

Experimental Study of a Coupled River and River-plume System: Backwater Controls on Source-to-sink Sediment 75 Transfer*

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Search and Discovery Article #50712 (2012)**

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Editor's note: Please refer to companion article by Lamb et al., entitled "Backwater and River plume Controls on Scour Upstream of River Mouths: Morphodynamic Implications," [Search and Discovery Article #50711 \(2012\)](#).

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Abstract

Sediment transfer from rivers to the ocean is the fundamental driver of continental sedimentation with implications for carbon burial, reservoir exploration, and unraveling global climate change and Earth history from sedimentary strata. Despite the important role of source-to-sink sediment transfer, substantial uncertainty exists about the behavior of rivers near their mouths and sediment routing from rivers to their offshore plumes. Here we aim to better understand the morphodynamics and deposits in the transitional river-to-river-plume zone that is characterized by backwater hydrodynamics by using flume experiments. Our experiments were performed in a 7.5-m flume where a 10-cm wide river channel was connected to a 1-m wide "ocean basin" allowing for offshore spreading of the experimental plume. The first experiment set shows that (1) during low flows backwater hydrodynamics cause spatial flow deceleration and sediment deposition in both the river channel and offshore plume areas, and (2) during high flows the backwater zone becomes a region of drawdown, spatial flow acceleration and bed scour. The second set of experiments shows that with a suite of flood events with different discharges and durations, a persistent backwater/drawdown zone exists and controls the patterns of deposition and erosion, which cannot be reproduced using a single characteristic discharge (as is often assumed). We find that backwater hydrodynamics can extend onto the prograding delta and that alternating periods of erosion and deposition lead to rapid formation of levees and channel elongation. This in turn confines the offshore plume, which can affect backwater dynamics upstream, delta evolution and stratigraphic generation. Results are compared to numerical simulations presented in a companion study by Lamb et al. (2011).

Selected References

Chatanantavet, P., M.P. Lamb, and J.A. Nittrouer, 2012, Backwater controls on avulsion location on deltas: *Geophysical Research Letters*, v. 39/L01402, 6 p.

Lamb, M.P., J. Nittrouer, D. Mohrig, and J. Shaw, 2012, Backwater and river-plume controls on scour upstream of river mouths: Implications for fluvio-deltaic morphodynamics: *Journal of Geophysical Research Earth Surface*, v. 117, 15 p.

Lane, E.W., 1957, A study of the shape of channels formed by natural streams flowing in erodible material: Missouri River Division Sediment Series No. 9, US Army Engineer Division, Missouri River, Corps of Engineers, Omaha, Nebraska, 121 p.

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Edmonds, D.A., and R.L. Slingerland, 2007, Mechanics of river mouth bar formation: Implications for the morphodynamics of delta distributary networks: *Journal of Geophysical Research*, v. 112/F2, F02034, 14 p., DOI: 10.1029/2006JF000574

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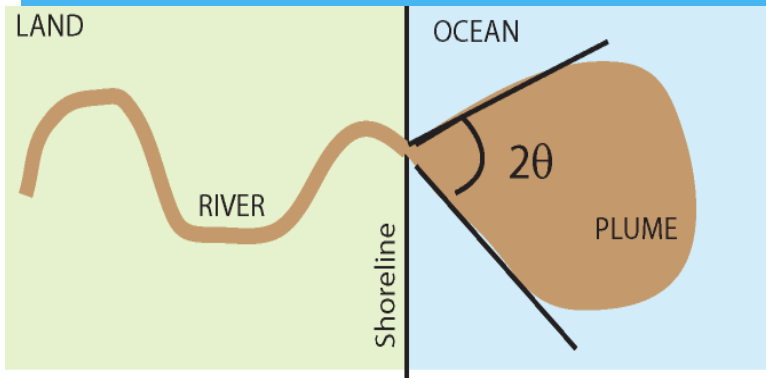
Funding: American Chemical Society, Petroleum Research Fund



Research Significance/Motivation

- * Sediment transfer from rivers to ocean is driver of continental sedimentation, important for land use dynamics.
- * The study has important implications for hydrocarbon reservoirs and sediment strata analysis (e.g., global climate change and Earth history).
- * Rivers near their mouths are affected by static water, creating a dynamic “**backwater zone**” where most of previous delta models ignored.
- * Previous works have neglected backwater zone by assuming only one normal flow (incl. topographic diffusion models) or eliminating backwater effects due to high slope and high Froude number in flume experiments.

Coupled backwater and river plume dynamics



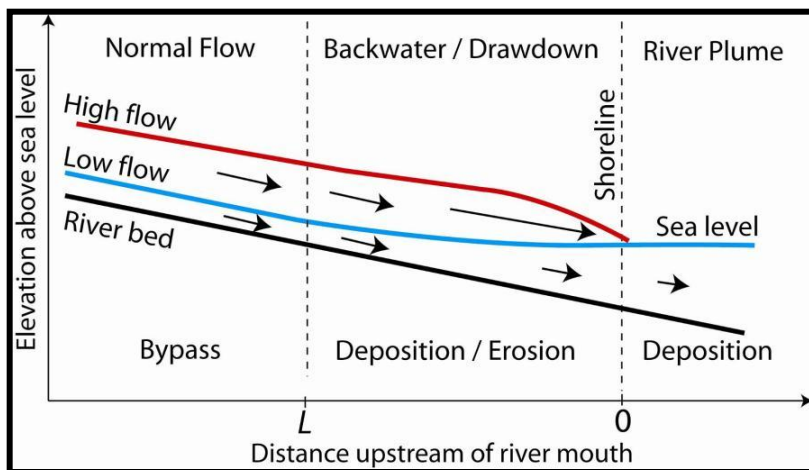
- * Lane [1957] – lowermost parts of rivers become erosional at high discharges due to drawdown.

- * Key is lateral spreading of river plume, fixing water level at river mouth constant.

- * M1, low flow, spatial deceleration, deposition; **most studies focused on**

- * M2, very high flow, spatial acceleration, erosion/scour; **most studies neglected**

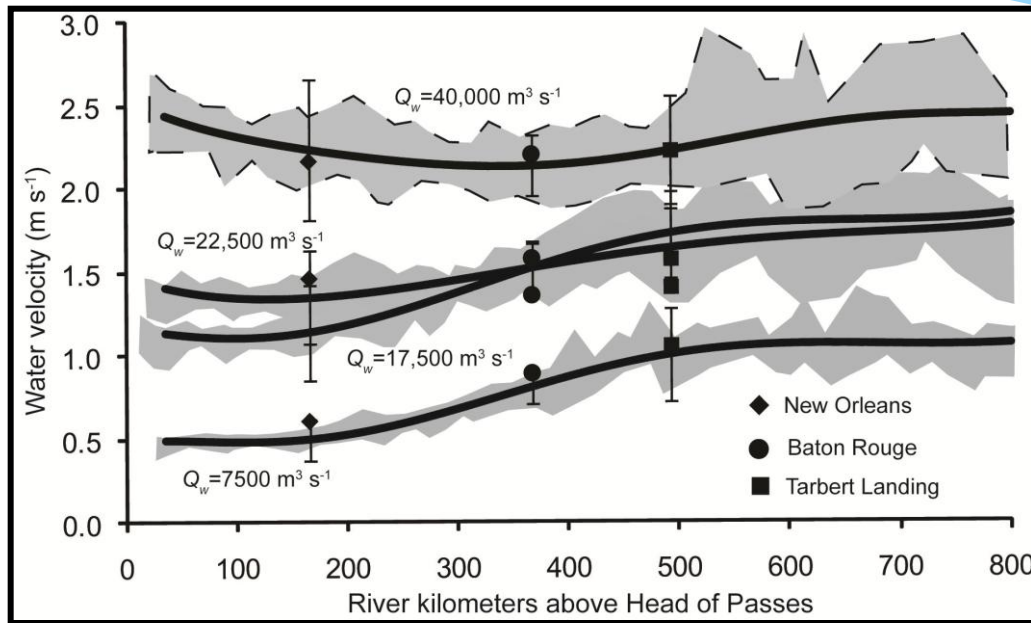
- * The transitions between low flows and high flows make this zone dynamic; variable discharges important; backwater zone acts as a filter that traps sediment during low flows but enhances sediment flux to ocean during big floods due to scour.



Schematic of M1 and M2 flows

Lower Mississippi River shows evidence for spatial acceleration and erosion at high flows

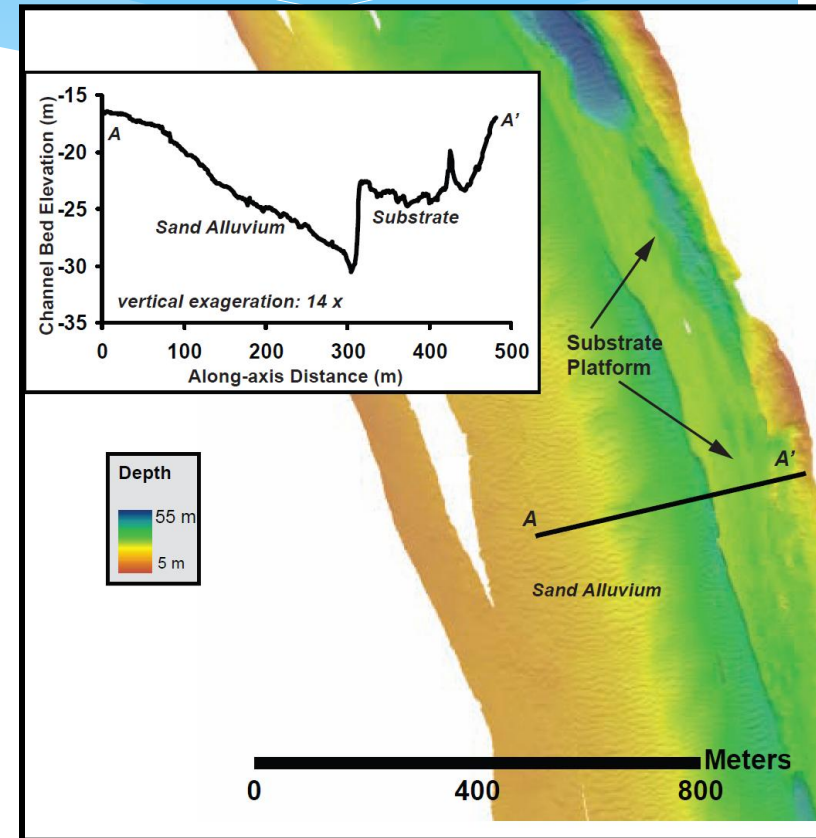
Spatial acceleration of flow at high stage



Nittrouer et al. (2012)

In stratigraphic analysis, this erosional process should not be interpreted as a result of climate change or sea-level rise/fall.

Scoured substrate

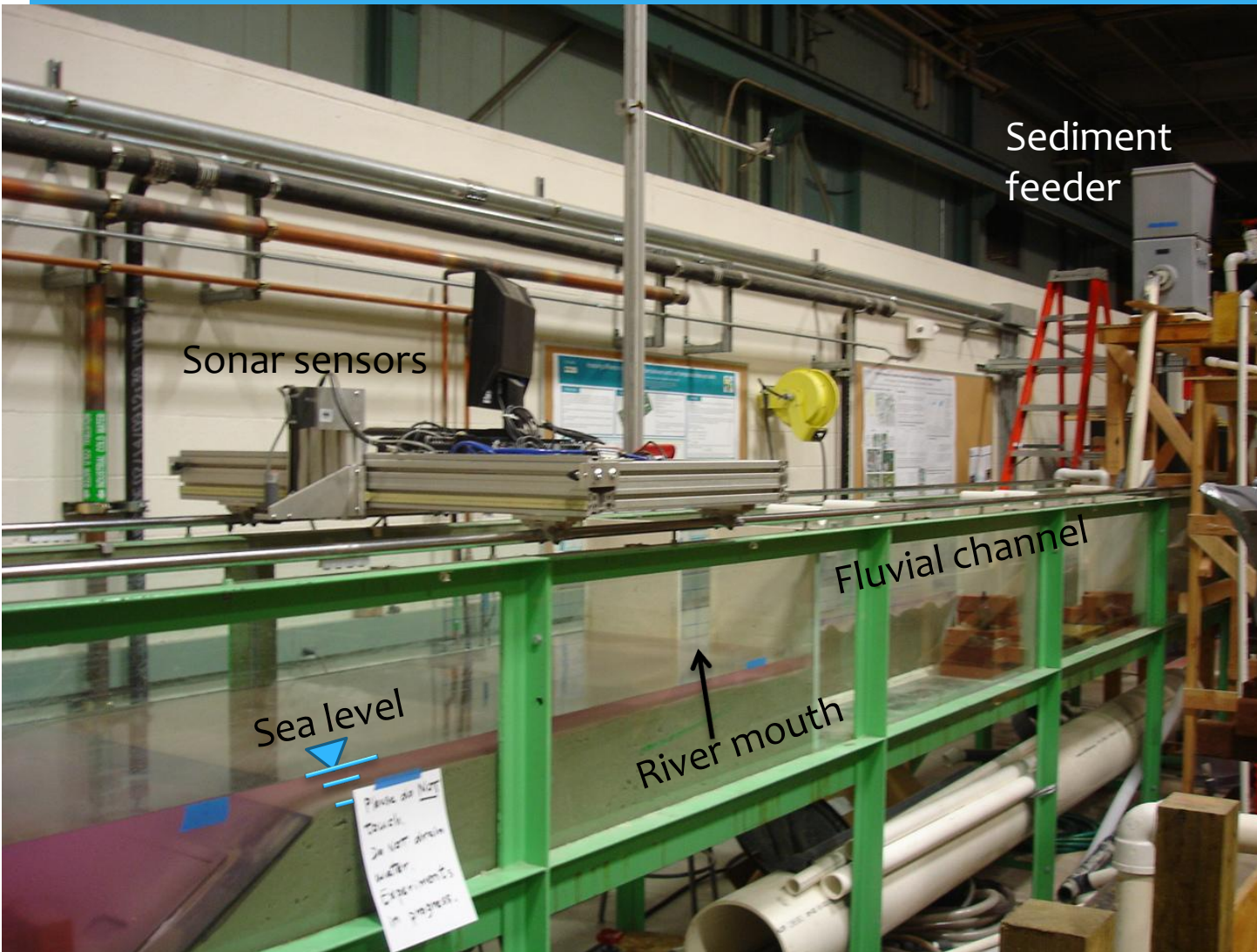


Nittrouer et al. (2011)

Research Goals

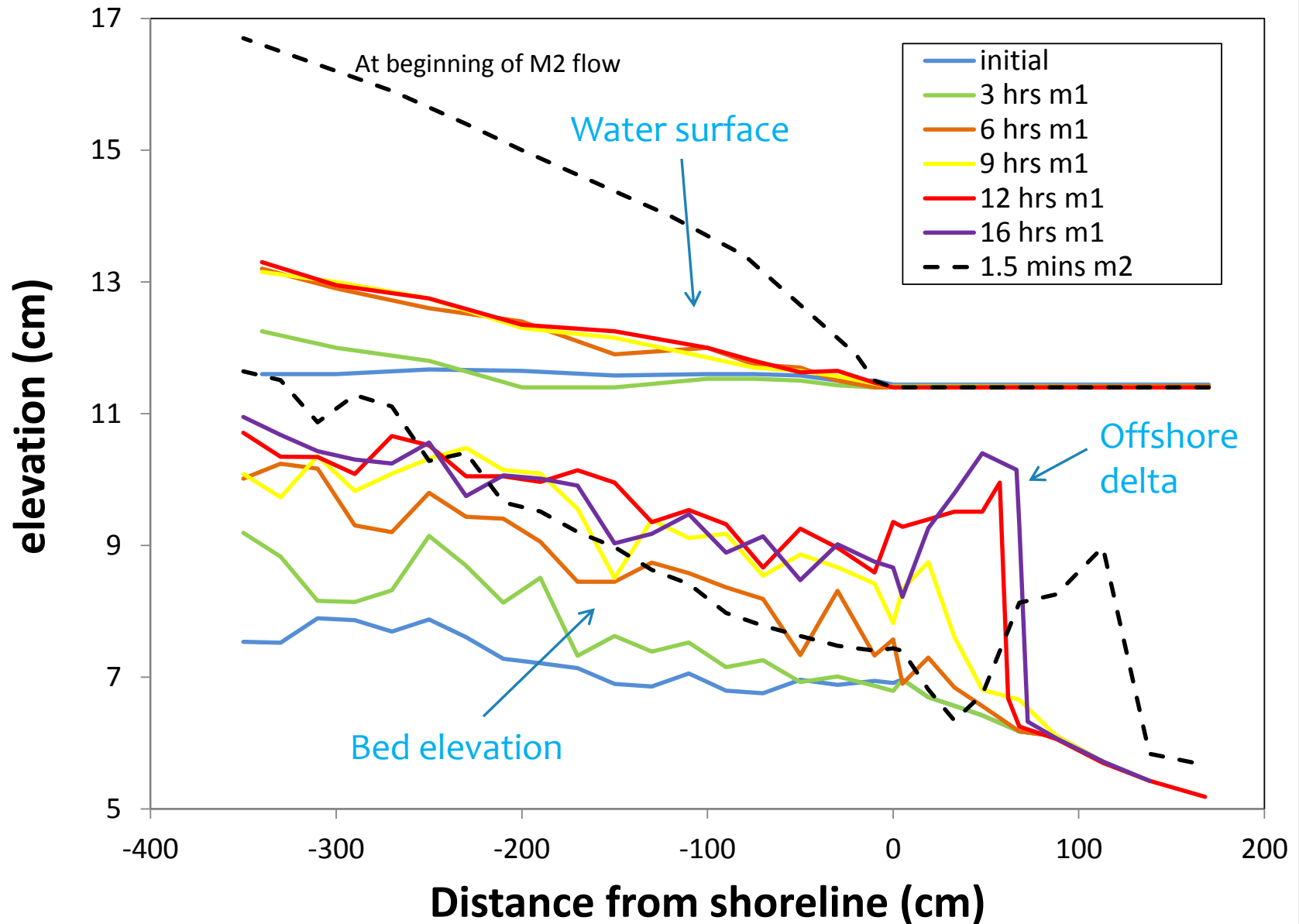
- * To test the theoretical concepts of backwater morphodynamics by using flume experiments that couple river and river plume systems
- * To investigate how spreading of the offshore plume and variable discharges affect fluvial sediment flux and offshore morphology, and how changes to these in turn affect the character of the offshore plume through feedback

Experimental Flume

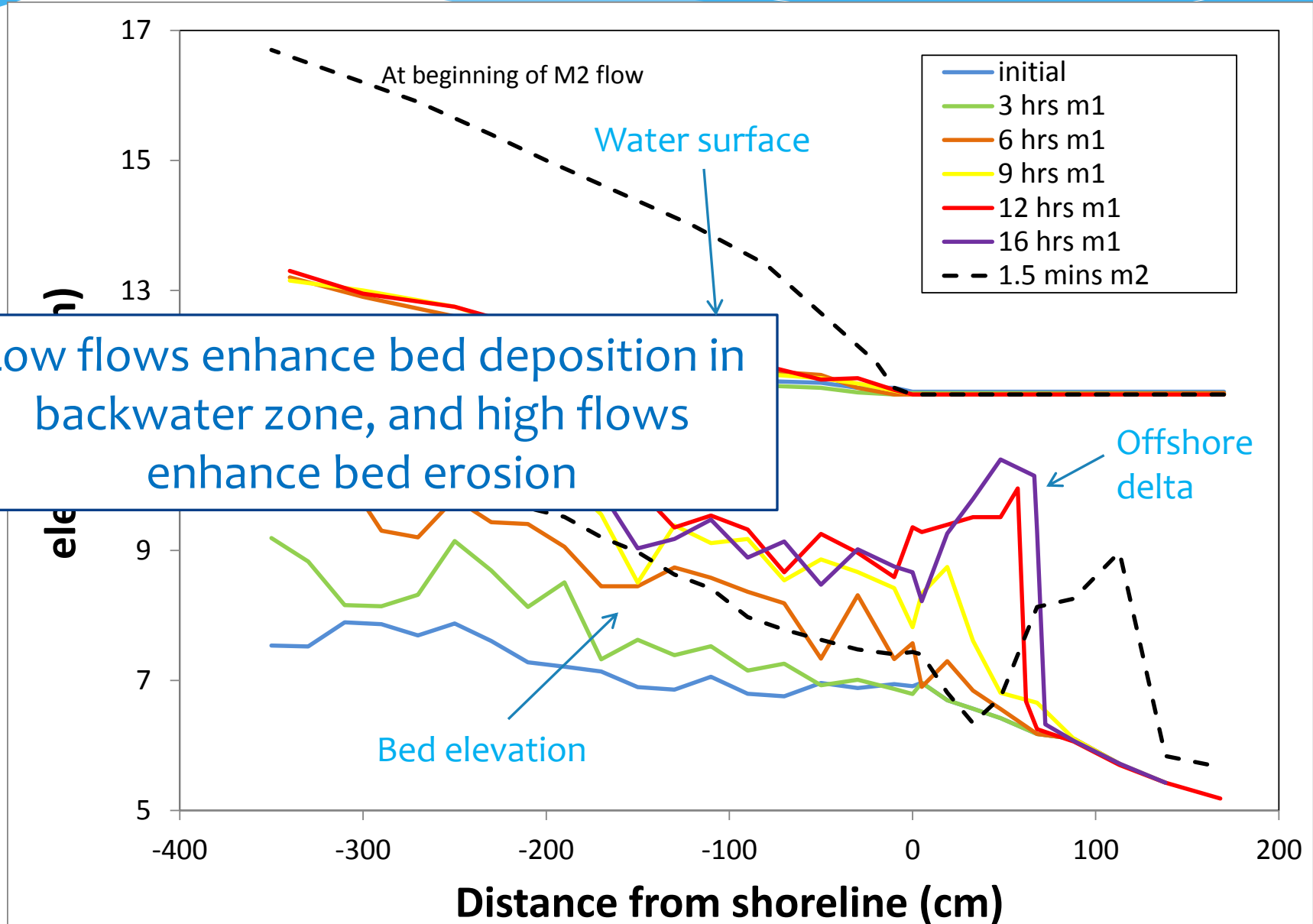


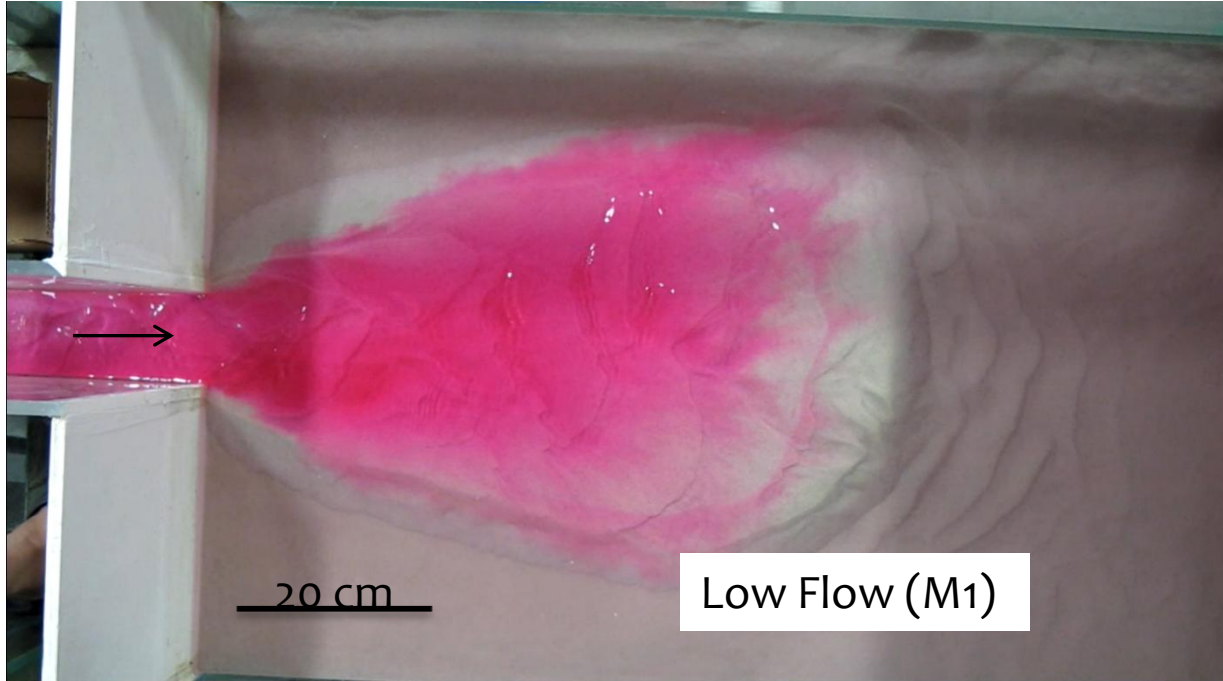
- Sonar sensors
- Dye tracking of velocity
- Three cameras
- Sand, $D = 270$ microns
- Low flow (0.72 l/s), $Q_s = 0.6$ g/s
- High flow (3.8 l/s), $Q_s = 12.5$ g/s

Long profile from flume experiments: Side view



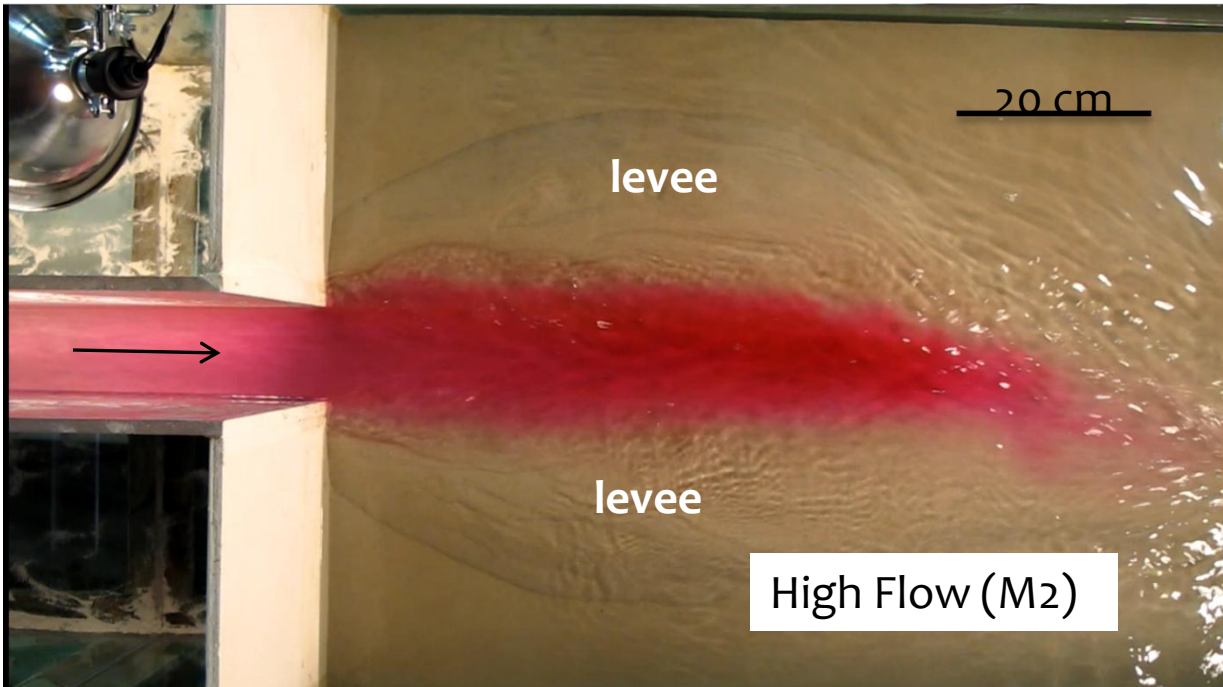
Long profile from flume experiments: Side view

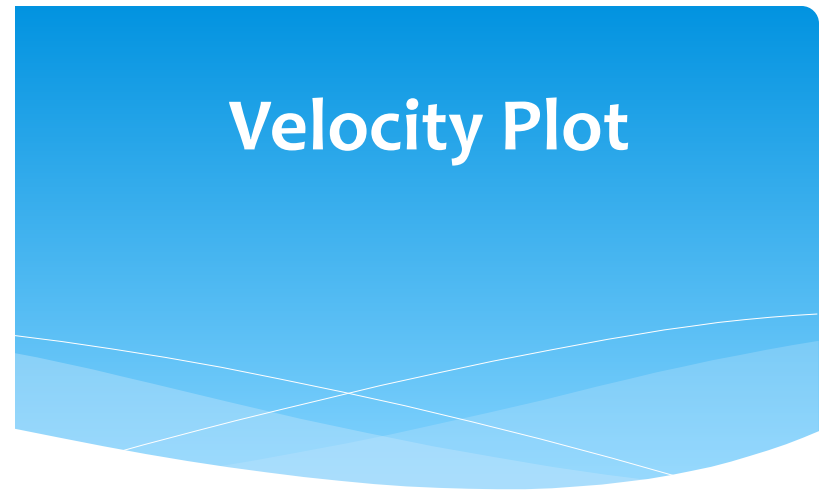
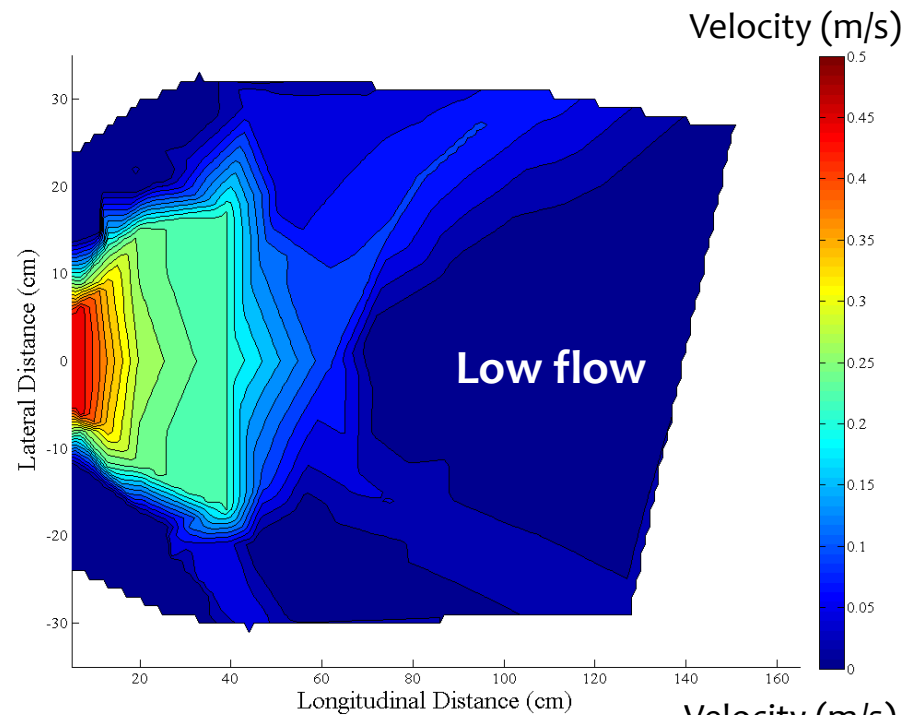




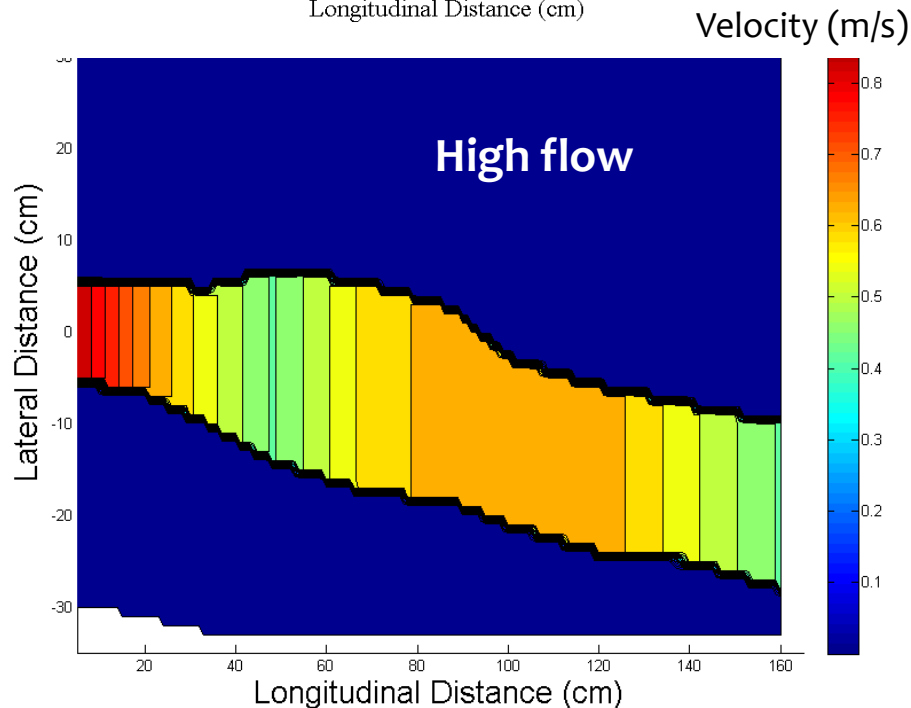
Top View

- * Low flow alone does not build levees.
- * High flow channelizes the bed & builds levees.
- * In natural deltaic rivers, clay/mud and vegetation may help stabilize levees and enhance the levee-top deposits resulting in elongated delta farther downstream. Similar to *Slingerland and Edmonds'* numerical modeling work in a much larger scale.

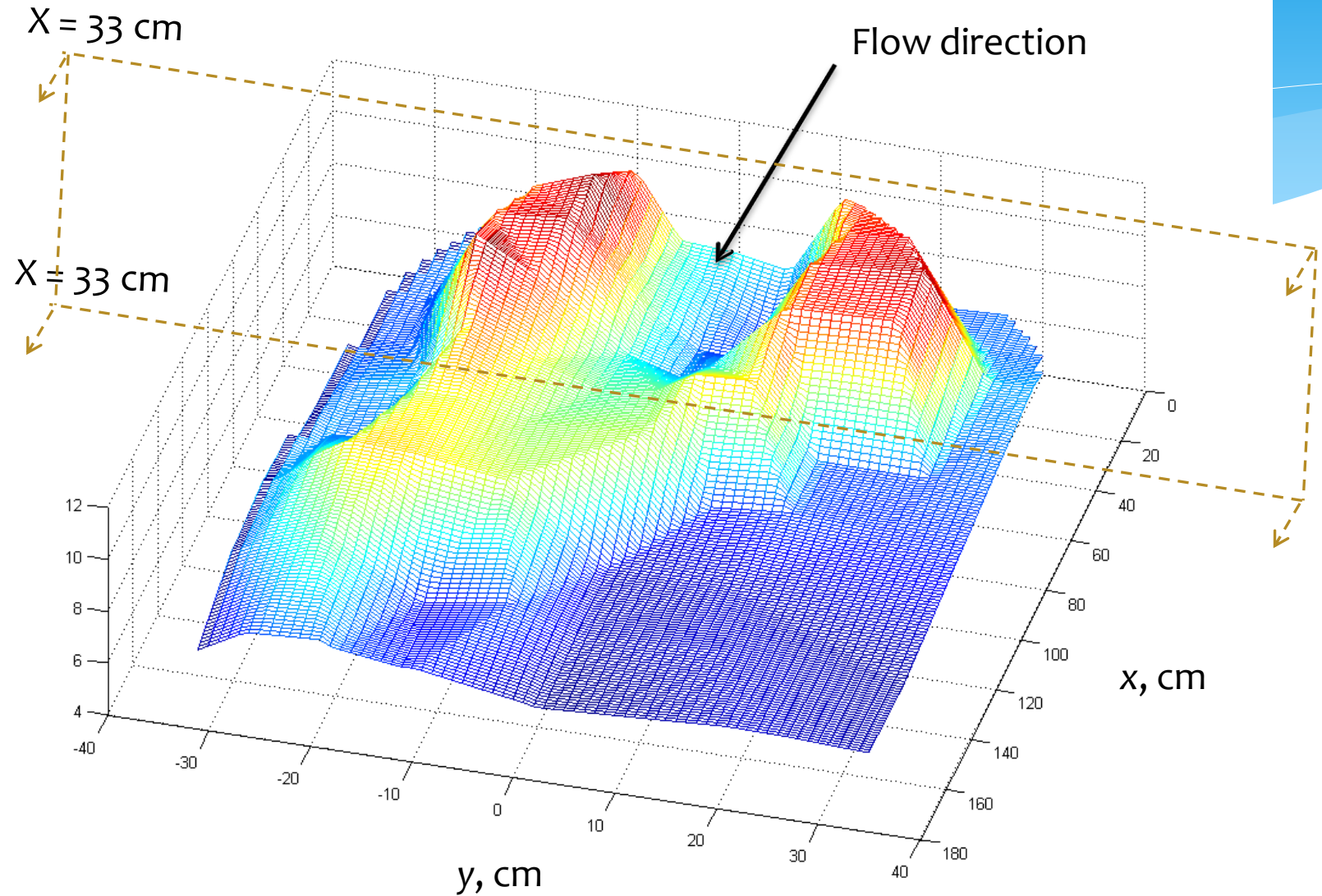


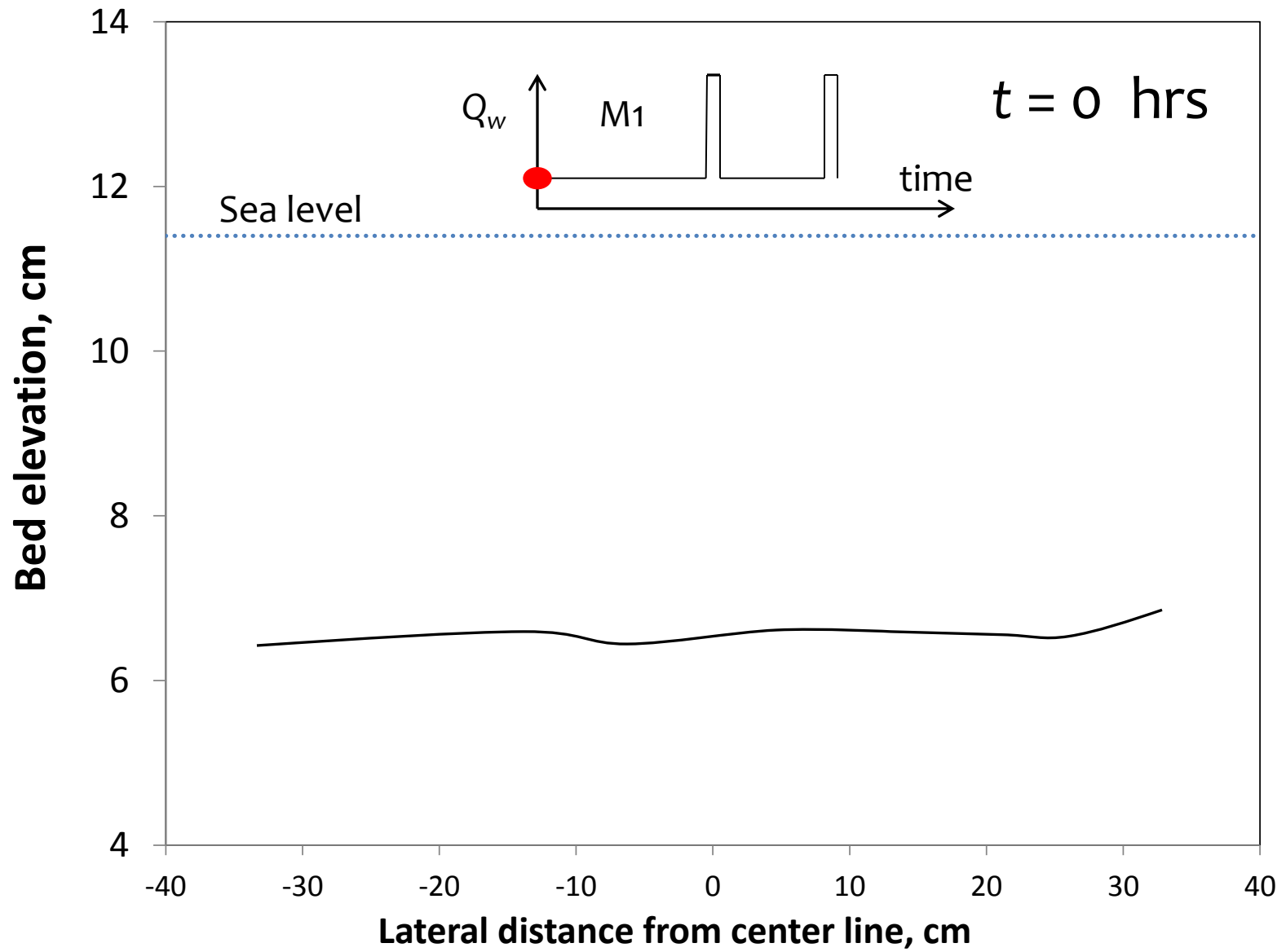


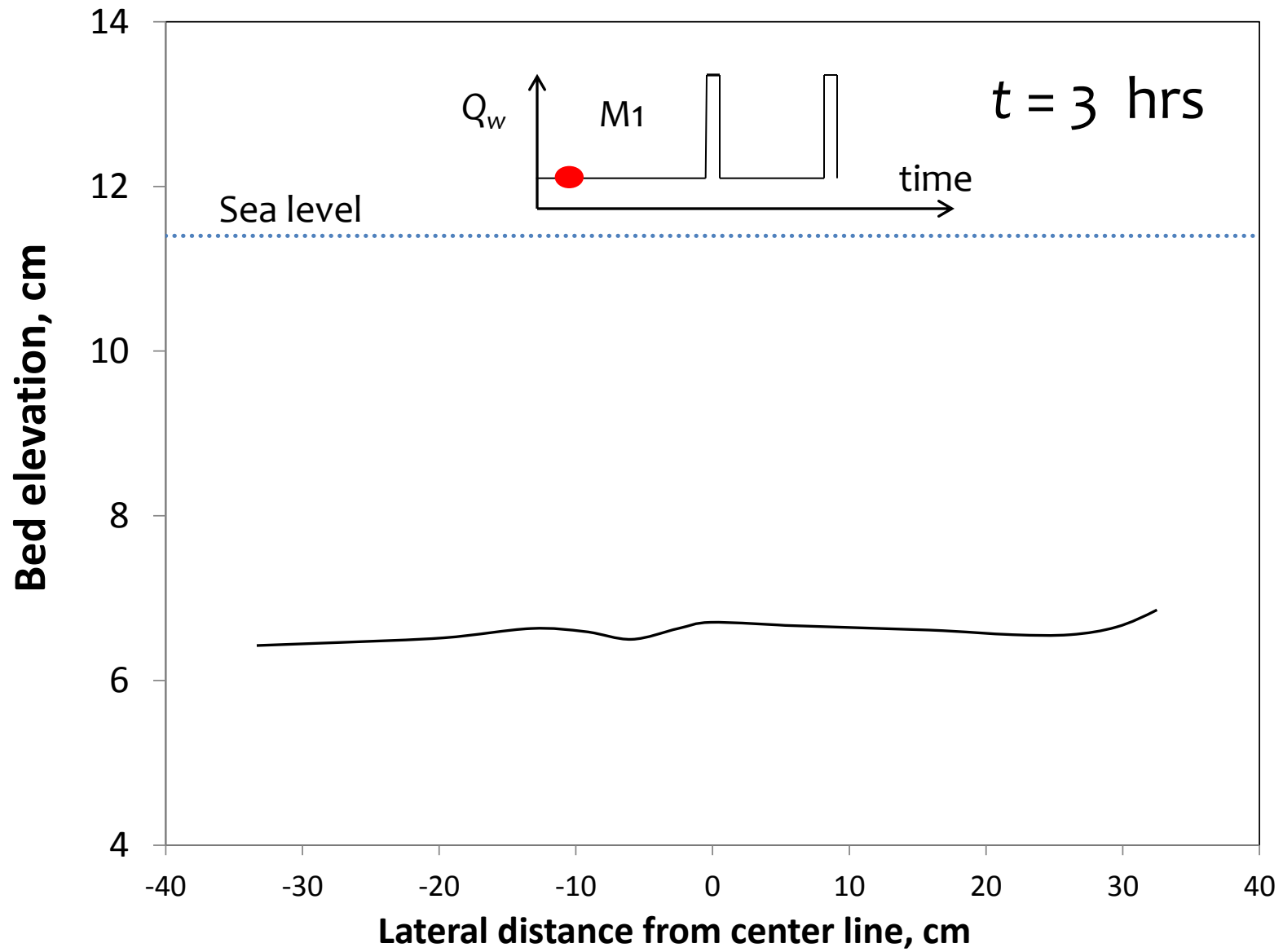
- * The flow field does not follow Gaussian distribution profile as in turbulent plane jet theory because there is strong interaction between bed morphology and plume spreading.

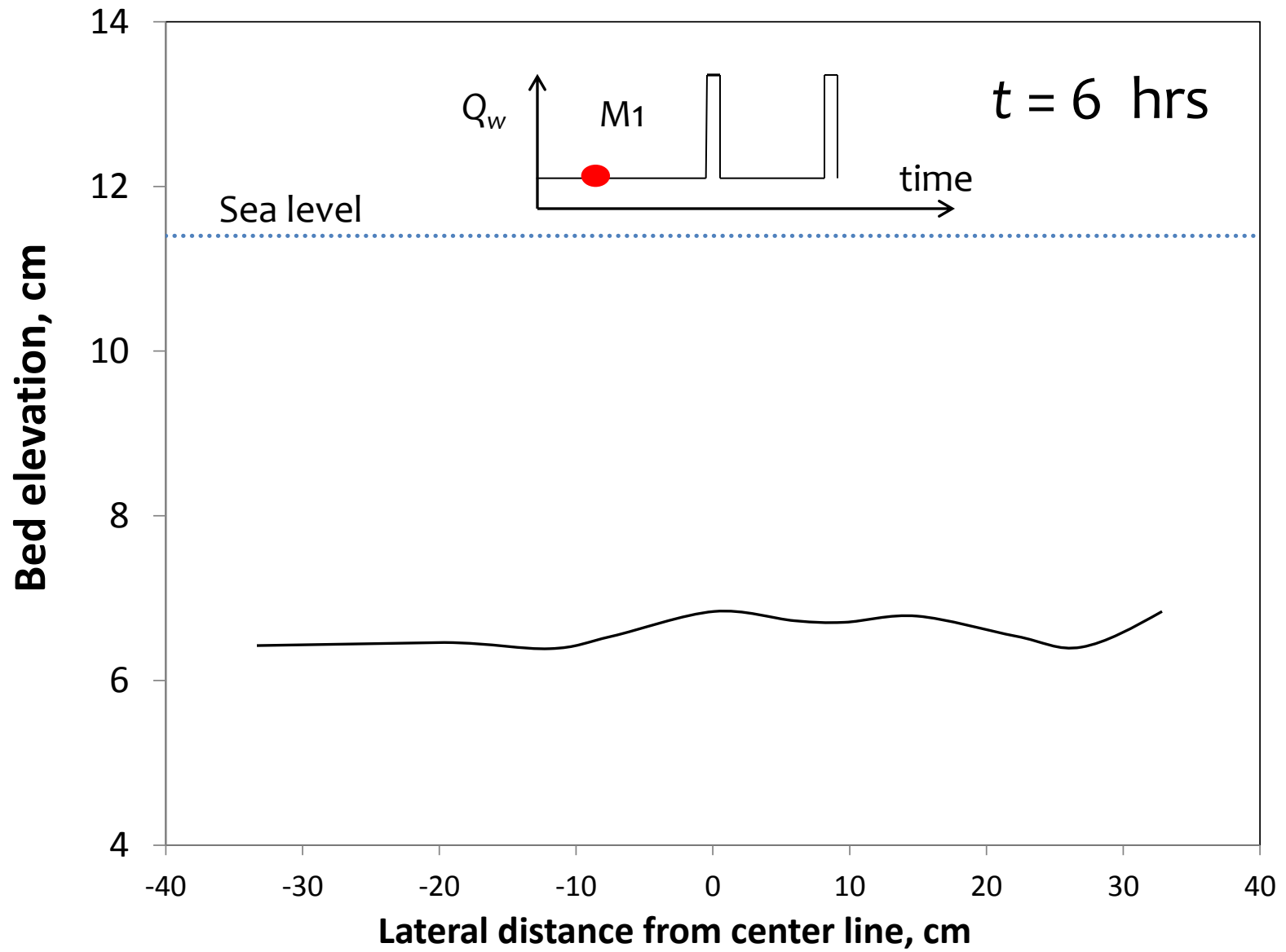


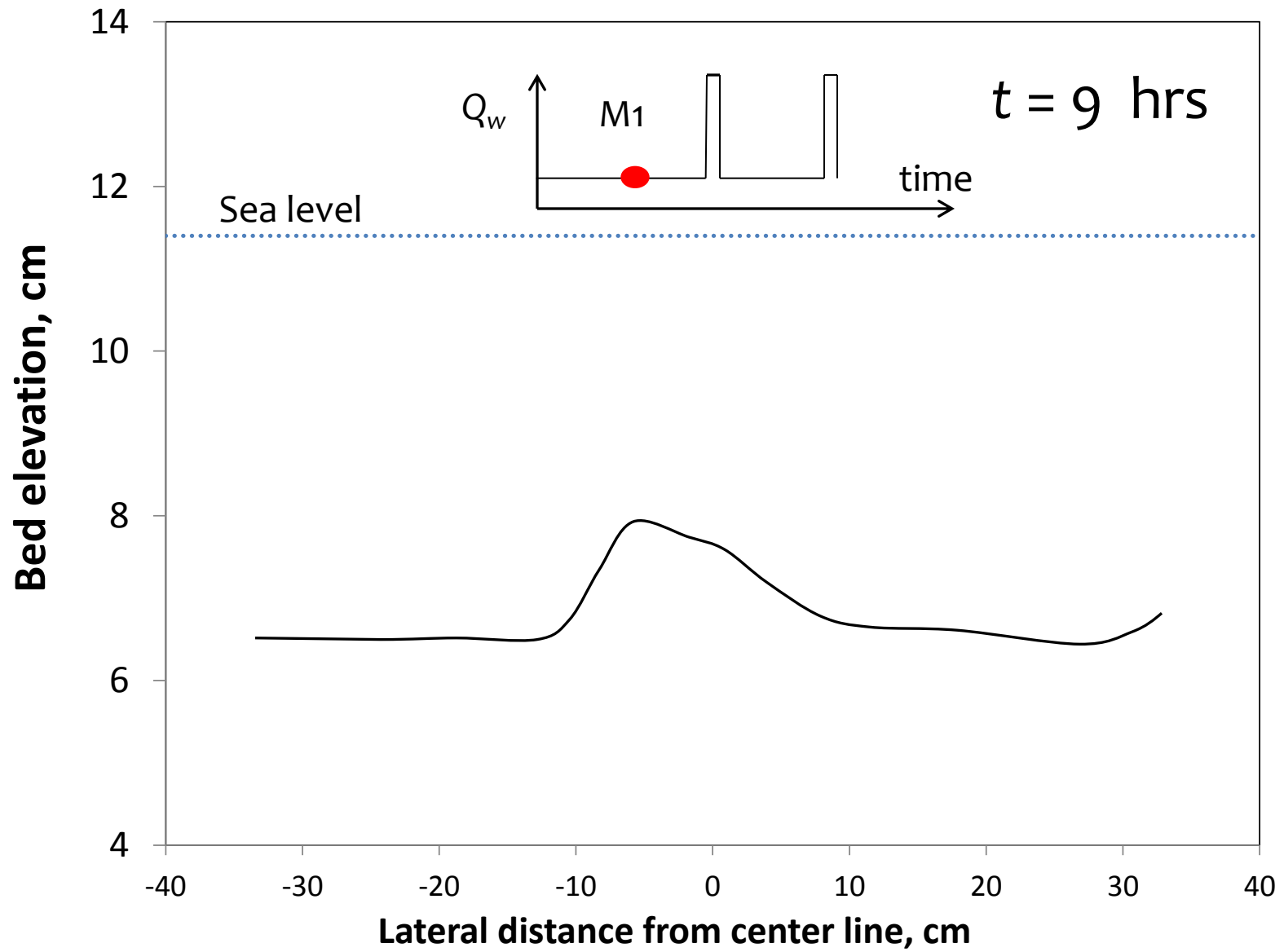
Offshore levee development; DEM after M1 & M2 flows

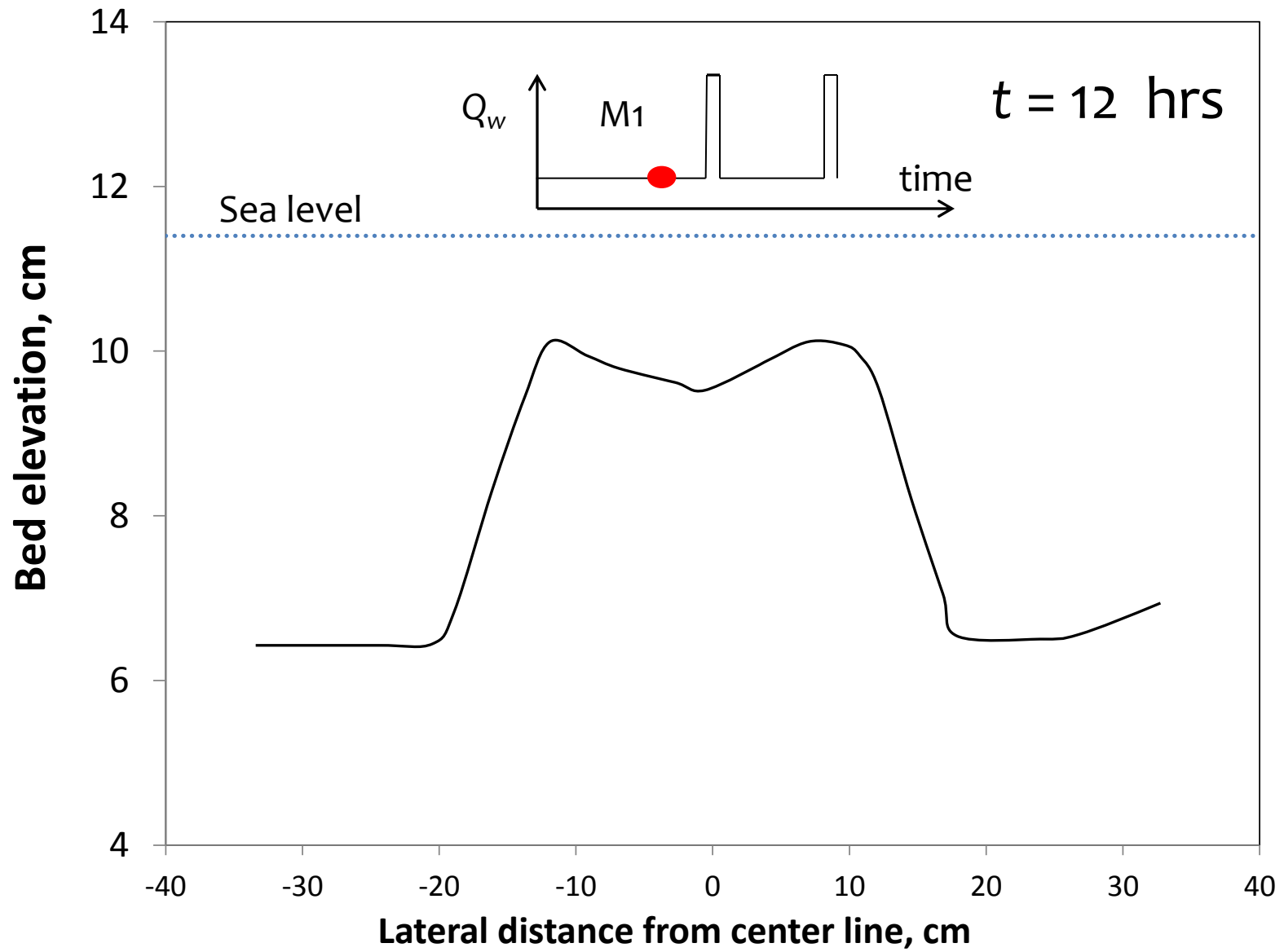


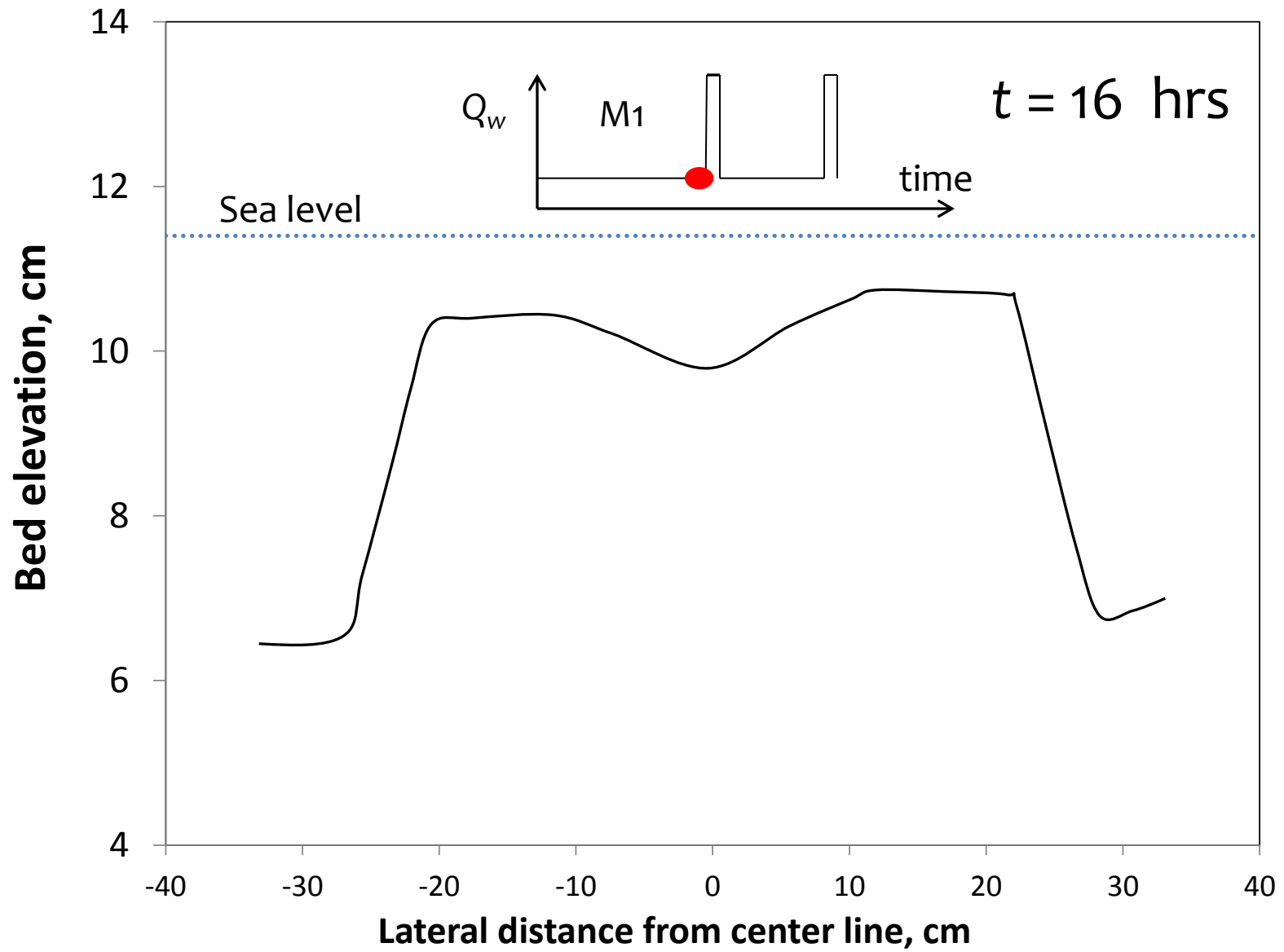


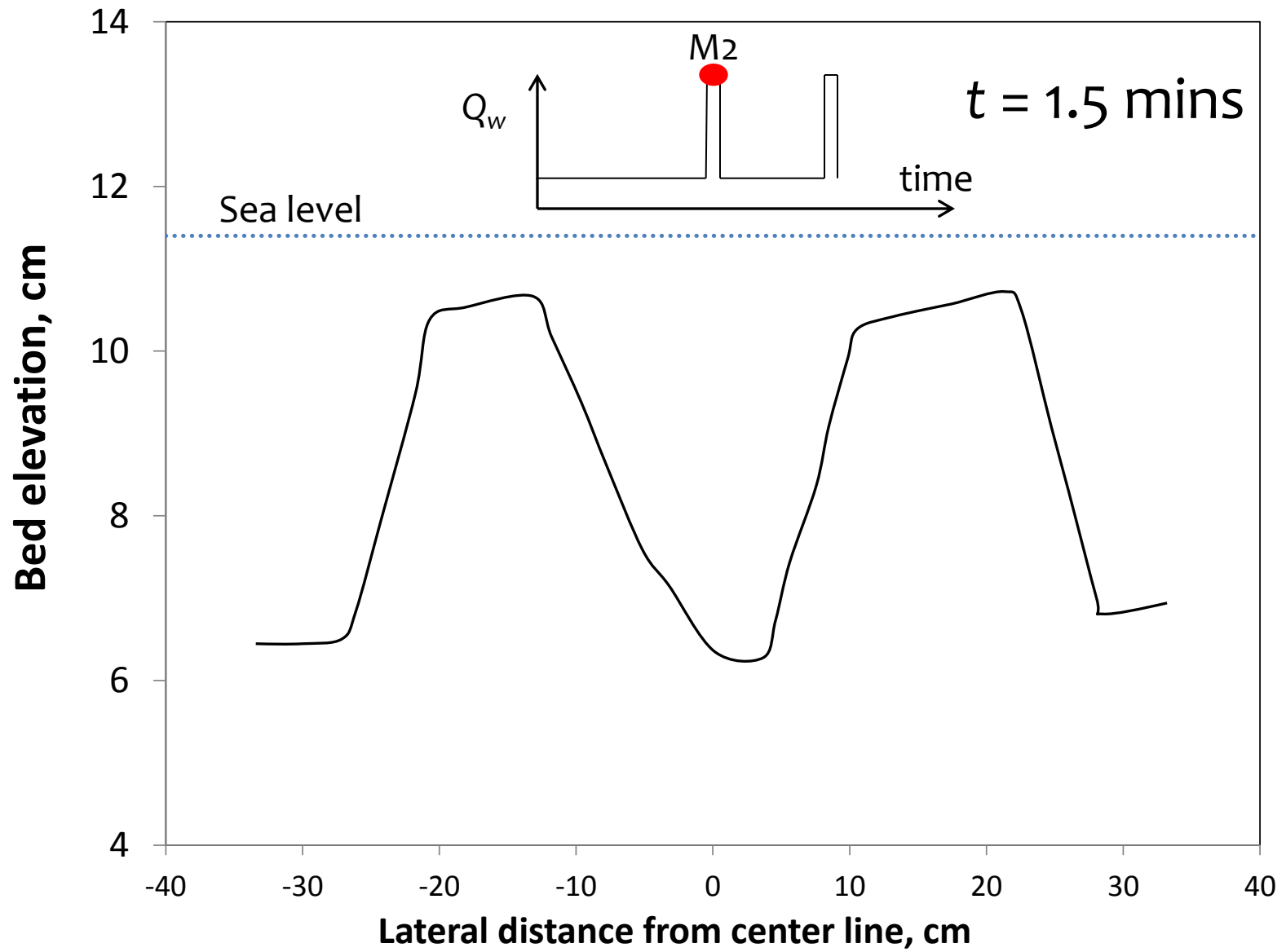


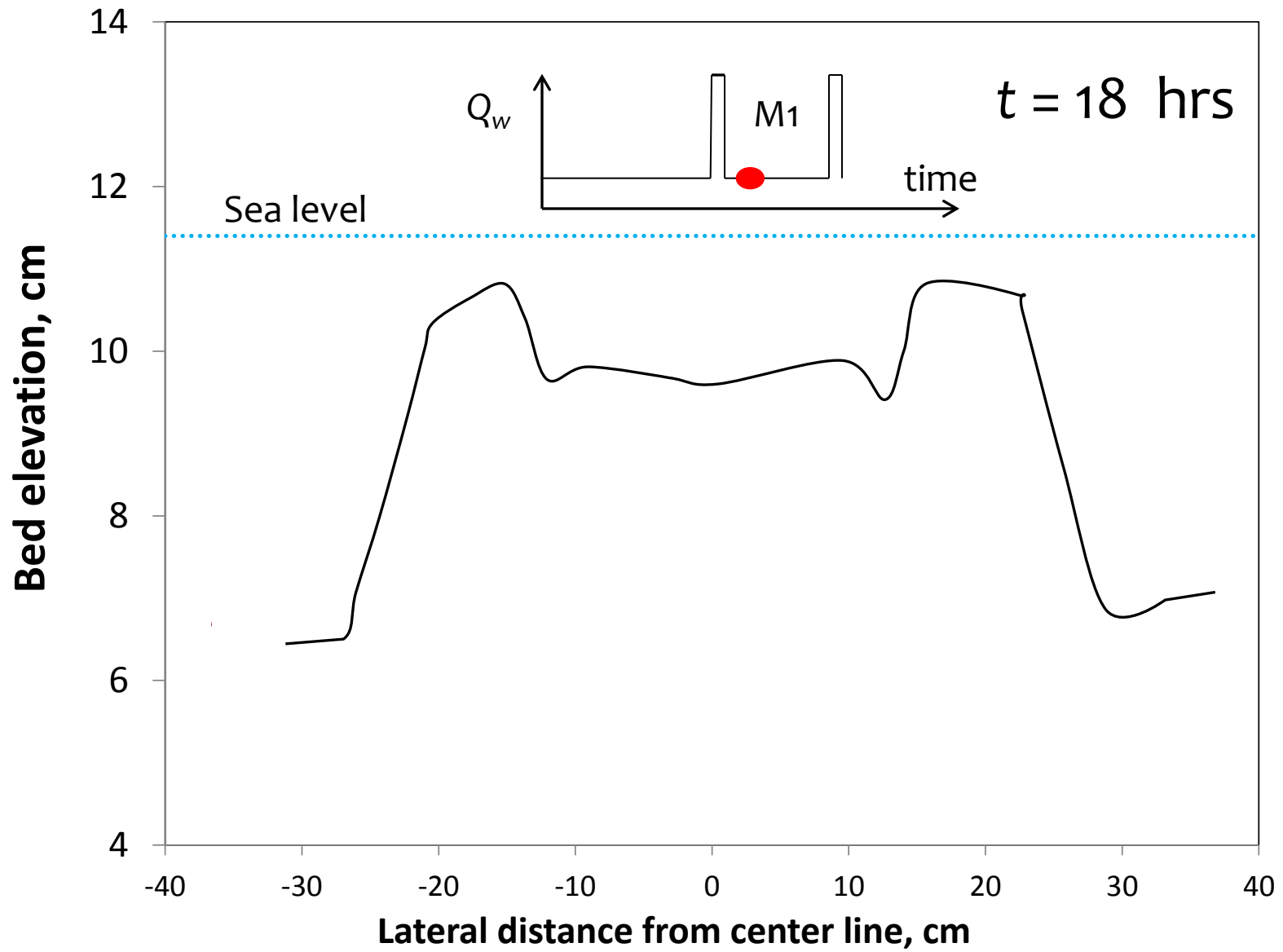


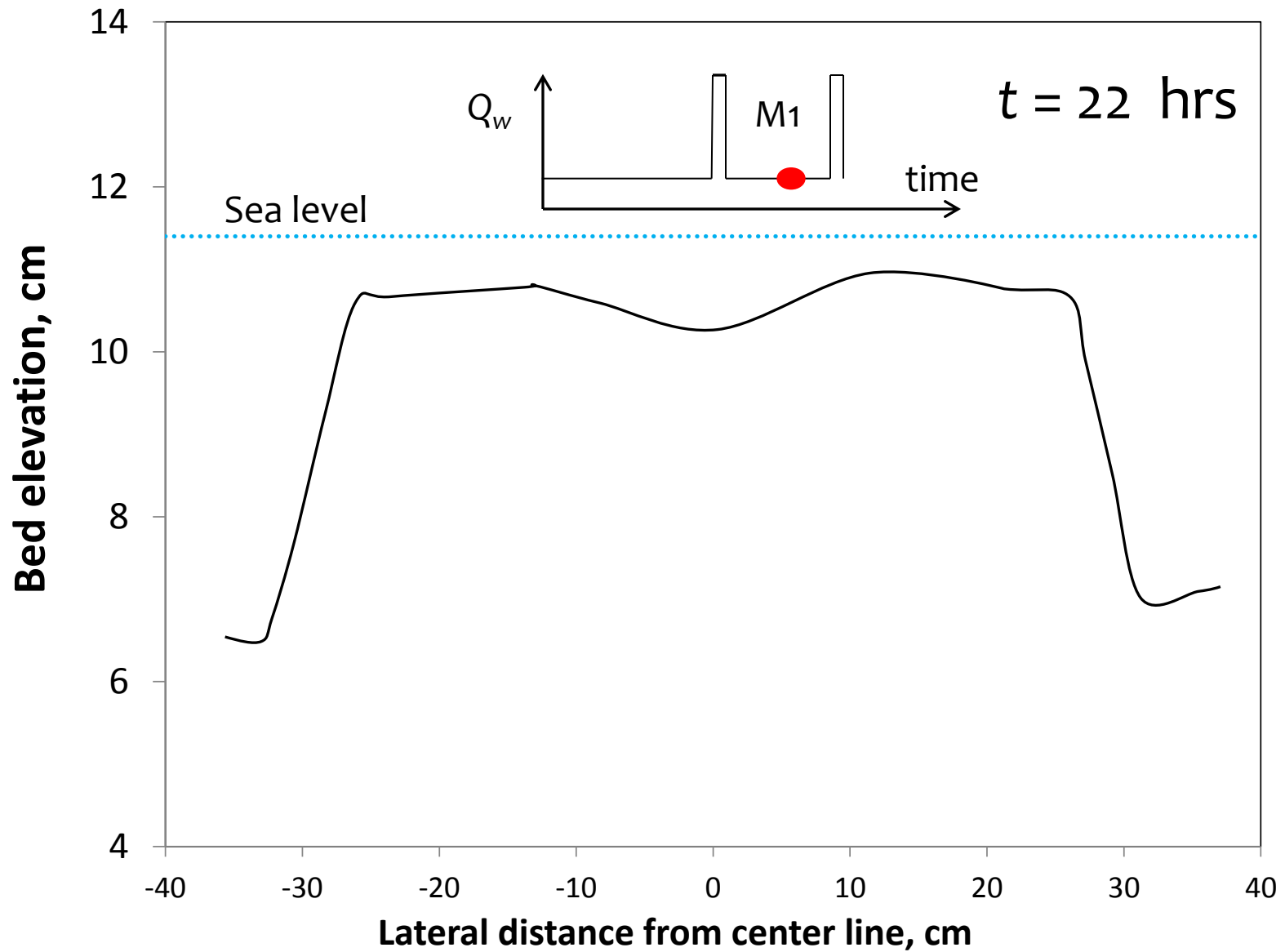


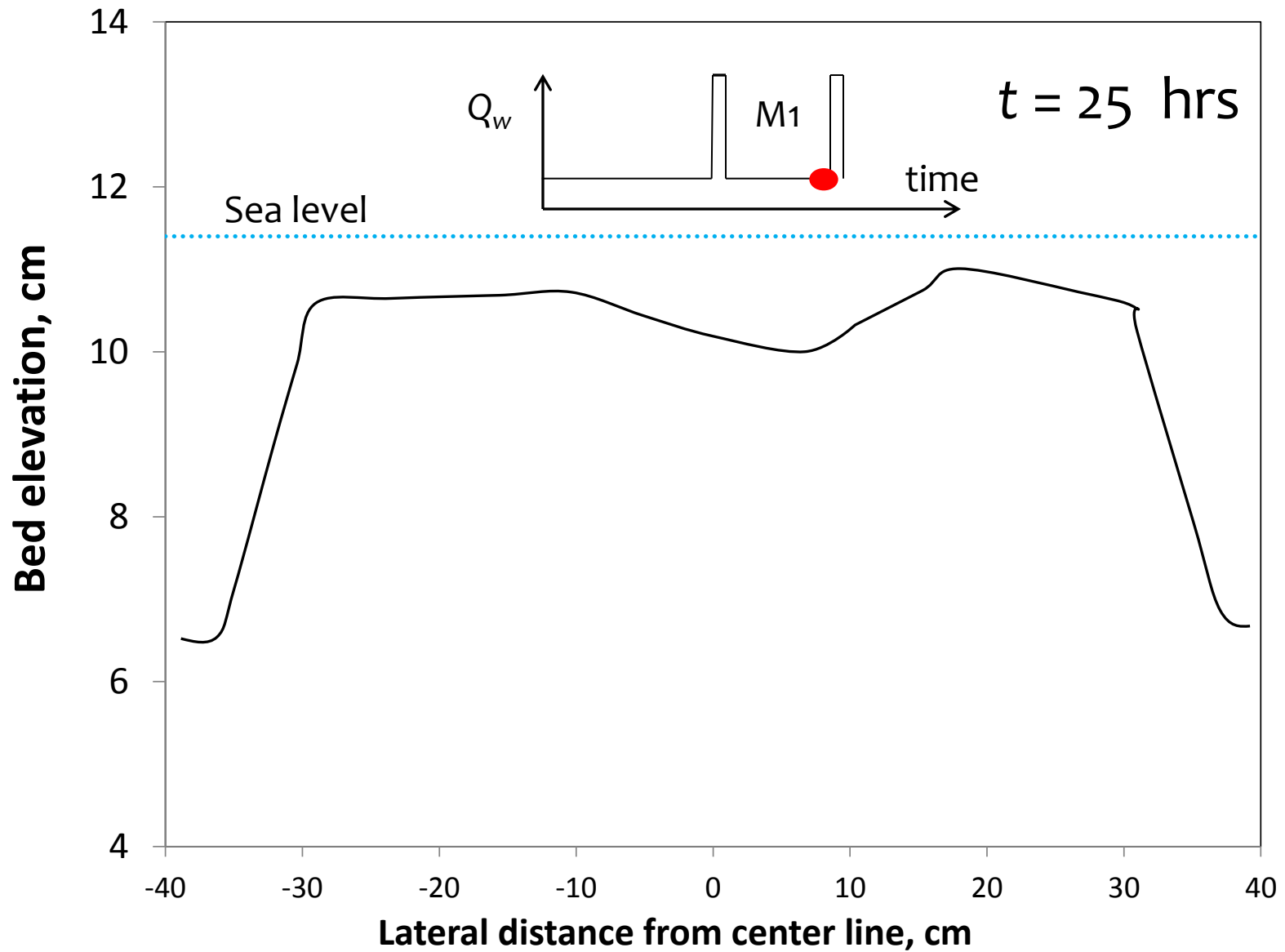


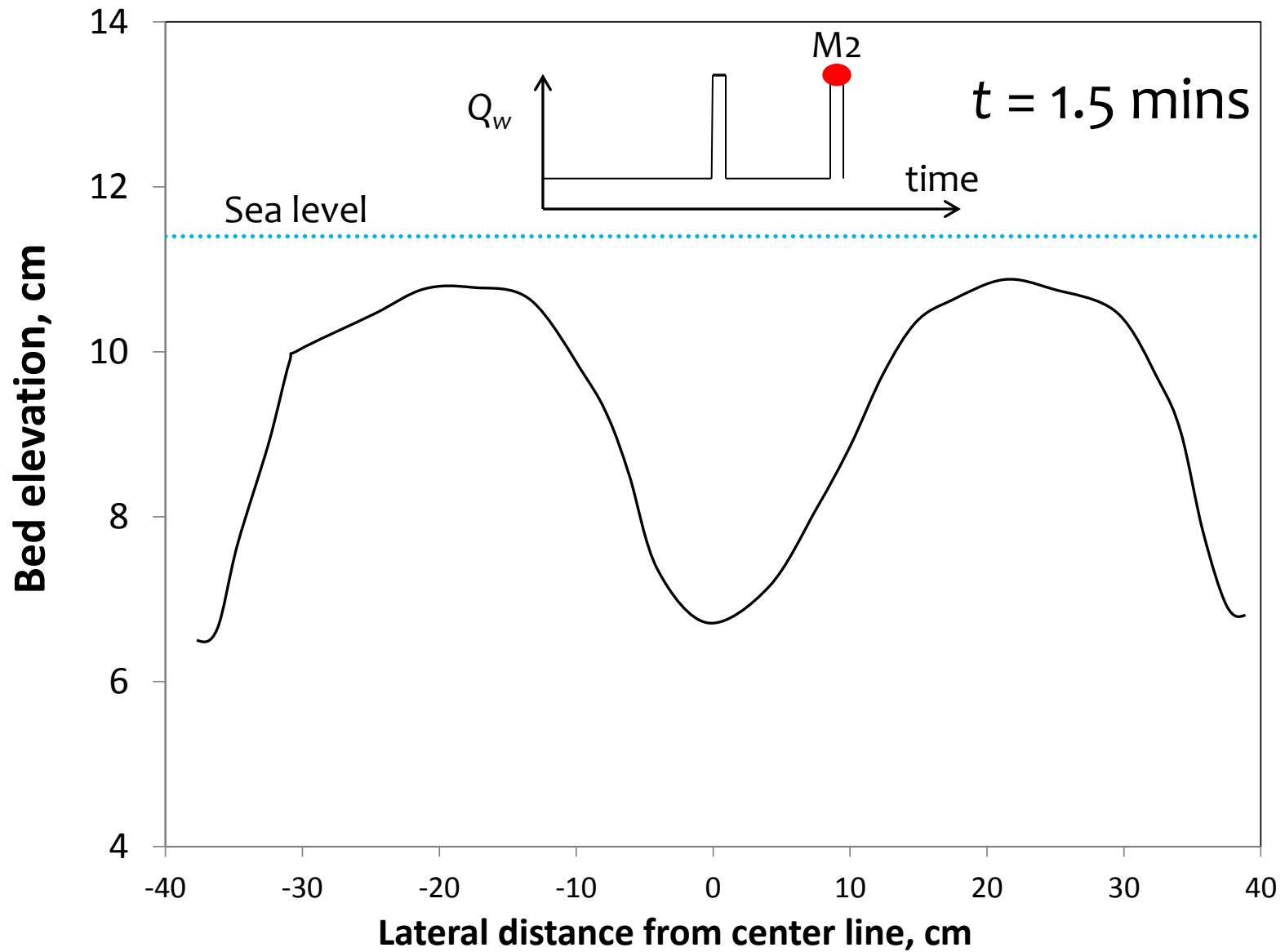


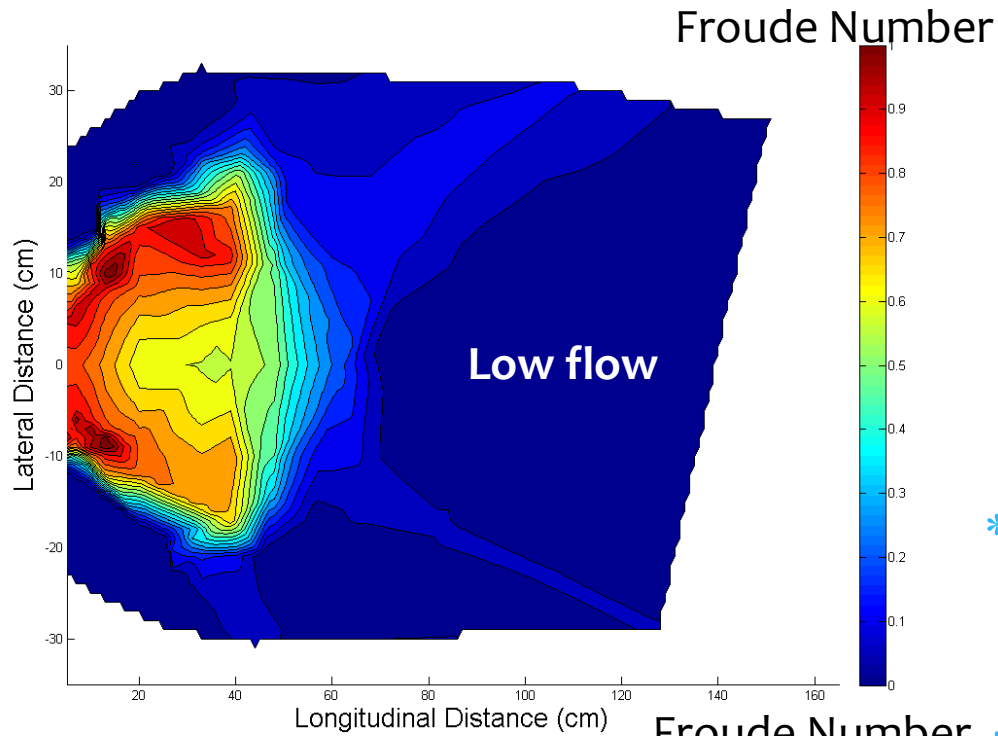






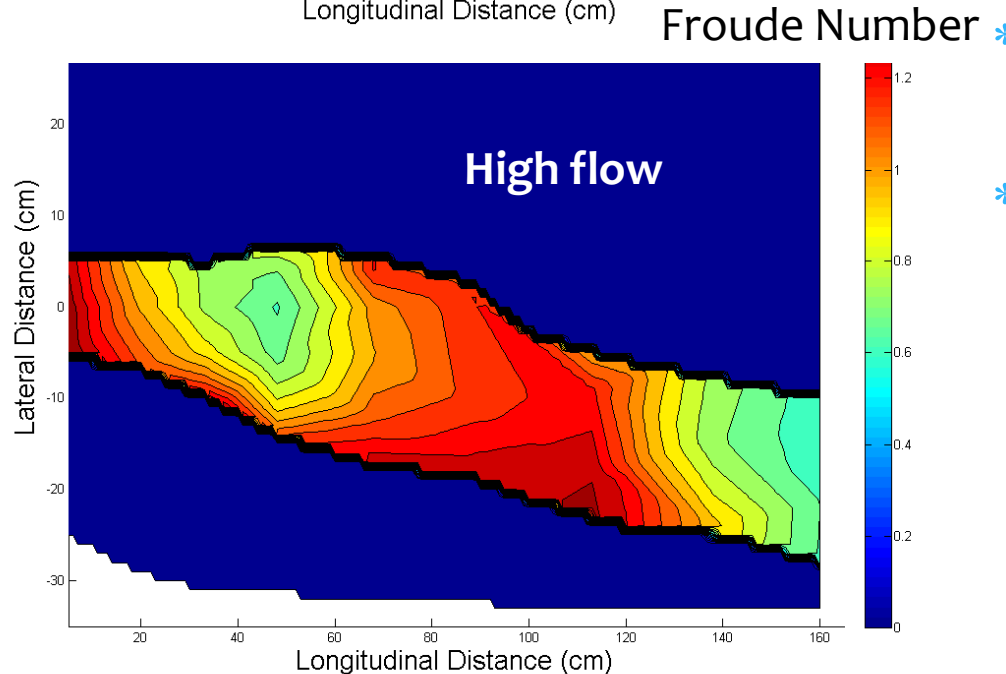






$$Fr = U/(gH)^{0.5}$$

* In the fluvial section, $Fr = 0.5$ for low flow at normal flow and $Fr = 0.9$ for high flow at normal flow.



* During transient state, Fr can be as high as 2.7

* It is expected that the Mississippi River maintains $Fr < 1$ even during the biggest floods. However, for steep/smaller rivers (e.g., the Eel River) supercritical flow ($Fr > 1$) can prevail.

Sediment changed to walnut shells

Ongoing work

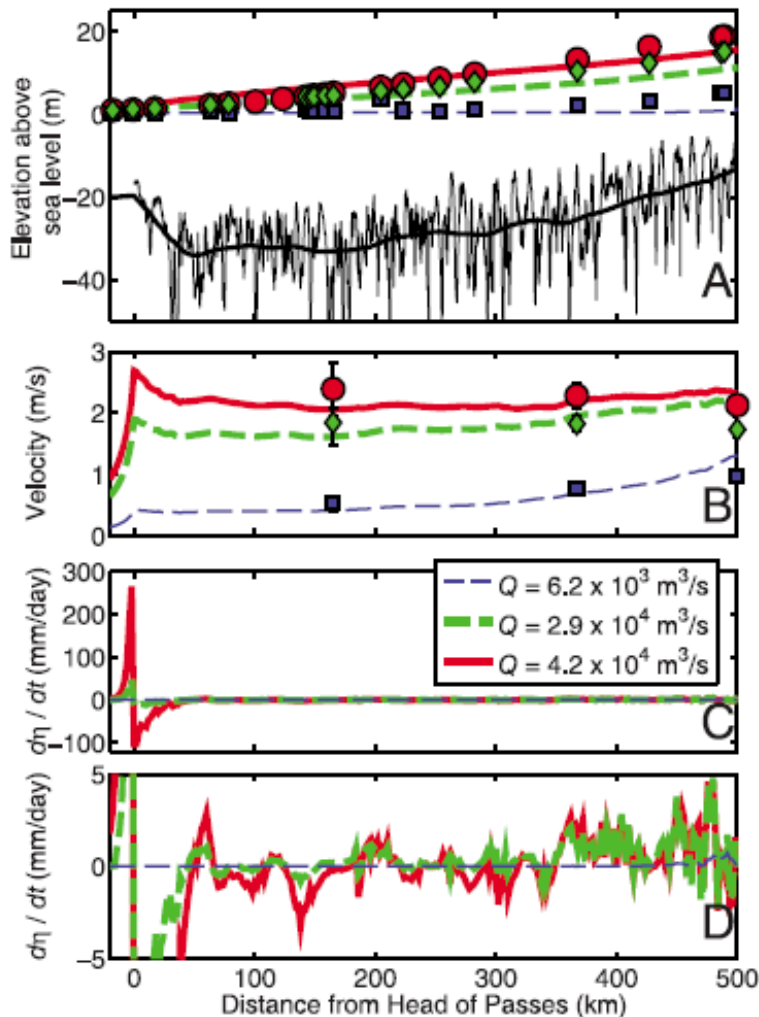
- Suppress dunes
- Lower bed slope and Froude number
- Make sure $Fr < 1$ at all time
- $D = 700$ microns, $R = 0.3$



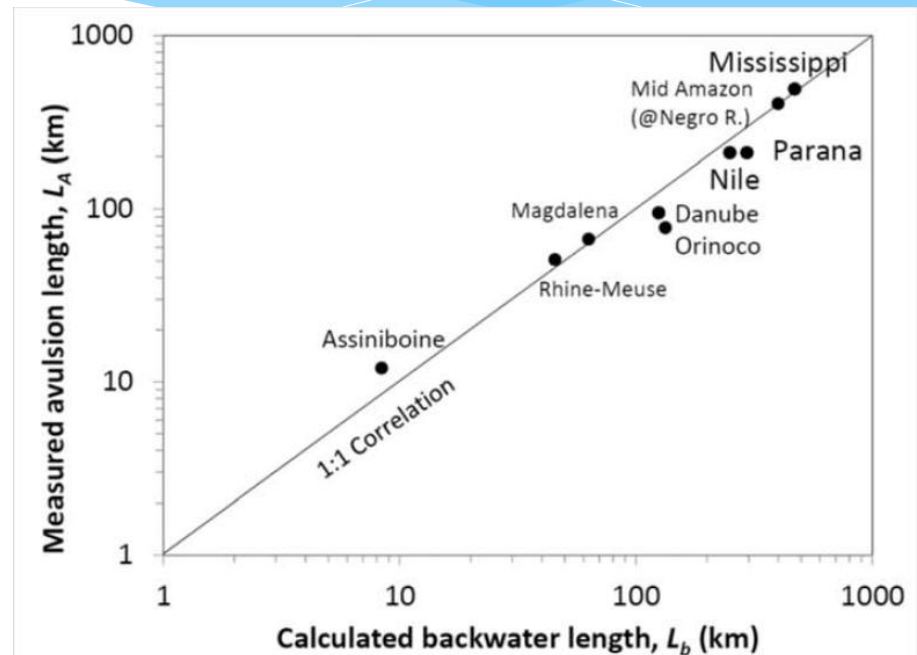
Mike Lamb's Presentation ACE 2012

[Search and Discovery Article #50711 \(2012\)](#)

Numerical modeling, Mississippi data, Avulsion



Lamb et al. (2012a) JGR-ES



Chatanantavet et al. (2012) GRL

Conclusions

- * Our experiments confirm that low flows enhance bed deposition in backwater zone, and high flows enhance bed erosion.
- * In the source-to-sink context, backwater zone thus acts as a filter that traps sediment during low flows (with minimal sediment flux passing onto the ocean), but enhances sediment transfer during big floods due to bed scour.
- * Bed erosion during high discharges should be common near river mouth or in delta due to the drawdown dynamics in backwater zone. In stratigraphic analysis, this effect should not be interpreted as a result of climate change or sea-level rise/fall.
- * Our experiments suggest that levee growth is enhanced by oscillation between low and high flows. This dynamics has implication in the formation of elongated river deltas.