STREAM CHANNEL PROPERTIES AND HYDRAULIC ROUTING METHODOLOGIES:

TOWARDS REGIONALLY-SPECIFIC CHANNEL ROUTING ALGORITHMS AT A CONTINENTAL SCALE

Eric D. White, Ehab Meselhe, & Chia-Yu Wu

Tulane University, River-Coastal Science & Engineering

Acknowledgements

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Related Presentation @ UFS 2020:

Continental Scale Heterogeneous Channel Routing Strategy for Operational Forecast Models

Ehab A Meselhe, Nazmul Beg, James Halgren, Dong Ha Kim, Fred Ogden, Trey Flowers

National Water Model (NWM)

- Short (18 hr), Medium (10 day) and, and Long (30 day) range forecasts
- Atmospheric forcings from a variety of sensor and model datasets (e.g., UFS)
- Hydrologic surface and subsurface routing
- Hydraulic channel routing (WRF-Hydro) uses Muskingum-Cunge in NHDPlusV2 network

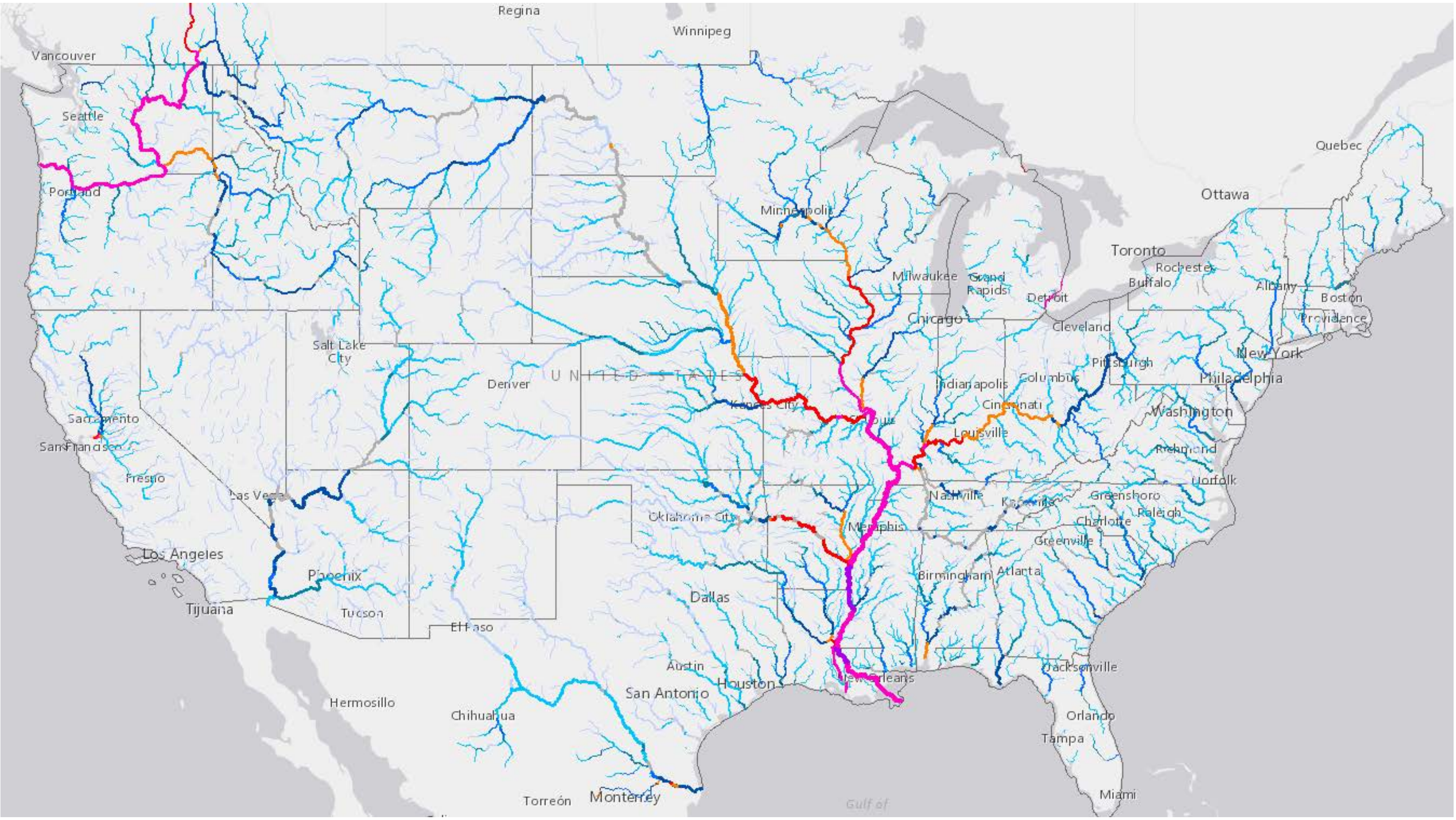

Figure from: https://water.noaa.gov/map

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St. Venant Equations

- Conservation of Volume:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

- Conservation of Momentum:

Inertia *Pressure* *Gravity* *Friction*

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial y}{\partial x} - gA(S_0 - S_f) = 0$$

Kinematic Wave

Muskingum-Cunge

Diffusive Wave

Dynamic Wave

Dimensionless Scaling Parameters (DSP)

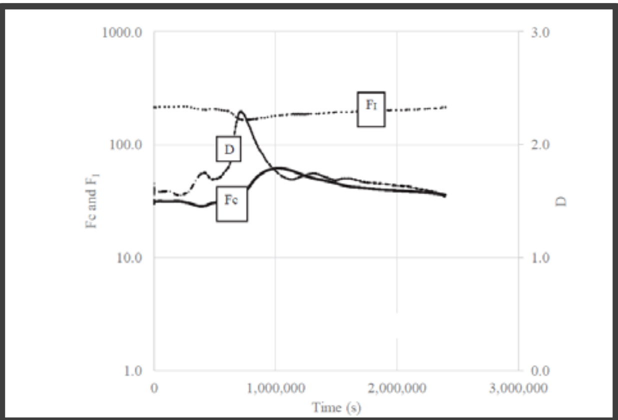
- Ferrick (1985) identified several parameters to estimate relative influence of dynamic vs diffusive & kinematic waves.
- Meselhe et al. (2020) revisited this approach to quantify need for dynamic wave routing in the NWM.
- The magnitude of each momentum term was also analyzed.

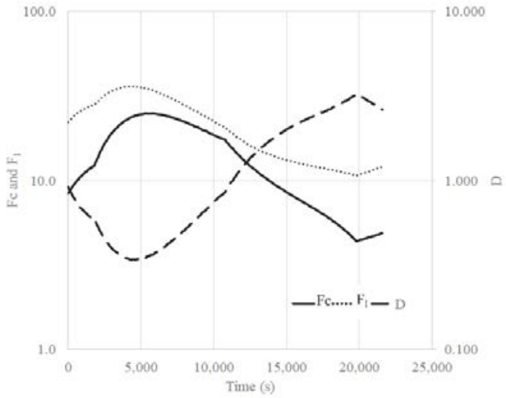
DSP	Equation	Physical interpretation
C_r	$C_r = v_0\left(\frac{\Delta t}{\Delta x}\right)$	Courant number: Ratio of mean flow velocity to measured wave celerity
F_0	$F_0 = \frac{v_0}{\sqrt{g y_0}}$	Froude number: Ratio of surface wave to mean flow velocity
S	$S = \frac{S_0}{S_f}$	Ratio of channel bed slope to energy gradient
D_I	$D_I = \left(\frac{C_r}{F_0}\right)^2$	Ratio of Courant to Froude numbers; or surface wave to measured wave celerity
F_I	$F_I = \frac{2C_r}{(C_*)^2}\left(\frac{k\Delta x}{y_0}\right)$	Friction parameter: influence of friction effects on river flow
F_c	$F_c = F_I C_r$	Friction parameter: reflecting influence of F_I and Courant number
D	$D = \frac{D_I}{F_c}$	Dimensionless diffusion coefficient: ratio of wave diffusion to wave advection

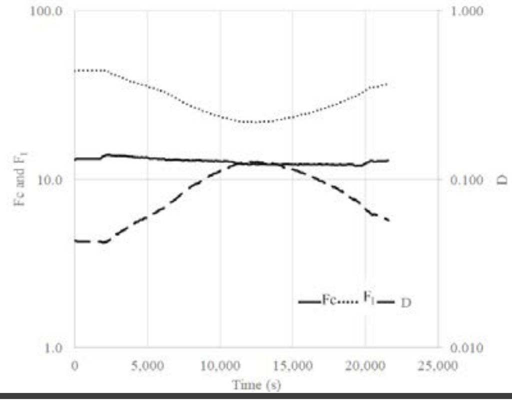
Table (after Ferrick, 1985) from Meselhe et al. (2020)

Test cases from Meselhe et al. (2020)

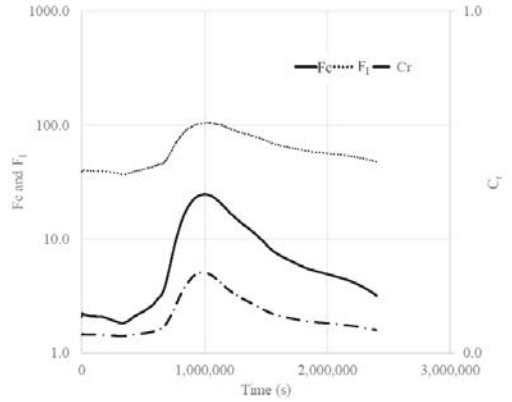
Normal Depth @ Downstream

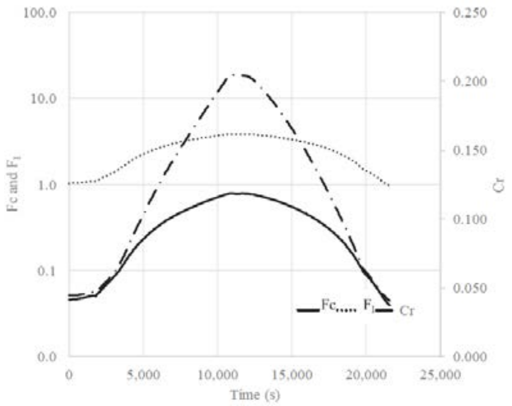






Backwater Curve





			Range of changing variables		
Flow state	Back water	Downstream stage (m)	Q_{peak} (m^3/s)	Slope	$1/n$
Unsteady	Yes	2 × ND	200–700	—	—
	Yes	2 × ND	—	5×10^{-5}–1×10^{-3}	—
	Yes	2 × ND	—	—	10–90
	No	ND	200–700	—	—
	No	ND	—	5×10^{-5}–1×10^{-3}	—
	No	ND	—	—	10–90

‘100-yr’ Flood in Red River @ Shreveport, LA

Idealized channel geometry and hydrographs

Test cases from Meselhe et al. (2020)

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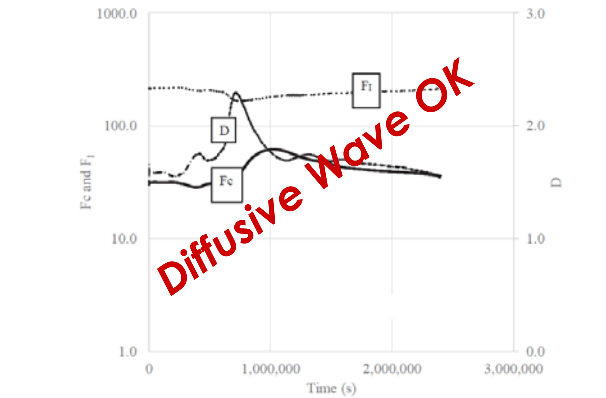

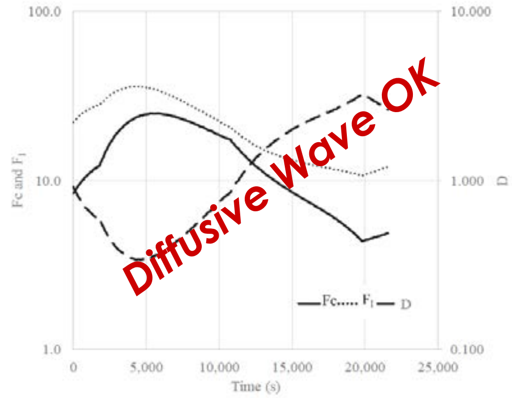

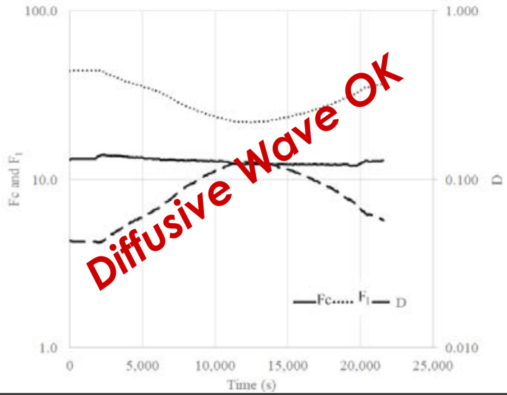

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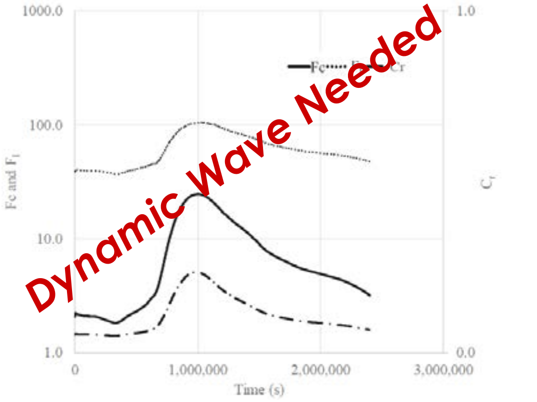

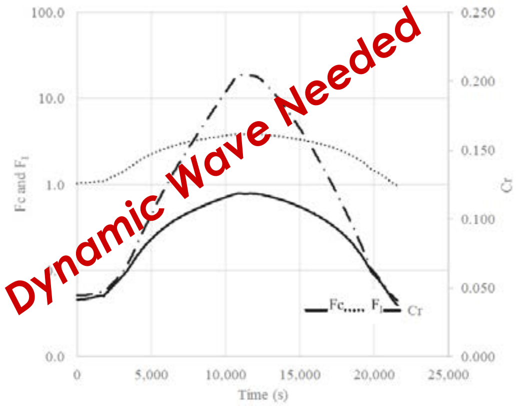

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'100-yr' Flood in Red River @ Shreveport, LA

Idealized channel geometry and hydrographs

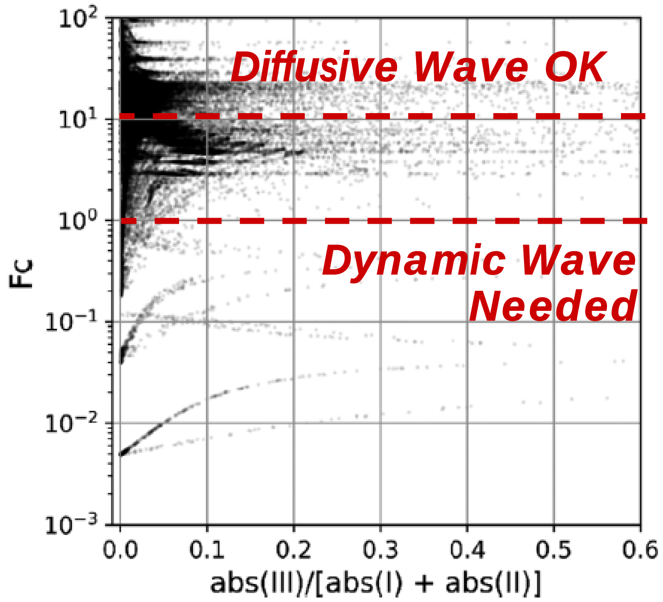
Prevalence of Dynamic Waves

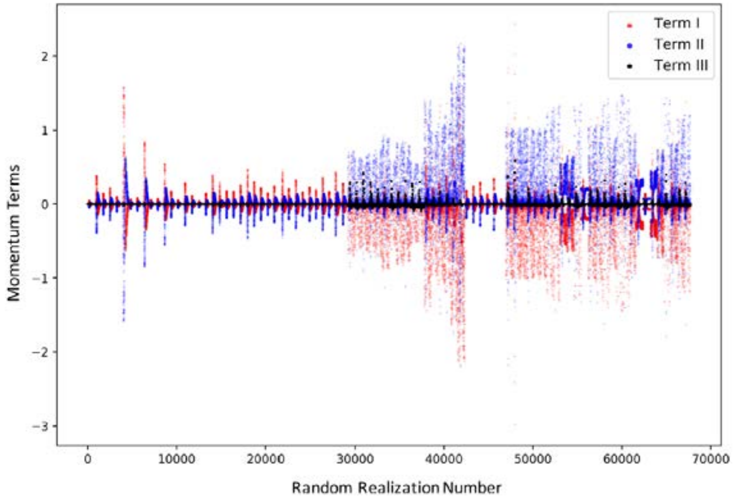
- Pressure gradient is non-negligible[1] in 97% of sampled points in test cases
  - Kinematic Wave only useful in 3% of cases

- Inertia terms are negligible[2] in 76% of sampled points in test cases
  - Dynamic Wave needed in 24% of cases
  - Therefore, Diffusive Wave appropriate in roughly 73% of cases

- Ferrick's F_C indicates inertia is negligible in 60%–80% of sampled points in test cases

[1]considered negligible when momentum term due to pressure is less than 10% of that due to friction
[2]considered negligible when momentum term due to inertia is less than 10% of that due to friction





Figures from Meselhe et al. (2020)

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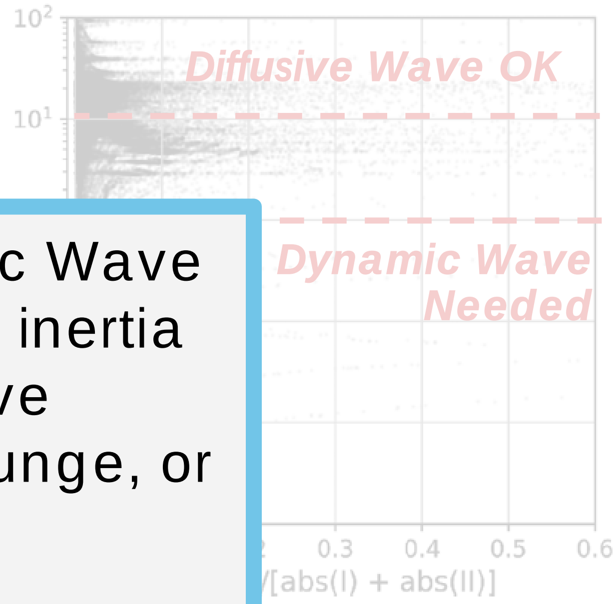
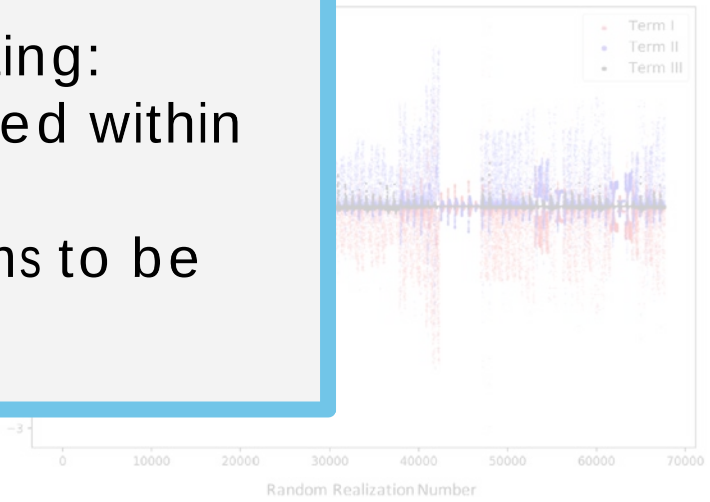
Prevalence of Dynamic Waves



We want to know *a priori* whether we need to run the Dynamic Wave or can 'make do' with Diffusive Wave. But, these DSPs and the inertia momentum term are only calculated via the full Dynamic Wave model; they are not available if Diffusive Wave, Muskingum-Cunge, or Kinematic wave routing algorithms are used.

For the ~ 25% of conditions that require Dynamic Wave routing:

- can we identify **where** these channel reaches are located within CONUS, and
- **when** conditions will allow for simplified routing algorithms to be used without loss of accuracy?



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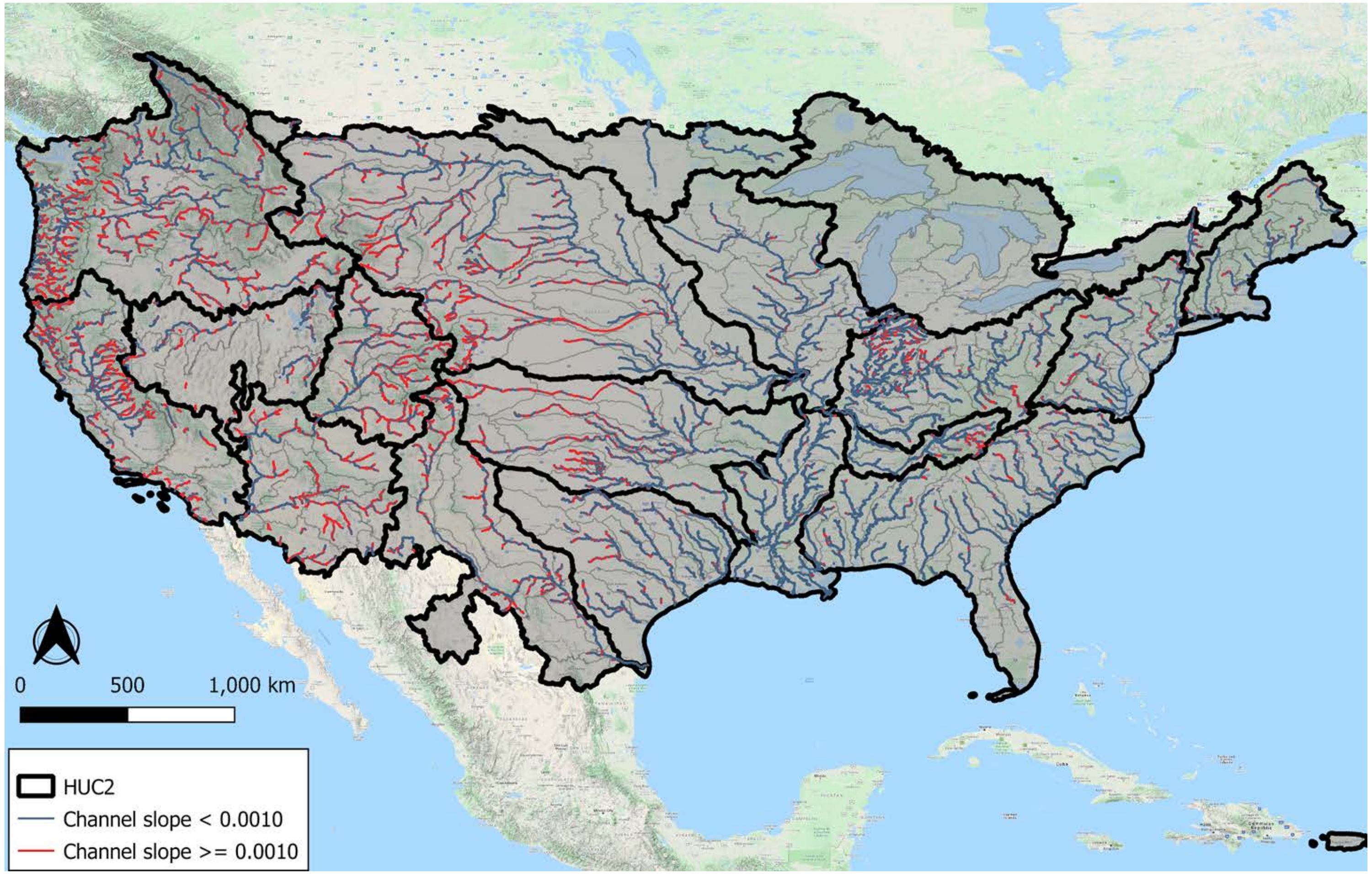
Figures from Meselhe et al. (2020)

Work Flow: Continental Scale Properties

National Hydrography Dataset - NHDPlusV2

- channel alignment
- channel slope

Network is reduced to channel reaches that have the two highest stream orders within each HUC04



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Work Flow: Continental Scale Properties

Estimate bankfull channel width from:

- contributing drainage area (Wilkerson et al., 2014)
- corresponds to '2-yr' peak flowrate, which is calculated via USGS StreamStats

Bankfull width chosen so that channel reach can be represented with a rectangular cross-section

- removes complexities of modeling floodplain connectivity
- no need for cutting cross-sections from DEMs
- only using in order to flag need for Dynamic vs Diffusive wave algorithms, ultimately flood inundation will be modeled with the operational model/cross-sections

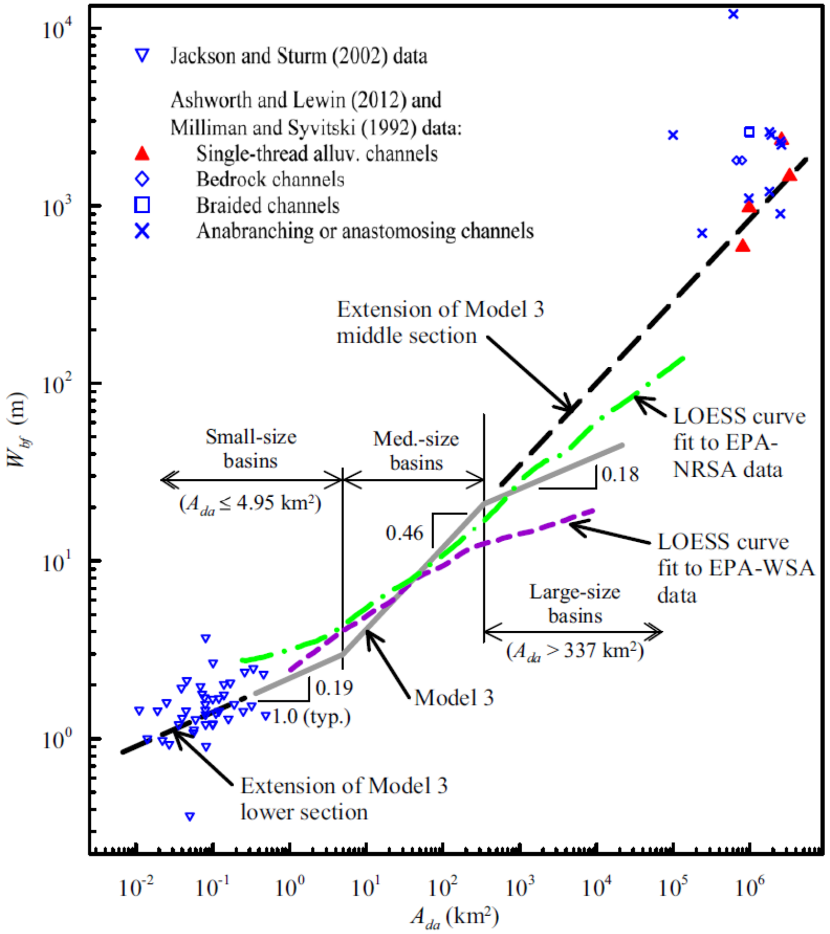
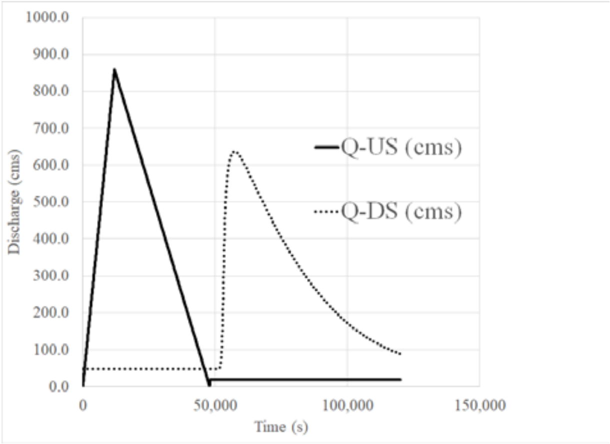
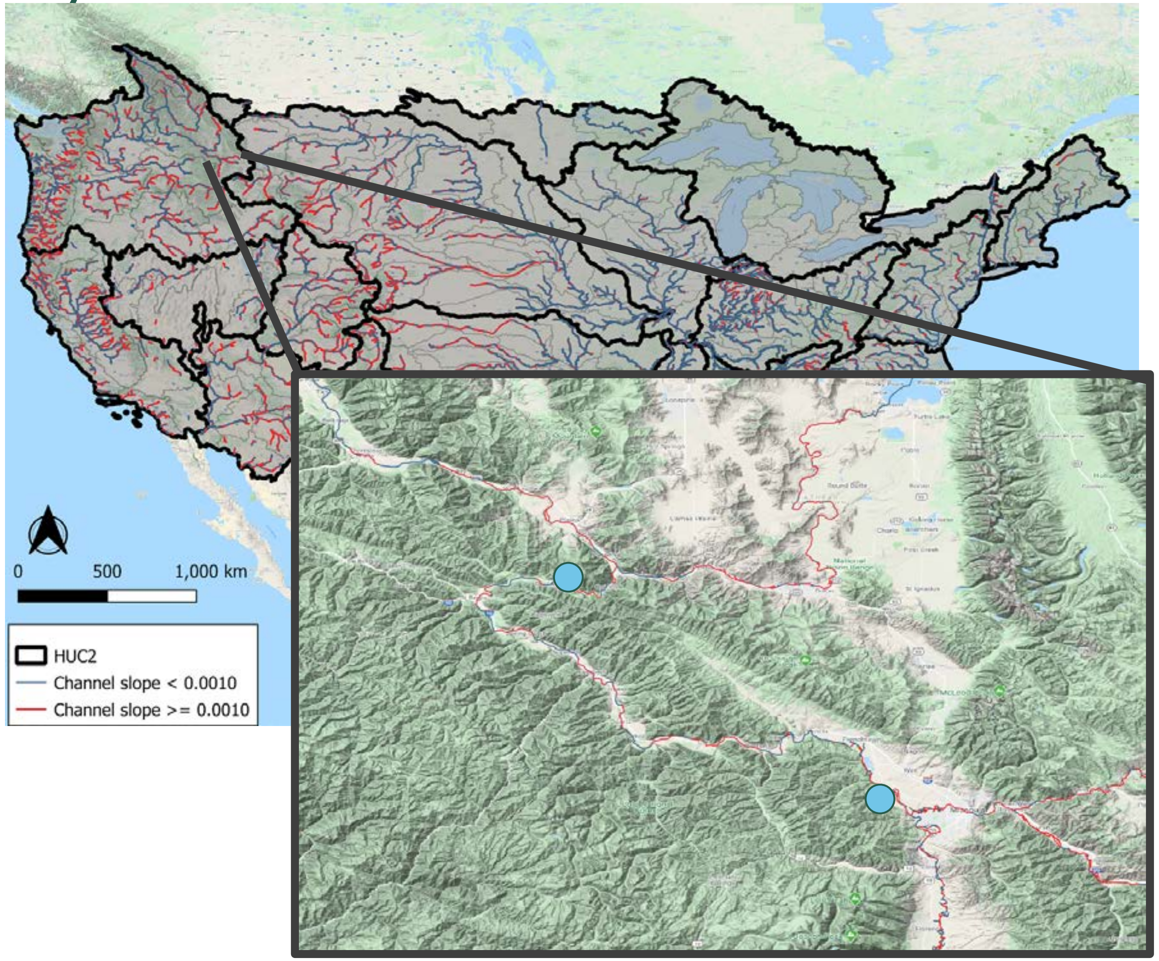


Figure from Wilkerson et al. (2014)

Test case: Clark Fork River, Montana

- ‘2-yr’ Peak Discharge = 858 cms
- Basin area = 23,310 km^2
- Bankfull width = 45 m
- Mean channel slope = 0.0012
- Manning’s roughness = 0.03
- Channel reach length = 165 km
- No backwater or drawdown





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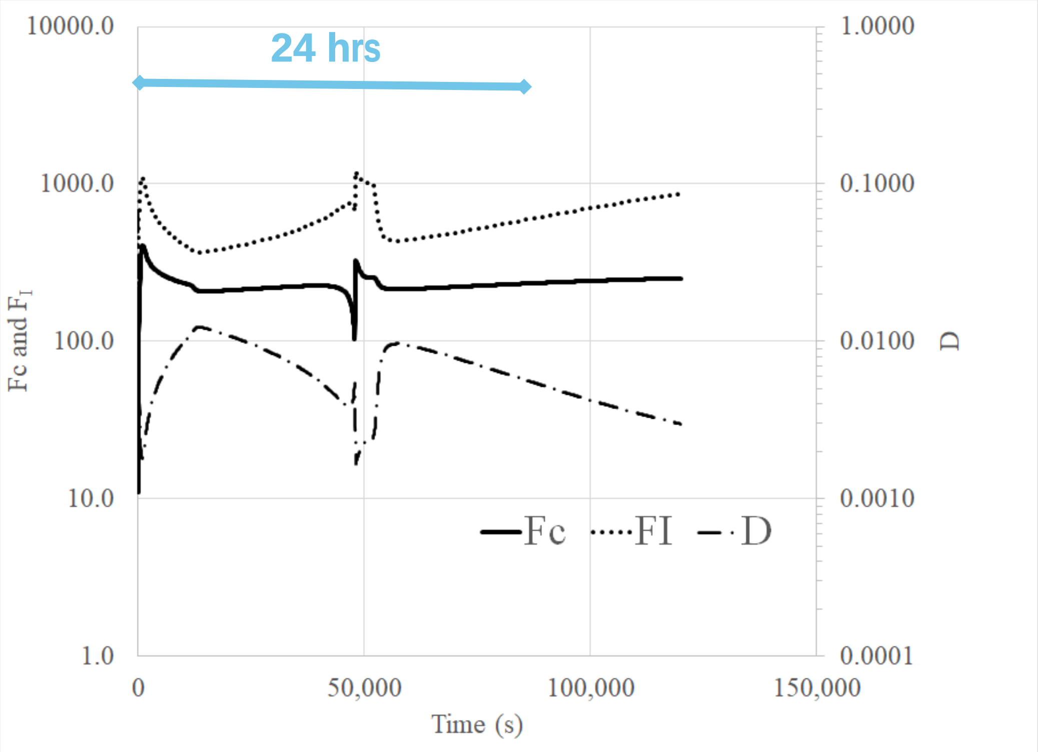
Dynamic wave not required (F_C >> 10)

Kinematic wave would suffice (D << 0.1)



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Next Steps:

- For mainstem reach within each HUC04 model:
  - bankfull flowrates with varying downstream boundaries
    - drawdown
    - backwater
    - normal depth
  - more frequent flowrates than bankfull (e.g., 1-year flood and smaller)
  - varied hydrograph shapes and durations
- Repeat above analysis with detailed slopes (as opposed to average slope per reach)
- Repeat above analyses with varying channel roughness values
- Analyze sensitivity of complex channel cross-sectional geometry
  - will be done for select basins with detail cross-sections available
    - Vermilion River, LA; Goodwin Creek, MS; more
- Compare simulations of Dynamic & Diffusive wave to assess accuracy and computational costs of different methods

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Thank you.

Questions?

References:

Ferrick, M.G. 1985. “Analysis of River Wave Types.” *Water Resources Research.* 21 (2): 209–20.

Meselhe, E.A., et al., 2020. “Continental scale heterogeneous channel flow routing strategy for operational forecasting models.” *J. American Water Resources Assoc.* 1-13. https://doi.org/10.1111/1752-1688.12847

Wilkerson, G.V., et al., 2014. “Continental-scale relationship between bankfull width and drainage area for single-thread alluvial channels.” *Water Resources Research.* 50: 919-936. https://doi.org/10.1002/2013WR013916