Effect of Columbia River Flow Changes on Tsunami Wave Propagation

Hamed Moftakhari Rostamkhani** (hamed2@cecs.pdx.edu)**, David Jay and Stefan Talke
Portland State University, College of Civil and Environmental Engineering, Portland, OR

Portland State UNIVERSITY

Abstract

In this study we analyze the effects of a tsunami along the Eastern Pacific subduction zone, similar to what happened in March 2011 at Tohoku, Japan. Hydrodynamic model calculations were carried out using Delft-3D. Three different scenarios of steady low flow, mean flow and high flow have been used to analyze the effect of river flow variability on tsunami wave propagation. Model results suggest that tsunami wave propagation into the system is strongly affected by frictional interaction with the river discharge. Increasing river flow decreases the tsunami amplitude and decreases the propagation speed into the upstream river. For large flows, the tsunami wave is damped out more quickly.

Background

The effect of fresh water discharge on damping tides has been studied by different scientists theoretically and experimentally [Godin, 1985; Godin, 1999; Kukulka and Jay (2003)]. Tsunami waves are long waves. Tsunami is caused by earthquakes along the coastlines, that can cause tremendous damage to coastal areas and also, can propagate up rivers and cause damage on similar scale kilometers upstream from the mouth [Yasuda, 2010]. Some scientists have studied the propagation of tsunami waves up river channels, through measurements and experiments [Abe, 1985 ;Yasuda, 2010].

Case Study

"The Columbia River (CR) is a major river in North America, and is vital to North West American economy (e.g. fisheries, hydropower, ship-traffic) [Kukulka and Jay 2003]". Many studies have investigated CR hydrodynamics [Giese and Jay, 1989; Jay et al., 1990; Sherwood et al., 1990; Kukulka and Jay, 2003]. In this study, the effect of a hypothetical tsunami, similar to what happened in March 2011 at Tohoku, Japan, is studied for the Columbia River estuary.

Figure 1: Columbia Gorge, Columbia River, near Portland, OR, 2011

Method

- **Theory**

In the presence of river flow and a single long wave, the absolute value of bed stress (τ_B) can be represented using the Chebyshev polynomial as:

$$\frac{\tau_B}{\rho} = C_D|U|U \approx C_D U_0^2\left(a_1(U_T+U_R)+a_2(U_T+U_R)^2+a_3(U_T+U_R)^3\right) \quad \text{Eq. (1)}$$

where: C_D is the drag coefficient, a_i are coefficients that depend on ratio of river flow to total flow, U is a dimensional velocity, U_0 is a velocity scale, and U_R and U_T are non-dimensional steady river flow and tidal velocity, respectively.

As suggested by Eq.(1), an increase in discharge increases τ_B and results in damping of the wave and modification of its timing [Kukulka and Jay (2003); Godin, 1999]

We are not including tides in the simulations. Because this is a preliminary study with limited computation time. However, the earthquake is rapid, but waves enter the estuary at all phases of the tide for several days.

- **Hydrodynamic Model**

The effect of change in river flow on tsunami wave propagation has been studied using the Delft-3D software. Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation [Deltares 2010]. The hydrodynamic Delft-3D model of CR which are used in this study originally has been gotten from USGS and and hypothetical tsunami wave data prepared by Hydrodynamic Processes and Ecosystem Group at College of Civil and Environmental Engineering of Portland State University.

- **Scenarios for River Flow**

Tsunami occurs over short period of time (couple of hours), so assuming a steady river flow during tsunami wave propagation is a reasonable first approximation. Three different scenarios of steady low flow, mean flow and high flow are used to analyze the effect of changes in river flow on tsunami wave propagation. Records of CR discharge show a wide range of probable discharge, though reservoir management has reduced natural variability (USGS 2011). Low flow is considered as 2000 m^3/s, mean flow 7000 m^3/s and high flow 20000 m^3/s.

Scenario	Number 1	Number 2	Number 3
Discharge (m^3/s)	2000	7000	20000

Results

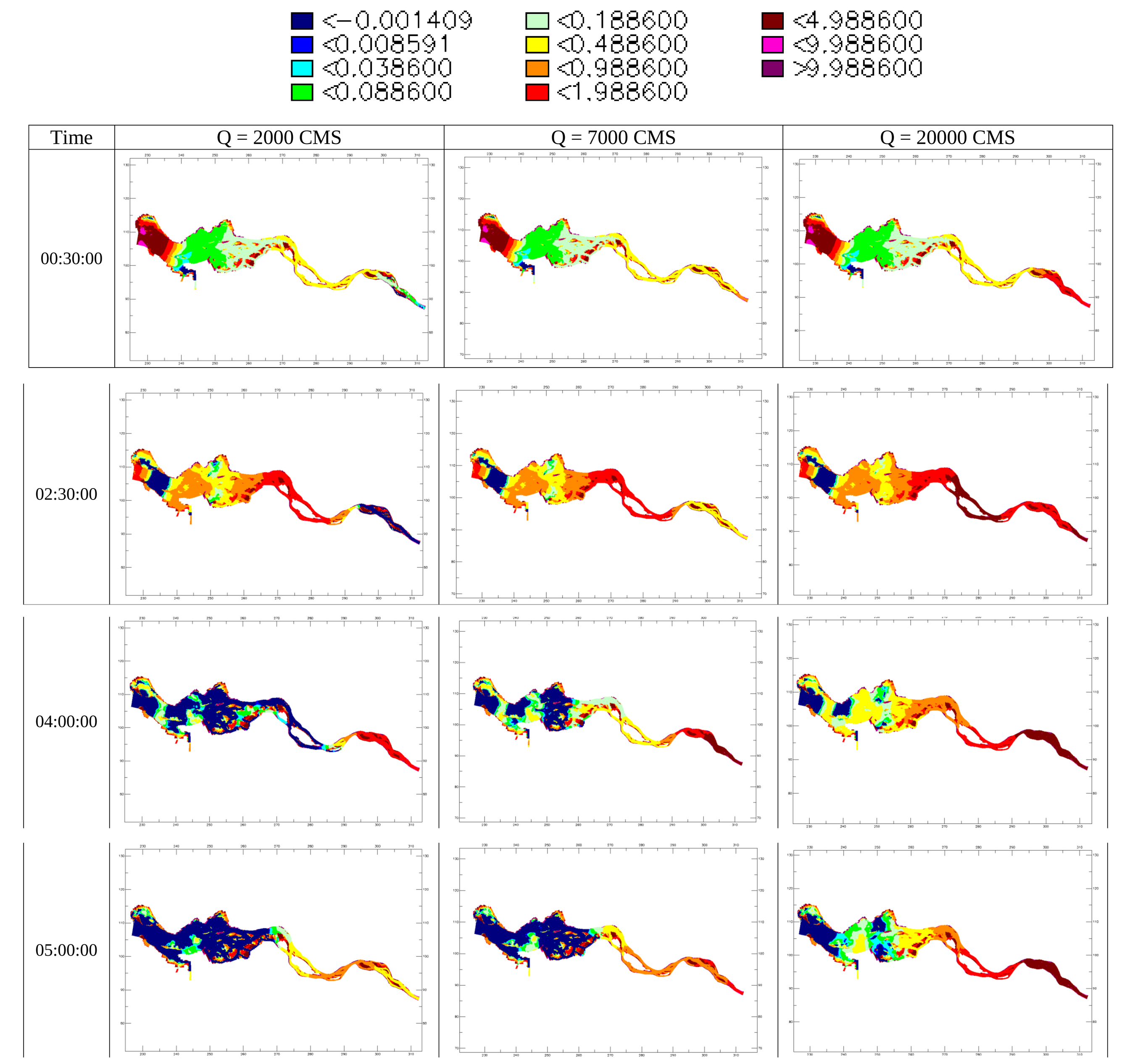

Figure 2: Water Level (m)

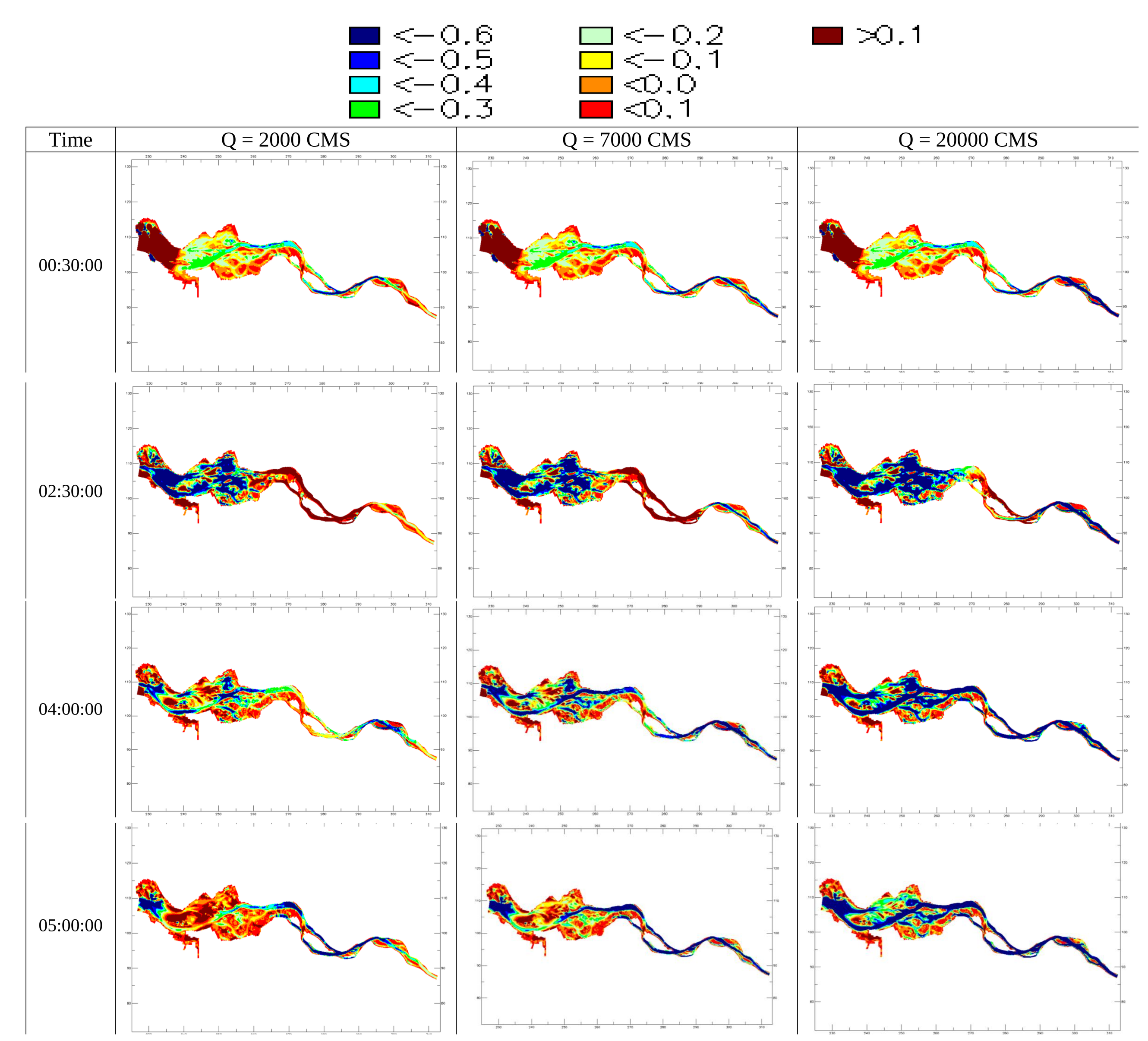

Figure 3: Along Channel Velocity (m/s)

Discussion

In this study spatial and temporal variability of water level and along channel velocity during the first 5-hours of a subduction event tsunami are chosen as representatives of hydrodynamic characteristics of flow. Velocity is assumed negative in seaward direction and positive landward.

Because the outer estuary is wide, the cross sectionally averaged river flow is small and no significant difference is observed between flow scenarios, before reaching the tsunami wave to the upstream of estuary(first 2 hours).

Upstream of estuary the channel is narrow and river flow is dominant. After 2 hours, more river discharge results in damping the tsunami wave and decreasing the wave crest's velocity toward upstream and finally wave becomes attenuated more seaward at higher flows. After two hours at scenario #1 (low flow) river current is not strong enough to damp over the tsunami waves and changes the flow direction toward ocean in first 4 hours. At scenario #2 (mean flow) when the tsunami wave reaches upstream estuary, the velocity of wave's crest decreases and a weak seaward current in estuary could be seen . In the case of high flow (scenario #3) the tsunami wave is damped and reflects by river flow. That is why in Figure 3, scenario #3 (Q=20000 CMS), indeed, a seaward current is observed along the channel and estuary at t = 2 hours.

Conclusion

It is known that an increase in discharge damps the tide in a river and modifies its timing. Three different scenarios of steady mean flow, low flow and high flow have been studied to analyze the effect of change in river flow on tsunami wave propagation. Results show that before the time that tsunami wave reaches upstream estuary where the channel is narrow, there is no significant difference between scenarios along the estuary. But after that, tsunami wave properties differs for different river flows and the larger river flow damps the tsunami wave more quickly. We are not including tides in the simulations. Because this is a preliminary study with limited computation time, and waves enter the estuary at all phases of the tide for several days.

Acknowledgement

Support for this project was provided in part by a grant to the Institute of Sustainable Solutions at Portland State University, and in part by the National Science Foundation project: Secular Changes in Pacific Tides. Also, the USGS contribution to the Delft3D model by Edwin Elias and Guy Gelfenbaum is acknowledged, and the assistance of Ed Zaron in setting up the Delft3D model is gratefully acknowledged.

References

- Abe, K., (1986) "Tsunami Propagation in Rivers of the Japanese Islands", Continental Shelf Research, Vol. 5, No. 6, pp. 665 to 677.
- Deltares (2010) "Delft-3D Flow, User Manual", © 2010 Deltares, Version 3.14, Revision 12556, September 2010, Netherland.
- Giese, B.S. and Jay, D.A., (1989) "Modeling Tidal Energetics of the Columbia River Estuary", Estuarine, Coastal and Shelf Science 29, 549-571.
- Godin, G., (1985) "Modification of River Tides by the Discharge", Journal of Waterway, Port, Coastal and Ocean Engineering ©ASCE, Vol. 111, No. 2.
- Godin, G., (1999) "The Propagation of Tides up Rivers with Special Considerations on the Upper Saint Lawrence River", Estuarine, Coastal and Shelf Science 48, 307-324.
- Jay, D.A., Giese, B.S. and Sherwood, C.R., (1990) "Energetics and Sedimentary Processes in the Columbia River Estuary", Prog. Oceanog. Vol. 25, pp. 157-174, 1990.
- Kukulka, T., and Jay D.A., (2003) "Impacts of Columbia River Discharges on Salmonid Habitat: 1. a Nonstationary Fluvial Tidal Model", Journal of Geophysical Research, Vol. 108, no. C9, 3293.
- Sherwood, C.R., Jay, D.A., Harvey, B., Hamilton, P. and Simenstad, C.A., (1990) "Historical Changes in the Columbia River Estuary", Prog. Oceanog., Vol. 25, pp. 299-352, 1990.
- USGS (2011) "USGS 14105700 Columbia River at the Dalles, OR", United States Geological Survey, Retrieved December 2011, http://waterdata.usgs.gov/nwis/uv?14105700.
- Yasuda, H., (2010) "One-Dimensional Study on Propagation of Tsunami Wave in River Channels", Journal of Hydraulic Engineering, ©ASCE, Vol. 136, No.2, February 2010.