

# Geomorphic influences on sediment transport in the Willamette River

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**ABSTRACT** The erosion, transport, and deposition of coarse sediment in the lower tributaries and main stem of the Willamette River are described. Geomorphic and other physical controls on the sediment transport regime are discussed. Major natural influences include the river's recent geological history, meandering, natural streambed armoring, constraints on bedform development due to natural channel constrictions, and the presence of bedrock outcrops and old cemented gravels. Major human influences include bank stabilization revetments, gravel mining activities, and upstream reservoir regulation. Together, these influences are modifying the Willamette's channel morphology and sediment transport regime.

## THE WILLAMETTE RIVER BASIN

The Willamette River Basin encompasses an area of Western Oregon of about 31,000 square kilometers. It is bordered by the Coast Range to the west, the Cascade Range to the east and part of the Calapooya Mountains to the south. It extends northward to the Columbia River. The valley may be described in geological terms as a structural depression or downwarp with hills of moderate relief in places separating broad alluvial flats (Baldwin, 1981). The valley floor consists of lake deposits and other consolidated and unconsolidated alluvium deposited and reworked during various stages of the Pleistocene and Recent periods. The valley is surrounded by resistant volcanic and sedimentary rocks which also extend beneath the alluvial fill comprising the valley floor. The edges of the valley are covered by alluvial fans.

The Willamette River is the 12th largest river in the United States in terms of discharge. Its total runoff averages about 31 billion cubic meters (25 million acre-feet) per year. This represents over 10 percent of the average annual flow of the Columbia River.

The Willamette River has a general northward course. It has numerous tributaries from the Coast and Cascade Ranges, the drainage areas of Coast Range streams being considerably smaller than those for Cascade Range streams. The tributaries tend to flow in east-west directions from the mountains to the main-stem Willamette. The river and its main tributaries (in their lower reaches) have broad floodplains and meander belts. These tend to be larger in the southern two-thirds of the valley than in the northern end of the valley nearer to the basin outlet, where the rivers are somewhat more confined by the adjacent topography. A few tributaries in the northern third of the basin tend to flow northward across the valley floor to the Willamette once they leave the foothills.

From the foregoing speculation and from observation of the present condition of the river, some additional speculation is possible. It would appear that during roughly the past 13,000 - 18,000 years the Willamette River has been in a general state of erosion and downcutting of its bed profile. The rate of vertical channel downcutting has been significantly limited by the occurrence of the basaltic bedrock sill that forms Willamette Falls at the lower end of the valley. This has served to control the downstream end of the river's profile. Presumably, the Falls have been slowly wearing down over the centuries. Local bedrock outcrops also occur along the river upstream of the falls (e.g., near Salem, Albany, and Eugene). These have locally limited the rate of downward erosion of the river. In many other places, the Willamette Silts form eroded river banks up to 20 meters high. The river channel at the base of such cut banks, and elsewhere, has generally eroded a few feet downward into the Linn Gravels, a "tight" formation of "cemented" gravel. Apparently, the Linn Gravels have also served to limit the downward erosion of the channel.

A wealth of features is evident: terrace deposits, meander scars, oxbow lake accumulations, abandoned channels.

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## GENERAL GEOMORPHIC FEATURES OF THE MODERN WILLAMETTE RIVER

The Willamette Valley generally forms a flat surface except near the Willamette River and its tributaries. This surface is cut by meanders and flood plain terraces that are small in the upstream tributary areas and grow in lateral extent in the downstream direction. These surfaces have resulted from erosion and deposition as sediment has been reworked by the river over the last several thousand years.

The present-day Willamette River is a meandering system where channel change, bank erosion and sediment deposition are continual occurrences. The river and its main tributaries have broad flood plains and meander belts. Extensive lateral migration appears to have occurred over recent centuries, particularly upstream from Newberg. In the southern part of the valley upstream of Corvallis, the abandoned and present channels indicate that the meander zone covered a 5-mile width in some places, even though the channel itself is only about 300 feet wide. Downstream from Newberg, in contrast, the river has become entrenched in the valley floor over the centuries, with limited room for lateral meandering. The lateral movement of the Willamette appears to be limited mainly by the local occurrence of relatively resistant sediment or by bedrock outcrops near hills found on the valley floor. The river profile remains constrained from vertical erosion by the basalt sill at Willamette Falls and by local bed rock outcrops as well as by the general roughness and resistance of coarse gravels along the length of the river. The longitudinal gradient of the river can be divided into three sub-profiles: steepest upstream of Corvallis to Eugene (about 0.00071); intermediate from Corvallis downstream to Newberg (about 0.00034); and flat from Newberg to the Falls across the dredged-out Newberg Pool (about 0.00007). For most of the length of the valley, the Willamette flows nearer to the western foothills than to the eastern foothills. This may be the result of greater floods and sediment loads coming from the Cascades than the Coast Range, forcing the river away from these large tributary inputs.

A wealth of features associated with alluvial meandering are evident: terrace deposits, sloughs, eroded banks, bars, islands, meander scars, oxbow lakes, stranded trees and other debris accumulations, abandoned channels, multiple channels, and high-water channels.

## WILLAMETTE RIVER SEDIMENT CHARACTERISTICS AND TRANSPORT PROCESSES

Alluvial processes

The Willamette River and the downstream reaches of all of its tributaries have alluvial channels that consist of material quite susceptible to scour, transport, and redeposition. Both the energy of the flowing water and the size of the sediment particles present are important to such processes.

Meanders occur because part of the water's energy, as it moves downriver to progressively lower elevations, is expended not only to

overcome the frictional resistance of the channel boundary but also to scour out streambank and streambed material and to transport this in suspension or as bed load. This is especially the case during floods, when a great amount of river energy is available. The scoured sediment is transported to zones of weaker streamflow where it can again be deposited.

The meandering process and other geomorphic processes are enhanced by velocity components in directions transverse to as well as parallel with the downstream longitudinal axis of the river. These transverse velocity components help establish "secondary" currents which act with the primary downstream velocity component to produce "helical" or "spiralling" flows throughout the river. These move sediment particles laterally as they are transported in a general downstream direction. The macro-scale spiralling effects are typically found in river bends. They reverse rotational direction from one bend to the next, due to changes in centrifugal force. In general, curved flow causes water to go toward the outside of the curve, but since all of the water cannot pile up there, some water is forced back toward the inside of the curve. Because surface velocities are larger than these near the bed, a secondary flow toward the inside of the curve takes place near the bed. Spiralling flows are greatly diminished or non-existent in straight reaches of the river. However, smaller secondary currents occur at most flow obstructions along the channel, including large woody debris and large boulders or man-made structures. These form wakes and eddies and contribute to lateral erosion and sediment deposition.

If the river velocities are large, such as during floods, or if the bed and outside banks of bends are easily eroded, then the secondary currents will transport sediment laterally toward the inside of the bends. There, velocities are weaker and the sediment is redeposited. The net effect of eroding the outside, concave banks and depositing material at the inside, convex banks is to increase the degree of meandering. The whole process can be drastically altered if the bend becomes too large and is cut off at its base, either by gradual erosion that causes a "necking down" or by an abrupt avulsive change that might result from overbank flow and the carving of a pilot channel that rapidly enlarges during high water periods. When a bend is cut off, this results in locally steepening the river's gradient and initiates processes of upstream scour, downstream deposition, and general channel instability.

Many local events in the Willamette River can cause erosion-deposition situations. A toppled tree or a stranded snag can deflect currents to cause eddies in the flow, with scour in one place and deposition elsewhere. A weak bank, saturated during the rainy season, might collapse sufficiently to cause a local widening of the river, thereby reducing mid-channel velocities sufficiently to cause the growth of a bar that in turn deflects more flow against the banks, encouraging further scour and an amplification of the developing situation.

The sediment transport regime is highly dynamic, simultaneously reflecting past and present influences that have residual effects measurable in years or decades. Erosion-deposition events occur at different times and places and with different ranges of influence.

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#### Recent documentation and processes

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At any instant the river is in the midst of numerous superimposed adjustments to altering physical conditions, some of which tend to aggravate others and some of which tend to cancel out the effects of others. This makes difficult the identification of what is happening or is likely to happen.

#### Recent documentation of Willamette River characteristics and processes

An investigation of the supply, movement and replenishment of coarse sediment was conducted for the Willamette River and its principal tributaries during 1979-81 (Klingeman, 1981). This was done to obtain quantitative information on the river's sediment transport regime. The streambed was found to be well armored and stable for most river discharges. Consequently, the downstream movement of main-stem Willamette River bed material appears to be quite limited. Tributaries generally exhibit similar features to the main-stem Willamette in their lower reaches, such that replenishment of main-stem gravel from tributary sources appears to be highly dependent upon the occurrence of appreciable flood runoff, which varies greatly from year to year. Bank erosion along the main-stem Willamette may be the principal source of coarse sediment input to the river in most years. During periods of high water, bed load transport probably moves coarse sediment only relatively short distances, from banks to bars or from one bar to the next. Hence, the transport that occurs may mainly involve moving stored gravel and cobbles from one place to another within a reach.

Critical human activities that affect the river's transport of coarse sediment are construction of bank protection works, reservoir flood control operations, and sand-and-gravel extraction. Revetments limit local coarse-sediment input, reservoirs limit tributary coarse-sediment input, and gravel mining depletes coarse-sediment storage. All three affect the availability of coarse-sediment for downstream transport. Hence the sediment budget for downstream reaches is affected over time by upriver activities. Impacts may take several years to fully develop.

Streambed characteristics The bed of the Willamette River is generally coarser than had been previously reported. Earlier reports (e.g., Willamette Basin Task Force, 1969) depict a decrease of bed-sediment particle size in the downstream direction, based on mid-channel data giving median particle diameters of 55 mm, 16 mm, and 0.6 mm for the Willamette River at Springfield, Salem and Portland, respectively. But in the 1979-81 study it was observed that the typical bed material remains coarse over the entire investigated main stem from above Springfield to Willamette Falls. Representative characteristics of the bed were determined at Harrisburg, Albany, and Salem, based on composite samples taken over the full river width for a considerable length of channel. Bed material characteristics were also determined at Wilsonville, based on limited local sampling in a representative area. The median particle diameters for combined armor and subarmor bed material at those sites are 42 mm, 14 mm, 27 mm, and 19 mm in the downstream direction.

The tributaries entering the Willamette River from foothills of the Cascade Range also have very coarse bed material, similar to or coarser than that found in the main-stem Willamette. However, the tributaries entering the Willamette River from foothills of the Coast Range have finer sized gravels and considerable sand (these sizes are also found commonly in the main-stem Willamette).

Bedrock outcroppings occur at places along the main-stem Willamette near foothills (e.g., near the Adair water intake upstream of Albany). Those provide limited local sources of coarse bed material; rock fragments of various sizes are presumably broken from the outcrop by the impact of bed load and debris.

Streambank characteristics Local areas where bank erosion is active can add large volumes of coarse sediment to the river bed within a few year's time. Typical erosion zones have layers of sand and silt 0 - 6 m or more thick over gravel layers that extend up to 3 m or more above summer water levels. Erosion often extends along banks for distances of 100 - 1000 m or more and progresses into the bank at rates of 3 m/year or more. Hence, several thousand cubic meters of coarse sediment are added to the river each year due to bank erosion. Most of this coarse material appears to deposit in the bed or on bars within a short distance downstream. The coarse particles found in the bank are similar to those in the bed of the river.

Typical characteristics for an eroding bank were analyzed in detail for eight erosion zones by means of aerial photographs for the period 1936-1976. These banks added over 2 million cubic meters of sediment to the Willamette River; about half of this was gravel. The average annual sediment input per erosion zone has 7,000 cubic meters as the bank retreated 2 m per year, yielding 10 cubic meters per year per lineal meter of bank.

All actively eroding banks consisted of alluvial material. Such banks formed in past years, decades, or centuries through bar formation, channel shifting, and sedimentation during floods. These banks have only limited compaction and cohesiveness. Hence, they are highly susceptible to erosion whenever river meandering allows the flows to be redirected against them.

Some banks on the east side of the river seem to be actively eroding but actually are not, in spite of their raw appearance. Such banks tend to be 6 m or more high (above low water) and usually consist of compacted Willamette silts over the old, semi-cemented Linn gravel deposits. Evidently, these banks represent the easternmost points of river meandering over the last few thousand years, rather than more recent alluvial deposits. Signs of erosion can be found and individual gravel and cobble particles can be pried loose, but the erosion rates are small.

#### Uniformity and variability of bed material conditions

Straight or nearly-straight reaches of the main-stem Willamette River exhibit surprisingly uniform bed material features over great distances and for most of the low-flow channel width. That is, the bed material is everywhere heterogeneous but the relative proportions of different sizes are quite similar. In such areas, bars exposed by summer flows tend to have relatively smaller particle

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The greatest diversity in bed material composition is found at river reaches where channel meandering is active. Such reaches may typically be a simple curve where rapid bank erosion and point bar growth have occurred. There, the point bar will show gravel depositional patterns of arc-like nature, those more distant from the present channel becoming covered with sand. Diversity also occurs at reaches having complex changes, such as where a horseshoe bend is cut off and a series of erosion-deposition events result.

The Willamette River between RM (river mile) 135 and RM 137 is an excellent example of the latter situation. Bank erosion has occurred at variable rates for three decades upstream of a bend that was cut off circa 1950. As a result, the high-water channel is very wide. Deposition between the banks, both of locally eroded material and of bed load from upstream, has led to the formation of a group of bars. Low flows follow a major and minor channel past the bars. The bars have become vegetated, due to long periods of non-submergence and to minimal shear stresses during floods (because of the great width of the high water channel). As a consequence, bed material in some locations consists of sand, in others of pea gravel, and in still other locations of coarse gravel like that found in straight reaches.

From field observations such as just described, it appears that bed material diversity can be anticipated on the basis of channel planform shape: if the channel maintains a rather constant width and a fairly straight alignment, the heterogeneous bed material should be fairly constant in its characteristics from place to place; if channel width varies and/or the channel is quite curved, the characterizing sizes of bed material should be quite variable from place to place, with largest sizes in zones of strongest currents.

River reaches where bed material characteristics are spatially highly variable are likely to be reaches where sediment "sources" and sediment "sinks" occur -- bank erosion and bar growth. It may be that some such reaches are zones of net accumulation and storage of bed materials. It was observed that for short reaches where previously eroding banks are now revetted and the opposite-bank point bars have been scalped to low water levels, net accumulation occurs.

Required discharges for bed load transport Field data were obtained on the hydraulic characteristics of river reaches to supplement the data on bed material characteristics for calculation of incipient motion and general bed material transport. Various analytical techniques are available which relate particle size to critical shear stress and which relate bed load transport rate to water discharge rate. However, it was found that the different formulas produced a wide range of results, such that a reliable bed load function could not be determined by calculations alone.

Field measurements of bed load were attempted during January-April 1980, but little transport occurred at the prevailing

discharges. Hence, data could not be obtained to show bed load transport in different parts of the Willamette River.

Nevertheless, the armored condition of the streambed and the limited field observations of bed load transport (or its absence) demonstrated that the required river discharges for initiating bed load transport exceed the mean annual flow of the river reach by a factor of two or more. Such discharges occur during only a small part of each year. During winter 1979-80 they were exceeded for only a few days.

Tributary gravel production The Santiam, North Santiam, and South Santiam Rivers provide interesting examples of the availability of gravel from tributaries of the Willamette. Detroit and Foster Dams intercept bed load from upper-basin source areas on the North and South Santiam Rivers, respectively. Thus, the reaches downstream of these dams have no up-river gravel input. The channels are dominated by bedrock outcroppings for several miles. Small source areas of gravel occur along narrow alluvial zones. Low diversion dams block each channel downstream of the large dams and intercept much of the limited gravel supply. Tributary streams tend to be dominated by bedrock outcroppings and to yield only small amounts of gravel. Not until the rivers reach the alluvial fringes of the main Willamette Valley does gravel become abundant. Meandering, bank erosion, and gravel bar formation then become ongoing processes. Below the confluence of the North and South Santiam, the Santiam River resembles the Willamette River upstream of Harrisburg, although somewhat narrower. Bedrock outcroppings occur until the last foothills are passed between Jefferson and Interstate Highway 5.

In terms of gravel budgets, it appears that the North and South Santiam Rivers below Detroit and Foster Dams, respectively, have small inputs and moderate outputs of gravel, the differences being made up by material taken from storage at river banks and bars. Some of the stored material undoubtedly originated upstream of the dams, prior to their construction, from source areas now blocked from providing replenishment gravel. Hence, a net natural "mining" of the lower North and South Santiam Rivers now appears to be occurring.

For the main Santiam River, it appears that the gravel input from its tributaries is still able to balance gravel output to the Willamette River. Hence, only relatively minor changes are believed to be occurring in the amount of gravel in storage.

The annual rate of gravel movement through the Santiam, North Santiam, and South Santiam Rivers is believed to be lower now than in years prior to completion of Detroit and Foster Dams. Altered flow duration curves and reduced flood peaks from reservoir flow regulation are the principal causes. The bed load transport rate is exponentially related to the water discharge rate; hence, the bulk of annual bed load transport occurs during a very few days of large discharge. If, for example, peak flood discharges are halved by reservoir regulation, the concurrent bed load transport rates will be more than halved. Furthermore, the increased proportion of time for moderately large flows, during partial reservoir evacuation following peak storm runoff, does not appear to adequately

compensate for the peak regulation.

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#### HUMAN INFLUENCES ON CHANNEL CHANGE AND SEDIMENT TRANSPORT

Today, all major population and industrial centers of the Willamette Basin — Portland, Salem, Albany, Corvallis, Eugene, Springfield — and most smaller centers are situated along the Willamette River or its tributaries. Many of these were established during the early days of the Oregon Territory, when rivers were a principal (and sometimes the only) link between the settlements.

Erosion, channel changes, and floods have generally adversely affected human settlement and use of the Willamette Valley near the river. Therefore, the most significant human activities concerning the river have been directed at controlling these natural processes.

Measures at channel stabilization along the main stem of the Willamette over the past century have mainly consisted of snag removal, temporary flow deflectors, bank revetments, pile dikes, spur dikes, dredging and similar measures. Today, the river still flows in a generally unconfined manner except for numerous revetments along the outside of bends to restrict further local migration of the channel. The hydrology of the river has also been modified due to flow regulation by 13 federal dams and several other smaller dams, all on tributaries of the main-stem Willamette.

The result of channel stabilization activities and upstream impoundments upon the gravel transport regime in the Willamette has been the subject of much speculation and opinion based upon scattered fragments of information that have never been gathered together for comprehensive evaluation. For instance, a study of streamflow records showed that recent streambed degradation was occurring along the main-stem Willamette River at a rate of about 1 foot per decade. The lower McKenzie River was found to be locally degrading by 6 feet in the 26 years of record analyzed. (Klingeman, 1973). Another study showed that channel stabilization activities has significantly reduced the number of multiple channels upstream of Harrisburg (Sedell and Froggatt, 1984).

Boating and navigation uses of the river have resulted in a considerable amount of gravel dredging of shoals and dredge spoil disposal in the past. Sand-and-gravel removal from the river for construction materials has also been commonplace over the years. These activities have generally had local effects on the river's physical processes.

#### CONCLUSIONS

The geomorphic features of the Willamette River continue to reflect the longer term dynamic natural processes common to coarse-bedded alluvial rivers. Nevertheless, human activities have produced severe local changes and more-subtle changes over extensive distances. The river's planform has become stabilized, there is a trend of reduced channel complexity, and streambed degradation is



indicated. A complex system is slowly becoming altered and more-simplified through a wide range of human activities.

#### REFERENCES

- Baldwin, E.M. (1981) Geology of Oregon, 3rd ed. Kendall-Hunt, Dubuque, Iowa.
- Balster, C.A., & Parsons, R.B. (1968) Geomorphology and Soils, Willamette Valley, Oregon. Agriculture Experiment Station, Oregon State University, Special Report 265.
- Klingeman, P.C. (1973) Indications of Streambed Degradation in the Willamette Valley, WRR1-21, Water Resources Research Institute, Oregon State University, Corvallis, Oregon.
- Klingeman, P.C. (1981) Willamette River Sediment Transport Investigation, Draft Project Completion Report, Water Resources Research Institute, Oregon State University, Corvallis, Oregon.
- Sedell, J.R. & Froggatt, J.L. (1984) Importance of Streamside Forests to Large Rivers: The Isolation of the Willamette River, Oregon, U.S.A., from its Floodplain by Snagging and Streamside Forest Removal. Verh. Int. Ver. Limnol., V. 22, pp. 1828-34.
- Willamette Basin Task Force. (1969) Pacific Northwest River Basins Commission, The Willamette Basin Comprehensive Study of Water and Related Land Resources; Appendix B Hydrology, Vancouver, Washington.

#### NOTATION

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b	expone
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D	mean w
f	expone
H	basin
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