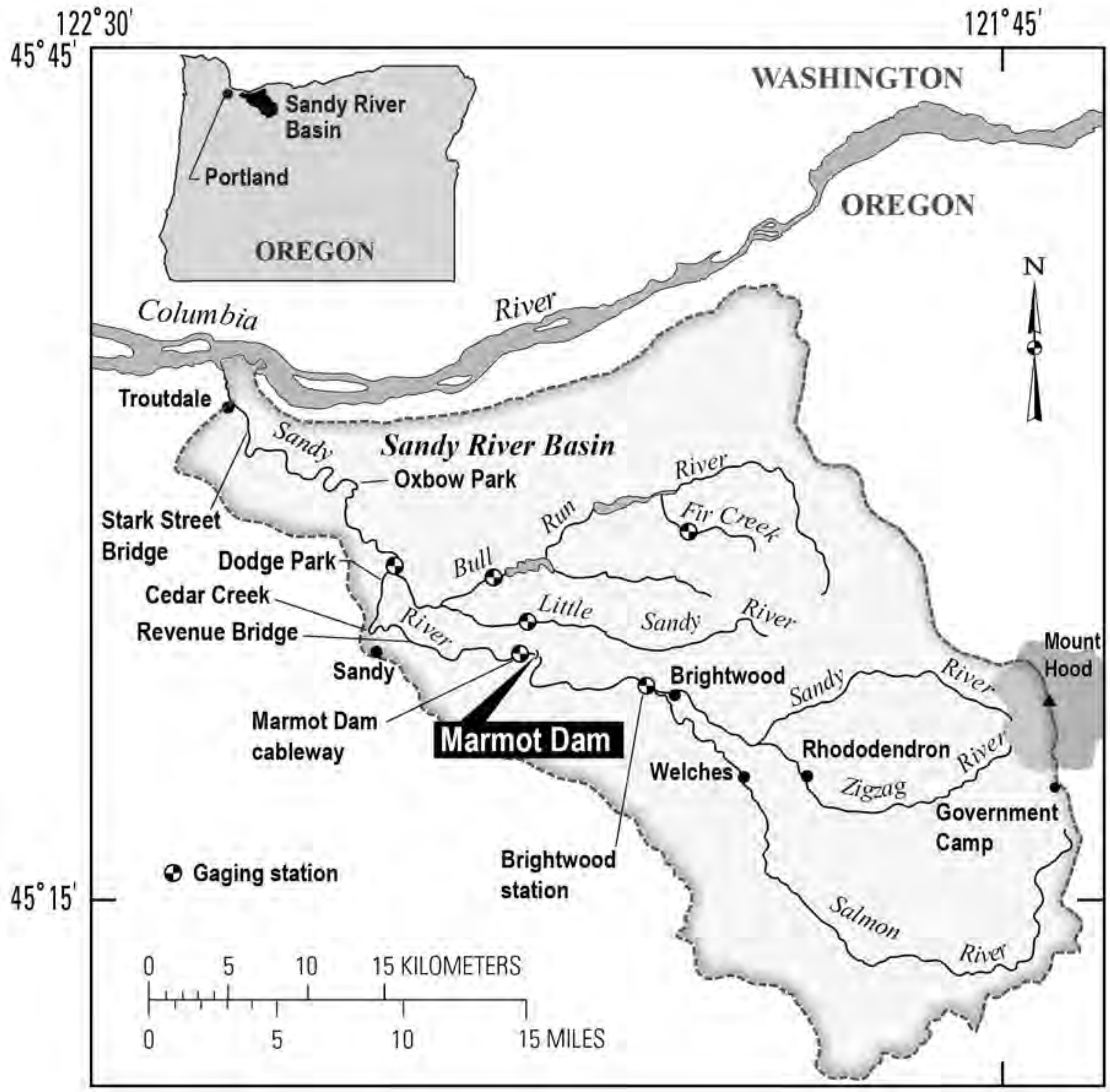


Figure 1. Location map of Sandy River Basin, Oregon, showing Marmot Dam and various sampling sites, gaging stations, and geographic locations discussed in text. Figure 1 from Major and others (2012).

Sandy River Basin

The Sandy River drains 1,300 square kilometers (km^2) of the western Cascade Range in Oregon—including the west-southwest flank of Mount Hood volcano—before joining the Columbia River 20 km east of Portland (fig. 1). The river's volcanic and glaciated headwaters produce abundant sediment, which are reflected in the river's name and in its abundant alluvial features. The Sandy River was originally named the 'Quicksand River' by the Lewis and Clark expedition in 1805 for its extensive sand deposits resulting from the 1781 Old Maid eruptive episode.

Above Marmot Dam, the Sandy River is high-gradient (~0.008 m/m) bedrock and boulder controlled channel with isolated gravel deposits; farther downstream it transitions to an alluvial river with abundant sand and gravel (Stewart and Grant, 2005; Cui, 2007). Two kilometers below the dam site, the Sandy River enters and flows through a 7-km-long, high-gradient (0.01 m/m) bedrock gorge having patchy deposits of boulder-cobble gravel and long, deep bedrock pools separated by coarse-bedded riffles and boulder rapids (Stewart and Grant, 2005). Below the gorge, the river valley widens considerably and over the 10-km-reach between the gorge and the confluence with the Bull Run River, its average gradient declines to 0.006 m/m. By the time the river reaches the Columbia, its average gradient is <0.001 m/m. Basin elevation ranges from 3,428 m at the summit of Mount Hood to 3 m at the river's confluence with the Columbia River with a mean elevation of 796 m.

The climate of the Sandy River basin is characterized by cool, wet winters and warm dry summers. Mean annual precipitation exceeds 2,000 millimeters (mm) for much of the basin (Oregon Climate Summaries, 2009). The seasonal hydrograph of the Sandy River is driven largely by prolonged rainfall during the fall and winter, augmented by spring melt of high-elevation snowpack, with the peak floods resulting from rain-on-snow events. The 2-year return interval flow is 415 m^3/s and the 100-year return interval flow is 1,425 m^3/s.

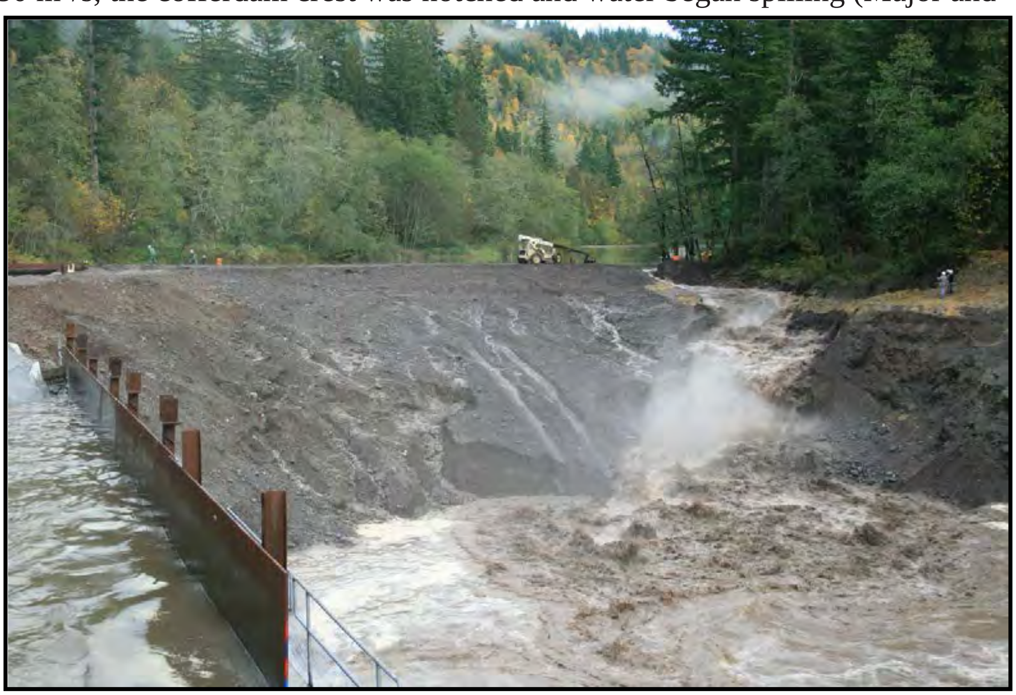
Removal of Marmot Dam

Marmot Dam was the only dam on the main-stem Sandy River and was located near the middle of the basin at RK 48.3 (fig. 1). The original dam, a rock-and-timber crib structure completed in 1913 by the Mount Hood Railway and Power Company (Taylor, 1998), was modified in 1989 resulting in a 15-m-high, 50-m-wide concrete dam. Behind the dam, a narrow, sediment-filled reservoir extended about 3 km upstream. Portland General Electric (PGE) owned and operated the dam, which diverted water from the Sandy River as part of the company's 22 megawatt Bull Run Hydropower Project, an elaborate infrastructure that delivered water from the Sandy River to a powerhouse 9 km distant using a system of canals, flumes, tunnels, and off-channel storage (Esler, 2009). In 1999, facing a 2004 expiration of its Federal Energy Regulatory Commission operating license and high anticipated costs (relative to revenue) for future maintenance and upgrading of fish passage around the dam, PGE announced it would surrender its license and decommission the hydropower project (Esler, 2009). That decommissioning culminated in the removal of Marmot Dam and associated facilities in 2007, as well as the removal of a smaller structure on the Little Sandy River in 2008.

Of the many issues surrounding the decision to remove the dam, one of the most difficult concerned handling of the sediment that had accumulated in the reservoir reach (Esler, 2009). At the time of decommissioning, the 3-km-long reservoir behind the dam was filled with nearly 750,000 m^3 sand and gravel (Squier and Associates, 2000), a volume equivalent to about 5 to 10 years of average annual sediment load. Most sediment transported by the river had been passing the dam for decades. Ultimately, PGE opted, with consensus from several local stakeholder groups and various Federal, State, and local agencies, to remove the dam as quickly as possible with minimal manual removal of stored sediment (Esler, 2009), a scenario informally termed the "blow-and-go" option. The attractive elements of this approach were its low cost and minimal in-channel disturbance during demolition. The primary drawbacks of this plan were (1) the uncertain consequences (and possible adverse effects to downstream aquatic habitat) of providing an energetic, high-gradient mountain river unfettered access to a large volume of unconsolidated, coarse-grained sediment and (2) the possibility that incomplete incision of reservoir sediment might produce a barrier to fish passage.

Heavy rainfall, a rising river, and a discharge forecast for 68 m^3/s prompted PGE to begin the breaching process at about 1000 Pacific Daylight Time (PDT) on October 19, 2007. Pumps dewatering the cofferdam and underlying sediment were removed beginning around 1200 PDT. At about 1330 PDT, water began seeping through the earthen dam and triggering small but growing mass failures on its downstream face. At about 1700 PDT, with flow approaching 50 m^3/s, the cofferdam crest was notched and water began spilling (Major and others, 2010).

The party begins….



Reservoir Erosion

Reservoir erosion resulted mainly from interactions among knickpoint migration, channel incision, and lateral erosion. Headward erosion began after an approximately 2-m-high knickpoint developed at the dam crest during breaching. The knickpoint split immediately into two arcuate knickpoints that advanced rapidly upstream at meters per minute for the first several minutes. Rapid incision associated with knickpoint passage swiftly formed a narrow channel upstream of the cofferdam along river left, a channel that maintained a nearly constant width for several hours before it progressively widened (Major and others, 2010). The migrating knickpoint advanced 150 m upstream within 50 minutes of breaching of the cofferdam but then slowed substantially, requiring more than 15 hours to advance an additional 250 m.

Within 90 minutes after breaching, the Sandy River had incised as much as 10 m vertically at the cofferdam site, and after several hours, the river formed a channel as much as 40 m wide through much of the lower 300 m of the reservoir (Major and others, 2010). The river incised the sediment at and near the cofferdam at rates as great as 12 m per hour (m/hr) in the first 2 hours after breaching. Rapid incision promoted nearly continuous collapse of meters-high vertical banks of unconsolidated fill (Major and others, 2010), leading to channel widening at rates as great as 10 m/hr. The breaching flow and ensuing 60 hours of high flow eroded approximately 125,000 m^3 of sediment from the reservoir reach. This large amount of erosion, about 17 percent of the volume of impounded sediment and approximately equal to the average annual sediment load of the Sandy River at this location, was associated with a peak flow of about 80 m^3/s—a flow just twice the mean annual river flow and only 20 percent of the 2-year return-interval discharge at this position in the basin.

The day after…..

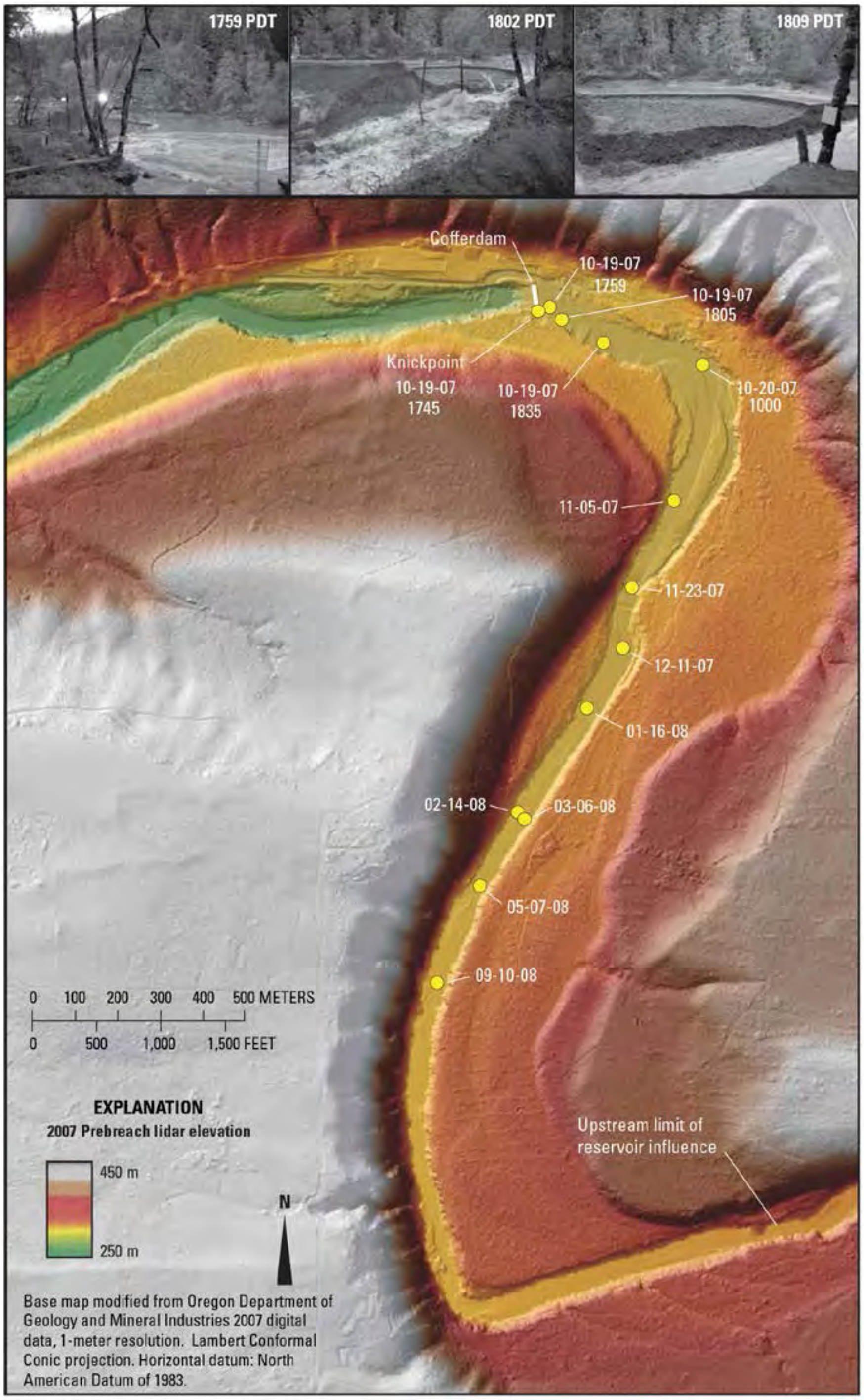


Figure 2. Knickpoint migration through the reservoir reach following breaching of Marmot Dam. Photographs taken on October 19, 2007, shortly after breaching was initiated show the remnant arcuate knickpoint that advanced toward the north side of the reservoir and the cap of fine sediment that overlies the sand and gravel that composes the bulk of the reservoir sediment. On the lidar image, dates and times of knickpoint position are shown. By October 20, 2007, the knickpoint had diminished to a low-relief riffle. Approximate position of the knickpoint riffle in February and March 2008 were obtained using a handheld Global Positioning System (GPS) during visits between reservoir surveys. Figure 10 from Major and others (2012).

After the first 60 hours, the knickpoint had evolved to a low-relief (<1 m tall) riffle several meters long. Subsequently, its rate of migration through the reservoir slowed considerably, from tens of meters per day in the first month following breaching to just a few meters per day during the 7- to 12-month period after breaching. By early November 2007, this discontinuity had migrated about 700 m through the reservoir, and by mid-December 2007, following the year's peak discharge, it had migrated about 1 km. About a year after breaching, the riffle had migrated nearly 2 km. Following large storm flows in November 2008 and January 2009, the riffle had migrated farther upstream, but had become less well defined, and its exact position was uncertain because our surveys in January and September 2009 did not reach far enough upstream. Within 2 months, nearly 40 percent of the initial sediment volume was removed. By January 2008, the magnitude and rate of erosion had slowed substantially, and after 1 year approximately half of the initial sediment volume had erode. The only subsequent episodes of substantial reservoir erosion occurred when a net volume of 43,000 m^3 was evacuated during the second year following breaching in conjunction with two large flows in November 2008 and January 2009, the latter of which exceeded the 10-yr return-period discharge. Cross section surveys indicate that much of this later erosion further widened and incised the channel, particularly between 620 m and 2,180 m upstream of the dam site. By September 2009, nearly 2 years after breaching, a total of 425,000 m^3 of sediment had been eroded—nearly 60 percent of the total reservoir volume. This volume of sediment is not an unusual load for the Sandy River, probably about double the average annual sediment load for this 2-year period.

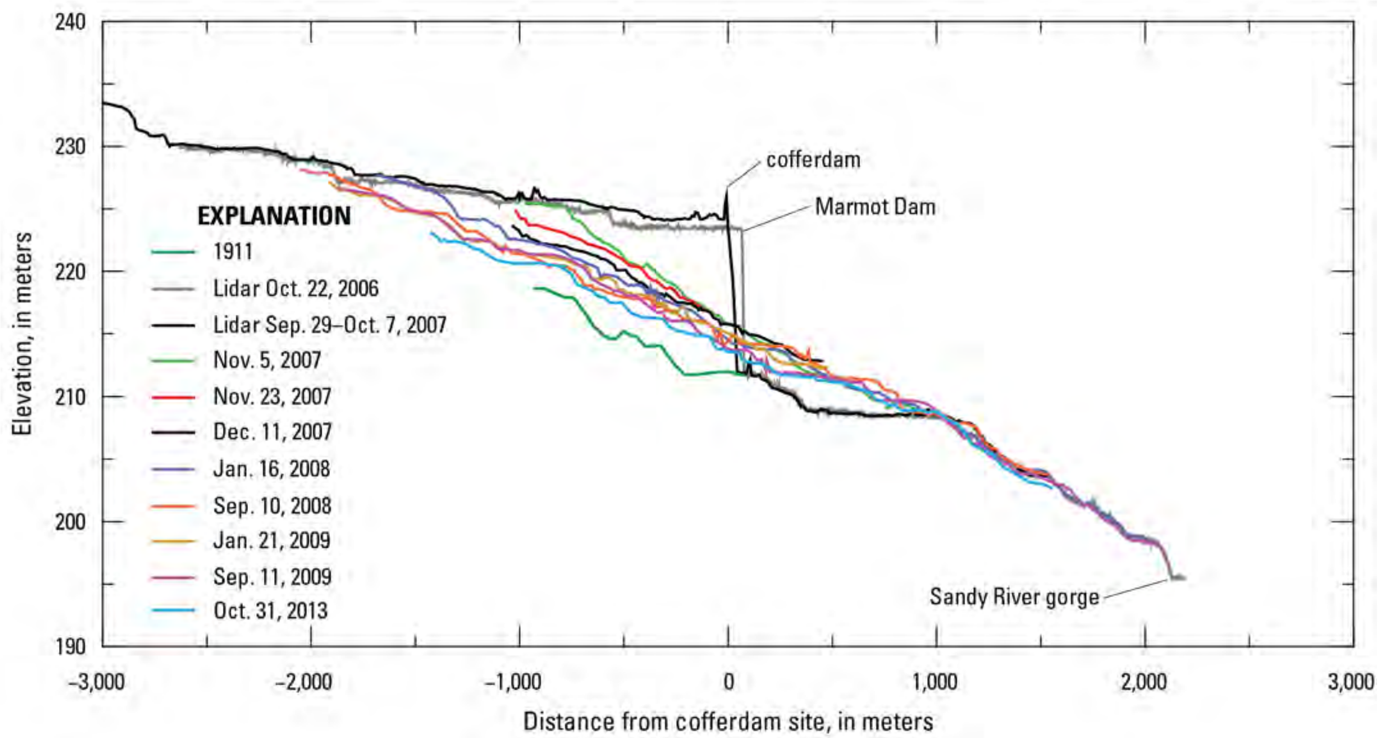
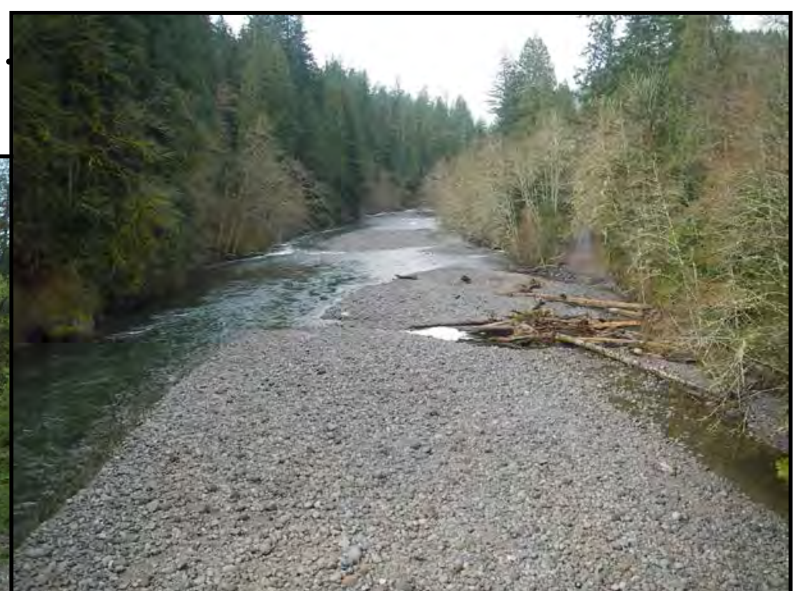


Figure 3. Longitudinal water-surface profiles of Sandy River before and after breaching of Marmot Dam. The water surfaces at times of surveys were generally within one meter of the channel thalweg. Surveyed profiles extend from about 2 kilometers (km) upstream of dam site to about 2 km downstream of dam site. The 2006 lidar profile shows the concrete structure in place; the 2007 lidar profile is of the cofferdam after the concrete dam was removed. The 1911 profile is a triangulate-irregular-network generated reconstruction of topography digitized from a 1911 partial topographic map (Portland General Electric archives) and rectified to create a pre-dam topographic surface. Modified from Figure 14 of Major and others (2012).

Before and 5 months after, from the bridge…



Sediment Deposition

After breaching, sediment eroded from the reservoir reach was deposited rapidly along the 2 km of channel and valley bottom between the dam site and the Sandy River gorge. Deposition produced a 1.3-km-long sediment wedge tapering from approximately 4 m thick at the site of the cofferdam to the prebreach channel bed at its distal end. This deposit largely maintained its form for the 2 years following breaching. Over the following 39 hours (through 1200 PDT on October 21), stage (and the channel bed) rose at an average rate of 0.063 m/hr. Consequently, the channel immediately downstream of the dam site transformed rapidly from a single thread, boulder-cobble bed to a multithread channel with a sand-and-gravel substrate flanked by mobile sandy gravel bars.

About 65,000 m^3 of sediment—50 percent of the sediment eroded from the reservoir reach in the first 60 hours—deposited in the sediment wedge formed in the 2 km of channel below the cofferdam site immediately after breaching. Channel soundings 18 km downstream showed no net aggradation during the first 60 hours following breaching, and at 9 km downstream showed only minor deposition within a month after breaching.

Surveys and soundings conducted after the initial postbreach survey of November 2007 showed diminished rates of change during the ensuing 2 years as the valley bottom between the site of the cofferdam and the Sandy River gorge evolved from an accumulation zone to a zone primarily of transport. During the first year after breaching, about 30 percent of the approximately 375,000 m^3 of eroded sediment accumulated in the 2-km-long wedge below the dam site; the remainder passed farther downstream. In the second year after breaching, as the rate of reservoir erosion declined markedly, the channel reach immediately below the dam site incised, resulting in net erosion of sediment from the depositional wedge. Differences between channel surveys in 2008 and 2009 showed as much as 1.5 meters of channel incision over a several-hundred-meter-long reach immediately downstream of the dam site and channel soundings at the Marmot Dam measurement station showed a lowering of the mean bed elevation of as much as 0.6 m between December 2007 and September 2009, and incision of the sediment wedge has continued through our last survey in October 2013.

7 November 2007, two weeks after breaching

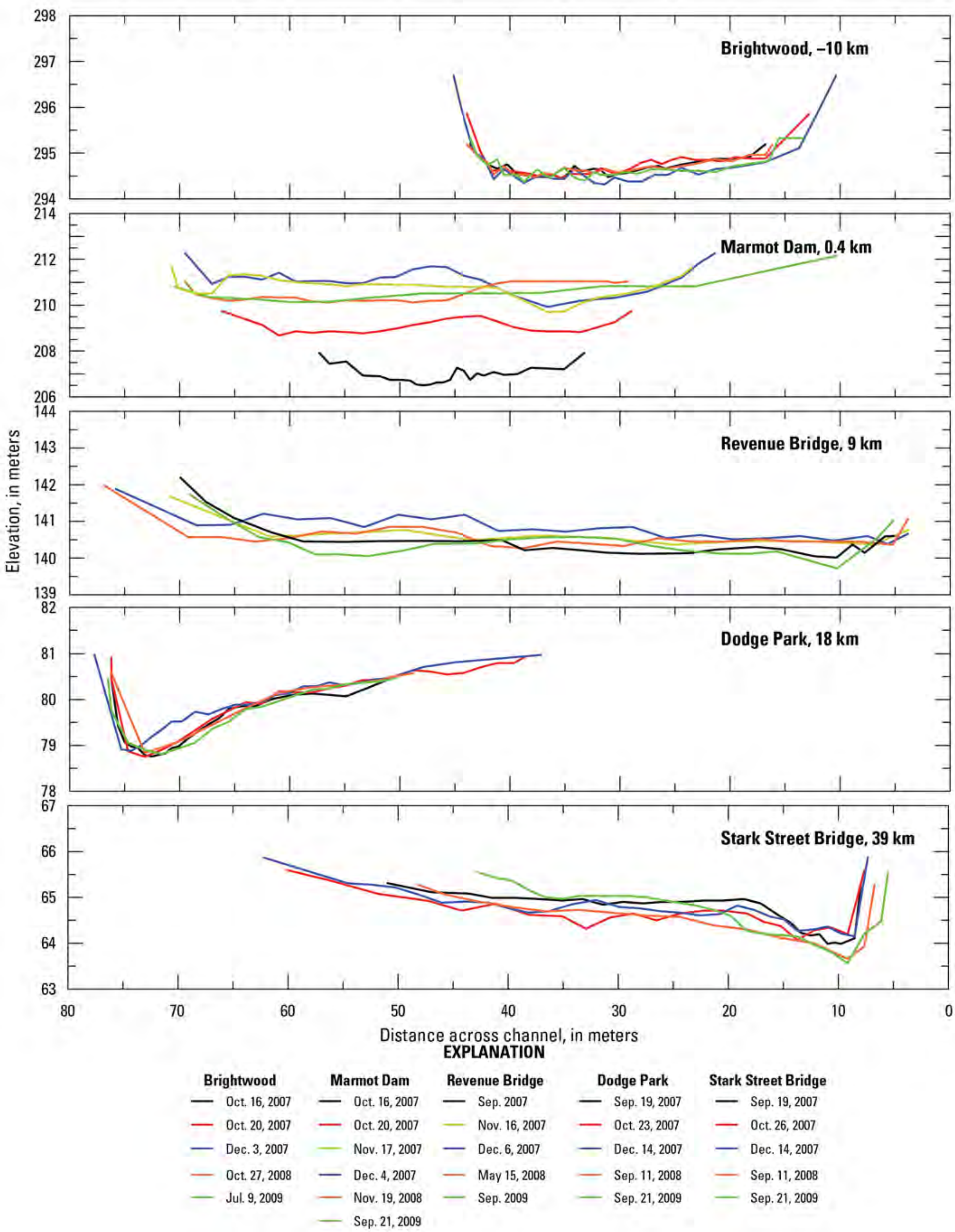


Figure 4. Time series of channel cross-section changes based on soundings at various measurement stations following breaching of Marmot Dam. See figure 1 for station locations. Figure 21 from Major and others (2012).

Sediment Transport

Suspended load-Reservoir erosion markedly increased suspended-sediment transport below the dam site for the year after breaching, but the magnitude of the transported load diminished within 18 km downstream at the Dodge Park measurement site. Upstream of the dam site, about 120,000 Mg of suspended sediment, composed of about 90 percent sand, passed the Brightwood measurement station. At the Marmot Dam station, the annual suspended-sediment load was about four times larger (about 465,000 Mg) and composed of about 80 percent sand. A similar load of suspended sediment (about 480,000 Mg) passed Revenue Bridge, 9 km farther downstream, and it was also composed of about 80 percent sand. Another 9 km downstream, however, the suspended-sediment load at Dodge Park had declined about 30 percent to about 340,000 Mg, yet remained about 80 percent sand.

The rise of sand concentrations below the dam site represents interactions among the river, its discharge magnitude, and sediment sources along the channel. The rapid rise in sand concentration at the Marmot Dam station clearly resulted from breaching of the cofferdam and erosion of sand from the reservoir. Farther downstream, interpretation of increasing sand concentration is more complicated because the higher postbreach flows would be expected to transport more sand in suspension even in the absence of erosion of reservoir sediment. The constant, high percentage of sand for all downstream sites for the remainder of WY 2008 after breaching, however, suggests that sand transport past both Revenue Bridge and Dodge Park was probably augmented by sediment supplied from the eroding reservoir. A lack of significant sediment source other than the reservoir between the dam site and Revenue Bridge bolsters this interpretation for that site. At Dodge Park, however, such an interpretation is more tenuous because the sand concentration at Brightwood (upstream of the eroding reservoir reach) also remained high and relatively constant throughout WY 2008 and because there are substantial sources of sand exposed in banks and bluffs between Revenue Bridge and Dodge Park (for example, see Bauer, 2009).

Bedload-Erosion of reservoir sediment sharply increased bedload flux below the dam site, but that increased flux diminished as the sediment migrated downstream. Our estimates of annual bedload flux indicate that about 280,000 Mg of bedload passed the Marmot Dam station during WY 2008. That flux, composed of about 55 percent (160,000 Mg) sand and 45 percent (120,000 Mg) gravel, greatly exceeded the estimated bedload entering the reservoir (170,000 Mg past Brightwood). Nine kilometers downstream, the bedload flux at Revenue Bridge had declined by about one-third (to 190,000 Mg), and consisted of about 85 percent (160,000 Mg) sand and 15 percent (30,000 Mg) gravel. The difference in fluxes above and below the Sandy River gorge appears to be mainly the result of gravel deposition, although gravel attrition owing to abrasion may have been a contributing factor. Nine kilometers farther downstream, about 35,000 Mg of bedload, which consisted of 85 percent (30,000 Mg) sand and 15 percent (5,000 Mg) gravel, passed Dodge Park. The marked loss of bedload between the exit of the Sandy River gorge and Dodge Park was likely the result of deposition owing to the reduction in river gradient along this reach. Some of that loss, however, may also be the result of gravel attrition. If the loss was due solely to deposition, and if the sediment was dispersed uniformly across the reach, the resulting deposit would average 0.05 m thick over the average floodplain width of 200 m.

The declining amounts of bedload transport with respect to water discharge at the Marmot Dam station in WY 2008 coincided with temporally increasing gravel content of the bedload. Multiple factors possibly contributed to these trends, including (1) coarsening of the reservoir channel bed in conjunction with incision of the reservoir sediment, which reduced overall sediment supply, transport rates, and sand content of bed material; (2) an overall sand content that may have been greatest in the downstream part of the reservoir (Squier and Associates, Inc., 2000), which was the source of much of the sediment initially evacuated from the reservoir reach; and (3) coarsening of the channel bed below the dam site as sand from the channel bed and bars was winnowed, which increased channel roughness.

Estimated Sediment Budget

Measurements of sediment erosion, transport, and deposition in the context of a sediment budget demonstrate three key elements of the short-term geomorphic response to abrupt sediment loading of the Sandy River channel near the site of Marmot Dam. First, the sediment flux immediately downstream of the dam site following dam removal increased substantially owing to entrainment of impounded reservoir sediment. As a consequence of nearby deposition, however, that increase did not translate downstream in its entirety. Second, the valley bottom immediately below the dam site accommodated significant sediment storage. Approximately 200,000 Mg (120,000 m^3) were stored in the 2-km-long reach between the site of the cofferdam and the entrance to the Sandy River gorge. This deposition was about evenly split between the 0.4-km-long reach between the site of the cofferdam and the Marmot Dam measurement station and the 1.6-km-long reach between the Marmot Dam station and the entrance to the gorge. Storage within the 7-km-long Sandy River gorge may account for as little as a few thousand to as much as several tens of thousands of cubic meters of sediment (as much as 100,000 Mg) released from the reservoir. Third, the 9-km-long channel reach between the exit of the gorge and Dodge Park may have stored about 250,000 Mg (~150,000 m^3) of sand and (minor) gravel. Deposition along this reach, however, had not been detected by the sparse and discontinuous measurements of channel-bed elevation made in the two years following breaching (Bauer, 2009; Podolak and Pittman, 2011).

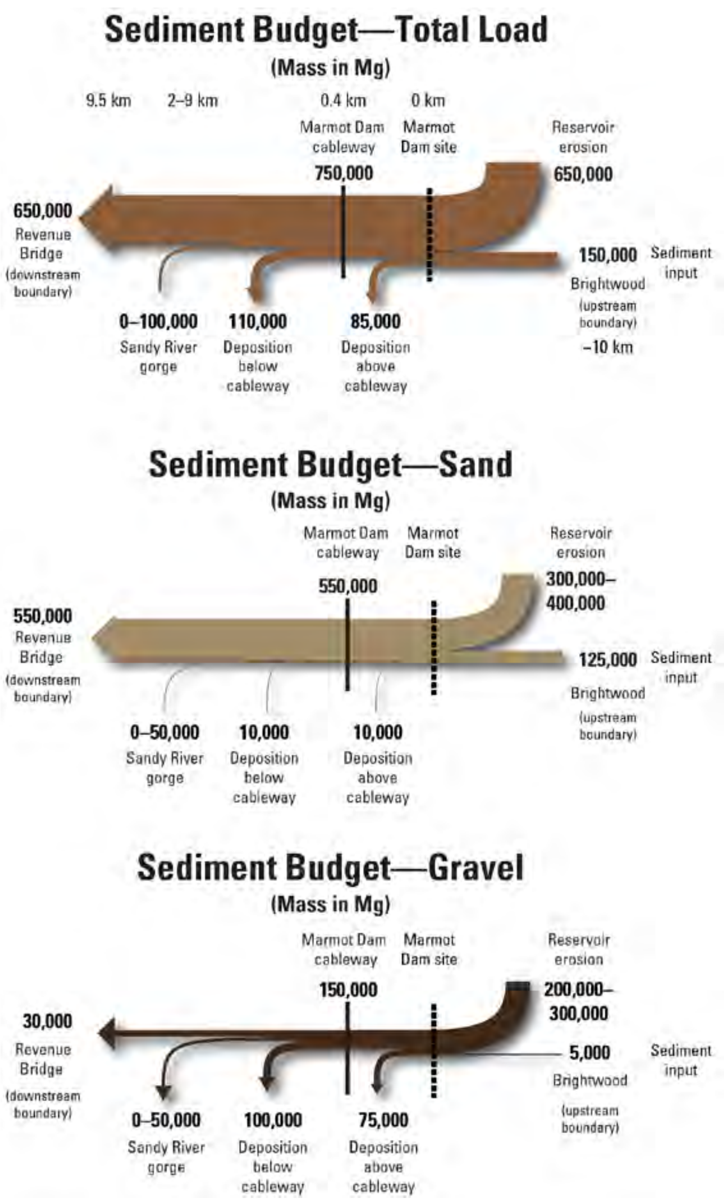


Figure 5. Schematic representations of estimated sediment budgets for total sediment, sand, and gravel eroded, transported, and deposited by the Sandy River in the vicinity of Marmot Dam during the first year following breaching of the dam in October 2007. Figure shows estimated upstream input to reservoir reach, erosion from reservoir reach, loss to depositional storage, and output at the exit of the Sandy River gorge in megagrams (Mg). Our measurements of reservoir erosion and channel deposition were converted from volume to mass assuming a bulk sediment density of 1.7 megagrams per cubic meter (Mg/m^3). Figure 35 from Major and others (2012).

References

Bauer, T.R., 2009, Profile survey of the Sandy River for Marmot Dam removal: U.S Bureau of Reclamation Report SRH-2009-44, 17 p., accessed March 26, 2012, at *http://www.usbr.gov/pmts/sediment/projects/index.html*.

Cui, Y., 2007, Examining the dynamics of grain size distributions of gravel/sand deposits in the Sandy River, Oregon with a numerical model: River Research and Applications, v. 23, p. 732-751.

Esler, J., 2009, Going, going, gone—Reflections on the retirement of the Bull Run hydroelectric project: Open Spaces, v. 9, no. 4, p. 21–25.

Oregon Climate Summaries, 2009, Oregon climate summaries: http://www.wrcc.dri.edu/summary/climsmor.html (last accessed 24 June 2009).

Podolak, C.J., and Pittman, S., 2011, Marmot Dam removal geomorphic monitoring and modeling project—Final report June 2007–October 2011: Report prepared for Sandy River Basin Watershed Council, 111 p., accessed March 26, 2012, at http://digital.library.ucr.edu/cdri/?record=1191.

Major, J.J., O'Connor, J.E., Podolak, C.J., Keith, M.K., Grant, G.E., Spicer, K.R., Pittman, S., Bragg, H.M., Wallick, J.R., Tanner, D.Q., Rhode, A., and Wilcock, P.R., 2012, Geomorphic response of the Sandy River, Oregon, to removal of Marmot Dam: U.S. Geological Survey Professional Paper 1792, 64 p

Major, J.J., Spicer, K.R., and Collins, R.A., 2010, Time-lapse imagery of the breaching of Marmot Dam, Oregon, and subsequent erosion of sediment by the Sandy River—October 2007 to May 2008: U.S. Geological Survey Data Series 521, 5 p., available at http://pubs.usgs.gov/ds/521/.

Squier Associates, Inc., 2000, Sandy River sediment study, Bull Run Hydroelectric Project (FERC Project No. 477): Final report prepared for Portland General Electric, 37 p., plus 11 figures and 10 appendices.

Stewart, G.B., and Grant, G.E., 2005, Potential geomorphic and ecological impacts of Marmot Dam removal, Sandy River, OR: Final report prepared for Portland General Electric, 70 p.

Taylor, B., 1998, Salmon and steelhead runs and related events of the Sandy River basin—a historical perspective: Report prepared for Portland General Electric December 1998, 61 p., accessed March 26, 2012, at http://www.portlandgeneral.com/community_environment/initiatives/protecting_fish/sandy_river/docs/sandy_river_history_full.pdf.