



Tidal Influence on Remediation Sites: Understanding Predominant Gradients and Flow Inversion Effects on Mass Flux

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The Tide

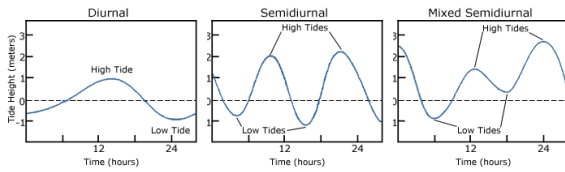
- The tidal cycle is of 24 hours and 50 minutes¹
- In the Bay of Fundy, the tidal range is about 16 meters (53 feet)²
- In the Caribbean Sea, the tidal range is between 10 and 20 centimeters (4-8 inches)³



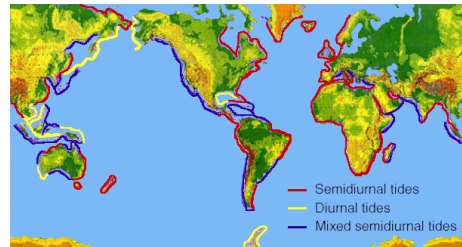
¹ NOAA. How frequent are tides? National Ocean Service website, <https://oceanservice.noaa.gov/facts/tidefrequency.html>, 10/10/17
² NOAA. Where is the highest tide? National Ocean Service website, <https://oceanservice.noaa.gov/facts/highesttide.html>, 10/10/17
³ Kerline, S. (1981). Tides of the Caribbean Sea. J. Geophys. Res., 86(C5), 4243-4247



Tidal Patterns



Tides Across The World



Where Is It Important to Consider Tidal Effects?



Anthropogenic "Tides"
 (Dam Controlled Rivers and Reservoirs)



Influences on the Tide

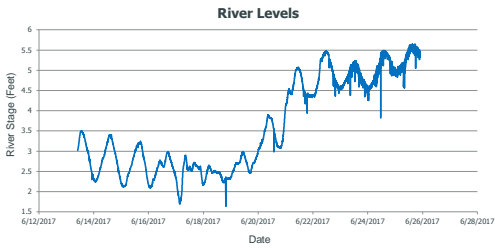
Though tidal cycles can be predicted, the effective tide at a given location on a tidally influenced water body can be affected by external factors.

- River flows from upstream precipitation or meltwater
- Barometric pressure
- Wind patterns

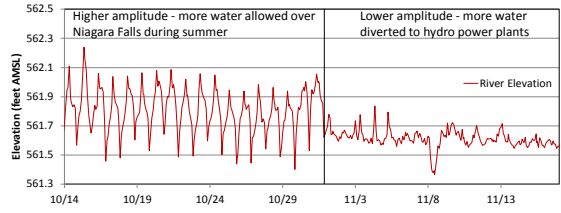
For this reason, it is important to monitor the tidal fluctuations at your specific site and not rely on predictions or nearby measurement locations.



Tidally Influenced River



Anthropogenically Controlled River



Tidal Effects on Groundwater

- Tidal fluctuations affect gradients
 - Tidal efficiency (amplitude)
 - Time Lag (period)
 - These are a function of the hydraulic properties between the water body and the measurement point
- Tidal effects dissipate with distance from the water body
- Pressure wave transmits through confining layers, without actual groundwater flow



Confined vs. Unconfined Conditions

- Tidal efficiency is higher in confined aquifers vs. unconfined
- Related to storativity of the aquifer
 - Based on the skeletal compressibility of the aquifer material under confined conditions
 - Based mostly on porosity under unconfined conditions
- Responses are related to loading, in an unconfined aquifer pressure dissipates more easily than in a confined aquifer.
- Tidal induced head changes do not indicate groundwater flow to surface water



Implications for Remediation

- Groundwater capture plots may be inaccurate
- Groundwater capture systems may be under-pumping (risk to environment) or over pumping (potential efficiency gain)
- Groundwater velocity calculations could be affected
- Mass flux calculations could be under or over estimating vs. reality



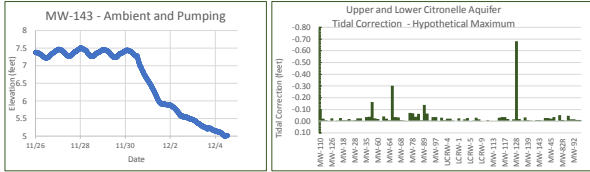
Example Site

- South US Coastal Plain
- 6 Linear miles from coast
- Adjacent to tidally influenced river
- 3 contaminated aquifers (lower 2 are confined)



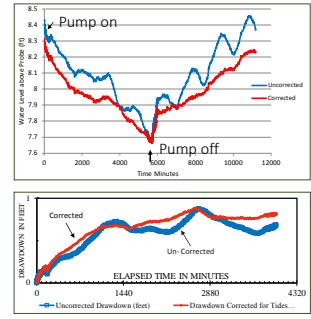
Two Examples of how tide can effect water levels

- Transient data - Constant rate pumping tests
- Synoptic Water Level Gauging (typical accuracy is 0.01')



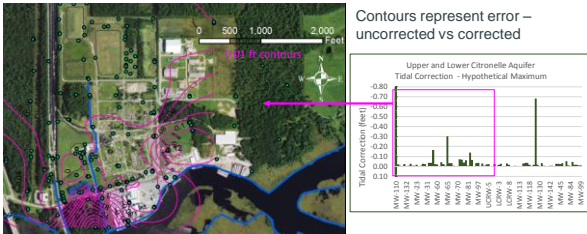
Tidal Correction

- Long term pumping test can be affected
- Can completely mask response to pumping stress
- Cause difficulty curve fitting
- Tidal Influence can be reduced /removed through corrections
- Need Tidal Efficiency and Tidal Time Lag
- Corrections can be imperfect

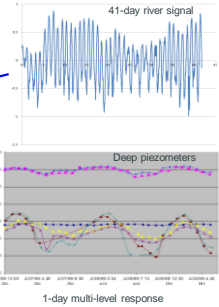


Tidal Correction

- Groundwater potentiometric surfaces can be affected
- Important for low gradient areas



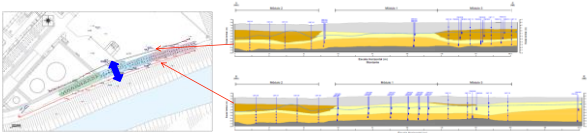
Tidal Case Study in South America



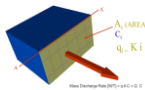
- Objective:
- Determine mass fluxes and define remedial goals
- Challenges
- Benzene plume discharging to tidally influenced river
- Approach:
- Mass discharge transects
 - Fully transient F&T modeling



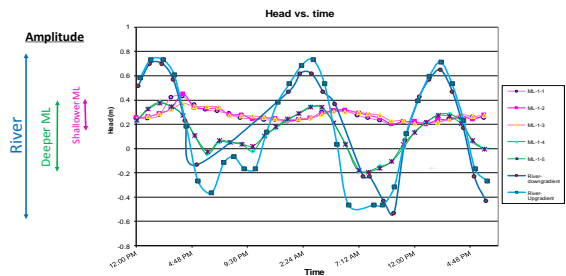
Mass Transect Locations



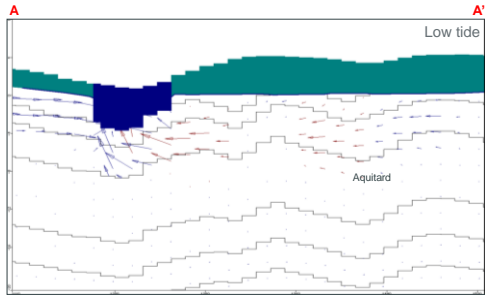
- Challenges:
- How to calculate mass discharge under tidal conditions?
 - Calculating clean up goals to protect receptor?



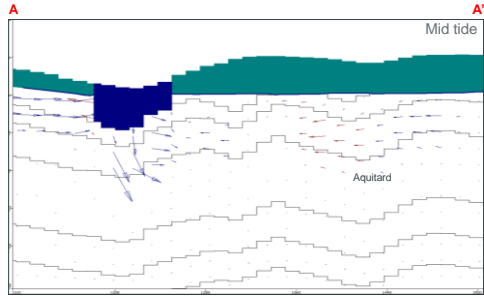
Tidal Influence on Multi-Levels Along the River Edge



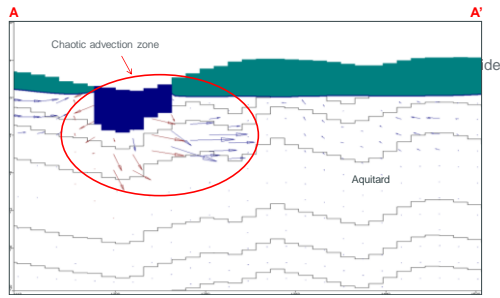
Transient Flow Cross-section



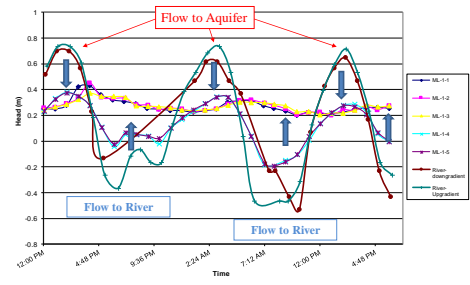
Transient Flow Cross-section



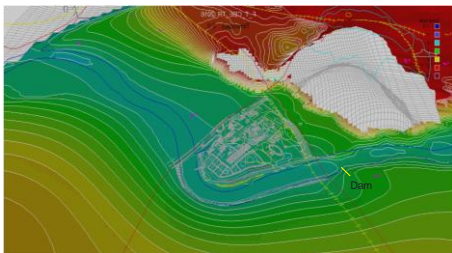
Transient Flow Cross-section



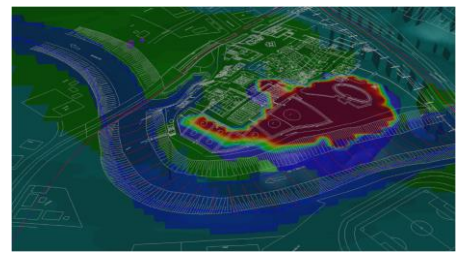
River – Aquifer flow inversions



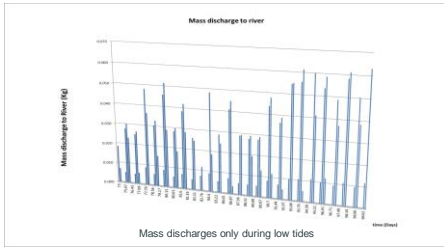
Now in 3D...



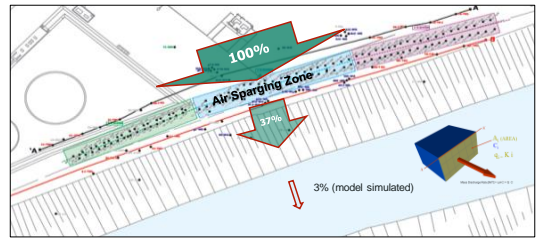
Transient Plume Under Influence of Tides



Transient Plume Under Influence of Tides



Calculated Mass Discharge



Establishing Remedial Goals

Risk Assessment found no risks to human health or ecology

Required goals:

- protective of river water quality
- no dilution in receiving body is allowed

Used fully transient model to include the dilution effects at the subsurface flow inversion zone



Establishing Remedial Goals

Groundwater intervention value:

50ug/L

River water quality:

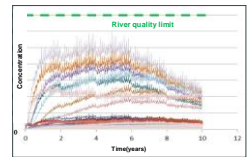
51ug/L

Steady-state model calculated goal:

70ug/L

Transient model calculated goal:

150ug/L



What does this mean?

Transient tidal model resulted in:

- More accurate predictions accounting for tidal attenuation processes
- Less restrictive remediation goals
- Significant cost savings in the long run



Key Takeaways

- Tidal effects should be accounted for, even several miles from the coast.
- Tidal fluctuations must be measured at the site itself not estimated from predictions or off-site measurement stations.
- Confined units show greater tidal efficiency than unconfined units.
- Head responses do not indicate a direct connection with the tidal water body.
- Understanding tidal influences on mass flux can prevent over-estimation of risk.



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