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M. Bayani Cardenas

2025 Birdsall-Dreiss and LaMoreaux Lecturer
Geological Society Of America Hydrogeology Division

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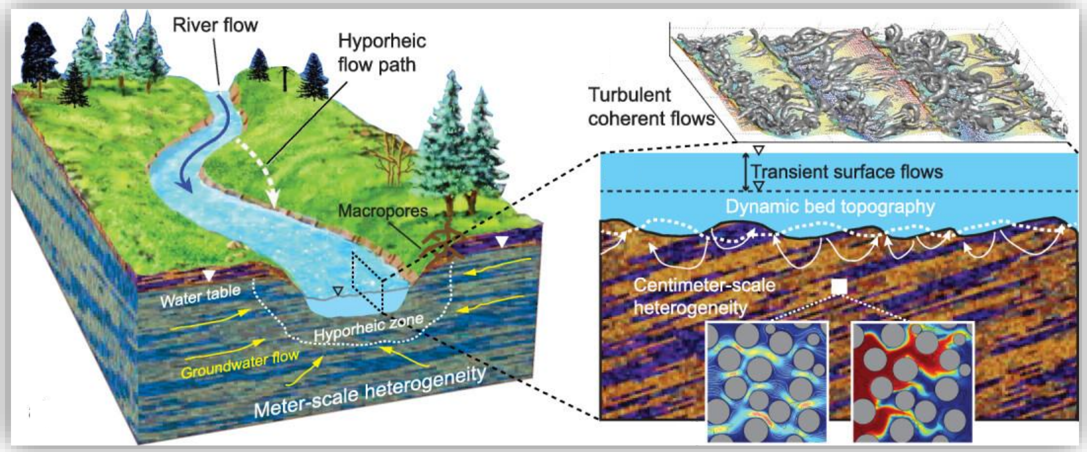
Speaker Biography: M. Bayani Cardenas is a hydrology professor in the Department of Earth and Planetary Sciences of the Jackson School of Geosciences at the University of Texas at Austin. His research seeks to understand flow and transport processes across different hydrologic settings, water quality and quantity problems, and scales, using a combination of theoretical, computational, and observational methods. He received his education from the University of the Philippines, the University of Nebraska, and the New Mexico Institute of Mining and Technology.

Lectures

1. Hydrobiogeochemistry of terrestrial-aquatic interfaces from pore to continental scales
2. How a river's periodic pulse affects its liver: hyporheic zones in the Anthropocene
3. Tidal and seasonal groundwater-surface water mixing zones: hot or cold spots for arsenic contamination?
4. Groundwater on ice: hydrogeology and the fate of permafrost carbon in Arctic watersheds
5. Land-ocean connectivity in Arctic lagoons due to groundwater
6. Ridge to reef volcanic hydrogeology: submarine groundwater in the world’s most biodiverse coasts
7. Devastation of a sole source coastal aquifer from the most powerful storm ever
8. Insights on groundwater renewability from age and residence time analysis
9. Beyond Darcy and Fick – Micro-scale insights on nonlinear continuum flow and transport

- **Hydrobiogeochemistry of terrestrial-aquatic interfaces from pore to continental scales**

- The parts of a river corridor - shallow aquifers, alluvium, floodplains, and the river itself - are intricately intertwined. Many important hydrologic and biogeochemical processes take place where the parts meet, which are the sediment adjacent to and below the river called hyporheic zones, and also more broadly referred to as terrestrial-aquatic interfaces. Because of mixing of surface- and groundwater, the hydrobiogeochemical processes at terrestrial-aquatic interfaces are characterized by steep physical and chemical gradients. These processes determine water quality and ecosystem health from the scale of individual pores, to bedforms, to reaches, and eventually integrate to impact watersheds spanning continents. This presentation is a primer and a synthesis of research that explains the mechanics and chemistry of river–hyporheic–aquifer processes from millimeter to megameter scales.



- Key contributors: Alec Norman, John Wilson, Adam Kessler, Perran Cook, Matt Kaufman, Lizhi Zheng, John Nowinski, Jesus Gomez-Velez, Jud Harvey, Brian Kiel, and many other collaborators

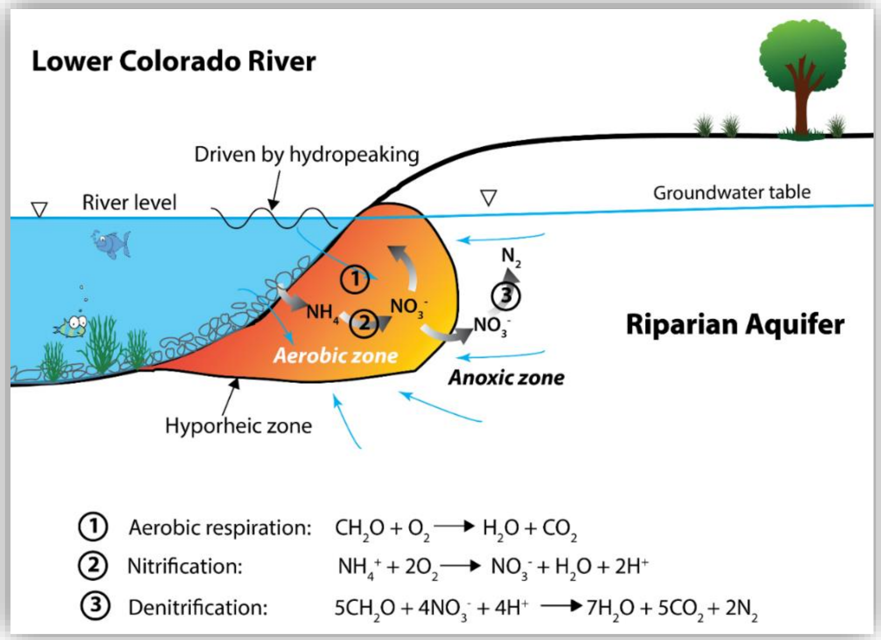
- Major funding sources: Department of Energy (DE-SC0018042) and National Science Foundation (EAR-0836540 and 0955750)

- Suggested reading and references: 1, 2, 3, 4

Lecture 2

- **How a river's periodic pulse affects its liver: hyporheic zones in the Anthropocene**

- Sixty percent of the world's major rivers are regulated by dams. This presentation discusses water, nutrient, and thermal energy transfers throughout a dam-regulated river corridor. It showcases measurements from hyporheic zones, which function as the river's liver, of the Lower Colorado River in Texas taken during periodic releases, natural flooding, and baseflow. Simulations of river hydraulics, groundwater flow, and energy and reactive transport generalize the observations. The models and observations collectively show how river regulation has drastically changed hydrobiogeochemical processes over potentially thousands of kilometers of rivers, reflecting the state of most large river corridors in the Anthropocene.



- Key contributors: Audrey Sawyer, Katelyn Kaproth-Gerecht, Blair Francis, Jeffery Watson, Stephen Ferencz, Sebastián Muñoz, Bethany Neilson, Philip Bennett, Peter Knappett, Pin Shuai and many other collaborators

- Major funding source: National Science Foundation (EAR-1343861 and 1344547)

- Suggested reading and references: 1, 2, 3, 4

- **Tidal and seasonal groundwater-surface water mixing zones: hot or cold spots for arsenic contamination?**

- Wet season flooding combines with tides going far inland in lowland rivers. This complex flooding situation is common in fluvial-deltaic systems in Asia where many aquifers are contaminated with arsenic. This brings up the question of what happens to the arsenic when water moves back and forth between rivers and aquifers over flood cycles. The different time scales and magnitude of flooding can induce complex and highly dynamic hyporheic zone mixing. The mixing of oxic river water and anoxic groundwater controls the precipitation of iron oxides which traps arsenic and dissolution which releases arsenic. This presentation discusses investigations along the banks of the tidal and seasonally-flooding Meghna River in Bangladesh. Prior studies at a different nearby site suggested that iron oxides accumulate in the Meghna's mixing zones, and these are associated with high levels of sediment-bound arsenic and low levels of dissolved arsenic. However, our observations show this may not be true everywhere and that mixing zones may remain mostly anoxic. Flow and reactive transport simulations help explain and generalize the observations.

- Key contributors: Peter Knappett, Saugata Datta, Tom Varner, Harshad Kulkarni, Kyungwon Kwak, William Nguyen, Lichun Wang, Pin Shuai, Alamgir Hossain, Kazi Matin Ahmed and others
- Major funding source: National Science Foundation (EAR-1852652, 1852653, and 1940772)

- Suggested reading and references: 1, 2, 3, 4

Lecture 4

- **Groundwater on ice: hydrogeologic processes and the fate of permafrost carbon in Arctic watersheds**

- The rapid warming of the Arctic where permafrost is prevalent is threatening to release carbon which would accelerate global warming if it reaches the atmosphere. There are still large uncertainties regarding carbon cycling and budgets in Arctic watersheds. This presentation shows that active layer soils above permafrost function as a thin but extensive unconfined aquifer mostly made up of peat. The supra-permafrost aquifer has relatively high porosity and permeability, creating efficient subsurface flow paths above otherwise impermeable permafrost. Observations and modeling reveal that much of the water and carbon going through Imnavait Creek, a headwater river in the North Slope of Alaska, has passed through the supra-permafrost aquifer and contributes significantly to the river's flow and carbon load. Remote sensing showed that supra-permafrost groundwater is prevalent during summer across the region while extensive sampling showed that there is substantial carbon within the supra-permafrost aquifers, as much as those estimated for permafrost. The crucial task of predicting the fate of carbon in Arctic watersheds thus depends on understanding the hydrogeologic processes.

- Key contributors: Bethany Neilson, George Kling, Jingyi Chen, Mike O'Connor, Sophy Wu, Neelarun Mukherjee and others

- Major funding sources: National Science Foundation (ARC-1204220, DEB-1637459, and 2224743, PLR-1504006, and OPP-1936759), National Aeronautics and Space Administration (80NSSC18K0983), Department of Energy (DE-SC0024091)

- Suggested reading and references: 1, 2, 3, 4

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Lecture 5

- **Land-ocean connectivity in Arctic lagoons due to groundwater**
- Aside from rivers and estuaries, water also flows below-ground from land to the ocean through coastal and submarine aquifers. While the global fresh submarine groundwater discharge (SGD) is less than 1% of river discharge, it is chemically important as groundwater nutrient inputs are 25% of riverine inputs. In some climatic and geologic settings, the solute and nutrient inputs from SGD are larger than rivers, and SGD can be the only hydrologic pathway. Land-ocean connectivity through SGD is thus important for coastal ecosystems. However, this connection is unclear in the Arctic because permafrost, which presumably inhibits the existence of aquifers and groundwater flow, extends continuously from land to far offshore. This presentation shows and explains SGD along the Arctic coast of Alaska. It covers detailed studies measuring SGD and characterizing the hydrogeology and hydrogeochemistry of coastal tundra, beaches, and lagoons. SGD in the Arctic appears to be larger than other parts of the world including the tropics. The multi-faceted investigations support the hydrobiogeochemical significance of SGD for Arctic coastal ecosystems.

- Key contributors: James McClelland, Matthew Charette, Cansu Demir,
  Emily Bristol, Emma Bullock, Julia Guimond, Craig Connolly,
  Micaela Pedrazas, Philip Bennett and other collaborators

- Major funding sources:
  National Science Foundation (OPP-1656026, 1938820, 1938873, and 2322664)

- Suggested reading and references: 1, 2, 3, 4

- **Ridge to reef volcanic hydrogeology: submarine groundwater in the world's most biodiverse coasts**
- Aside from rivers and estuaries, water also flows below-ground from land to the ocean through coastal and submarine aquifers. While the global fresh submarine groundwater discharge (SGD) is less than 1% of river discharge, it is chemically important as groundwater nutrient inputs are 25% of riverine inputs. This land-ocean connectivity is important for sensitive ecosystems such as coral reefs if the groundwater delivers solutes that are either necessary for or harmful to reef life. Here, we present the interesting but potentially common situation of dramatic SGD in a volcanically active area in the Philippines which has been identified as the world's most biodiverse coastal area and whose coral reefs provide for local communities. We studied coastal and submarine thermal springs associated with high fluxes of acidic waters and carbon dioxide, some of which are within or close to thriving coral reefs. The SGD fluxes are amongst the largest in the world and the SGD carbon dioxide fluxes overwhelm coastal carbon budgets. The presentation delivers explanations for the high SGD, discussing the mechanics and different sources and pathways of water, by bringing together multiple lines of evidence from different methods including deep diving, drones, novel sensors, geochemical tracers, thermal remote sensing, and modeling.

- Key contributors: Raymond Rodolfo, Mark Lapus, Fernando Siringan, Rogger Correa, Isaac Santos, Ebony Williams, Ryan Lardizabal, Chris Kratt, Scott Tyler, and many other collaborators
- Suggested reading and references: 1, 2, 3

- **Devastation of a sole source coastal aquifer from the most powerful storm ever**

- The northwest Pacific Ocean is a hot spot for sea level rise and increasing frequency of stronger storms. It is where Supertyphoon Haiyan formed, the strongest storm on record to hit land, which provided a window into the hydrologic impacts of an extreme storm. This talk presents results of detailed documentation of flood levels, groundwater table elevations, groundwater geochemistry, electrical resistivity, and flow and transport modeling. Through repeat surveys soon after the storm, we found that Haiyan's storm surge reached 7 m above sea level along Samar Island, Philippines, which led to contamination of crucial aquifers by infiltrating seawater. The seawater infiltration had short- and longer-term effects. A contaminated surficial aquifer would take years to recover. While groundwater in an underlying deeper aquifer saw widespread contamination immediately after the storm, salinity decreased significantly after 8 months. However, this deeper aquifer remains vulnerable to seawater slowly percolating through the surficial aquifer. As warmer seas generate more powerful storms, the vulnerability of aquifers to persistent contamination from intense storm surges is a growing concern for coastal communities.

- Key contributors: Raymond Rodolfo, Mark Lapus, Hillel Cabria, Peter Zamora, Kevin Befus, Philip Bennett and many others

- Major funding source: National Science Foundation (EAR-1439410)

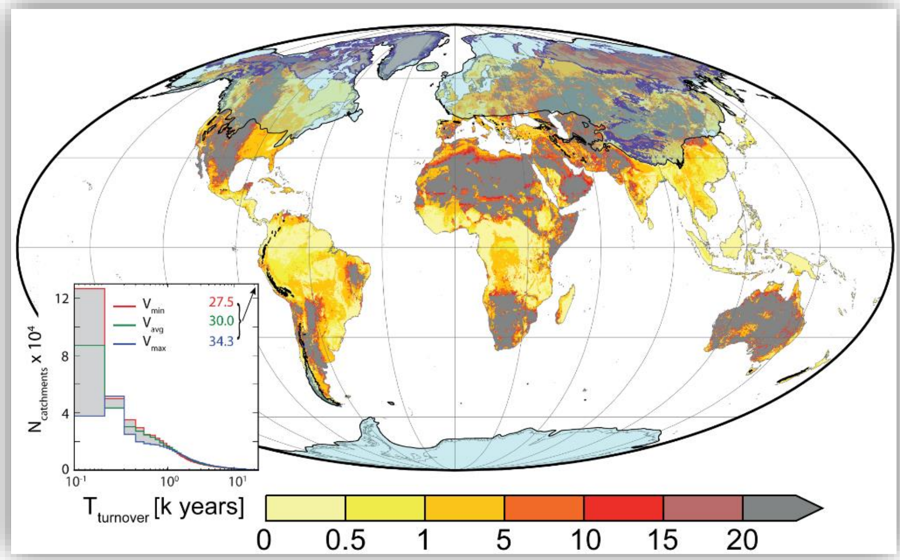
- Suggested reading and references: 1, 2, 3, 4, 5

- **Insights on groundwater renewability from age and residence time analysis**

- Groundwater is important for energy and food security, human health, and ecosystem quality. Groundwater age, the time since groundwater was recharged, is useful information for the different contexts noted above. It is also directly important for diverse geologic processes, such as chemical weathering, surface water eutrophication and climate change, for example. However, measured groundwater ages range from months to millions of years. This presentation summarizes results of collaborative efforts to globally map how much groundwater is present, the age distribution of groundwater, and the timescales for replenishment to assess groundwater renewability.

- Key contributors: Tom Gleeson, Kevin Befus, Scott Jasechko, Elco Luijendijk

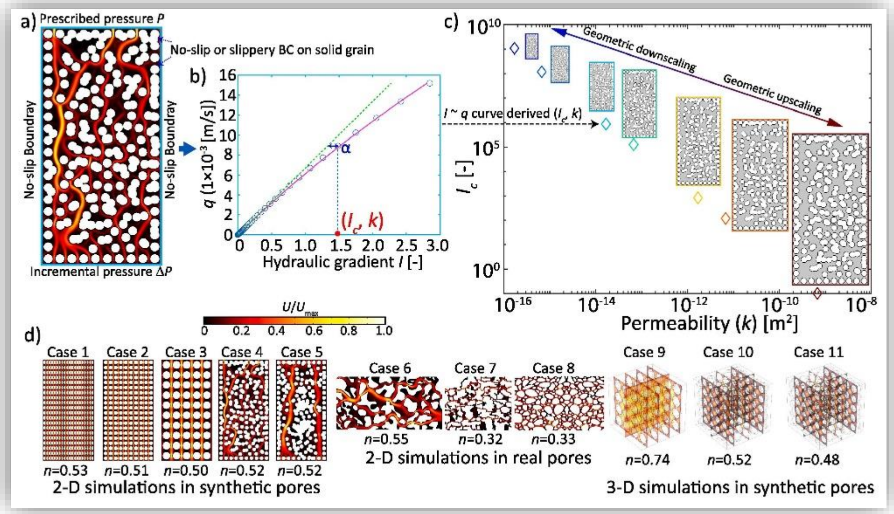
- Suggested reading and references: 1, 2, 3, 4, 5



Lecture 9

- **Beyond Darcy and Fick - Micro-scale insights on nonlinear continuum flow and transport**

- Darcy’s Law and Fick’s Law linearly relate flux to their driving gradient, respectively of hydraulic head and solute concentration. While these laws are foundational to hydrogeology, there are exceptions. This presentation focuses on cases which are potentially not that uncommon - non-Darcian flow (NDF) and non-Fickian transport (NFT). While NFT has long been known to be a consequence of many scales of heterogeneity, here we focus on a specific common culprit for NFT and NDF- eddies or recirculation zones (RZ) inside pores and fractures. Micro-scale models of flow and transport using computational fluid dynamics simulations with the Navier-Stokes equations using real and idealized pore and fracture geometry revealed the prevalence of RZs and dead zones. The computational experiments help explain how nonlinear behavior arises and eventually diminishes in the case of transport. Strategies on how to model NDF and NFT using alternative flow and transport formulations and for predicting coefficients of nonlinear laws will be discussed.



- Key contributors: Lichun Wang, Jiaqing Zhou, Kuldeep Singh, Yi-Feng Chen, Jack Sharp, Richard Ketcham, Philip Bennett and other collaborators

- Major funding sources: Department of Energy (DE-SC0001114) and National Science Foundation (EAR-0439806 and EAR-0345710)

- Suggested reading and references: 1, 2, 3, 4, 5

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