Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History
A	Coastal Lowlands Entrance-Mixing	River Km 4-23 (RM-2—RM 14)	Rare example of continental scale river entering ocean at a convergent tectonic margin; uplifting fore arc; multiple espisodes of filling and incising (and transformations between freshwater and estuarine conditions) in conjunction with eustatic sea level changes driven by Quaternary glaciation cycles.	Estuarine, aggrading river mouth, flanked by bays and tributary entrances	Entrance to Pacific Ocean, Baker Bay, Youngs Bay, Lewis and Clark River, Youngs River	• Aqueous: Shoals, Channel bottoms, channel flanks • Intertidal: Narrow wave-cut beaches, bay mud flats, flood delta sands, •Flood plain: Eolian dunes, rocky outcrops, human constructs	• 120 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low of ~120 below present sea level at ~15,000 years ago (Baker, 2002). • Continuous and episodic inputs of fluvial sediment from Columbia River basin, minor Eolian sediment from prograding beaches, minor mostly biogenic sediment from ocean, and local tributary sediment (Sherwood and Creager, 1990). • Completely freshwater environment until about 11,000 yrs BP (Baker, 2002). • Westward progradation of Holocene beaches, especially Clatsop Plains, during last 5000 yrs, 0.5 to 0.7 m/yr prehistorically; 1 to 9 m/yr after jetty construction (Woxell, 1998)

							• Subduction zone earthquake cycle (~700 years) produces repeated episodes of coseismic subsidence (of ~2 m), followed by tectonic uplift. Tsunami invasion likely within this reach. Events in A.D. 1700, ~1100 yr BP, ~1800 yr BP (Atwater and Hemphill-Haley, 1997). • Volcanogenic sediment pulses; for example A.D. 1479-82 Mount St. Helens (Kalama) eruption (has left distinctive stratigraphic marker bed in estuary; Atwater, 1994). • Historical shoaling of Baker Bay, Trestle Bay, Youngs Bay, on order of 1-2.5 cm/yr (Sherwood and others, 1990).

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History
B	Coastal Uplands Salinity Gradient	River Km 23-61 (RM 14-38)	Backfilling valley incised into uplifting accretionary fore arc range.	Opening from confined fluvial valley to estuarine bay; bay head delta, flanked by marginal bays and tributary entrances. Primary latest Holocene sand depocenter.	Mid-channel islands (Hunting, Tenasillahe, Welch, Woody, March) and shoals; Cathlamet Bay, Brix Bay, Grays Bay; tributaries Elochoman River, Skamokawa Creek, Big Creek	• Aqueous: shoals, Channel bottoms, channel flanks, sloughs and distributary and tidal channels. Channel thalweg dominated by med-coarse sand; about 86 percent of channel covered by sand waves downstream of Cowlitz confluence (Whetten and others, 1969). • Intertidal: Narrow wave-cut beaches, bay mud flats, sandy shoals, grading upriver to supratidal swampy islands with tidal channels	• ~120 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low of ~120 below present sea level at ~15,000 years ago (Baker, 2002). • Continuous and episodic inputs of fluvial sediment from Columbia River basin; local minor tributary sediment inputs.

						• Flood plain: Rocky outcrops, swampy flood plain islands, diked flood plain islands (Tenasillahe), small tributary valley fills, emergent fill, constructed levees, railroad grades. Flood plains typically at maximum (natural) elevations of less than 10 ft asl.	• Subduction zone earthquake cycle (~700 years) produces repeated episodes of coseismic subsidence and pervasive liquifaction. Events in A.D. 1700, about 1100 yr BP, and about 1800 yr BP; the A.D. 1700 event resulted in local subsidence of ~0.5 m, locally placing island surfaces back into intertidal zone (Atwater, compiler, 1994; Atwater and Hemphill-Haley, 1997). • Construction of infrequently inundated mud-capped swampy islands at sites that had been occupied by channels or subtidal bars within the last 2000 years, with average sedimentation rates (of the muddy caps) of 1-4 mm/yr (Atwater, compiler, 1994). • "along the lower Columbia River itself, a net rise [of sea level] of barely 1 m in the past 1000 years is suggested by the radiocarbon-dated *S. fluviatilis* tubers in the muddy cap at Marsh, Price, and Hunting Islands", indicating local sea-level rise rates of about 1 mm/yr (Atwater, 1994).

							• Volcanogenic sediment pulses; for example A.D. 1479-82 Mount St. Helens (Kalama period) eruptions (has left distinctive stratigraphic marker bed in estuary; Atwater, 1994). • Lateral channel migration and historical shoreline erosion, particularly of fluvial islands; up to 350m at Marsh Island, up to 250 m at Price Island (Atwater, 1994). • Historical shoaling of Cathlamet Bay (area termed "bay-head delta" by Peterson and others, 1999), Brix Bay, Grays Bay, Mid Estuary Sands, on order of 1-6 mm/yr (Sherwood and others,, 1990).

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History
C	Volcanics Current Reversal	River Km 61-103 (RM 38-64)	Bisecting eastern Coast Range, an uplifting accretionary fore arc range, filling valley incised during sea-level low stand.	Confined valley through Coast Range; upstream boundary is just downstream of Cowlitz River confluence; dominantly fluvial environment.	Large mid-channel islands (Lord, Fisher, Crims, Wallace, Puget); Cathlamet Channel (north around Puget Island), Westport Slough, Coal Creek Slough; tributaries Coal Creek, Beaver Creek and Clatskanie River; Mount Solo	• Aqueous: Multiple channels, sand bars, sloughs and distributary and tidal channels. Channel thalwegs dominated by medium to coarse sand (Sherwood and Creager, 1990); about 86 percent of channel covered by sand waves downstream of Cowlitz confluence (Jordan, 1962; Whetten et al. 1969). • Intertidal: Narrow wave-cut beaches flanking alluvial and rocky shorelines, sandy shoals, locally transitioning to supratidal swampy islands with tidal channels.	• ~100 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low of ~120 below present sea level at ~15,000 years ago (Baker, 2002). • Continuous and episodic inputs of fluvial sediment from Columbia River basin; local minor tributary sediment inputs.

						• Flood plain: Rocky outcrops, swampy flood plain islands, diked flood plain islands (Tenasillahe), small tributary valley fills, emergent fill, constructed levees, railroad and highway grades. Flood plains typically at maximum (natural) elevations ranging from 4 ft (Puget Island) to slightly higher than 10 ft asl (Fish and Lord Islands).	• Subduction zone earthquake cycle (~700 years) produces repeated episodes of coseismic subsidence and pervasive liquifaction. Events in A.D. 1700, about 1100 yr BP, and about 1800 yr BP (described by Atwater, 1994, for Wallace Island); at least four subsidence episodes recorded by auger sampling in the Clatskanie flood plain area (Peterson and others, 2003, Appendix 2).
							• Construction of infrequently inundated mud-capped swampy islands at sites that had been occupied by channels or subtidal bars within the last 2000 years, with average sedimentation rates (of the muddy caps) of 1-4 mm/yr (Atwater, 1994).
							• Volcanogenic sediment pulses; for example A.D. 1479-82 Mount St. Helens (Kalama) eruptions (has left distinctive stratigraphic marker bed at Wallace Island; Atwater, 1994); Mazama ash at 19.3 m below sea level, perhaps $\sim 100 \cdot 10^6$ m^3 of sediment input into upstream end of reach between 1980 and 1987 from early ‘80s Mount St. Helens eruptions (Gates, 1994)
							• Lateral channel migration and historical shoreline erosion, particularly of fluvial islands; up to 650 m or erosion at Wallace Island (Atwater, 1994).

							• Historical (1868-1958) shoaling of upper estuary, which includes lower part of Reach C, averaged 1.7 mm/yr (Sherwood et al., 1990).

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History
D	Western Cascades Tributary Confluences	River Km 103-119 (RM 64-74)	River trends north-northwest in Neogene structural trough corresponding with Kalama structural zone, associated with the N-S oriented Puget-Willamette Lowland, near boundary between Oregon coast Range crustal block and the Cascade volcanic arc.	Confined valley expanding into broad bottomlands at Cowlitz River confluence; upstream boundary at Kalama River confluence.	Broad bottomland at Cowlitz River confluence, Cottonwood Island, Carrolls Channel; confluence of Cowlitz River, Kalama River, Coweeman River, Goble Creek, Coffin Rock, Mt. Coffin.	• Aqueous: Channels; about 80 percent of channel covered by sand waves between Willamette and Cowlitz confluences (Whetten and others,. 1969); in-channel and near-channel rocks, sand bars, some tidal channels and back-bar sloughs, tributary rivers • Intertidal: Narrow wave-cut muddy beaches flanking alluvial and rocky shorelines, sandy shoals, locally transitioning to supratidal swampy backwater areas with tidal channels.	• ~100 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low ~15,000 years ago (Gates, 1994; Baker, 2002). • Continuous and episodic inputs of fluvial sediment from Columbia River basin; major episodic sediment inputs via Kalama and Cowlitz Rivers from Mount St. Helens eruptive activity.

						• Flood plain: Rocky outcrops, sandy but mud-capped flood plain islands, diked flood plain areas (Longview, Trojan areas), expansive tributary deltas and jointly occupied flood plain surfaces (affected by Columbia River and tributary flooding) at Cowlitz and Kalama confluences, emergent fill, constructed levees, railroad and highway grades. Flood plains typically at maximum (natural) elevations slightly higher than 10 ft asl (Cottonwood Islands).	• Subduction zone earthquake cycle (~700 years) has produced repeated episodes of flood plain liquefaction (Obermeier and Dickenson, 2000) but perhaps not significant subsidence; from studies elsewhere (Atwater et al, 1997) events in A.D. 1700, about 1100 yr BP, and about 1800 yr BP.
							• Construction of infrequently inundated mud-capped and vegetated flood plain islands at sites that had been occupied by channels or subtidal bars within the last 2000 years (for example Cottonwood Island)

							• Volcanogenic sediment pulses, especially from Mount St. Helens; for example lahars and sediment via the Cowlitz associated with the Smith Creek (3900-3300 yrs BP), Pine Creek (3000-2500 yrs BP), Castle Creek (2200-1800 yrs BP), Kalama (1479 to ~1580 AD), 1980-1986 AD eruptive periods—The Pine Creek and Kalama episodes injected vast quantities of sediment down Cowlitz and probably Kalama Rivers, building out the extensive bottomlands at confluences; the recent Saint Helens eruptions were a *small* example, but still depositing ~100 $\cdot 10^6$ m^3 of sediment input via Cowlitz R. between 1980 and 1987 from early '80s Mount St. Helens eruptions (Gates, 1994) including up to 27 m of deposition in scour hole near Coffin Rock (Haeni, 1983); eruptions predating 3000-2500 yrs BP Pine Creek eruptive phase were during times of significant lower sea level and do not clearly affect present channel morphology, but are probably important components of the valley fill downstream from the Cowlitz River confluence.
							• Lateral channel migration, locally forming bar-and-swale morphology on islands and flood plains in conjunction with natural levee deposition.
							• Likely episodes of minor aggradation and incision in response to volcanogenic sediment inputs, especially near Cowlitz and Kalama River confluences.
							• Local channel shifting and bar deposition, especially near Cottonwood Island and Carrolls Channel

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History
E	Tidal Flood Plain Basin Constriction	River Km 119-137 (RM 74-85)	River trends north-northwest in Neogene structural trough corresponding with Kalama structural zone, associated with the N-S oriented Puget-Willamette Lowland, near boundary between Oregon coast Range crustal block and the Cascade volcanic arc.	Confined northwest trending valley from Lewis River confluence to Kalama River confluence, flanked by rocky valley margins and terrace gravels.	Lewis River confluence, Woodland bottoms, Kalama delta, Deer Island, just downstream of Multnomah Channel confluence.	• Aqueous: Channels; about 80 percent of channel covered by sand waves between Willamette and Cowlitz confluences (Whetten and others, 1969); in-channel and near-channel rocks, sand bars, some tidal channels and back-bar sloughs, tributary rivers • Intertidal: Narrow wave-cut muddy beaches flanking alluvial and rocky shorelines, sandy shoals, locally transitioning to supratidal swampy backwater areas with tidal channels. • Flood plain: Rocky outcrops, sandy but mud-capped flood plain islands, Columbia River flood plains, Lewis River and Cowlitz River volcanogenic deltas thinly capped by Columbia River overbank deposits (Woodland bottomland), diked flood plain areas (Deer Island), emergent fill, constructed levees, railroad and highway grades. Woodland bottomland locally greater than 20 ft asl; most other flood plain surfaces (for example Deer Island, Martin Island less than 20 ft asl.	• ~100 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low ~15,000 years ago; valley bottom 2-3 km east of present channel (Gates, 1994; O'Connor, unpublished inferences from well logs); aggradation to near present level by about 2.5 ka. • Holocene valley fill locally flanked by Pleistocene terraces and volcanogenic deposits (Evarts, 2004b&c). • Continuous and episodic inputs of fluvial sediment from Columbia River basin; major episodic sediment inputs via Lewis River from Mount St. Helens eruptive activity, episodic sediment input from other volcanoes, including ~1.5 m deposition from 7700 yr BP Mazama eruption (Gates, 1994; Vogel, 2005).

• Subduction zone earthquake cycle (~700 years) has produced repeated episodes of flood plain liquefaction along Columbia and lower Cowlitz R. (Obermeier and Dickenson, 2000; Vogel, 2005) but perhaps not significant subsidence. From studies elsewhere (Atwater and Hemphill-Haley, 1997), documented events in A.D. 1700, about 1100 yr BP, and about 1800 yr BP.

• Volcanogenic sediment pulses, especially from Mount St. Helens; for example lahars and sediment via the Cowlitz associated with the Smith Creek (3900-3300 yrs BP), Pine Creek (3000-2500 yrs BP), Castle Creek (2200-1800 yrs BP), Kalama (A.D. 1479- ~1580), and A.D. 1980-86 eruptive periods. The Pine Creek and Kalama episodes injected vast quantities of sediment down Cowlitz and probably Kalama Rivers, building out the extensive bottomland at Woodland; Woodland bottoms primarily constructed during Pine Creek eruptive period, but aggradation during Kalama episode filled Cowlitz channel across middle of bottoms, forcing Lewis River to south; Woodland bottomlands sandy but with coating of Columbia River fine sand and silt overbank deposits (Vogel, 2005).

							• Lateral channel migration, locally forming bar-and-swale morphology on islands and flood plains in conjunction with lateral bar and natural levee deposition. Deer Island has formed by eastward river migration over last 1000 yr (O'Connor, unpublished data), leaving lower, swampy flood plain surfaces to west. • Likely shifting of main Willamette River confluence from near Lewis River confluence to present Kelley Pt. location.

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History

F	Middle Tidal Flood Plain Basin	River Km 137-165 (RM 85-102.5)	River trends north-northwest in Neogene structural trough corresponding with Kalama structural zone to north, bound to the west by Portland Hills uplift, associated with the N-S oriented Puget-Willamette Lowland, near boundary between Oregon coast Range crustal block and the Cascade volcanic arc.	Wide alluvial valley through northwest margin of Portland basin; western valley bound by basaltic uplands of Portland Hills, eastern margin bound by younger terraces and basin fill deposits; Willamette River confluence to Lewis River confluence, and includes lowermost reaches of Willamette River valley.	Willamette River confluence, Multnomah Channel, Sauvies Island, Bachelor Island, Vancouver Lake., Deer Island, Scappoose Bay, Warrior Rock, Middlelands.	• Aqueous: Channels; about 80 percent of channel covered by sand waves between Willamette and Cowlitz confluences (Whetten and others, 1969); in-channel and near-channel rocks, sand bars, some tidal channels and back-bar sloughs, tributary rivers; many season ponds in scoured bedrock areas such as Middlelands, and in lower flood plain surfaces (flood plain wetland complexes) bounded by recent scroll-bar flood plain deposition (for example Sturgeon Lake, Vancouver Lake); small linear seasonal ponds and wetlands in swales within bar-and-swale complexes.	• ~100 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low ~15,000 years ago (Gates, 1994; O'Connor, unpublished interpretation from well logs); aggradation to near present level by about 2.5 ka; rapid Columbia aggradation has outpaced Scappoose Creek and Salmon Creek sediment delivery, resulting in drowned tributary valleys such as Scappoose Bay.
						• Intertidal: Narrow wave-cut muddy and sandy beaches flanking alluvial and rocky shorelines, sandy shoals, and circuitous tidal channels within flood plain wetland complexes.	• Likely switching of main Willamette River channel from Multnomah Slough route to Kelley Point confluence in late Holocene, as a consequence of valley aggradation

						• Flood plain: Rocky outcrops, including flood plain-surrounded rocky areas such as Middlelands and Warrior Rock; pre-Holocene terrace deposits (mostly above 20 ft asl, but up to 60 ft asl near Scappoose; eolian sand accumulations, up to 70 ft asl on Sauvie Island; large flood plain wetland areas, typically separated from Columbia River by slightly higher flood plain bar-and-swale deposits; expansive diked and locally filled flood plain areas (Sauvie Island, Willamette/Columbia flood plain east of Scappoose, Vancouver Lake area, north Portland along Willamette River, west Vancouver; emergent fill, constructed levees, railroad and highway grades; bar-and-swale surfaces have elevations up to 15-30 ft asl, flood plain wetlands mostly less than 10-20 ft asl Woodland bottomland locally greater than 20 ft asl; most other flood plain surfaces (for example Sauvie Island) have elevations less than 20 ft asl.	• Holocene valley fill locally flanked by Pleistocene terraces (Evarts, 2004a).
							• Continuous and episodic inputs of fluvial sediment from Columbia River and Willamette River basins; upstream of major Mount St Helens sources of fluvial sediment, but multiple episodes air-fall tephra deposition of up to ~ 3 cm; episodic fluvial volcanogenic sediment deposition from other sources, including Mount Hood and Mazama (10.8 m thick in Willamette River channel near Linnton; Gates, 1994).

							• Subduction zone earthquake cycle (~700 years) has produced repeated episodes of flood plain liquefaction along Columbia R. (Obermeier and Dickenson, 2000) but perhaps not significant subsidence in this reach. From studies elsewhere (Atwater and Hemphill-Haley), documented events in A.D. 700, about 1100 yr BP, and about 1800 yr BP. • Volcanogenic sediment pulses, especially from Mount Mazama (via Willamette R.) and Mount Hood via Sandy River (Gates, 1994; Vogel, 2005); downstream end of reach probably pushed west and aggraded in response to major sediment inputs from Mount St. Helens via Lewis River, especially during the Pine Creek and Kalama eruptive periods (Vogel, 2005). • Lateral channel migration, locally forming prominent bar-and-swale morphology on islands and flood plains in conjunction with lateral bar and natural levee deposition inside of channel bends. Bachelor Island has formed by eastward river migration and subsequent westward avulsion over last 2500 yr (O'Connor, unpublished data), leaving lower, swampy flood plain surfaces to west and Bachelor Island slough to east. • Likely shifting of main Willamette River confluence from near Lewis River confluence to present Kelley Pt. location. • Holocene eolian dune growth on south end of Sauvie Island

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History
G	Upper Tidal Flood Plain Basin	River Km 165-204 (RM 102.5-127)	Portland basin a structural trough through which the Columbia River has flowed for at least last 20 Ma; long-term depocenter of Columbia River sediment (Evarts and others, 2009).	Wide alluvial valley through axis of Portland basin; Holocene flood plain bounded north and south by Pleistocene fluvial deposits and isolated Quaternary volcanic centers.	Sandy and Washougal River confluence at upstream end of reach, Reed, Lady, Government and Government Islands; Columbia Slough, Prune Hill, Ione Reef; Portland International Airport, much industrial development.	• Aqueous: Channels; about 45 percent of channel covered by sand waves between Bonneville and Willamette confluence (Whetten and others, 1969); sand waves with lengths of about 100 m and heights of 1.5 to 2.4 m in main channel near Reed Island (Whetten and Fullam, 1967); in-channel and near-channel rocks, sand bars, some tidal channels and back-bar sloughs, many seasonal and perennial flood plain lakes (many more so historically), lakes in scoured bedrock areas (for example Blue Lake); small linear seasonal ponds and wetlands in swales within bar-and-swale complexes. • Intertidal: Narrow wave-cut muddy and sandy beaches flanking alluvial and rocky shorelines, sandy shoals, and circuitous tidally affected channels within flood plain wetland complexes.	• ~100 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low ~15,000 years ago (Gates, 1994; Evarts and O'Connor, 2008); aggradation to near present level by about 2.0 ka; 7.7 ka Mazama tephra at 14 m below sea level at Blue Lake (Gates, 1994). • Holocene valley fill locally flanked by Missoula Flood deposits and Pleistocene terraces (Evarts and O'Connor, 2008).

							• Flood plain: Local rocky outcrops, including flood plain-surrounded rocky areas such as upstream end of Lady Island and Blue Lake area; pre-Holocene terrace and Missoula Flood deposits (near Fairview); eolian dunes, particularly in eastern part of the reach); large flood plain wetland areas, typically separated from Columbia River by slightly higher flood plain bar-and-swale deposits (for example Steigerwald Lake); expansive diked and locally filled flood plain areas (flood plain of north Portland, Hayden Island, parts of the Sandy River delta, Steigerwald Lake area); emergent fill, constructed levees, railroad and highway grades; bar-and-swale complexes have elevations locally exceeding 30 ft asl, flood plain wetlands mostly less than 10-20 ft asl. Sandy River delta up to 35 ft asl; most other flood plain surfaces have elevations less than 30 ft asl.	• Continuous and episodic inputs of fluvial sediment from Columbia River; upstream of major Mount St Helens sources of fluvial sediment, but multiple episodes of air-fall tephra deposition of up to ~ 3 cm; episodic volcanogenic sediment deposition from other sources, including Mount Hood and Mt. Mazama (Gates, 1994; Rapp, 2005).
								• Major volcanogenic sediment inputs from Mount Hood via the Sandy River, totaling $340\text{-}640 \cdot 10^6$ m^3 within the 15 km length of flood plain downstream of the Sandy River confluence. Post-Mazama Sandy River sediment contributions account for 0.7-1.4% of the post-Mazama bedload sediment volume of the lower Columbia River valley (Rapp, 2005).

							• At least three lahars (volcanic mudflows) entered the Columbia River about 1500 years ago during the Timberline eruptive episode, introducing as much as $320 \cdot 10^6$ m^3 of sediment during and in the few centuries after the eruptions as volcanogenic sediment was transported down the Sandy River (Rapp, 2005); these lahars and associated sediments built out the Sandy River delta (locally with as much as 8 m of deposits), pushing the Columbia River northward, constricting it against the bedrock and older terrace deposits of the Washington shore.
							• Significant sediment and turbidity from the Sandy River followed the Mount Hood Old Maid eruptive period of 1781 AD, leading to local aggradation of the Sandy River delta and significant sand and turbidity into the Columbia River (Rapp, 2005; Clark, 1952).

							• Subduction zone earthquake cycle (~700 years) has produced repeated episodes of flood plain liquefaction along Columbia R. (Obermeier and Dickenson, 2000) but perhaps not significant subsidence. From studies elsewhere (Atwater and Hemphill-Haley, 1997), documented events in A.D. 1700, about 1100 yr BP, and about 1800 yr BP; documented liquefaction at Sandy River confluence and on Reed Island, which may owe to the 1700 AD subduction zone earthquake (Peterson and Madin, 1997; Obermeyer and Dickenson, 2000).
							• Formation and erosion of mid-channel islands, growing from sand shoals (probably formed in the lee of large woody debris accumulations); basal radiocarbon dates from Government Island and Reed Island indicate that these islands formed in the last 500 years; stratigraphy indicates islands generally grow in downstream direction (Evarts and O'Connor, 2008; O'Connor, unpublished data).
							• Lateral channel migration, locally forming bar-and-swale morphology on islands and flood plains in conjunction with lateral bar and natural levee deposition inside of channel bends.

Reach	Name	Location (RKm)	Geologic Context	Geomorphic Setting	Important Geographic Elements	Major Landforms	Key Elements of Holocene Geology History

H	Western Columbia River Gorge	River Km 204-233 (RM 127-145)	Present gorge cut in last 3-3.5 Ma (Evarts ; major uand others, 2009) plift (and consequent river incision) during last 1 Ma; slight southward dips and diverse rock types promote large landslide complexes moving south from north valley walls. Quaternary history of large landslides, mostly involving northern valley slopes, has in general pushed river against south valley wall (enhancing waterfall formation).	Confined valley through uplifted Cascade Range, isolated small areas of flood plain and mid-channel islands.	Bonneville Dam, Bonneville Landslide at upstream end of reach; Beacon Rock, Bradford, Hamilton, Ives, Pierce, Skamania, and Sand Islands; Rooster Rock, Crown Point	• Aqueous: Channels, in-channel and near-channel rocks and cliffs, sand bars, gravelly subaqueous deltas associated with local tributaries. Gravel channel thalweg, especially at upstream end of reach; about 45 percent of channel covered by sand waves between Bonneville and Willamette confluence (Whetten and others, 1969). Some sloughs, side channels and seasonal and perennial flood plain lakes (some formed by road and rail alignments); small linear seasonal ponds and wetlands in swales within bar-and-swale complexes.	• ~100 m of valley aggradation in conjunction with sea-level rise from last-glacial sea level low ~15,000 years ago at east end of segment (Gates, 1994; Evarts and O'Connor, 2008); Holocene fill extends to at least 32 m below sea level in vicinity of Bonneville Dam (according to drill hole D-1014 of USACOE Design Memorandum no. 17, 1976); aggradation to near present level by about 2.5 ka.
						• Intertidal/power-peaking zone: Range here is very small; narrow wave-cut sandy beaches flanking alluvial and rocky shorelines, sandy shoals, and circuitous tidally affected channels within flood plain wetland complexes.	• Holocene valley fill locally flanked by Missoula Flood deposits and Pleistocene terraces (Evarts and O'Connor, 2008), but much the river is bordered by bedrock, coarse-grained alluvial fans, colluvium, and large landslide complexes (especially on the north side).

						• Flood plain: Many rocky outcrops and cliffs, including flood plain-surrounded rocky areas such as Rooster Rock, Phoca Rock, Skamania Landing area; large eolian dunes, particularly in western part of the reach); sparse flood plains and flood plain wetlands, typically separated from Columbia River by rocky outcrops, eolian dunes, highway and railroad fills, and at the upstream end of the reach, coarse-grained bars left by the ca A.D. 1450 Bonneville Landslide dam flood; historic regime flood plains have elevations less than 50 ft asl; eolian dunes to 160 ft asl; Bonneville Landslide dam flood deposits to 100 ft asl at upstream end of reach.	• Continuous and episodic inputs of fluvial sediment from Columbia River; upstream of major Mount St Helens sources of fluvial sediment, but probably multiple episodes air-fall tephra deposition; episodic volcanogenic sediment deposition from other sources, including 1.5 ka and 0.2 ka eruptions of Mount Hood via Hood River and Deschutes Rivers, and 7.7 ka Mazama eruption via Deschutes and other eastern basin rivers.

							• Bonneville Landslide dammed the Columbia River to an elevation possibly as high as 300 ft asl sometime between A.D. 1415 and A.D. 1455; blockage probably maintained for several years or decades at elevation of at least 250 ft asl, but at least partially breached prior to A.D. 1479 resulting in large Columbia River flood, with a peak flow likely in the range of 110,000 to 220,000 m^3/s (three to six times the largest historic peak of 35,100 m^3/s in 1884) (O'Connor, 2004; unpublished data); this flood (or floods) formed Bradford, Hamilton, and Pierce Islands (bouldery flood deposits core these islands); flood probably attenuated significantly downstream, but seemingly left distinctive overbank deposits up to 8 cm thick on Wallace Island (Reach C) and as far downstream as March and Brush Islands in Reach B (grey marker bed of Atwater, 1984; O'Connor and others,, 1996); diversion of river south by landslide left Greenleaf Slough as abandoned river course downstream of landslide. • Episodes of late Holocene sand dune formation and growth, forming large dunes of Sandy Island and 3-km-long dune east of Rooster Rock in the last 2500 yrs; significant sand transport to flanking valley slopes (O'Connor, unpublished data)

							• Subduction zone earthquake cycle (~700 years) has produced repeated episodes of flood plain liquefaction along Columbia R. (Obermeier and Dickenson, 2000) but no reported evidence of subsidence or liquefaction features this far upstream. • Episodic inputs of coarse-grained sediment from steep valley wall tributaries, particularly in Warrendale area where rapidly eroding south gorge wall has been shedding debris flows (for example multiple 1996 debris flows) and has built out large active fan complexes, pushing river north. • Formation and erosion of mid-channel islands (such as Skamania Island), growing from sand shoals (probably formed in the lee of large woody debris accumulations). • Limited lateral channel migration resulting very small flood plain areas (for example Franz Lake area) and alluvial islands in conjunction with lateral bar and natural levee deposition; mostly in lee of rocky valley projections into river.

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes
• Ocean Waves (Clatsop Spit and Sand Island---recurved spits from wave-induced littoral drift--(Sherwood and Creager, 1990, p. 67).	• Sand dune stabilization, beginning circa 1935.
• Eolian transport, perhaps input of more than 10^6 m^3/yr from Clatsop spit dunes (Sherwood and Creager, 1990).	• Pile dike construction; Sand Island dikes constructed 1939 (Sherwood and others,, 1990)
• Bi-directional fluvial transport, resulting in flood- and ebb-tidal deltas	• Dredging, beginning substantially in 1909, has fixed South (navigation) Channel, 1956-1998 average of $1.3 \cdot 10^6$ m^3 dredged from mouth and "inside" estuary (Gelfenbaum and others, 1999)
• Columbia River floods; 1894 flood stage 15 ft (4.5 m) asl, 1948 stage 13.1 ft (4.0 m) at Astoria (U.S. Army Engineer District Portland Flood Profiles).	• Jetty construction, beginning in 1885, resulting in spit progradation and seaward migration of maximum tidal currents; erosion of sand from main channel in entrance area and deposition in deeper ebb-tidal bar, Clatsop and Peacock Spits, and inboard flood-tidal shoals (Sherwood and others,, 1990).

• Typical seasonal flow range (as documented by difference in 1946 flood profile and Columbia River datum, is about 10 ft [3 m]); (U.S. Army Engineer District Portland Flood Profiles); 1 June 1946 peak discharge 16,500 ft^3/s approximately equivalent to 2-yr recurrence interval peak flow.	• Shoaling in flanking bays may in part owe to post-jetty sand entrainment from entrance area (Sherwood et al, 1990).
• Tidal fluctuations and currents (tidal range at Astoria ranges between 2.0 and 4.0 m; Kukulka and Jay, 2003a)	• Filling, creation of new floodplain land, and reduction of tidal prism.
• Coastal subsidence events, 1-2 m subsidence in lower estuary, followed by interseismic rebound (Atwater and Hemphill-Haley, 1987; Peterson and others, 1999))	• Irrigation depletion has reduced by flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005)
• Episodic volcanogenic inputs.	• Decreased sediment supply owing to upstream storage; 10-15·10^6 tonnes to 7.6 ·10^6 tonnes (Sherwood and others,, 1990)

• Relative sea level rise of 0.4 mm/yr according to analysis of Astoria tidal gauge, but analysis of leveling data indicates crustal uplift of 3-4 mm/yr countered by about 2.3 mm/yr of regional eustatic sea level rise (Burgette and others,, 2009), indicating relative sea level fall of 0.7 to 1.7 mm yr; crustal uplift rates measured from leveling data decline markedly eastward, crossing to net sea level rise (uplift rates less than 2.3 mm/yr) at about RKm 52 (from fig. 4, Burgette and others, 2009); historical uplift about more than compensated by episodic subsidence associated with subduction zone earthquake cycle and eustatic sea level rise. • 45% sediment load is sand (Sherwood and Creager, 1990). • Net northward longshore transport • Some ocean sediment inflow, but mostly biogenic (Sherwood and Creager, 1990) • Some tributary sediment input, esp. Youngs and Lewis and Clark Rivers (Sherwood and Creager, 1990) • Salt water intrusion generally to Tongue Pt (RM 18); under ideal conditions to RM 23.	• Flow regulation, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from $8.7 \cdot 10^6$ m^3 to $4.3 \cdot 10^6$ m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum and others,, 1999)

- Entrainment of medium to coarse silt during late ebb tide (Sherwood and Creager, 1990).

- "Local variability in sediment size reflects the local variation in modern processes" (Sherwood and Creager, 1990, p. 46)—diverse transport conditions in this reach.

- "the lower estuary displays the most sediment-size variation because of the wide range of transport processes and environments in the region." (Sherwood and Creager, 1990, p. 46)

- "the absence of coarse sand in the entrance and lower estuary, and the general fining-seaward trend exhibited in sediment size, suggests that the coarsest fraction of the fluvial sediment is not being transported through the estuary." (Sherwood and Creager, 1990, p. 47)—little bedload transport out of Columbia River estuary.

- Shoaling due to bedload transport convergence (Sherwood and Creager, 1990p. 62); long-term deposition of fines in Baker Bay and margins of Youngs Bay. Long-term deposition of coarser sediment in association with channel migration (Desdemona Sands). Long term deposition of coarser sediments in association with spit growth along north side of south jetty. (Sherwood and Creager, 1990, p. 63, fig. 33)

- Channel shifting.
- "Desdemona Sands…displays many of the characteristics of the classic flood-tidal delta model of Hayes (1975)" (Sherwood and Creager, 1990, p. 67)

- Wind-wave erosion has produced modern scarps (>0.5 m) along most exposed shorelines (Petersen and others,, 2003, Peterson and others, 2003, Appendix 2).

• At least two tsunami invasions have left up to 3 cm of sand deposits (probably from A.D. 1700 and 1100 yr BP earthquakes) at Skipanon channel entrance (Peterson and others, 2003, Appendix 2).	

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes
• Bi-directional currents at time of low river flow, resulting in locally bidirectional fluvial transport. All net transport, however, downstream directed.	• Pile dike construction, isolating large secondary channels such as Prairie, Clifton, and those in eastern Grays Bay (Sherwood and others,, 1990).
• Columbia River floods. 1894 flood stage 15 ft (4.6 m) asl at Astoria, 17 ft (5.2 m) at Skamokawa; 1948 flood stage 13 ft (4.0 m) asl at Astoria, 15 ft (4.6 m) at Skamokawa (U.S. Army Engineer District Portland Flood Profiles).	• Diking and filling of marsh and swampland; in particular Tenasillahie Island, parts of Karlson and Long Islands, as well as extensive flood plain areas near Brownsmead and southeast of Skamokawa.

• Seasonal flow range as documented by difference in 1946 flood profile and Columbia River datum at Skamokawa, is about 10 ft (3 m), with about 6.4 ft (2 m) of maximum tidal influence (U.S. Army Engineer District Portland Flood Profiles).	• Dredging has deepened and maintained present channel location, including at least $1.44 \cdot 10^6$ m^3 since 1939 between RM-25 and RM-50 (Sherwood and others,, 1990) and resulted in emergent fill areas of Rice Island, Miller Sands, Jim Crow Sands and at the head of Tenasillahe Island. “The deposition of 4 to 6 $\cdot 10^6$ m^3 of dredged material has raised the elevation of three large bars along the river channel between RM-25 and RM-40 and converted another 1.1 km^2 from intertidal flats to supratidal land.” “Additional material was moved in creating Mott and Lois Islands in Cathlamet Bay” (Sherwood and others,, 1990).
• Tidal fluctuations and currents (amplitude up to 2.5 m), mean range decreases eastward.	• Astoria Megler Bridge (?); constructed 1962-1966.
• Bedload transport by downstream sand-wave propagation (Whetten and others,, 1967; Sherwood and others,, 1990).	• Irrigation depletion has reduced by flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005)

• Coastal subsidence events (Atwater and Hemphill-Haley, 1987; Peterson and others, 1999) followed by interseismic rebound). Evidence of subsidence at March, Price, Brush, and Hunting Islands (Atwater, 1994; Takada and Atwater, 2004)	• Decreased sediment supply owing to upstream storage; 10-$15 \cdot 10^6$ tonnes to $7.6 \cdot 10^6$ tonnes (Sherwood and others,, 1990)
• Episodic volcanogenic inputs; distinct layers of fluvial sediment in flood plain island muddy caps from A.D. 1479-82 St. Helens eruptions (Atwater, 1994).	• Flow regulation and depletion, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from $8.7 \cdot 10^6$ m^3 to $4.3 \cdot 10^6$ m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum and others,, 1999)
• 20^{th} century leveling data indicate crustal uplift rates of about 3.5 mm/yr decreasing to 2-2.5 mm/yr at the eastern end of the reach, resulting in general emergence 1.2 to 0 mm/yr despite sea level rise rates of about 2.3 mm/yr (uplift rates less than 2.3 mm/yr) east of about RKm 52 (from fig. 4, Burgette and others, 2009); historical uplift about balanced by episodic subsidence associated with subduction zone earthquake cycle.	
• Net sea level rise of ~0.5 mm/yr for last 2000 years (Atwater, 1994, compiler)	

- Some tributary sediment input, especially into Cathlamet and Grays Bays (Sherwood and Creager, 1990)

- Salt water intrusion generally to Tongue Pt (RM 18); under ideal conditions (low flow, big tides) to RM 23 (Fox and others,, 1984).

- Area of "minimum energy flux divergence" (Jay and others,, 1990), resulting in sediment deposition.

- "There is an intermediate, EFD [energy flux divergence] minimum reach (about RM 13-35 [RKm 21-56]) between the fluvial and tidal reaches already described" (Jay et al, 1990).

- "Most of the medium to coarse sands entering the system from the river are permanently retained within the EFD minimum. Much of this deposition takes place upstream of the limits of salinity intrusion and is not, therefore, related to baroclimc circulatory effects. Most of the fine sands and the silts and clays entering the system are not permanently retained." (Jay and others,, 1990).

- Main depocenter of sand--“the absence of coarse sand in the entrance and lower estuary, and the general fining-seaward trend exhibited in sediment size, suggests that the coarsest fraction of the fluvial sediment is not being transported through the estuary” (Sherwood and Creager, 1990, p. 47).

- Channel migration, resulting in point-bar deposition and fluvial island and flood plain edge erosion. Northward migration of Columbia River in latest prehistoric time (Peterson and others, 2003, Appendix 2).

- Fluvial islands grow taller and in downstream direction, resulting in upstream edges that are higher and typically eroding. Downstream edges typically undergoing deposition (Sherwood and Creager, 1990).

- Wind-wave and ship-wake erosion has produced modern scarps (>0.5 m) along most exposed shorelines (Atwater, 1994; Peterson and others, 2003, Appendix 2).

• "Modern tidal flats from the exposed areas of Grays Bay, Taylor Sands, and Cathlamet Bay are dominated by active wind-wave re-suspension superimposed on tidal currents" (Peterson and others, 2003, Appendix 2).	

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes
• Tidally driven current reversal measured as far upstream as Oak Point (RKm 85) and beyond at very low flows (Clark and Snyder, 1969). All net sediment transport, however, is downstream.	• Pile dike construction, channel deepening (13 m navigation channel completed ca. 1974-75) and maintenance dredging, likely resulting in reduced channel migration, formation of emergent-fill sandy islands (many with irregular shapes) and beaches, and possibly diminished flow and shoaling in channel branches such as Cathlamet Channel, Wallace Slough, and Bradbury Slough.
• Columbia River floods. 1894 flood stage 17 ft (5.2 m) asl at Skamokawa, 24 ft (7.4 m) at Longview; 1948 flood stage 15 ft (4.6 m) at Skamokawa, 21.1 ft (6.4 m) at Longview (U.S. Army Engineer District Portland Flood Profiles).	• Diking of large tracts of flood plains and flood plain islands, including Puget Island, Little Island, Clatskanie flood plain and the Longview flood plain area. Kukulka and Jay (2003b) report a 50 percent reduction in area of shallow inundation as a consequence of diking for the reach extending between RKm 50 and RKm 90.

• Seasonal flow range as documented by difference in 1946 flood profile and Columbia River datum at Longview is about 14.3 ft (4.4 m) with about 1.1 ft (34 cm) of maximum tidal influence.	• Irrigation depletion has reduced by flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005)
• Tidal fluctuations and currents (amplitude up to 2.0 m), mean range decreases eastward; minimal tidal effects on large floods (Kukulka and Jay, 2003; U.S. Army Engineer District Portland Flood Profiles).	• Decreased sediment supply owing to upstream storage; 10-15·10^6 tonnes to 7.6 ·10^6 tonnes (Sherwood et al., 1990)
• Coastal subsidence events (Atwater and Hemphill-Haley, 1987; Peterson and others, 1999) followed by interseismic rebound). Evidence of subsidence at Wallace Island and Clatskanie flood plain (Atwater, 1994; Peterson and others, 2003, Appendix 2).	• Flow regulation and depletion, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from 8.7·10^6 m^3 to 4.3·10^6 m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum et al., 1999). Such flow regulation has reduced that flood inundated area for RKm 50-90 by ~23 percent (Kukulka and Jay, 2003b).
• Episodic volcanogenic inputs; distinct marker bed in flood plain island muddy caps from A.D. 1479-1482 St. Helens eruptions (Atwater, compiler, 1994).	

• Historic sea level rise exceeds crustal uplift, resulting in relative sea level rise of 0 to 2 mm/yr (Burgette et al., 2009).

• Some coarse-grained tributary sediment input likely, especially from Clatskanie River as well as from steep terrain flanking river.

• Energy dissipation minimum at RKm 56; "Thus, dissipation upriver of about RM-35 (km-56) is almost exclusively the result of fluvial energy flux divergence and is generally much greater than at locations further downstream" (Jay et al., 1990).

• Flood profiles markedly steeper in this reach than upstream and downstream reaches, thus probably mainly a transport reach.

• Channel migration, resulting in point-bar deposition and fluvial island and flood plain edge erosion.

• Fluvial islands grow taller and in downstream direction, resulting in upstream edges that are higher and typically eroding. Downstream edges typically undergoing deposition.

• Wind-wave and ship-wake erosion has produced modern scarps (>0.5 m) along most exposed shorelines (Atwater, compiler, 1994; Peterson and others, 2003, Appendix 2).	

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes
• Little or no periods of current reversal, except for periods of very low flow, where reversal has been detected at Cowlitz confluence (Clark and Snyder, 1969).	• Pile dike construction, channel deepening (13 m navigation channel completed ca. 1974-75) and maintenance dredging, likely resulting in reduced channel migration, formation of emergent fill sandy islands and beaches, and possibly diminished flow and shoaling in channel branches such as Carrolls Channel.
• Columbia River floods. 1894 flood stage 24 ft (7.4 m) asl at Longview, 27.4 ft (8.4 m) at Kalama; 1948 flood stage 21.1 ft (6.4 m) asl at Longview, 24.3 ft (7.4 m) at Kalama, (U.S. Army Engineer District Portland Flood Profiles).	• Significant dredging and upland fill disposal after 1980 Mt. Saint Helens eruptions (Schuster, 1981).

• Seasonal flow range as documented by difference in 1946 flood profile and Columbia River datum at Kalama, is about 16.1 ft (4.9 m) with about 0.7 ft (21 cm) of maximum tidal influence (U.S. Army Engineer District Portland Flood Profiles).	• Diking of large tracts of flood plains and flood plain islands, including Longview flood plain area (Cowlitz delta), significantly restricting overbank flooding, especially for flows less than 24,000 m^3/s.
• Tidal fluctuations and currents (amplitudes less than 1.0 m), mean range decreases upstream; little documented tidal effects on large floods (Kukulka and Jay, 2003a; U.S. Army Engineer District Portland Flood Profiles).	• Flood plain and channel confinement by railroad and highway alignments

• Episodic seismic events trigger liquefaction of flood plain sediments.	• Irrigation depletion has reduced by flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005)
• Episodic volcanogenic inputs.	• Decreased sediment supply owing to upstream storage; 10-15·10^6 tonnes to 7.6 ·10^6 tonnes (Sherwood and others,., 1990)
• Historic sea level rise of 2.3 mm/yr (in reach of little crustal uplift; Burgette and others,, 2009).	• Flow regulation and depletion, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from 8.7·10^6 m^3 to 4.3·10^6 m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum and others,, 1999).
• Some coarse-grained tributary sediment input likely from local tributaries and steep valley drainages.	• Landscape modification surrounding Trojan nuclear plant.

• Local narrow valley segment (Kalama Narrows, Carrolls Bluff) result in this reach having steepest flood profile slopes, thus probably mainly a transport reach with respect to sediment. • Narrow valley and large sediment volcanogenic inputs (creating resistant valley bottom deltas) from Kalama and Cowlitz Rivers restricts channel migration. • Local scroll-bar deposition and flood plain accretion by natural levee deposition and flow interaction with riparian vegetation. • Fluvial islands such as Cottonwood Island, under natural conditions grew in downstream direction, resulting in upstream edges that are higher and typically eroding. Downstream edges typically undergoing deposition. Although these islands have been significantly affected by pile diking and addition of fill. • Wind-wave and ship-wake erosion has produced modern scarps (>0.5 m) along most exposed shorelines.	• Removal of Mt. Coffin for jetty rock.

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes
• Probably no main-stem current reversal due to tidal fluctuations.	• Pile dike construction, channel deepening (13 m deep, 180 m wide, navigation channel completed ca. 1974-75) and maintenance dredging, likely resulting in reduced channel migration, formation of emergent fill sandy islands (especially south part of Sandy Island) and beaches, and possibly diminished flow and shoaling in channel branches such as Martin Slough and Burke Slough.
• Columbia River floods: 1894 flood stage 27.4 ft asl (8.4 m) at Kalama, 31 ft (9.4 m) asl at Columbia City; 1948 flood stage 24.3 ft (7.4 m) at Kalama, 27.3 ft (8.3 m) at Columbia City, (U.S. Army Engineer District Portland Flood Profiles).	• Diking of large tracts of flood plains and flood plain islands, including Woodland bottoms and Deer Island, significantly restricting overbank flooding, especially for flows less than 24,000 m^3/s.
• Seasonal flow range as documented by difference in 1946 flood profile and Columbia River datum at Columbia City, is about 17.8 ft (5.4 m) with less than 0.5 ft (15 cm) of maximum tidal influence (U.S. Army Engineer District Portland Flood Profiles).	• Hydropower development of the Lewis River (1931-1958) significantly diminishes sediment entering Columbia via Lewis River and perhaps frequency of overbank flow affecting Woodland bottoms.

• Mean tidal range at Kalama 80 cm; little documented tidal effects on large floods (Kukulka and Jay, 2003a; U.S. Army Engineer District Portland Flood Profiles; http://tidesandcurrents.noaa.gov); some tidal channels and sloughs.	• Irrigation depletion has reduced by flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005)
• Episodic seismic events trigger liquifacation of flood plain sediments.	• Decreased sediment supply owing to upstream storage; 10-15·10^6 tonnes to 7.6 ·10^6 tonnes (Sherwood and others,, 1990)

• Episodic volcanogenic inputs; documented voluminous sediment inputs from Mount St Helens at ~2500 and 500 yr BP, and Mazama at 7700 yr BP (Gates, 1994, Vogel, 2005).	• Flow regulation and depletion, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from $8.7\cdot10^6$ m^3 to $4.3\cdot10^6$ m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum and others,, 1999).
• Net sea level rise of ~2.3 mm/yr (Burgette et al, 2009).	
• Some coarse-grained tributary sediment input likely from local tributaries and steep rocky slopes where flanking river near Columbia City and across from Deer Island.	
• Local scroll-bar deposition and flood plain accretion by natural levee deposition and flow interaction with riparian vegetation.	
• Wind-wave and ship-wake erosion has produced modern scarps (>0.5 m) along most exposed shorelines.	

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes

• Aqueous: Channels; about 80 percent of channel covered by sand waves between Willamette and Cowlitz confluences (Whetten and others,1969); in-channel and near-channel rocks, sand bars, some tidal channels and back-bar sloughs, tributary rivers; many season ponds in scoured bedrock areas such as Middlelands, and in lower flood plain surfaces (flood plain wetland complexes) bounded by recent scroll-bar flood plain deposition (for example Sturgeon Lake, Vancouver Lake); small linear seasonal ponds and wetlands in swales within bar-and-swale complexes.	• Pile dike construction, channel deepening (13-m-deep, 180-m-wide navigation channel completed ca. 1974-75) and maintenance dredging, likely resulting in reduced channel migration, formation of emergent fill sandy islands and sandy beaches.
• Intertidal: Narrow wave-cut muddy and sandy beaches flanking alluvial and rocky shorelines, sandy shoals, and circuitous tidal channels within flood plain wetland complexes.	• Local bank protection and revetments, reducing channel migration.

• Flood plain: Rocky outcrops, including flood plain-surrounded rocky areas such as Middlelands and Warrior Rock; pre-Holocene terrace deposits (mostly above 20 ft asl, but up to 60 ft asl near Scappoose; eolian sand accumulations, up to 70 ft asl on Sauvie Island; large flood plain wetland areas, typically separated from Columbia River by slightly higher flood plain bar-and-swale deposits; expansive diked and locally filled flood plain areas (Sauvie Island, Willamette/Columbia flood plain east of Scappoose, Vancouver Lake area, north Portland along Willamette River, west Vancouver; emergent fill, constructed levees, railroad and highway grades; bar-and-swale surfaces have elevations up to 15-30 ft asl, flood plain wetlands mostly less than 10-20 ft asl	• Diking and filling of large tracts of flood plains and flood plain islands, including much of Sauvie Island, area surrounding Vancouver Lake, Columbia and Willamette River flood plain in vicinity of Portland, especially for flows less than 24,000 m^3/s; much fill in urbanized/industrial areas.
	• Dams and reservoirs (including 13 U.S. Army Corps of Engineers dams) regulate ~27 percent of the runoff and have probably significantly diminished sediment and peak flows from Willamette River basin; mostly developed by 1980.

• Irrigation depletion has reduced by Columbia River flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005) • Decreased sediment supply owing to upstream storage; 10-15·10^6 tonnes to 7.6 ·10^6 tonnes (Sherwood and others,, 1990) • Flow regulation and depletion, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from 8.7·10^6 m^3 to 4.3·10^6 m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum and others,, 1999).

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes
• No current reversal, tidal fluctuations in sloughs and and connected flood plain lakes.	• Pile dike construction, channel-margin levees, channel deepening (8.2-m-deep, 90-m-wide navigation channel above Vancouver, 2.4-m-deep, 20 m wide south of Government Island) and maintenance dredging, likely resulting in reduced channel migration, formation of emergent fill sandy islands and sandy beaches.
• Columbia River floods. 1894 flood stage 33.2 ft (10.1 m) at Willamette River confluence, 43.6 ft (13.3 m) asl at Mount Pleasant; 1948 flood stage 29.7 ft (9.1 m) at Willamette River confluence, 40.9 ft (12.4 m) asl at Mount Pleasant (U.S. Army Engineer District Portland Flood Profiles).	• Local bank protection and revetments, reducing channel migration

• Historic 2-yr flow at Vancouver about 16,000 m^3/s (565,000 ft^3/s) with stage of 22.6 ft (6.9 m) asl), giving typical seasonal flow range of 22 ft (6.7 m) as measured with respect to Columbia River datum.	• Extensive diking and filling of large tracts of flood plains and flood plain islands has reduced areas of overbank flow, especially for flows less than 24,000 m^3/s; much fill in urbanized/industrial areas, especially flood plain north of Portland. Islands may be generally getting smaller because of reduced sediment supply and channel migration.
• Flood stage profiles have decreasing gradients in this reach in conjunction with widening valley bottom, enhancing deposition.	• Diminished sand supply (from upstream trapping in reservoirs; primarily Bonneville) is possibly the explanation for lesser area of sand waves in this reach.

• Bedload transport by sand wave migration, "0 to 2 feet per day during low-water discharge to 100 to 200 feet per day during high-water discharge" (Haushild et al, 1966, p. 5); for the period Oct. 1962 to September 1963, sand transport (>0.062 mm) accounted for about 25 percent of the total sediment discharge at Vancouver (Haushild et al, 1966, p. 5).	• Rerouting of Sandy River channel within delta ca. 1935; local bank protection along lower Sandy and Washougal Rivers.
• Mean tidal range 40 cm at Vancouver; no documented tidal effects on large floods (Kukulka and Jay, 2003a; U.S. Army Engineer District Portland Flood Profiles; http://tidesandcurrents.noaa.gov); some tidally affected channels and sloughs, especially in flood plain wetland complex areas.	• Irrigation depletion has reduced by Columbia River flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005).

• Episodic seismic events trigger liquefaction of flood plain sediments.	• Decreased sediment supply owing to upstream storage; 10-15·10^6 tonnes to 7.6 ·10^6 tonnes (Sherwood and others,, 1990).
• Episodic volcanogenic inputs of sand and gravel, particularly from Mount Hood via via Deschutes, Hood, and especially the Sandy Rivers (Rapp, 2005).	• Flow regulation and depletion, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from 8.7·10^6 m^3 to 4.3·10^6 m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum and others,, 1999).
• Net sea level rise of ~0.5 mm/yr for last 2000 years (Atwater, 1994, compiler)	

- Local scroll-bar deposition and vertical flood plain accretion by natural levee deposition and flow interaction with riparian vegetation, primarily on insides of bends, followed by abrupt channel shifting (avulsions) to lower flood plain areas.

- Most fluvial islands under natural conditions migrate downstream, and are typically taller and older at their upstream ends, where they are typically eroding. Downstream edges typically undergoing deposition. Although islands in this reach have been significantly affected by pile diking and addition of fill; Lady Island position fixed by bedrock outcroppings on upstream end.

- Episodic inputs of siliceous air-fall volcanic ash from volcanic eruptions, especially from Mount St. Helens.

- Relatively energetic and high-stage floods (prior to regulation) resulted in sand deposition, particularly on outside of natural, vegetation-covered levees (Dana, 1849; O'Connor, unpublished data).

• Eolian transport of sand from exposed beaches, during low Columbia River flows, has built sandy dunes on some flood plain surfaces, especially in eastern part of reach. • Inundation of many flood plain areas set back from main channel was by groundwater flooding during high Columbia River stages (Dana, 1849). • Wind-wave and ship-wake erosion has produced modern scarps (>0.5 m) along many exposed unprotected shorelines, especially on outsides of bends.	

Important Geomorphic and Hydrologic Processes and Attributes	Anthropogenic Factors Affecting Key Physical Processes

• No current reversal, very minor tidal fluctuations in sloughs and connected flood plain lakes at low flow stages.	• Pile dike construction, and local channel deepening (project depth 8.2 m, 30 m wide) and training and maintenance dredging, likely resulting in reduced channel migration.
• “tidal influence is weaker than power peaking from Bonneville Dam” (Kukulka and Jay, 2003a).	• Local bank protection and revetments, reducing channel migration

• Typical seasonal flow range (using 1946 profile as guide) of 28 ft (8.5 m) at Warrendale, decreasing to 26.3 ft (8 m) at Mount Pleasant measured with respect to Columbia River datum (U.S. Army Engineer District Portland Flood Profiles).	• Some diking and filling of flood plain areas, particularly by fill along transportation alignments; extensive modification of islands and flood plain areas near Bonneville Dam by dam construction in early 1930s and early 1970s construction of second powerhouse.

• Columbia River floods. 1894 flood stage 43.6 ft (13.3 m) asl at Mount Pleasant, 48.9 ft (14.9 m) at Warrendale; 1948 flood stage 40.9 ft (12.4 m) at Mount Pleasant, 43.9 ft (13.4 m) at Warrendale (U.S. Army Engineer District Portland Flood Profiles).	• Likely diminished sand supply (from upstream trapping in reservoirs; primarily Bonneville), in conjunction with boat wake erosion, may be causing local shoreline erosion (Skamania Island has eroded significantly in the last few decades) as well as lesser area of sand waves in this reach.
• Flood stage profiles steep in this reach, especially at upstream end, and this reach has the greatest difference between low and high stages, owing to confined canyon and few flood plain areas.	• Flow regulation has significantly reduced annual stage variation, reducing area of exposed beaches during low flow periods and consequently reduced eolian sand transport, resulting in dune stabilization.

• Mean tidal range less than 30 cm; no documented tidal effects on large floods; some tidally affected channels and sloughs, especially in flood plain wetland complex areas, but effects of daily power peaking generally greater (Kukulka and Jay, 2003a; U.S. Army Engineer District Portland Flood Profiles; http://tidesandcurrents.noaa.gov).	• Irrigation depletion has reduced by Columbia River flow by 7% (climate change has decreased average flow volume by >7%) (Naik and Jay, 2005).
• Episodic volcanogenic inputs of sand and gravel, particularly from Mount Hood via via Deschutes, Hood, and especially the Sandy Rivers (Rapp, 2005).	• Decreased sediment supply owing to upstream storage; 10-$15 \cdot 10^6$ tonnes to $7.6 \cdot 10^6$ tonnes (Sherwood and others,, 1990).
• Net sea level rise of ~0.5 mm/yr for last 2000 years (Atwater, 1994)	• Flow regulation and depletion, reducing volume of sediment transported to reach—transport capacity to the estuary has decreased from $8.7 \cdot 10^6$ m^3 to $4.3 \cdot 10^6$ m^3 between the periods 1878-1934 and 1958-1997 (Gelfenbaum and others,, 1999).
• Flood plain and bar deposition generally controlled by canyon and bedrock outcrop geometry, and locally by dune sand accumulations; little channel migration in this reach.	

• Isolated fluvial islands (for example Skamania Island) under natural conditions migrate downstream, and are typically taller and older at their upstream ends, which are generally eroding. Downstream edges typically undergoing deposition.	
• Although not documented for this reach, episodic inputs of siliceous volcanic ash from volcanic eruptions, especially from Mount St. Helens.	
• Eolian transport of sand from exposed beaches, during low Columbia River flows, has built large sandy dunes in the Rooster Rock area; modern flow regulation has stopped this process.	
• Wind-wave and ship-wake erosion has produced modern scarps (>0.5 m) along many exposed unprotected shorelines.	