Portland State University

Tidal River Dynamics at a Junction: Portland-Vancouver Harbor

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Why do we care about Tides and Water Levels? –

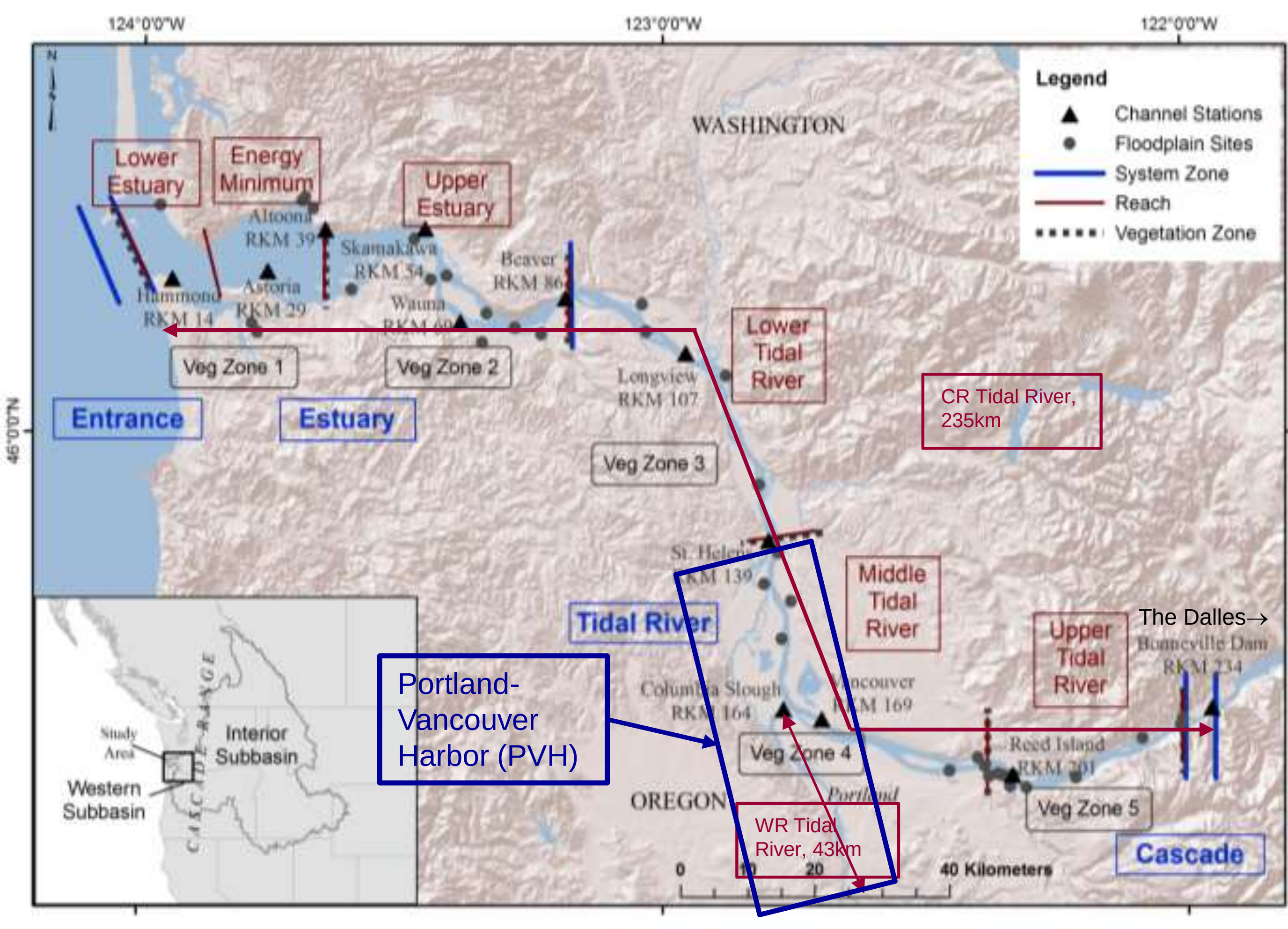
- Tide gauges are the longest ocean data records – use them!
  - Back to the 1950s (Astoria), 1870s (Portland) and ca. 1900 (Vancouver)
- Inundation/flooding involves the whole water level spectrum: tides + sea level + surge + waves
- Understanding water levels and water level dynamics improves our ability to predict coastal inundation and flood risks (see Talke and Helaire presentations)
- Water levels are closely related to habitat location, character & availability
- Water level analysis informs management:
  - Portland Superfund cleanup – when is erosion most likely to occur?
  - Mean sea level (MSL) rise and coastal inundation:
    - To date, harbor modification has outweighed global MSL rise in setting inundation frequency in the LCRE and many estuarine locations globally
    - For the future – coastal sea level rise will be considerably modified by estuarine process, engineered and natural
  - PDX Metro flood risk: backwatering and junction hysteresis are important factors

Roadmap –

- The setting: the Columbia and Willamette tidal rivers
  - AKA the Lower Columbia River Estuary (LCRE)
  - Focus on Portland-Vancouver Harbor (PVH)
- Data: 1870s to present
- Methods for non-stationary water levels
- Overall system view
- Some PVH processes and consequences:
  - Long-term changes
  - Backwatering during high-flow events
  - Junction hysteresis – why?
- Discuss LCRE tides based on the 1940-1943 data, because:
  - A water level data set with this level of spatial detail is rare
  - It has not yet been published
- Discuss PVH using early 1900s and modern data, to match Delft3D modeling (see Helaire et al. talk)

LCRE System Zonation –

- The CR is tidal for 235 km from the ocean to Bonneville Dam
  - River flows average 7300 m^3/s, range: 1700 to 25,000 m^3/s, mostly spring snowmelt freshets
  - CR flow is gauged at The Dalles and at Beaver
  - Mean tidal range is 2.6m at Astoria, varies from ~1.5 to 4m
- The WR is tidal for 43 km to the falls at Oregon City
  - Average flow 940 m^3/s, range: 100 to 15,000 m^3/s; winter freshets only; gauged at Portland (PDX)
  - Tidal range 0-1m, depending on flow
- PVH is in the Middle Tidal River



LCRE and PVH Data Sets –

Water levels:

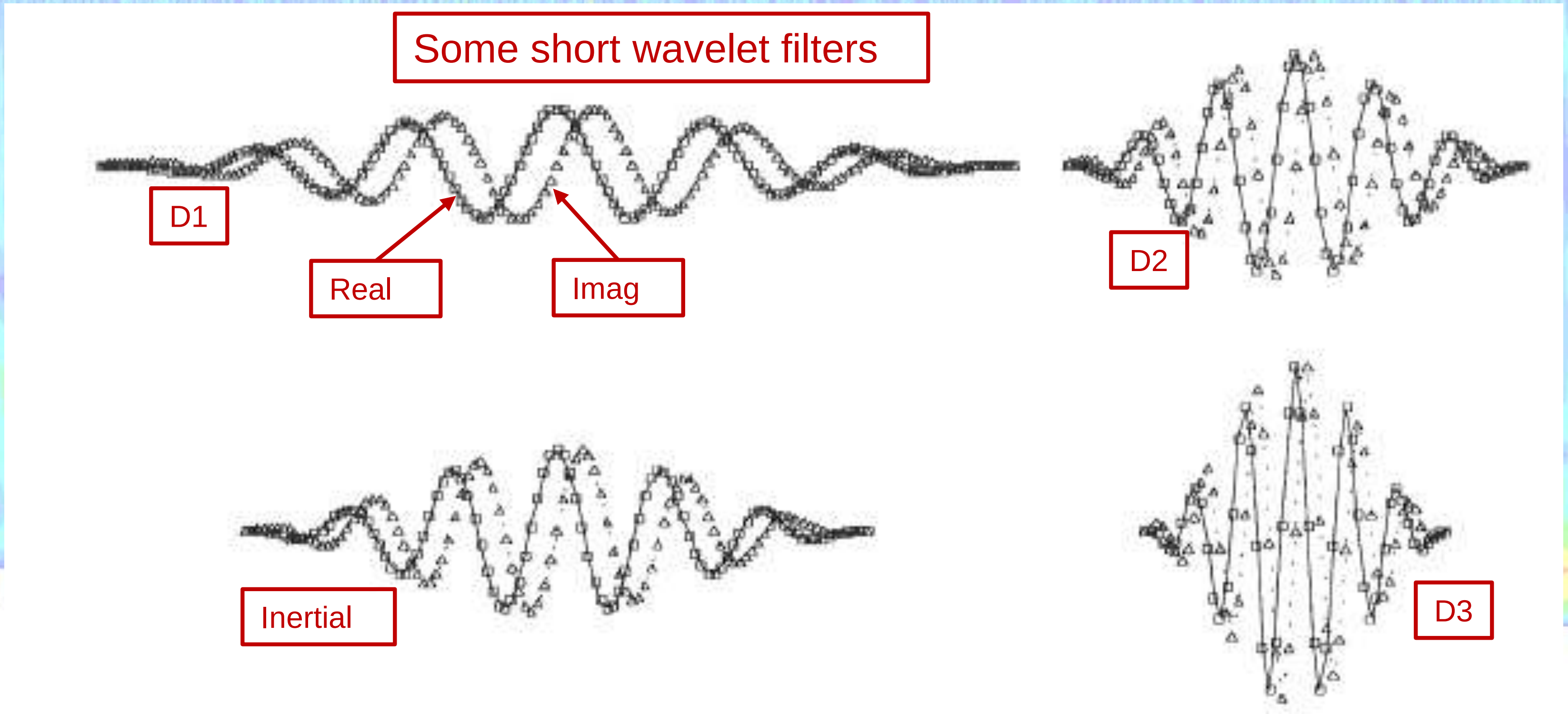
- Portland: daily (1879-1972), Hi-Lo (1972-date), sub-hourly (1988-date)
- Kelly Pt (WR mouth), 1-5X/day, 12 years, 1901-1914
- Vancouver: Daily (1870s, 1904-1972), Hi-Lo (1972-date), hourly or sub-hourly (1986-date)
- Astoria: Hourly or sub-hourly, 1853-1878 and 1925-date
- 18 stations LCR, 3 stations WR, 1940-1943, 16 to 28 mo
- 9 long-term stations LCR and 3 WR, 1986-date, many short-term & wetland

River flow:

- CR at The Dalles, 1878-date, Bonneville Dam 1949-date
- CR at Beaver (in tidal river) 1991-date (routed before 1991)
- WR at Portland (routed) 1878-1972, measured (1972-date)

Analysis Methods for Non-Stationary River Tides –

- The Heisenberg Uncertainty Principle limits what we can know about fluctuating tidal processes –
  - If the analysis period is too short, then frequencies are uncertain
  - If the analysis period is too long, then the "events" are averaged out
- Tidal analysis is the black art of cheating Heisenberg…
- We use Continuous wavelet transform (CWT) methods to optimally resolve fluctuating tides and currents
- Each filter has real (cos) and imaginary (sin) parts, so that amplitudes and phases can be resolved

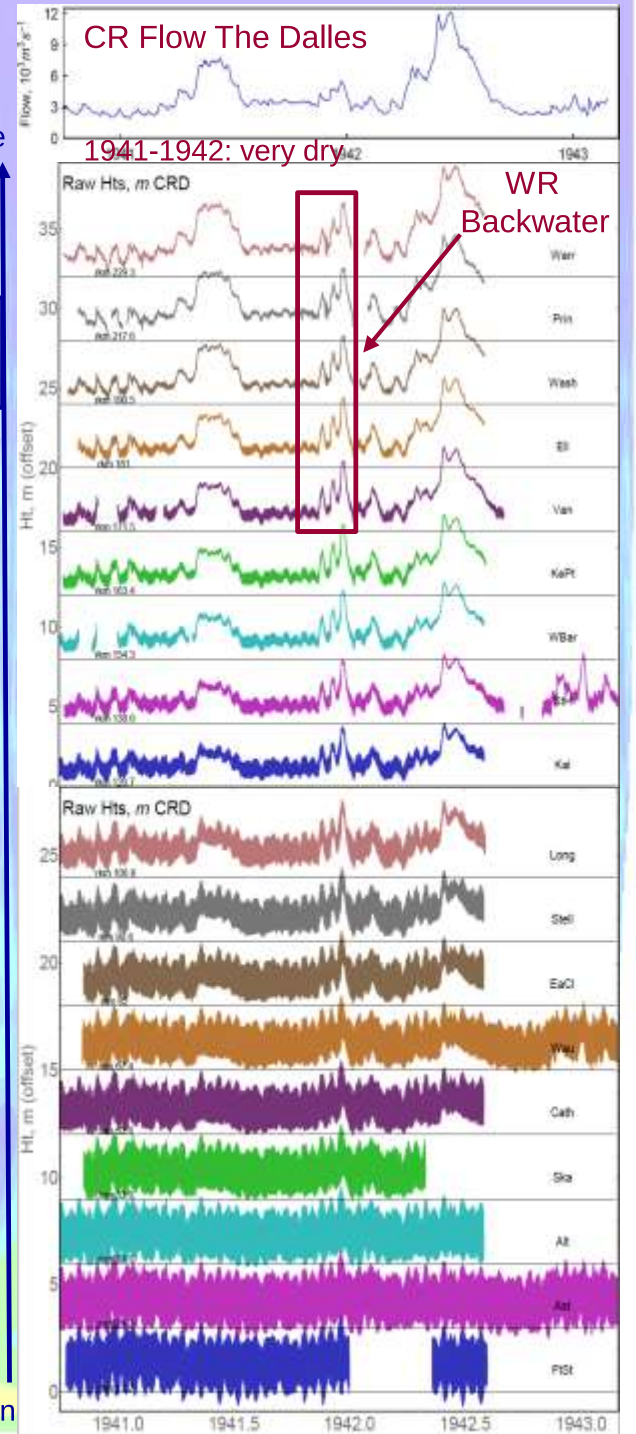


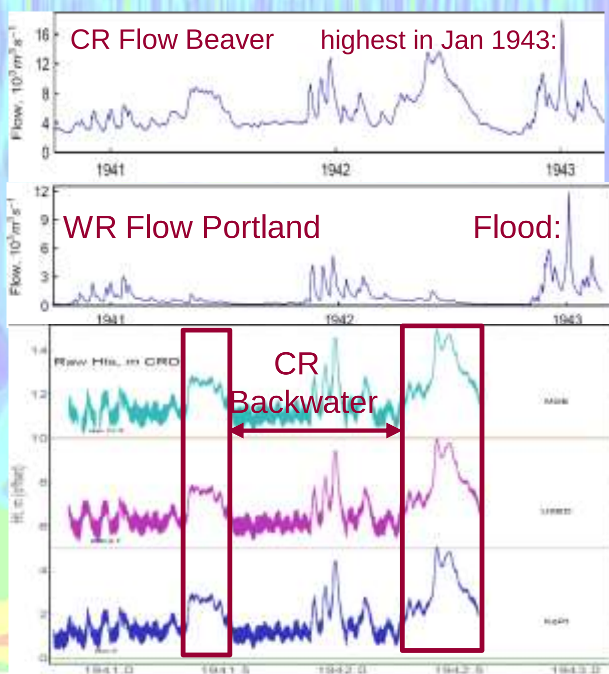
Analysis Methods for Non-Stationary River Tides (more) –

- To resolve rapid fluctuations in water levels (days to weeks), we need very short filters. But this introduces a problem –
  - Tidal constituents are arranged in tidal species (1X per day or D_1, 2X per day or D_2, 3X per day or D_3, etc.)
  - Such short filters only resolved the species, but we also want to know what happens with constituents within the species
- So we use two sets of filters:
  - Short (<100 hrs), to resolve D_1, D_2, D_3, D_4, etc.
  - Longer (300-400 hrs), to resolve the major constituents within tidal species, e.g., M_2, S_2, and N_3 within the D_2 species
- We also use a more direct analysis approach:
  - Physically based regression models of higher high water (HHW), lower low water (LLW), mean water level (MWL), and other tidal properties
  - Examine both species outputs on short time scales (49-97 hrs) and constituent outputs (353 hrs)

Alongchannel View of CR and WR Floods, 1940-1943 –

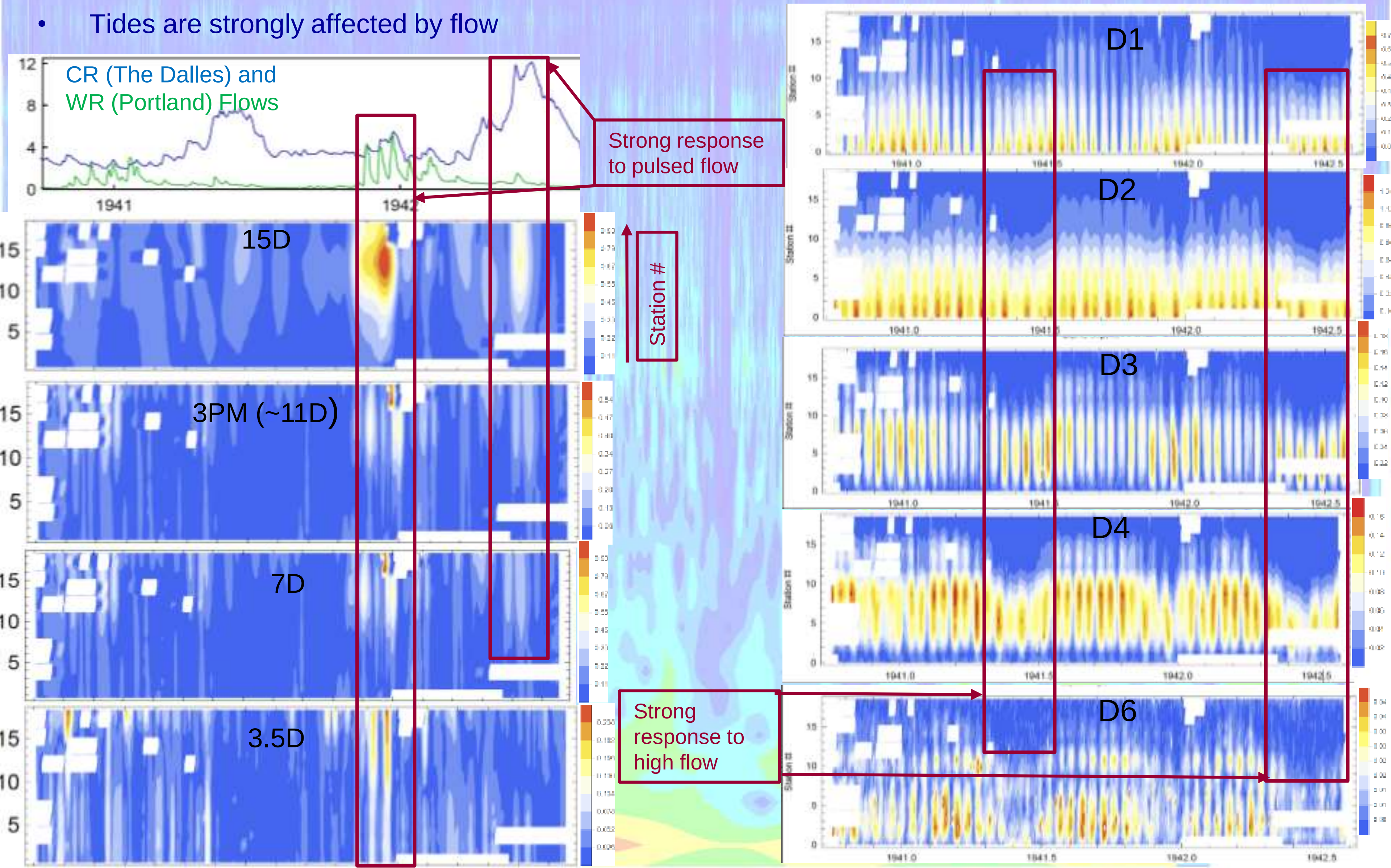
- Low flow except for Jan 1943 WR flood; 4th largest since 1920
- Beaver flow is sum of LCR+WR+ coastal tributaries
- Both CR and WR cause backwater effects
- Large historic PDX floods caused by CR backwater, e.g., 1894 and 1948





AlongChannel view of LCR Tides 1940-1943 –

- 1940-1943 tides reflect generally low flows; pulsed flows generate 3.5D to 15D response
- Tides at WR mouth (AKA Kelley Pt sta #13) are typical for WR, except during WR floods
- Maximum amplitudes move upriver with species number (D1 to D4)
- Tides are strongly affected by flow

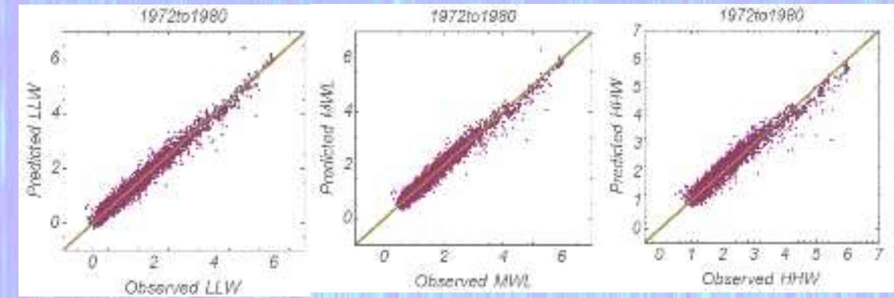


PVH Dynamics: Long-Term Changes –

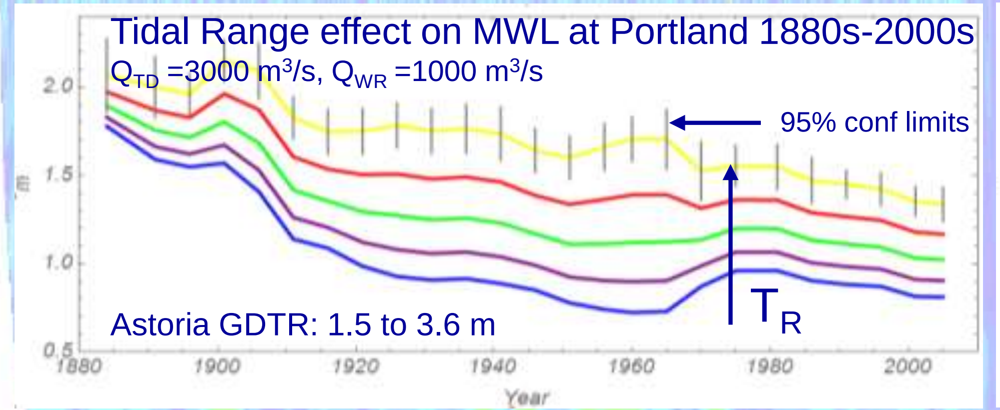
- Use daily and Hi-Low data to examine long-term changes in water levels
- Apply regression models to daily WL data in 10-year overlapping segments, e.g.,:

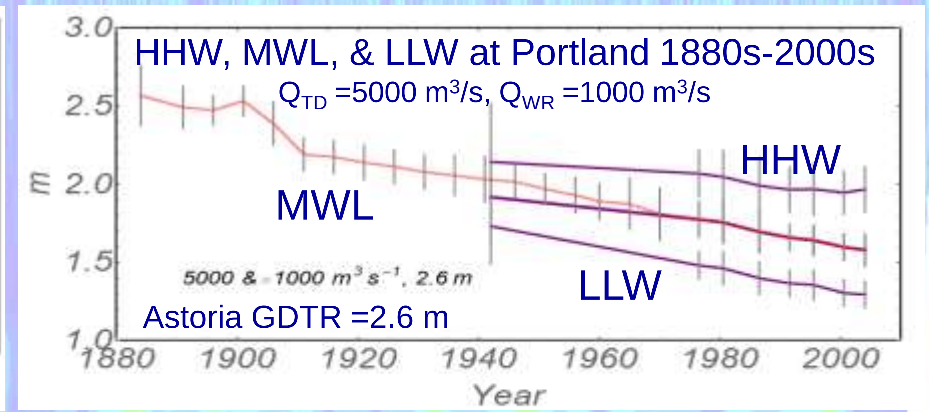
$$\mathrm{MWL} = c_{0k} + c_{1k}Q_{\mathrm{TD}}^{m} + c_{2k}Q_{\mathrm{WR}}^{m} + c_{3k}\left(\frac{T_{R,\mathrm{TP}}^{2}}{(Q_{\mathrm{TD}} + Q_{\mathrm{WR}})^{n_3}}\right)$$

And similarly for LLW and HHW
m=0.6 to 1.1, the n_i= 0.7 to 1;
(Kukulka & Jay,2003; Jay et al., 2010)



Models of LLW, MWL and HHW for the 1970s

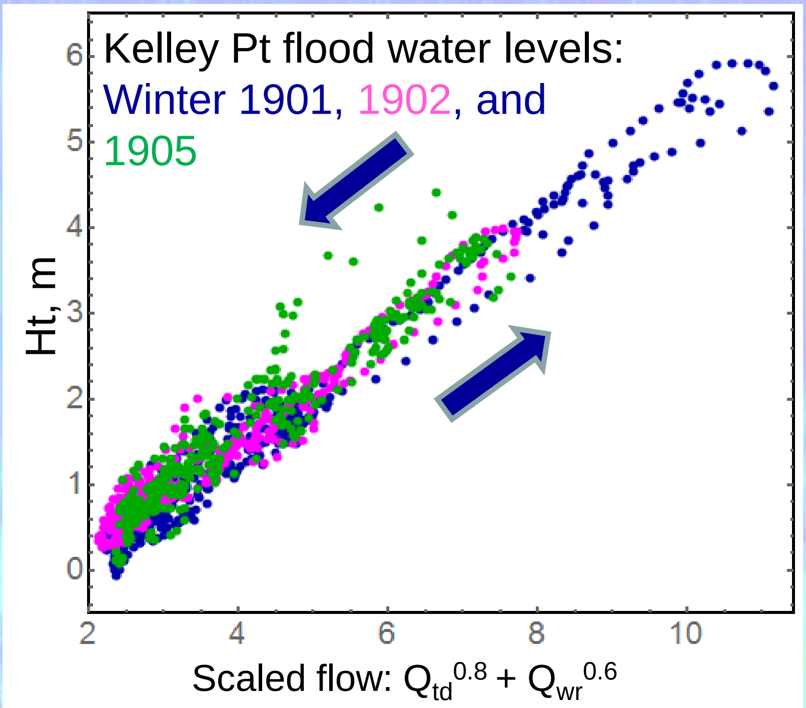




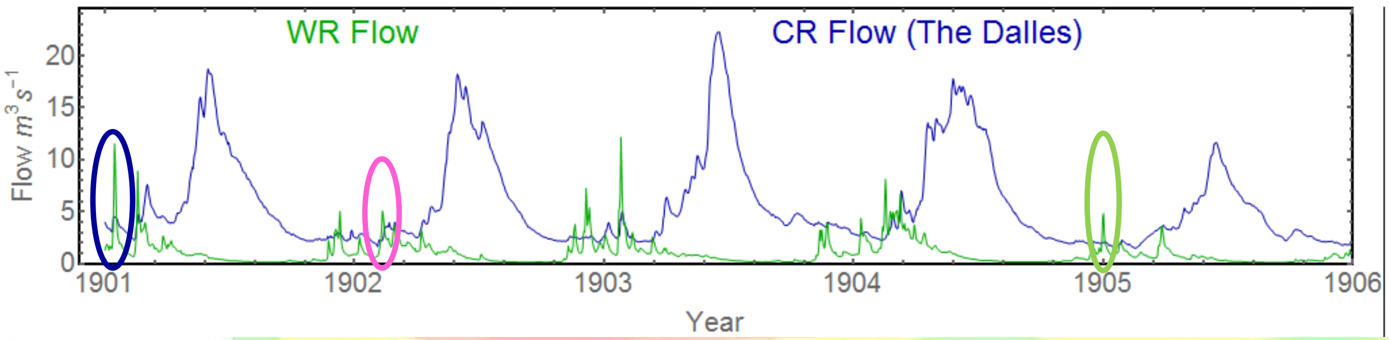
- Water levels are higher on spring tides – it's a tidal river!
- Water levels for any given flow have dropped since the 1880s
- Vancouver 1900s to 2000s shows the same pattern
- Dominant contributions to error in the models:
  - Datum uncertainty, especially before 1920 – gauged moved several times
  - Uncertainty in routed WR flow before ca. 1907

PVH Phenomena – Water Level Hysteresis during floods

- Kelley Pt has 1-5 WL points/day, 1901-1914 (gaps)
- Re-occupied in 1940-1942 (but no WR floods during the record)
- The modern USGS Columbia Slough station (1991-date) is nearby

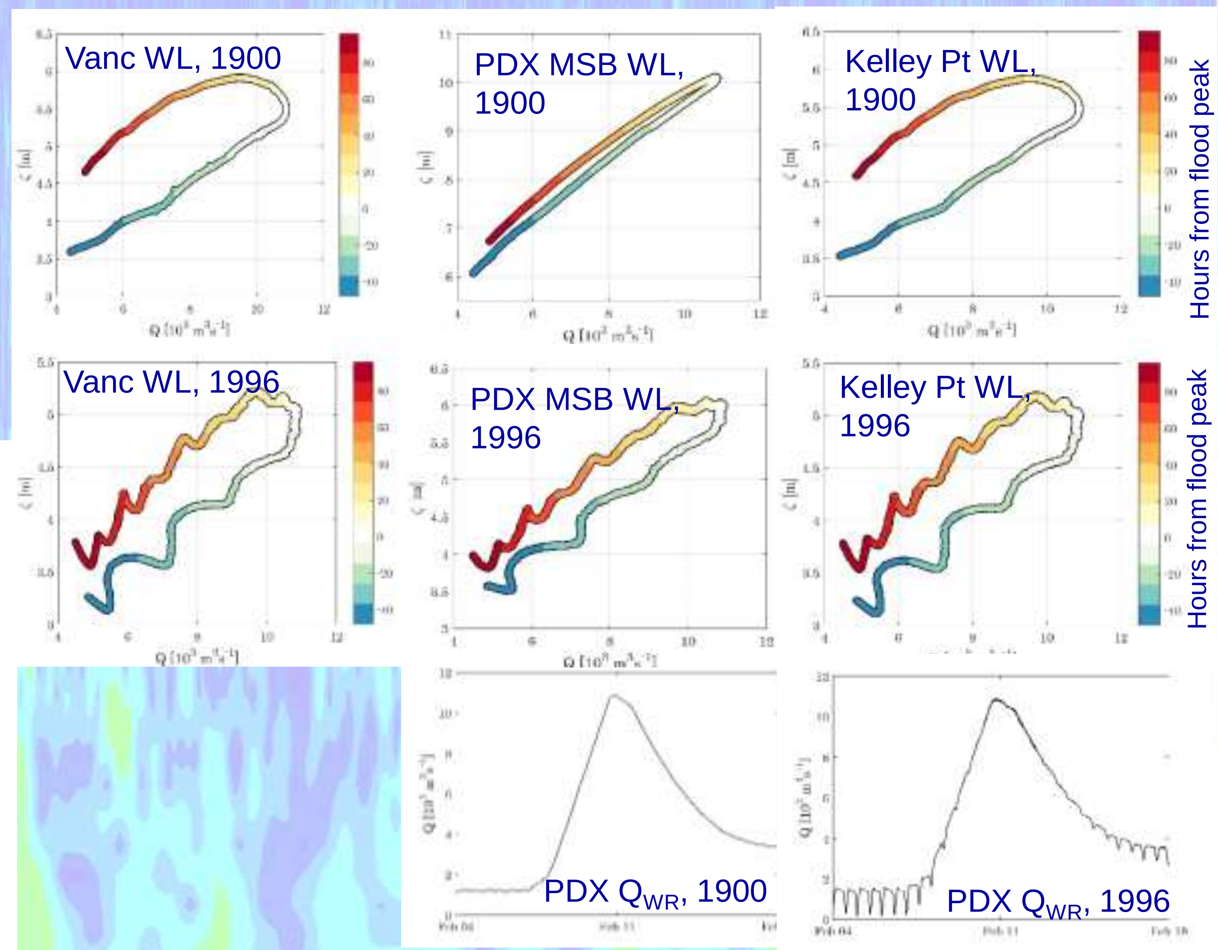


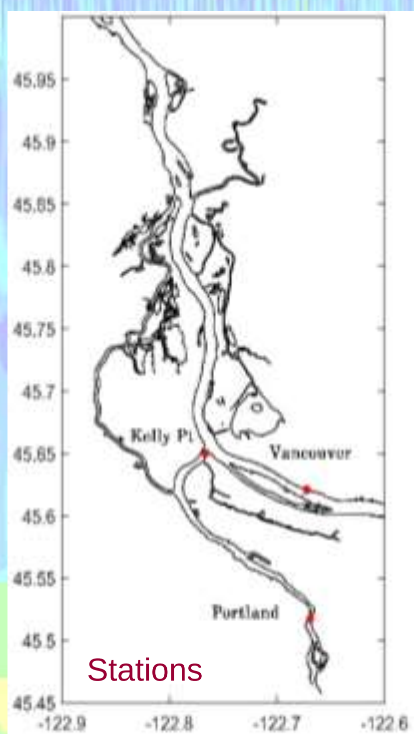
- ➢ High flows impact contaminated sediments in the PDX Harbor Superfund site
- ➢ WR floods rise and fall fast & cause high currents
- ➢ CR floods rise and fall slowly and backwater PDX harbor (weaker currents)
- ➢ The falling arm is higher (i.e., deeper water)
- ➢ Backwatering of CR mainstem and wetlands is the likely cause of slow rise and fall



Water Level Hysteresis: Model Results –

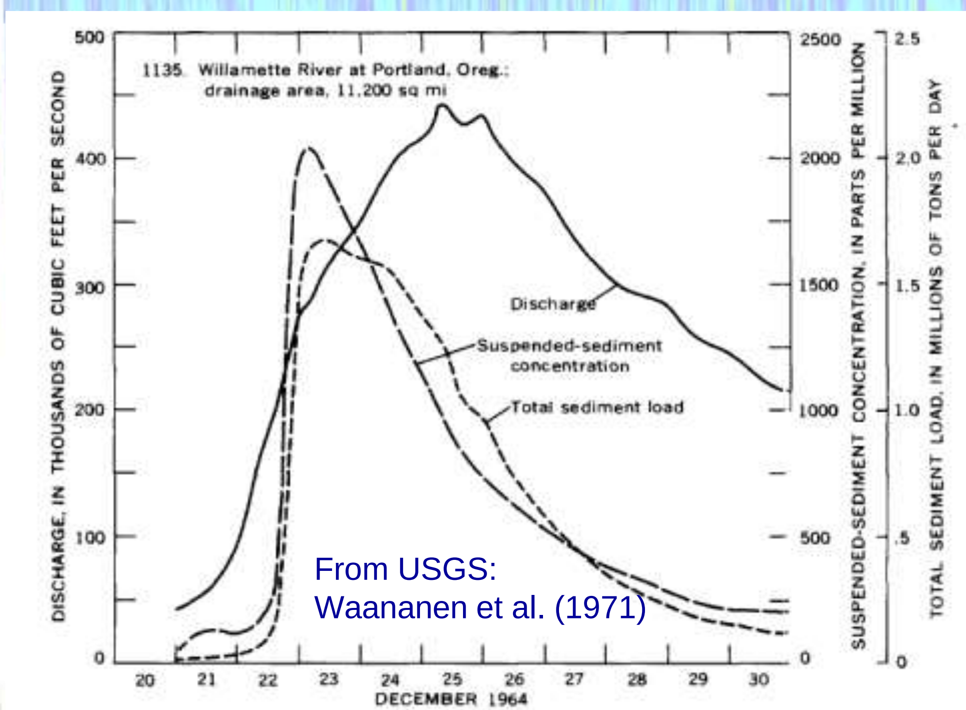
- Model shows hysteresis, in historic (ca. 1900) and modern (sort of 1996) cases
- Model flows: QTD =2500 m^3/s (much lower than 1996); WR flood (realistic)
- Hysteresis increased in PVH
- Tides have increased & water levels dropped in PVH
- Lower water levels early in flood may be important in PDX Superfund site
- See Helaire et al. talk



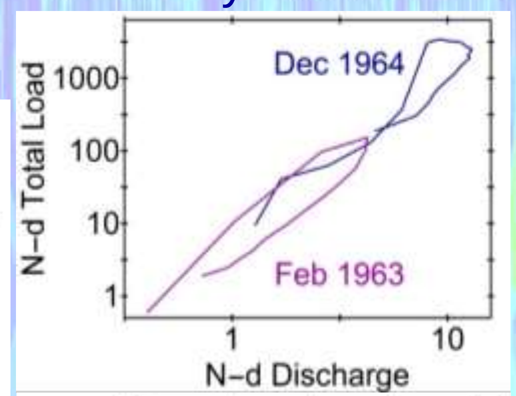


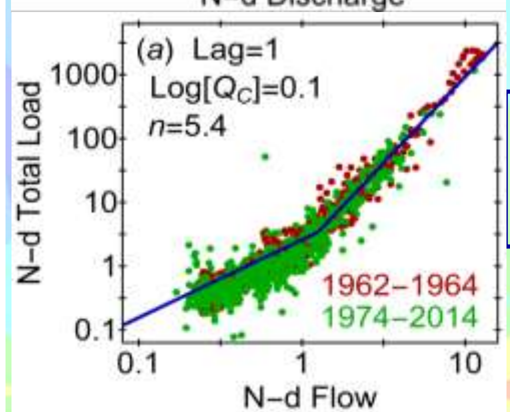
WR Sediment Supply Hysteresis –

- Suspended load in PDX Harbor also shows a strong hysteresis; causes:
  - Exhaustion of SPM supply of transportable material in mainstem
  - There is a flush of local sediment runoff associated with rapid snow-melt
- To these previously known issues, we add water level hysteresis:
  - The flow is shallower on the rising arm of the freshet than on the falling arm
  - Currents are stronger (see Helaire et al. talk)
- The source & fate of the large amounts of SPM present on the rising arm of a freshet are unknown
- Effects on contaminants have not been much analyzed



From USGS:
Waananen et al. (1971)





Two examples of SPM load hysteresis in PDX Harbor

Modeling SPM load with a total load model that includes hysteresis

Summary –

Causes of long-term drop in water levels –

- A deeper, narrower, better aligned channel
- More sand has been dredged than supplied since ca. 1915:
- Flow diversion lowers mean water levels
  - But reservoir system elevates summer-fall flows and water levels
  - An earlier snow melt will cause a drop in summer-fall water levels, absent management changes
- To date, sea level rise has not been a major factor in PVH changes
  - But just wait a few more decades….

Backwater effects –

- Occur in both the CR and WR
- Important in PDX harbor flooding

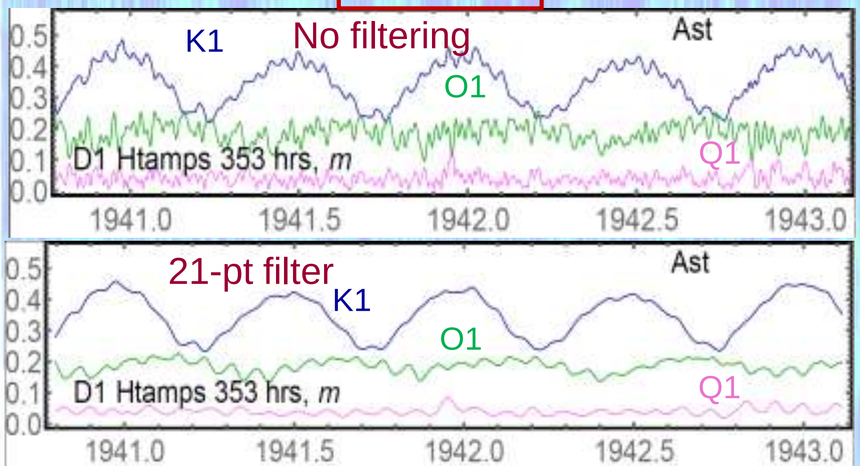
Hysteresis in water levels and sediment transport –

- Backwatering of the CR and flooding of wetlands slows rise of water levels
- The hysteresis in water levels is likely one cause of the observed hysteresis in sediment transport in PDX Harbor
- The importance of this for SPM and contaminant transport should be resolved

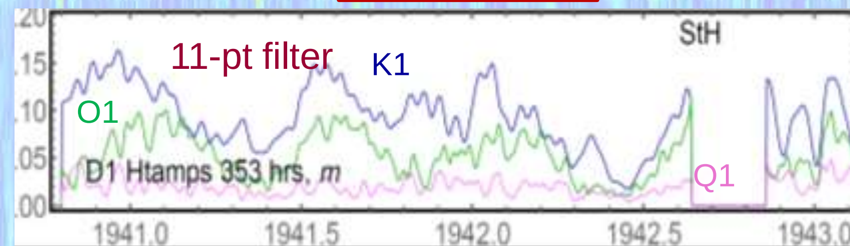
Uncertainty of CWT Tidal Estimates –

- Uncertainty estimates are necessary for any tidal analysis:
- We derived estimates for CWT methods, but they provide TOO MUCH information
- Use an intuitive approach for the D1 and D2 tides; 353 hr filters resolve 3 constits/species
  - After the estimates are smoothed to eliminate noise, is there any information left?

At Astoria



At St Helens



Upriver at St Helens (Rkm 139):
Averaging resolves O1 and K1 seasonal and flow-related variations nicely

At Astoria, near coast: (Rkm 29):
K1 resolves semi-annual variations
O1 seasonal modulation is barely resolved
Q1 no useful information in the Q1 signal

Summary:

>Individual estimates are quite variable
>For constits like K1, O1, M2, MK3 and M4, averaging allows investigation of dynamics
>For other constits, there is little useful information in variability
>For a non-stationary signal, the uncertainty is what can't be explained by the physics; i.e.,

- Filter noise and random errors are small
- Systematic errors and unexplained physics are large
- Conventional statistics are of limited help