Modeling Historic Columbia River Flood Impacts

Columbia River Estuary Workshop

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Data SIO NOAA U.S Navy NGA GEBCO

Why are Large Floods Important?

1948 Columbia River Spring Flood

May 30, 1948 Vanport, OR was destroyed when levee was breached
Vanport Extension Center later became **Portland State University**

*Photo available at http://www.offbeatoregon.com

Why are Large Floods Important

Floods are known for the negative impacts but they also have can have positive effects

Negative Impacts

- loss of life
- displacement of those affected
- destruction of property
- Interruption of commerce
- rising cost for goods

Positive Impacts

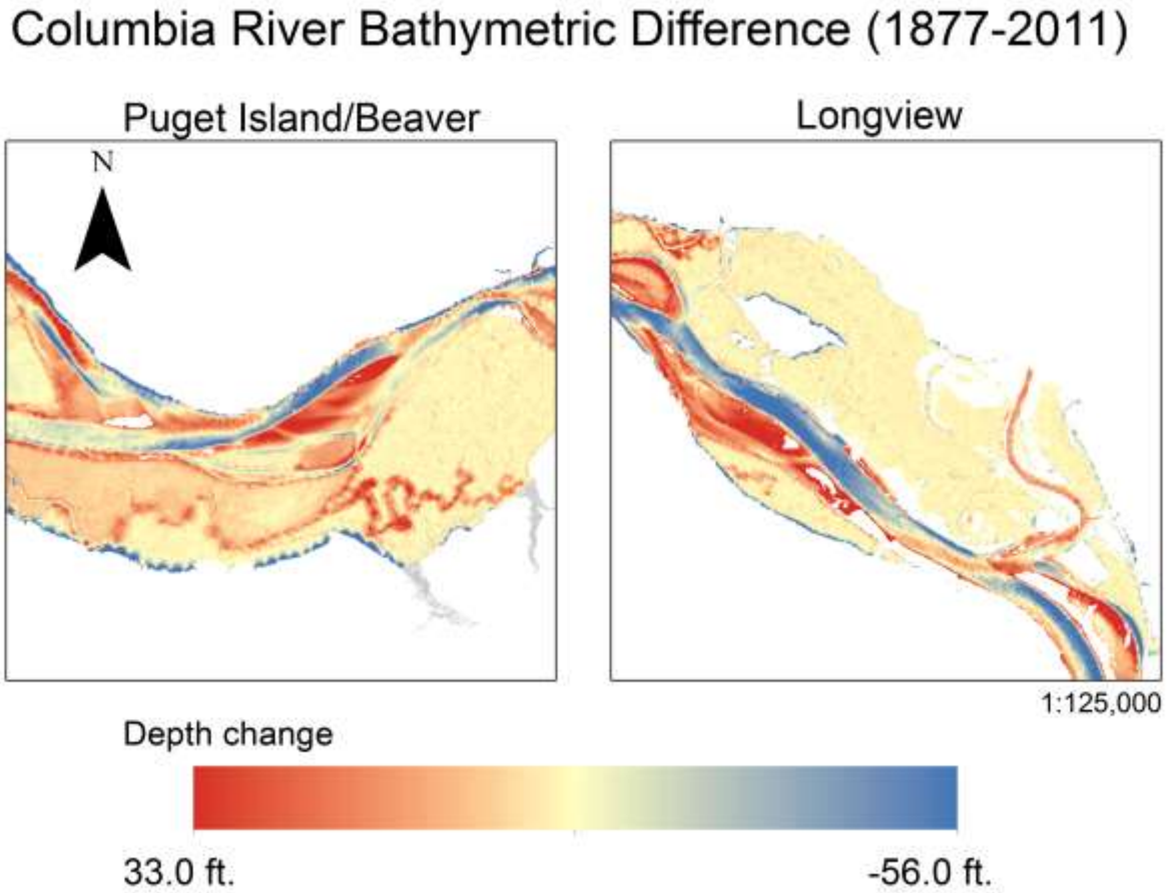
- supply sediment to estuaries and coast
- provide nutrients to floodplains
- flush pollutants from river systems

We have a developed Delft3D hydrodynamic model of the Lower Columbia River Estuary (LCRE) with batyhymetry of the late 19th Century.

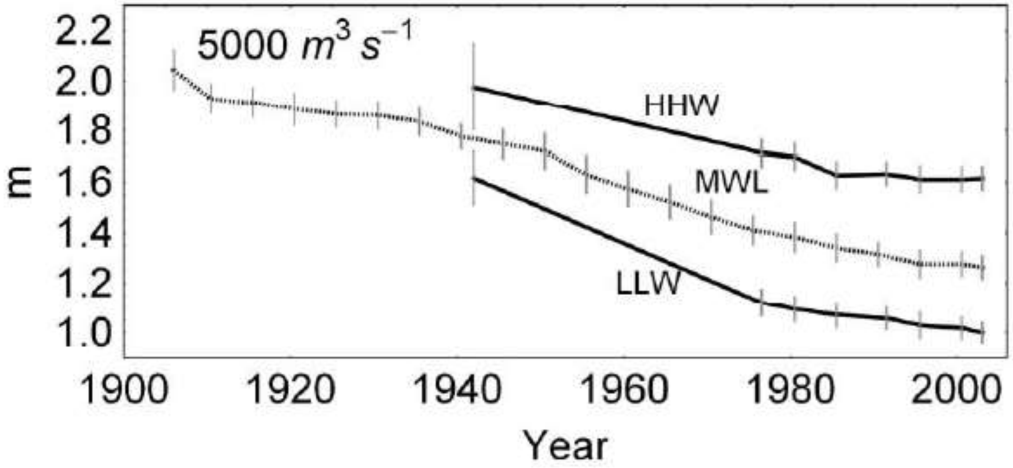
With that model we would like to focus on the following questions:

1. How have anthropogenic changes affected the movement of large flood waves
2. In the absence of flow regulation from dams how would historic floods propagate on a modern bathymetry.

Some the changes over the past 100+ years are quite drastic!

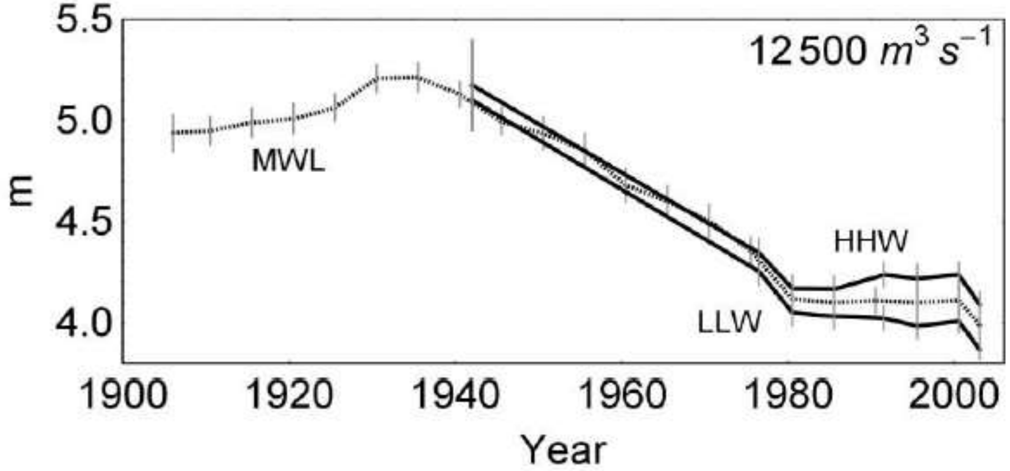


Depth increases are probably major factor in increased tidal range and lower MWL (mean water level).



Elevation referenced to CRD

Tidal Range for 5000 m3/sec CR Flow [5]



Tidal Range for 12,500 m3/sec CR Flow [5]

Tidal Range (HHW – LLW) has increased while MWL has decreased

[5] *Jay, Leffler and Deggens* [2011]

Modern and Historic Grids – Delft3D

Lower Columbia River Basin modeled with the Delft3D hydrodynamic modeling software

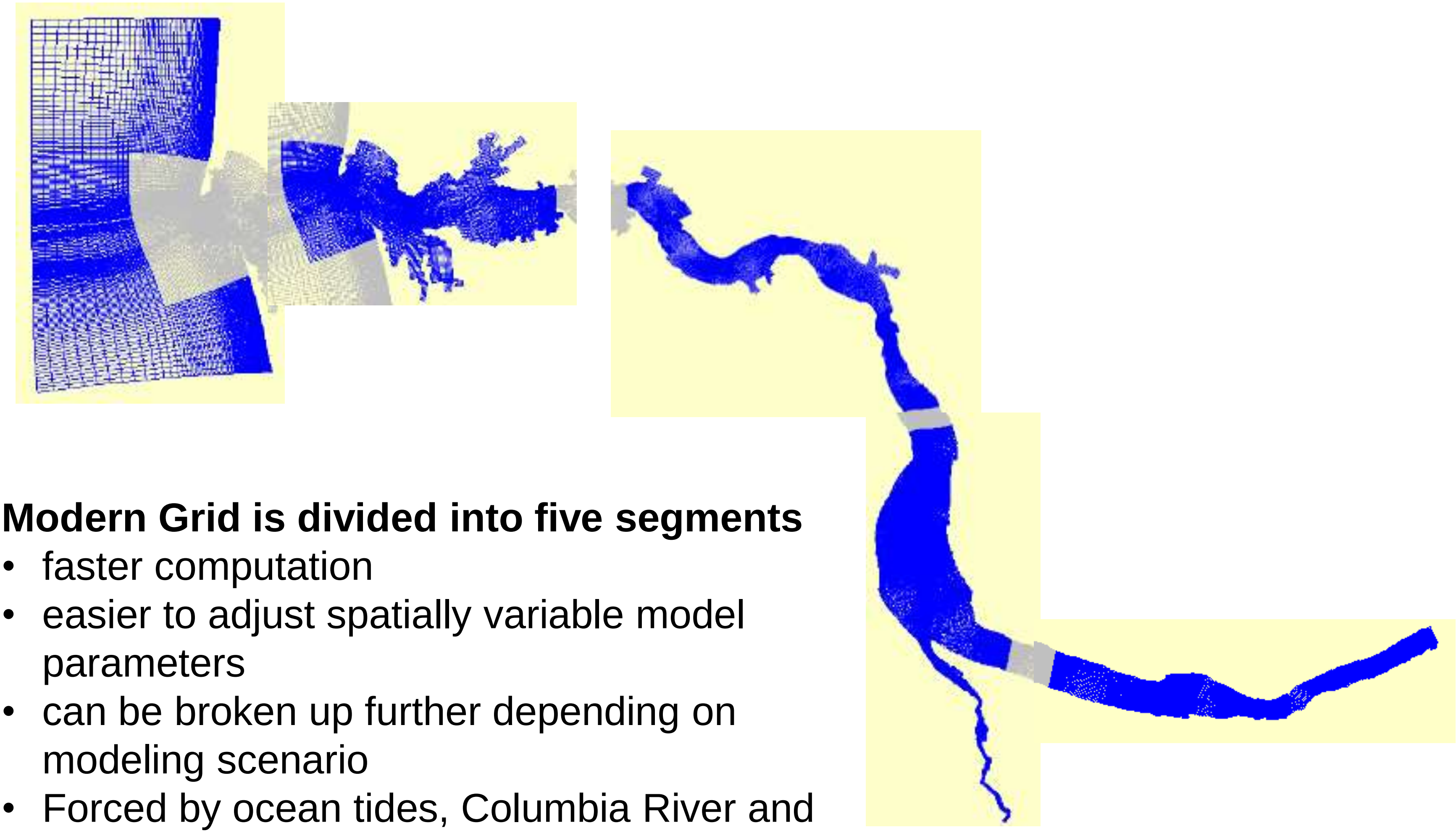
Modern Columbia River Grid

- Based on modern LiDAR (**Li**ght **D**etection **a**nd **R**anging) scans of Columbia and Willamette River Floodplain
- Roughly parallel to river channel
- 50m to 2000m grid resolution
- barotropic (depth averaged)

Historic Columbia River Grid

- Compile from digitized 19th century survey and some modern bathymetry
- 50m to 2000m grid resolution
- Roughly parallel to river channel
- No Astoria jetty
- Larger intertidal area throughout river system
- No levees or dikes
- More shallow river channel (minimal dredging)
- barotropic (depth averaged)

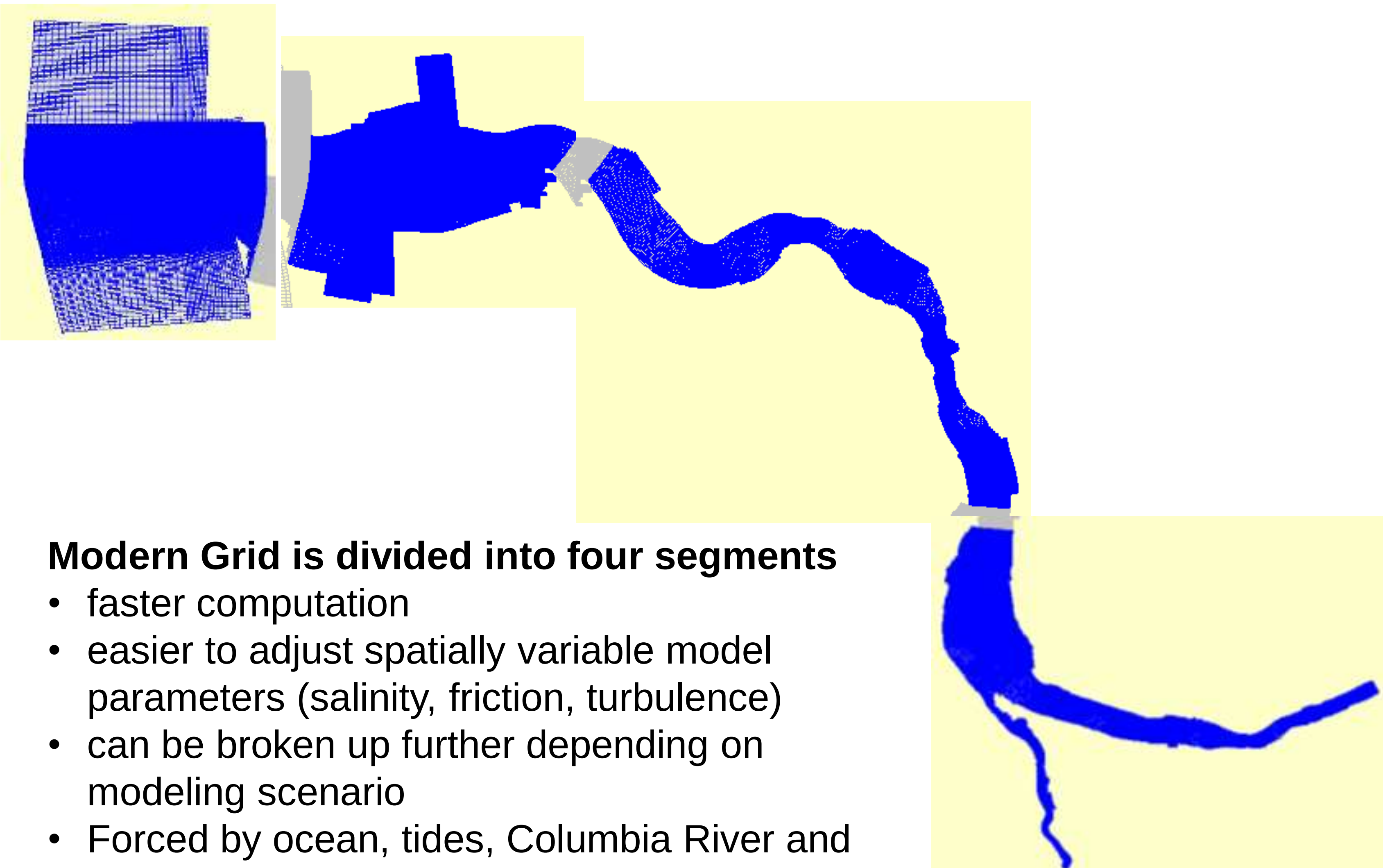
Delft3D Grid of Modern Lower Columbia River



Modern Grid is divided into five segments

- faster computation
- easier to adjust spatially variable model parameters
- can be broken up further depending on modeling scenario
- Forced by ocean tides, Columbia River and Willamette River

Deflt3D Grid of Historic Lower Columbia River

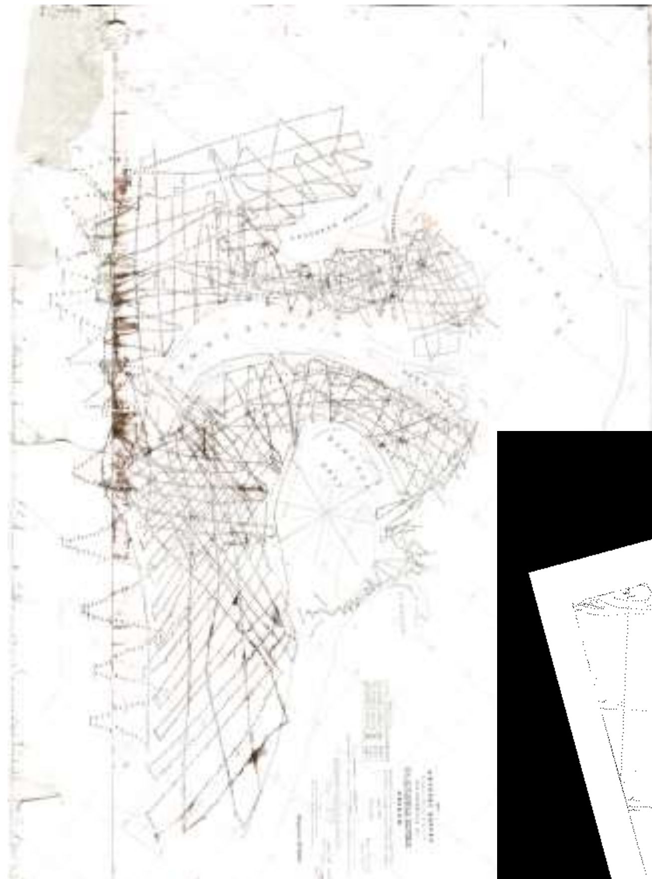


Modern Grid is divided into four segments

- faster computation
- easier to adjust spatially variable model parameters (salinity, friction, turbulence)
- can be broken up further depending on modeling scenario
- Forced by ocean, tides, Columbia River and Willamette River

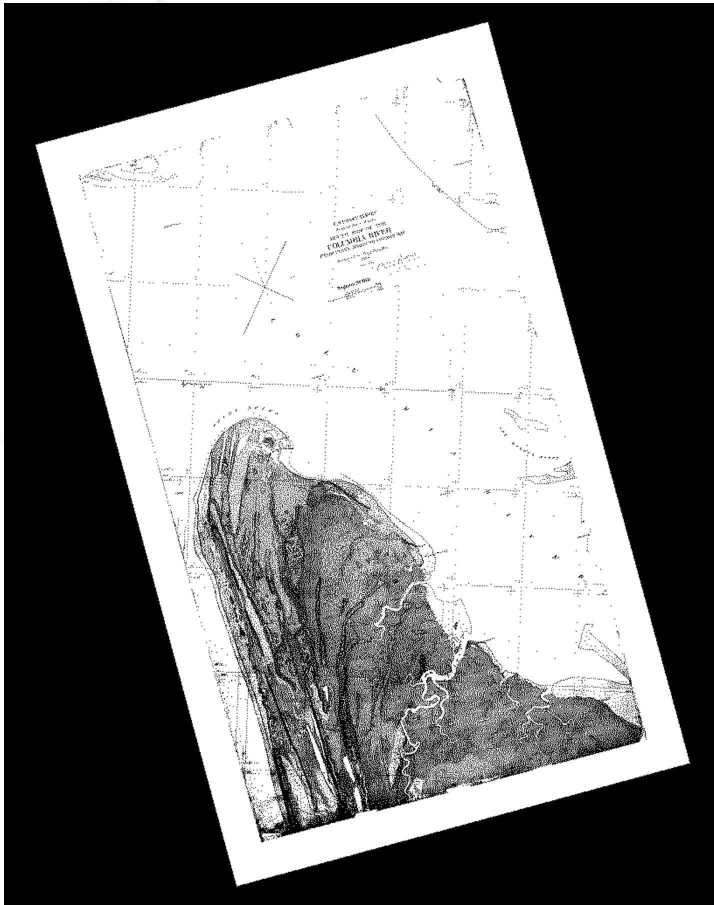
Historic Bathymetric Surveys

- USCGS H-sheet and T-sheets
  - Continental shelf to Bonneville Dam
  - 19 H-sheets (1877 – 1901)
  - 27 T-sheets
- Digitized by UW Wetland Ecosystems Team [1]
  - Georeferencing
  - Digitization
  - DEM interpolation
- Additional H-sheets of continental shelf
  - H01378 and H01379 (1877)



t1112

h01019



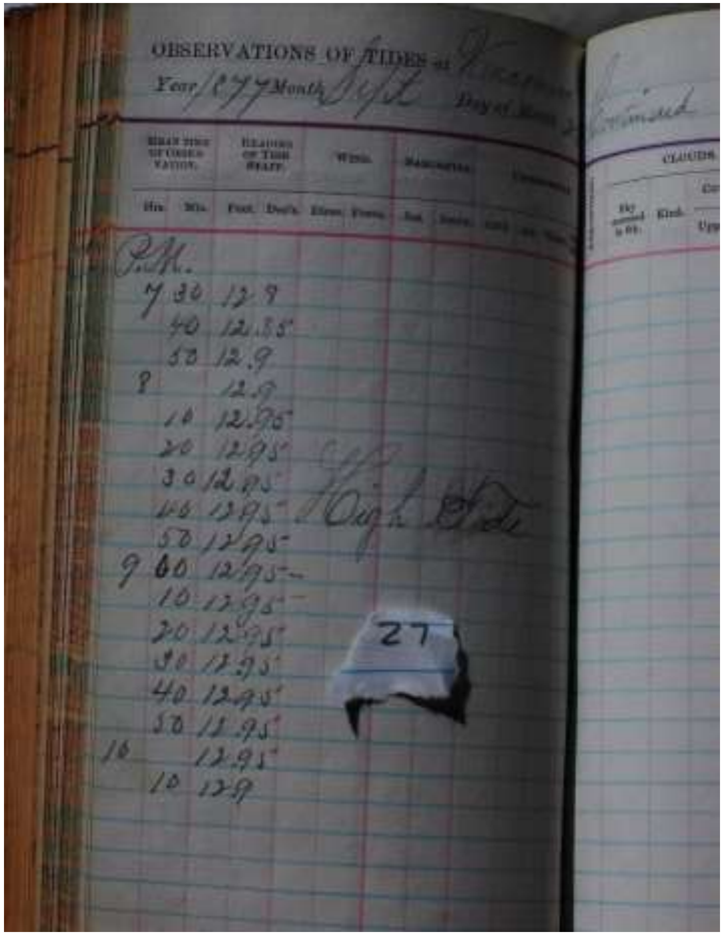
[1] *Burke,* [2010]

Delft3D – Model Development

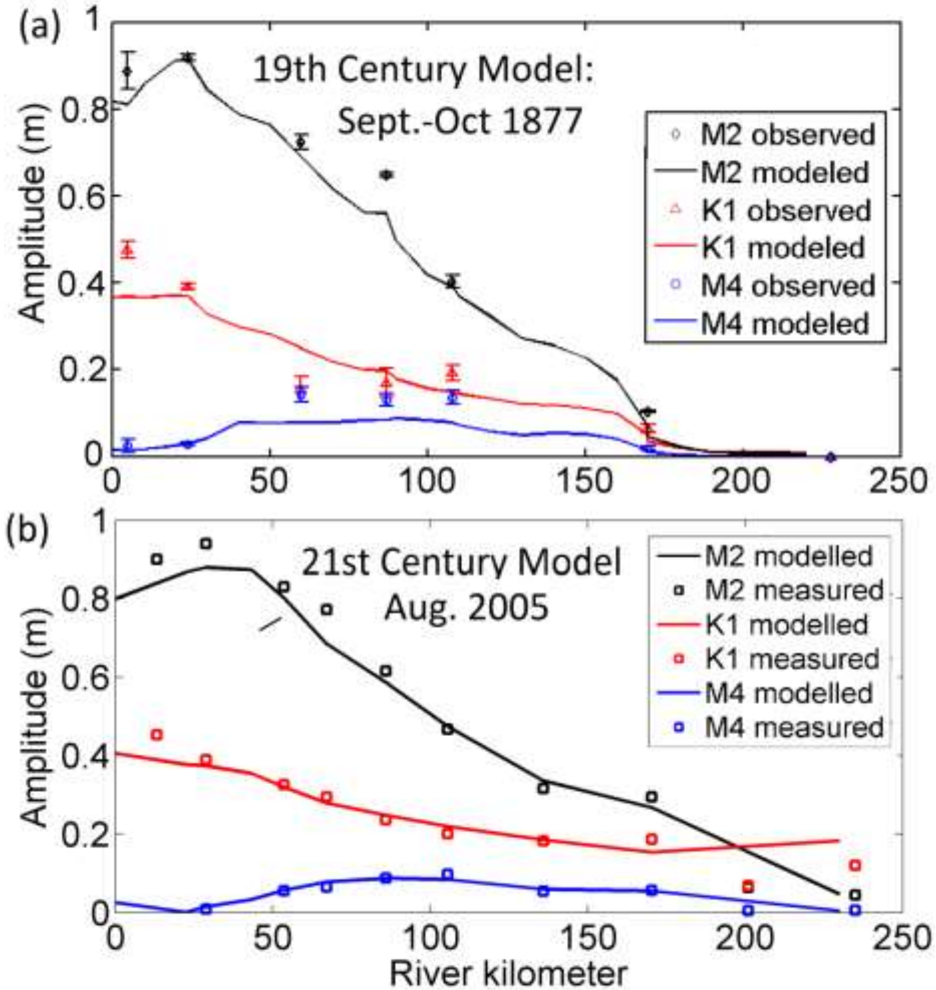
Data Sources

- Recently re-discovered and digitized tide logs and marigrams from the National Archives

Talke and Jay [2013]



Columbia River tide log from Vancouver, WA dated Sep. 27, 1877



Barotropic Model Run…

Delft3D Historic Model Calibration

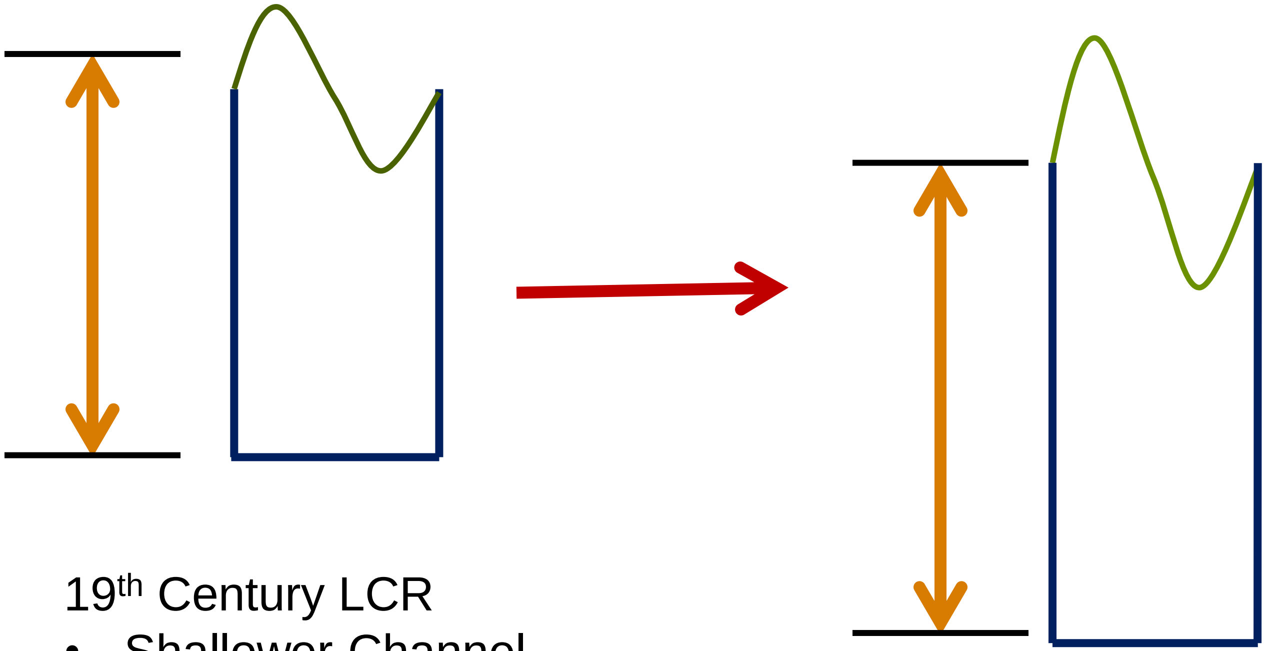
The model is currently calibrated to historic tide data and does as well as the modern model.

Delft3D Modern Model Calibration

Note: The M2 maximum has moved upstream from Astoria towards Astoria Tongue Point/ Cathlamet Bay.

Lower Columbia River – Morphology

Hypothesis…



19th Century LCR

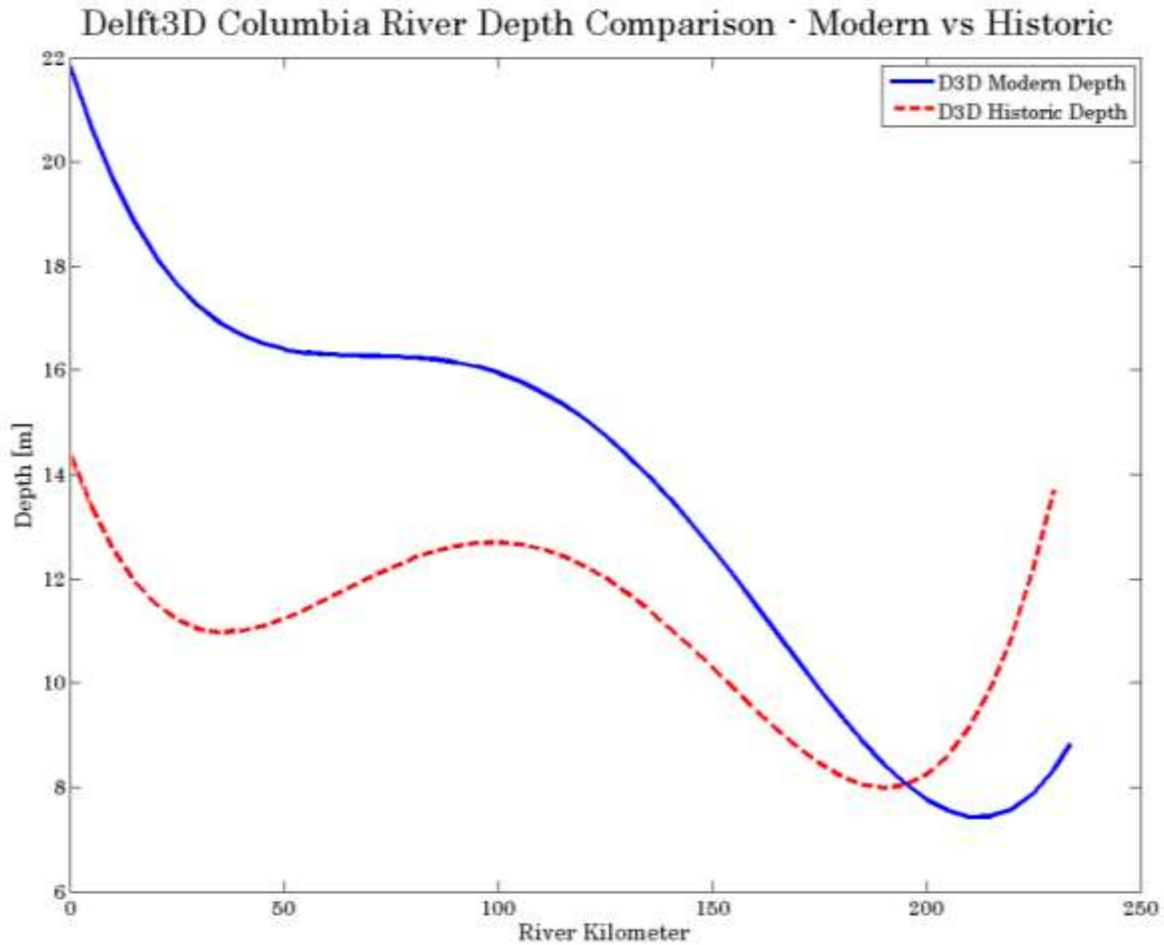
- Shallower Channel
- Larger tidal flats
- Higher MWL

Present Day LCR

- Deeper Channel
- Smaller tidal flats
- Lower MWL

Lower Columbia River – Morphology

Depth has increased in the Columbia River mostly due to dredging of the shipping channel
What are some of the consequences?



Tidal Propagation

Understanding how waves propagate can help to understand what has happened in the Lower Columbia River

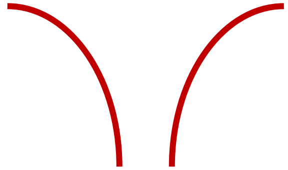
How does changing depth affect wave propagation?

According to *Friedrich and Aubrey*, [1994] in a convergent estuary (i.e. Columbia, Fraser), 1st order momentum balance is between friction and pressure gradient

$$0 = -g\frac{\partial \varsigma}{\partial x} - F$$

$$F = \frac{8}{3\pi}\frac{c_d U}{\bar{h}}u = ru$$

Convergent estuary

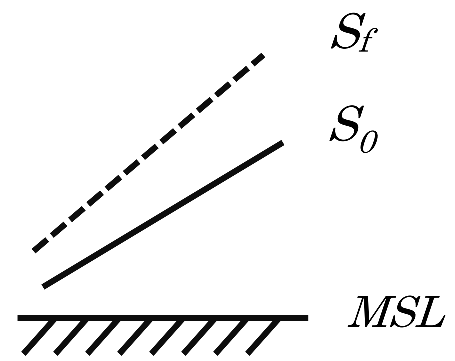


Increasing depth, reduces effective friction and reduced friction increases tidal or wave amplitude

Flood Routing

Instead of a tide let's consider a flood wave moving through a river channel

$$\underset{\text{small}}{\overset{\#1}{\frac{\partial u}{\partial t}}} + \underset{\text{small}}{\overset{\#2}{u\frac{\partial u}{\partial x}}} + \boxed{g\frac{\partial \varsigma}{\partial x} + g\left(S_f - S_0\right) = 0}$$



For a long slow moving flood wave

- t is large (very long period) ~ Term #1 is small
- small variation in u over flood length scale ~ Term #2 is small

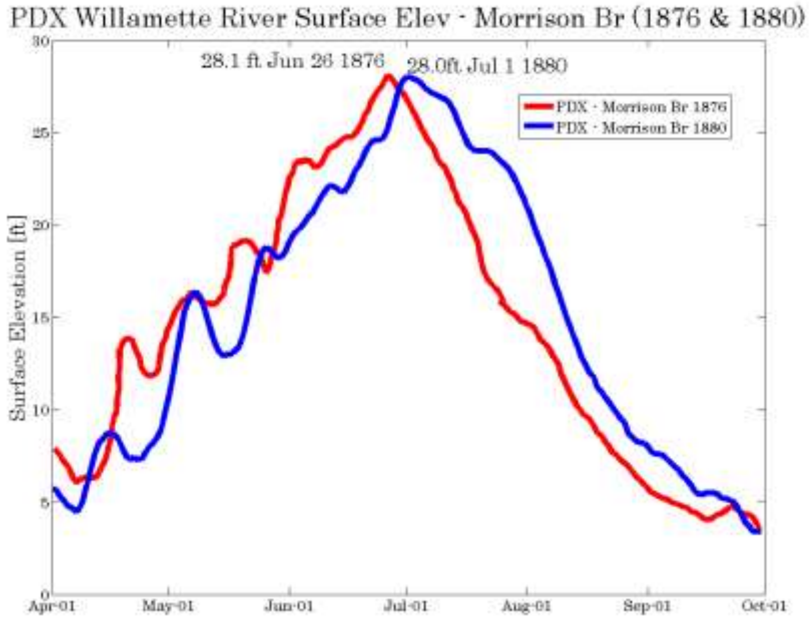
1st two term of the momentum are very small in 1876 Flood and can be neglected for most of the LCR

$$S_f = S_0 - \frac{\partial \zeta}{\partial x}$$

S_f = linear loss of hydraulic head
S_0 = channel bed slope (constant)

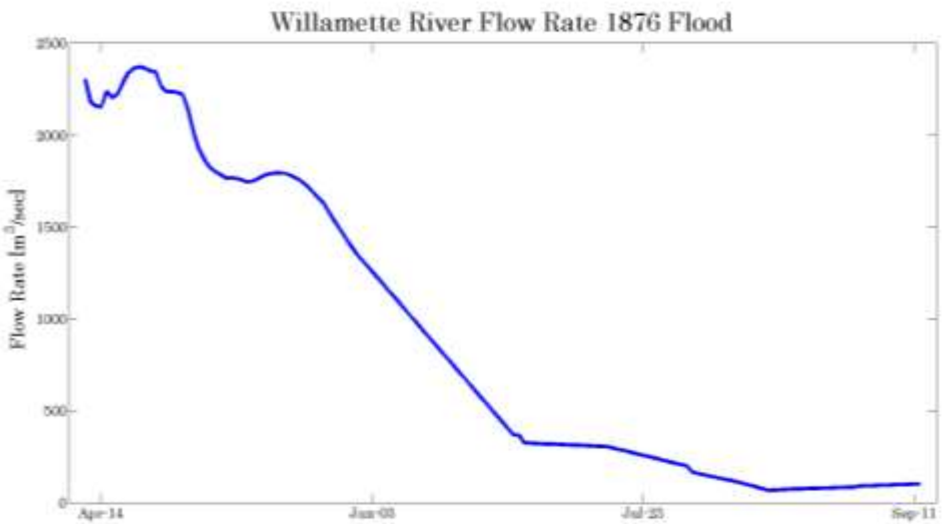
Changes in depth can also affect the movement of a flood wave

Simulation #1 1876 Columbia River Flood

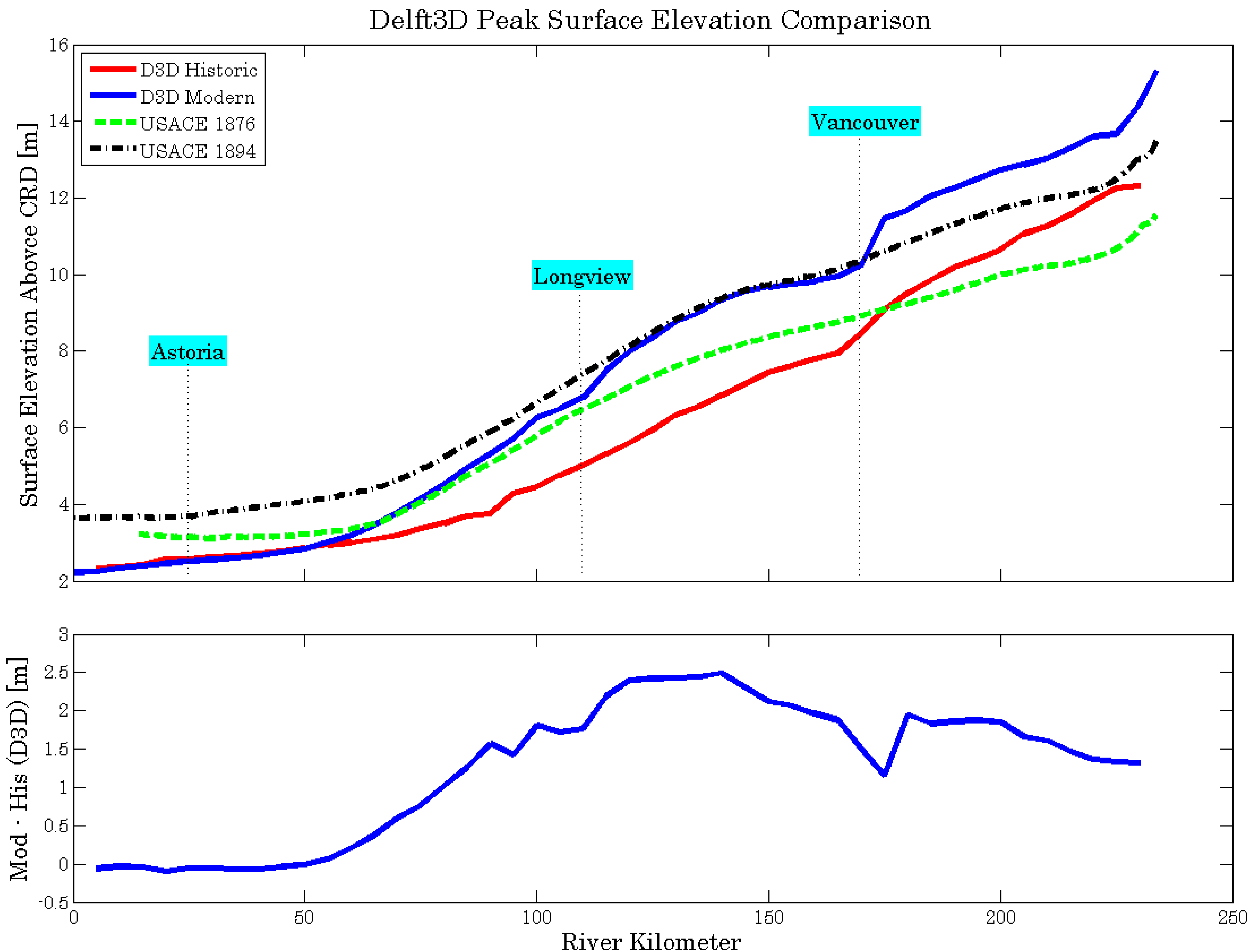


PDX Willamette River water level in 1876 & 1880 are similar

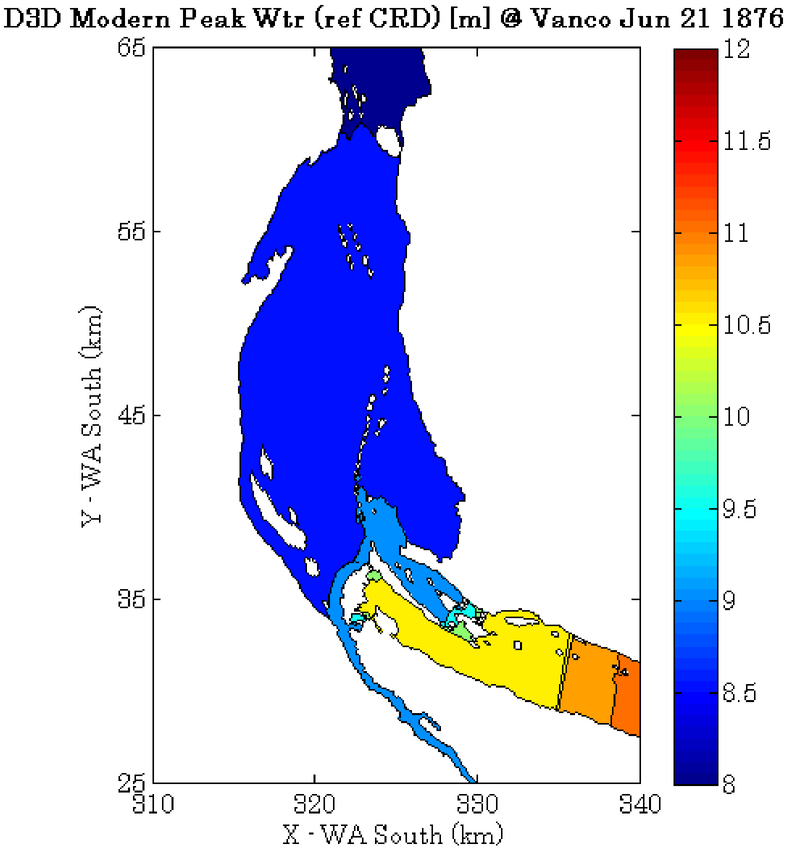
- 1876 & 1880 CR very close in magnitude
- 1876 & 1880 peaks flow are offset by several days
- Since 1880 Flow are available we can use them to estimate 1876 Flood

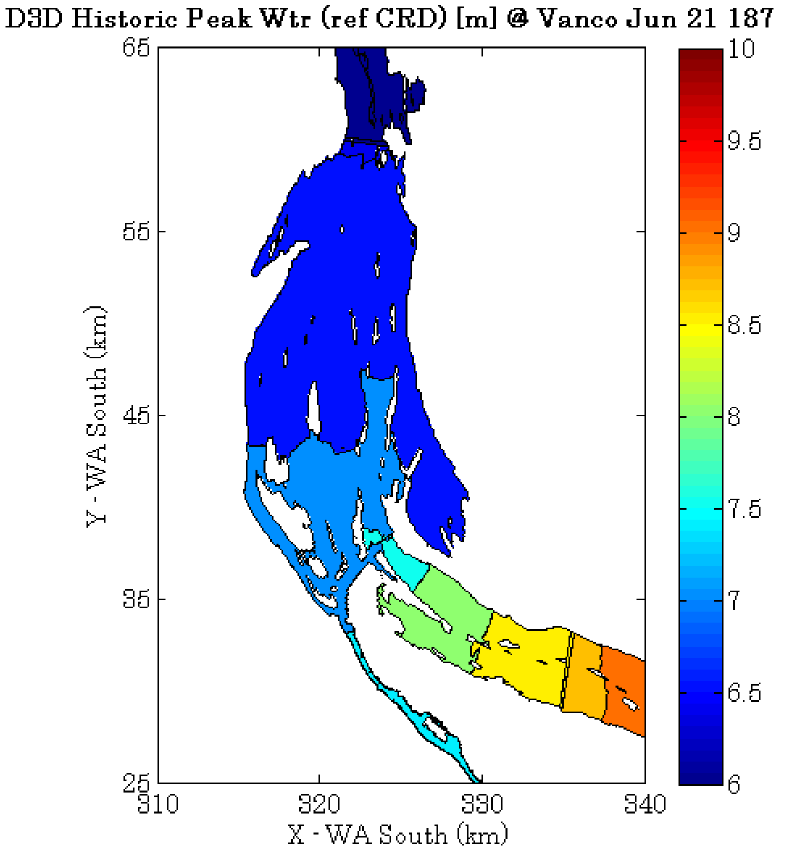


Willamette River Flow during the 1876 flood is estimated from average daily flow 1879-1888



Delft3D Peak Surface Elevation Comparison
D3D Historic
D3D Modern
USACE 1876
USACE 1894
Vancouver
Longview
Astoria
Surface Elevation Abovce CRD [m]
Mod - His (D3D) [m]
River Kilometer
16
14
12
10
8
6
4
2
3
2.5
2
1.5
1
0.5
0
-0.5
0
50
100
150
200
250





At the peak of the 1876 Flood water level in modern bathymetry are about 2m higher than in historic bathymetry

Results

- Developed a hydrodynamic model of the LCR with bathymetry of late 19th century
- Historic model is calibrated to match historic tide records
- Comparison of bathymetry of LCR shows increased channel depth and reduction in intertidal area
- Water level records from Vancouver indicate that Mean Water Level has dropped continually since the 1940’s and tidal range has increased since the 1940’s
- Simulation of the 1876 Flood indicate that peak water levels are 2m higher in Modern Bathymetry assuming no flow regulation
- Peak water levels of Modern 1876 Flood approach water level from 1894 Flood

Significance

- With a historic model we can evaluate how morphological changes affect channel dynamics
- The historic model can be used an educational tool in understanding how measurables such as salinity, turbulence, sedimentation have evolved over the past 150 years
- Hydrodynamic and analytical models can be used to help guide policy, foster sustainable development practices and aid in habitat restoration
- Help communities to be able to deal with issues such as climate change and sea level rise

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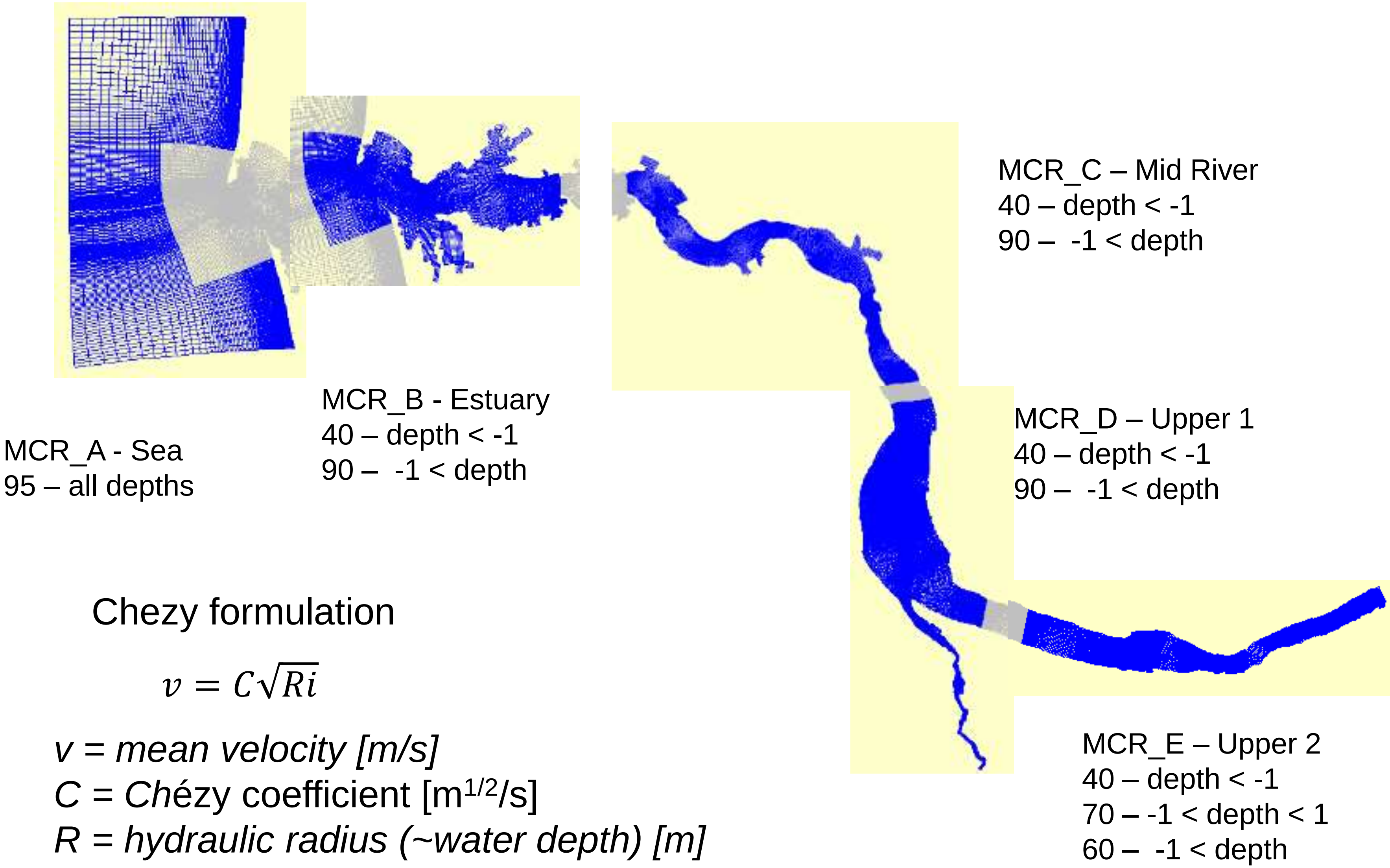
1. Burke, J.L. (2010), Georeferenced hostorical topographic survey maps of the Columbia River Estuary, School of Aquatics and Fisheries Sciences, University of Washington, Seattle, WA
2. Friedrichs, C.T., D.G. Aubrey, Tidal propagation in strongly convergent channels, *Journal of Geophysical Research: Oceans (1978-2012), 99*(C2), 3321-3336
3. Henshaw, F.F., H.J. Dean (1915), Surface water supply of Oregon (1878-1910), Washington, DC, Government Printing Press: *US Geological Survey Water Supply Paper 370*
4. Jay, David A. (1991) Green's Law Revisited: tidal long-wave propagation with strong topography, *Journal of Geophysical Research: Oceans (1978-2012), 96*(C11), 20585-20598
5. Jay, David A., K. Leffler, S. Degens (2011), Long Term Evolution of Columbia River Tides, *Journal of Waterway, Port, Coastal, and Ocean Engineering, 137*(4), 182-191
6. Moussa, R., C. Bouquillion (1996), Criteria for the choice of flood-routing methods in natural channels, *Journal of Hydrology, 186*(1), 1-30
7. Talke, S.A., D. Jay (2013), Nineteenth Century North American and Pacific Tidal Data: Lost or Just Forgotten?, *Journal of Coastal Research* 29(6a), 118-127

Delft3D Grid of Modern Lower Columbia River

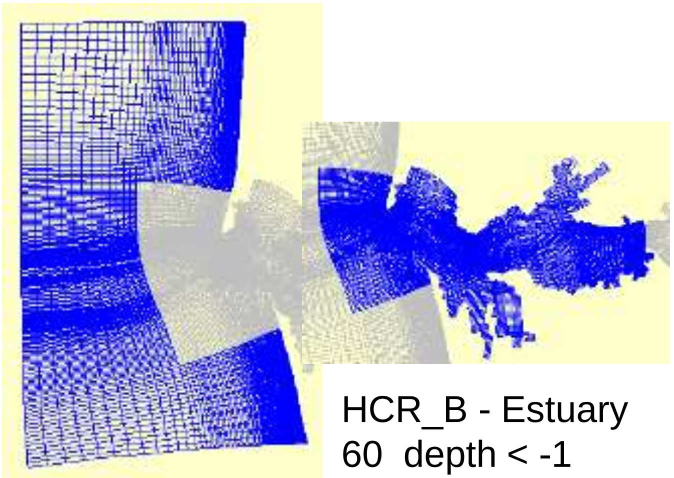


Chezy formulation

$$v = C\sqrt{Ri}$$

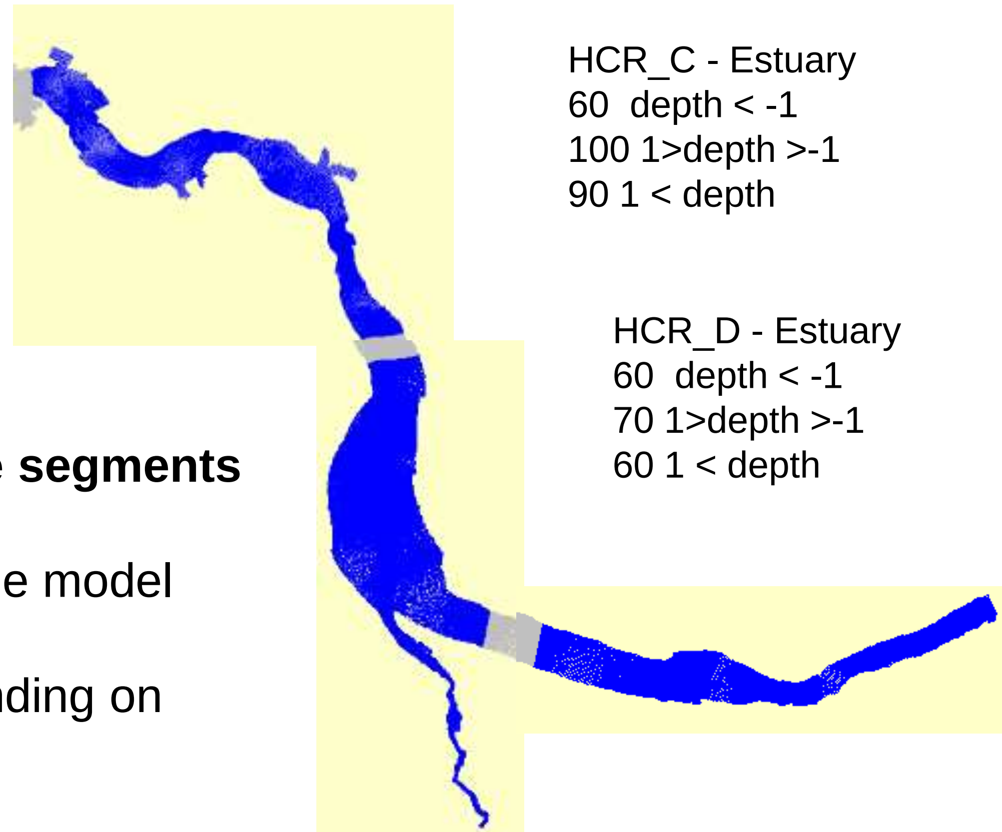
v = mean velocity [m/s]
C = Chézy coefficient [$m^{1/2}$/s]
R = hydraulic radius (~water depth) [m]
i = bottom slope (dimionless)

Delft3D Grid of Modern Lower Columbia River



HCR_A - Sea
95 – all depths

HCR_B - Estuary
60 depth < -1
100 1>depth >-1
85 1 < depth



HCR_C - Estuary
60 depth < -1
100 1>depth >-1
90 1 < depth

HCR_D - Estuary
60 depth < -1
70 1>depth >-1
60 1 < depth

Modern Grid is divided into five segments

- faster computation
- easier to adjust spatially variable model parameters
- can be broken up further depending on modeling scenario

Flood Routing

Simplified 1-D St. Venant Equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} + g\left(S_f - S_0\right) = 0$$

S_0 – Surface Slope ($1.27e^{-5}$) for Willamette River and most of Columbia River
S_f – Energy Grade Line

1 $S_f = nV^2R^{-m} \approx nV^2y^{-m}$
.

n = Manning roughness coefficient
V = average water velocity
R = hydraulic radius
y = channel depth

Nature of Wave depends on scaling of terms S-V equation

$S_f = S_0$	*Kinematic*	$S_f = S_0 - \frac{\partial h}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x}$	*Steady - Nonuniform*
$S_f = S_0 - \frac{\partial h}{\partial x}$	***Diffusional***	$S_f = S_0 - \frac{\partial h}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t}$	*Unsteady - Nonuniform*

1. Taken from Moussa and Bocquillion [1995]

Scaling of Momemntum - Modern

Spring 1996 Flood – Scaling

$S_0 = O\ (10^{-5})$
$S_f = O\ (10^{-3})$
$dy/dx = O\ (10^{-3})$
$(v/g)(dv/dx) = O\ (10^{-3})$
$(1/g)(dv/dt) = O\ (10^{-5})$

*Scales represent peak values
*Need to examine terms under normal conditions and peak flood conditions to understand spatial and temporal changes

Winter 1876 Flood – Scaling

$S_0 = O\ (10^{-5})$
$S_f = O\ (10^{-3})$
$dy/dx = O\ (10^{-3})$
$(v/g)(dv/dx) = O\ (10^{-3})$
$(1/g)(dv/dt) = O\ (10^{-4})$

Simulation #1 – 1876 Spring Columbia River Flood

1876 – Top 5 largest Floods in Columbia River since 1876 [3]

Complete Flow records for Columbia River at Bonneville go back only to 1879

Columbia River 1880 Flood peak flow is < 8% smaller than 1876 Flood and delayed by one week

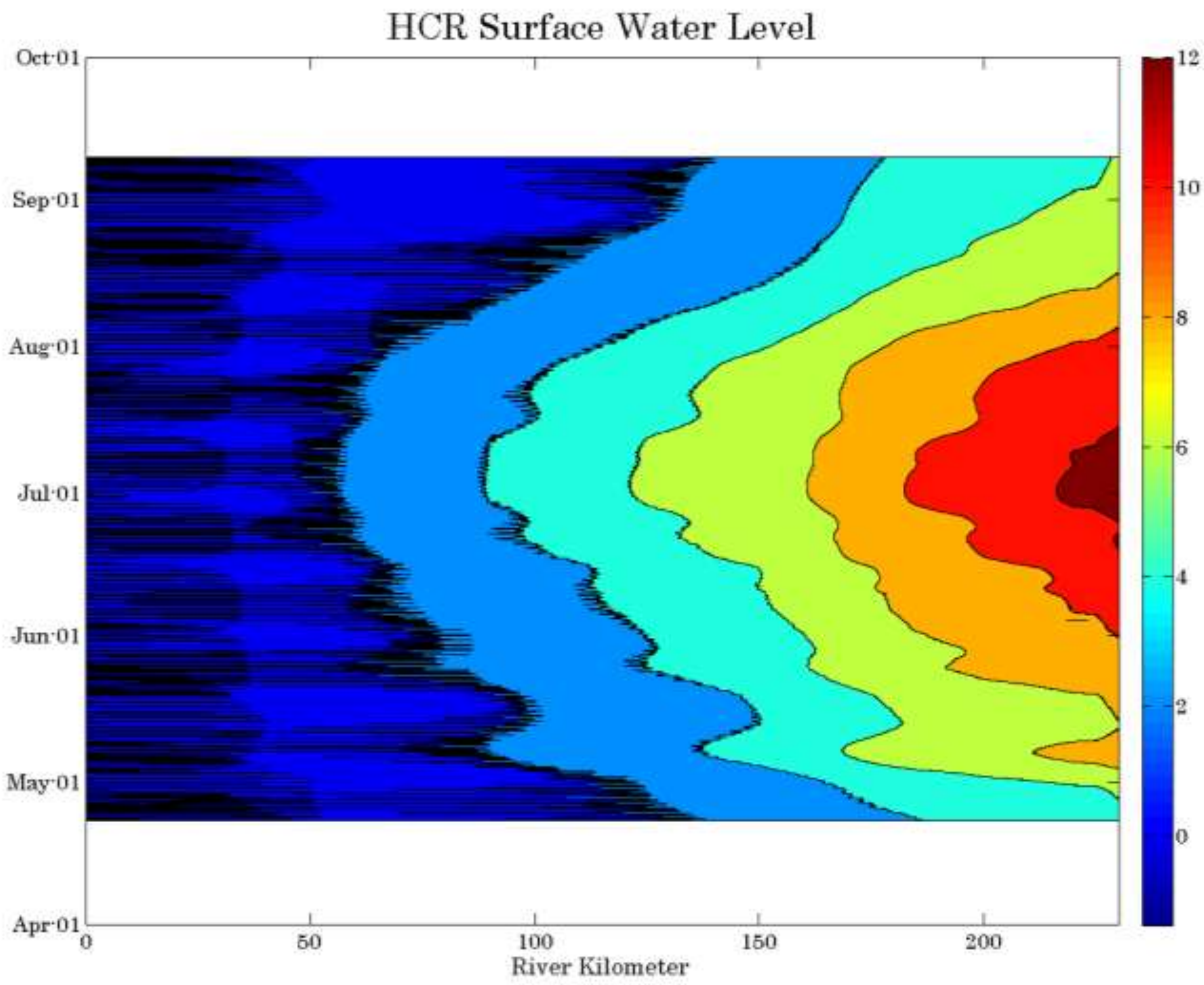
Flow estimate is based on peak water levels at Vancouver, WA

Willamette River flow estimate from 10 year average (1879-1888)

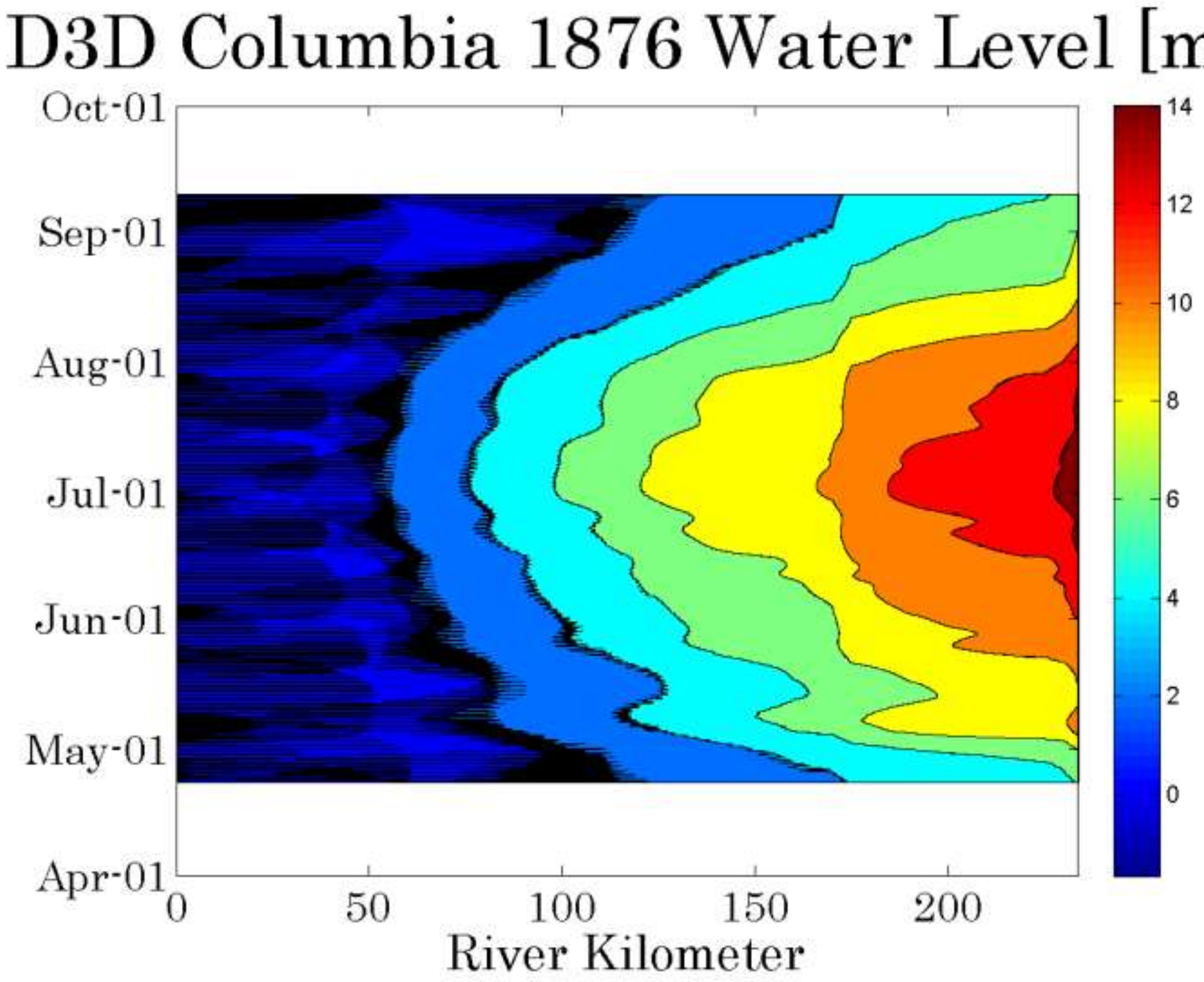
Assumptions

- Columbia River bathymetry is similar between 1876-1880
- Hydrograph in 1876 and 1880 has same shape
- Willamette River Flow daily flow in 1876 is similar to flows between 1879-1888
- Barotropic model – limited influence of ocean tides at during peak flood

Spring 1876 Flood – Water Level Historic Grid



Spring 1876 Flood – Water Level Modern Grid



Tidal Propagation

Tidal propagation theory can also begin to explain to drop in Mean Water Level

Jay, [1991] has shown that for critical convergent channels (i.e. Columbia)

- the water elevation (ζ) decreases with increasing depth
- transport (*Q)* increases with increasing depth

$$\varsigma \ \propto (b_T)^{-1/4} b^{-1/4} h^{-1/2}$$

$$Q \ \propto (b_T)^{+1/4} b^{+1/4} h^{+1/2}$$