A Novel Approach for Evaluating Optimal Groundwater–Surface Water Discharge Monitoring Periods for Source Control Evaluation in Portland Harbor

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Diurnal tidal fluctuations in the Willamette River propagate into upland groundwater with a variable time lag, which interferes with the accurate assessment of hydraulic gradients, and thus, groundwater discharge.

Background

- To assess groundwater source control, responsible parties in the Portland Harbor Superfund Site (PHSS) are conducting groundwater seepage studies to evaluate groundwater discharge and chemical flux from upland sites to PHSS sediment. The results will be used to assess the recontamination potential from groundwater and to inform remedial design.
- The PHSS is located near the confluence of the Willamette and Columbia rivers and is affected by daily and seasonal variations in river stage.
- Groundwater discharge (Q) is calculated using Darcy's law:

  $Q = -KiA$

  K = hydraulic conductivity

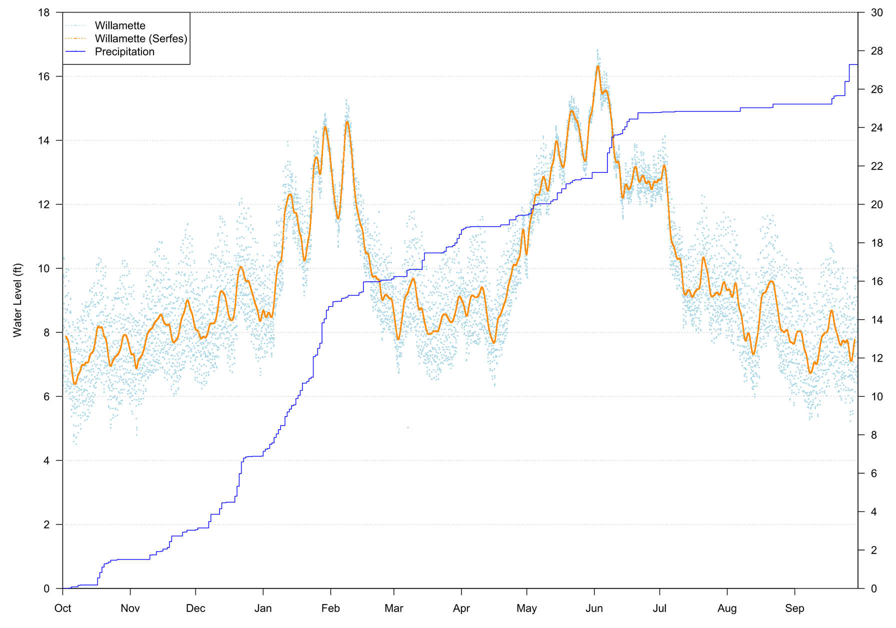
  i = hydraulic gradient

  A = cross-sectional area
- Chemical flux (CF) is the product of discharge and porewater concentration (c):

  $CF = Qc$
- Upland site well data are used to establish the hydraulic head in different groundwater zones (i.e., shallow, intermediate, and deep). Willamette River stage data, recorded near the PHSS at the Morrison Street Bridge, are used to establish the hydraulic gradient between the site and the river.

The purpose of this evaluation is to select one or more optimal porewater sampling periods to evaluate chemical concentrations in sediment porewater and to capture at least one period when a high chemical flux (i.e., "worst case") is expected.

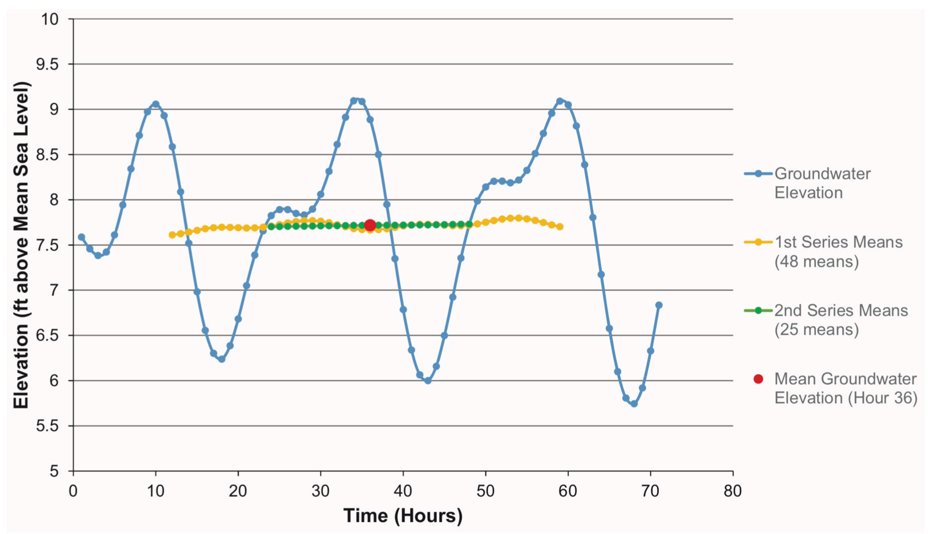
Willamette River–Columbia River Confluence

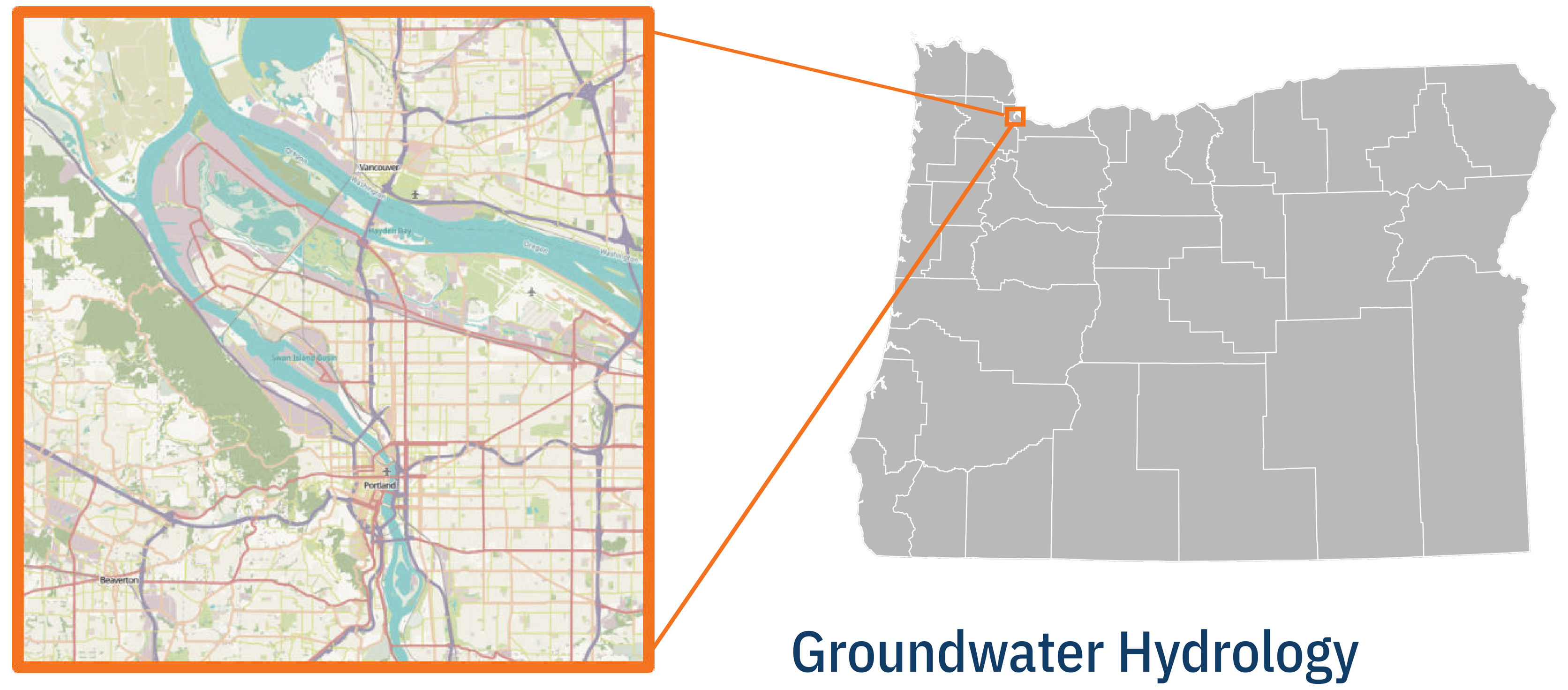


Hydrograph and Precipitation, 2019–20 Water Year

Mathematical Averaging Using Serfes (1991)

- Mathematical averaging was used to remove the diurnal tidal fluctuations from surface water or groundwater measurements.
- Serfes (1991) filtering uses 71 consecutive hourly water level measurements to obtain a single mean water level at hour 36.
- With each additional hourly water level measurement (e.g., hour 72, 73, 74), additional mean water levels were calculated.





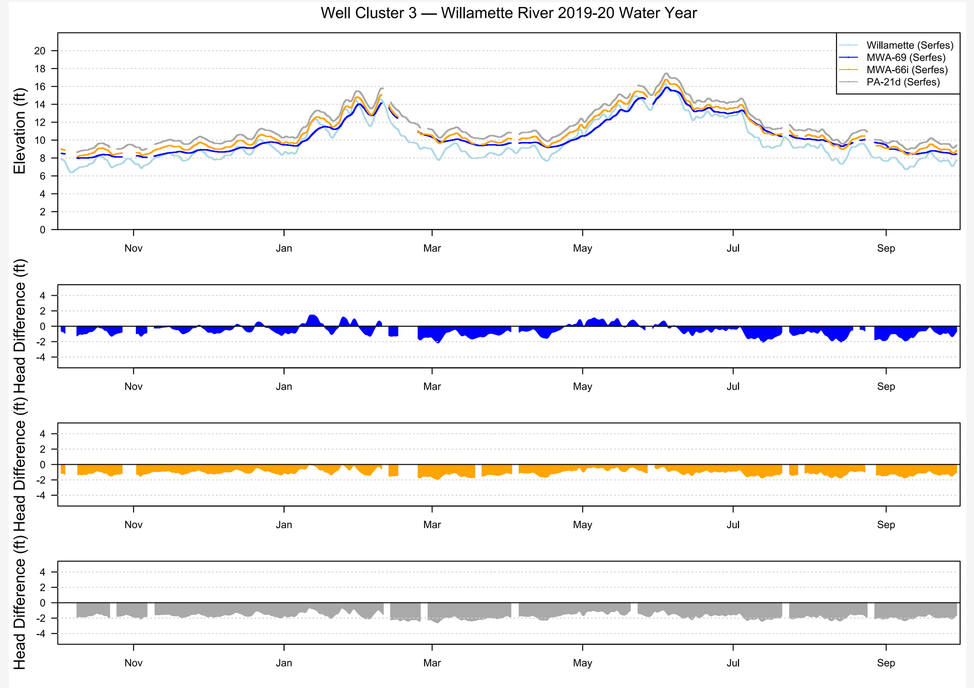
Surface Water Hydrology

- PHSS river stage changes are impacted by:
  - Diurnal tide fluctations from the Pacific Ocean along the Columbia River to the Willamette River (backwater effect)
  - Seasonal changes in river stage that result from precipitation events in the Willamette River basin (fall-winter-spring)
  - Columbia River stage peaks from freshet and Bonneville Dam releases (late spring).
- The Lower Willamette River is a freshwater system with tidal fluctuations. The diurnal fluctuations are a backwater effect; the saltwater wedge is located downstream in the Columbia River.
- Diurnal tidal fluctuations are largest, ranging from 3 to 4 ft, during lowest river stages in the fall, and decrease in magnitude with rising river stages in the winter and spring.

Groundwater Hydrology

- Groundwater in unconsolidated fill and alluvium is hydraulically connected to the river.
- Site wells classified as:
  - Shallow-unconfined: 20–30 ft below ground surface (bgs)
  - Intermediate-confined: 33–38 ft bgs
  - Deep-confined: 56–61 ft bgs
- Site groundwater is recharged by local precipitation. Typically, there are more precipitation and intense rainfall events from October through April.
- Groundwater levels in wells near the river shoreline respond to Willamette River tidal fluctuations, which propagate inland from the groundwater seepage face.
- Tidal fluctuation in confined groundwater (intermediate and deep) is a pressure wave that propagates inland from the seepage face boundary. Confined well tidal fluctuations have a higher amplitude and propagate further inland than unconfined groundwater (shallow).
- Shallow unconfined groundwater tidal fluctuations have a low amplitude and are likely the result of bank storage (i.e., physical dewatering of the aquifer).

Findings



Well Cluster Hydrographs and Head Difference Plots, 2019–20

Groundwater Discharge

- Groundwater discharge is unique to the vicinity of each well cluster and position onsite, but groundwater is generally discharging year-round.
- For the 2019–2020 water year, the largest head difference, and therefore hydraulic gradient (i) and discharge (Q), was in the late summer (Jul–Sep); however, large head differences also occurred in March and April between high river stages.
- When river stage peaks, the hydraulic gradient decreases and groundwater flow reversals can occur, but are generally of short duration (days to weeks).
- Head difference plots highlight variations between groundwater zones with shallow unconfined groundwater generally having a greater range of head difference than intermediate and deep confined groundwater zones.
- Groundwater discharge (Q) will vary by groundwater zone because of different hydraulic conductivity (K) characteristics.

Willamette River Stage

- Willamette River stage peak heights vary by water year.
- Annual winter–spring maxima vary from 14 to 18 ft (NAVD 88) and most often peak in January.
- In two of the study years, Columbia River stage peaks were responsible for the highest Willamette River stage.

Water Year	Willamette River Stage Peaks [river stage (month)]		Maximum Willamette River Flow (ft/sec)
	Winter-Spring (Willamette)	Late Spring (Columbia)	
2018–19	15.2 (Apr.), 10.5 (May)	9.0 (Jun.)	4.0 (Apr.)
2019–20	14.0, 14.2, 14.7 (Jan.)	16.7 (Jun.)	3.2 (Jan.)
2020–21	13.2 (Nov.), 14.1, 17.9 (Jan.)	13.0 (Jun.)	3.6 (Dec.)
2021–22	17.1 (Jan.), 14.6 (Mar.), 15.7 (May)	21.4 (Jun.)	3.6 (Jan.)

Typically, the greatest hydraulic gradient and groundwater discharge will be in spring, between winter and summer river stage peaks, and in the fall.

Reference

Serfes, M.E. 1991. Determining the mean hydraulic gradient of ground water affected by tidal fluctuations. *Groundwater* 29: 549–555.

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