Research Priorities to Incorporate Terrestrial-Aquatic Interfaces in Earth System Models

Workshop Report
Draft Executive Summary

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The complete report will be available in February 2017 at science.energy.gov/ber/news-and-resources/ and tes.science.doe.gov. Any questions should be directed to Dr. Daniel Stover (daniel.stover@science.doe.gov)

Workshop Executive Summary

What are Terrestrial-Aquatic Interfaces?

Terrestrial-aquatic interfaces (TAIs) are highly dynamic and complex components of the Earth system that are transitional between fully terrestrial and aquatic environments. They possess unique biological, hydrological and biogeochemical attributes that produce exceptionally high rates of biological productivity and biogeochemical cycling. TAIs regulate the Earth system at a level that far exceeds the area they occupy. They capture, store, transform and release carbon, nitrogen, phosphorus, sediments, water and energy, and thereby participate in Earth system cycles that ultimately feedback on the atmosphere, climate, and aquatic ecosystems. Recent developments make it clear that a comprehensive understanding of the Earth system is not possible without a detailed understanding of the phenomena that occur where terrestrial and aquatic ecosystems meet.

The past decade witnessed significant advances in our understanding of the role that major Earth biomes play in regulating the Earth system, including tropical forests, northern peatlands, arctic landscapes, rivers, lakes, estuaries and oceans. These research efforts have been largely independent of one another, with relatively little interest in the question of how terrestrial and aquatic environments interact to form a planet-wide system. The next frontier toward a holistic understanding of Earth surface processes is to explicitly couple the dynamics of terrestrial and aquatic systems, a daunting challenge because of the many unique processes that arise in the TAI. We presently lack both the observational data and models to adequately describe how the key biogeochemical, hydrological, and physical processes in the TAI interact and feedback to influence the Earth system and climate. Solving this problem will require new observations, modeling frameworks and conceptual advances that can capture both fine-scale and large-scale phenomenon that differ fundamentally in the separate coupled systems.

Terrestrial Aquatic Interfaces are best defined by their characteristic processes rather than by ecosystem type. The common traits that TAIs share are unique biological communities (plants and microbe), rapid rates of biological productivity and microbial activity, rapid change in the availability of oxygen, carbon rich soils and sediments, high potential greenhouse gas emissions, and sensitivity to anthropogenic disturbances and climate change impacts. These areas are typically recognized as marshes, mangroves, peatlands, floodplains, hyporheic zones, groundwater seeps, lake margins and similar transitional areas. However, while they all tend to be limited in areal extent, at the scale of the landscape TAIs collectively constitute a large area of importance for the cycling of critical biogeochemical elements. A workshop of scientists who study terrestrial, aquatic and TAI systems was held in September, 2016 in Washington DC to begin planning a strategy to advance research at the terrestrial aquatic interface.

Why are TAIs important?

Although small in areal extent at the scale of the landscape, interfaces between terrestrial and aquatic systems constitute areas of importance for the cycling of critical biogeochemical elements. As such, TAI have been referred to as 'hot spots', and the same concept applies to time with punctuated periods of intense change and/or activity constituting 'hot moments'. TAIs are particularly vulnerable to the pressures of climate and environmental change such as changing precipitation patterns, and sea level rise/introduction of saline or brackish water, and to disturbance from extreme events. Extreme events that deleteriously affect TAIs include rapid pulse-type disturbances such as fire and storm surges, or more persistent and extended events such as drought, altered species composition, and groundwater extraction. Other extreme events that can have profound impacts on TAIs include floods or sediment erosion and deposition from storms and meltwaters.

The multiscale nature of both temporal and spatial gradients across interfaces represents one of the greatest research challenges in Earth systems. At all scales, strong gradients control the fluxes and transformations in these systems that will alter the state of TAI clearly occur at different tempo-spatial scales, as do the mechanisms of the ecological, biogeochemical and hydrological responses. Researchers must integrate physics, hydrology, biogeochemistry, biology, human interactions, and Earth system feedbacks to understand these dynamic systems.

Terrestrial-Aquatic Interfaces differ from other ecosystem types in that relatively subtle changes in boundary conditions can impact their very existence *and* their spatial location. There is a high potential for state change or ecosystem collapse with even minor changes to vegetation, or surface properties. For instance, many tidal wetlands build soil vertically by trapping exogenous and *in situ* sediment to maintain despite sea level rise (Kirwan and Megonigal 2013). Any perturbation that interrupts the soil-building mechanisms that naturally sustain tidal wetlands, can result in their conversion to mud flats or open water. Such a dramatic state change is irreversible on human time scales and has enormous consequences for how an area functions biogeochemically. Spatially, floods and sea level rise will push the interface further inland, while other processes can change the location and magnitude of configuration of the TAIs. Therefore, traditional ecosystem-based research which can be based on repeated studies of the same geographic location may not be appropriate; the TAIs may need research focused on the hallmark properties of the system, specifically the hydrologic continuum between the terrestrial and aquatic ecosystems and the accompanying redox and transport processes.

From this perspective, the distribution of relevant processes may be steepest near the physical boundary between domains and diminish rapidly into the aquatic realm while attenuating gradually over large distances into terrestrial systems. The reverse perspective is likely for research interests that lie predominantly in estuaries, large rivers and open water.

Development of observational and modeling approaches that span these transitions while remaining faithful to the process representations is needed both within the interface regions and in the discrete aquatic and terrestrial systems.

How should we represent our understanding of TAIs?

Existing hydrological, subsurface, biogeochemical, and Earth system models fail to address the key knowledge gaps unique to TAIs most frequently because they do not capture mechanisms across scales. For instance, understanding when parameters can be empirically up-scaled versus when process models are required is a major challenge in terrestrial aquatic ecosystems due to their inherent multiscale organization. Knowledge of which features and processes can be represented as directly up-scaled parameters, and which cannot, is essential for efficiently coupling empirical data from multiscale experiments to predictive multiscale models. Phenomena that cannot be directly up-scaled require particular attention to understanding the mechanisms behind the transitions across scales. An inability to predict such scale transitions may indicate structural deficiencies. In this case, additional experiment-model iteration would be needed to elucidate processes that cause observed scale dependencies.

Because multiscale approaches combine controlled manipulations with cross-system observations and process models across scales, experimental investments should (*i*) provide empirical constraints—that likely vary across systems—to calibrate and evaluate models, and (*ii*) reveal mechanisms that underlie observed context dependencies and, in turn, improve process representation in predictive models.

The TAI as a National Priority – Research Challenges

Because terrestrial-aquatic interfaces are globally ubiquitous, a fundamental understanding of the hallmark processes in these systems is needed to extend our site-specific observations to a more globally-relevant knowledge base and integrate models across process domains and spatial scales. Workshop participants have identified several priority research challenges to focus these efforts:

- Despite their known importance, we currently lack an accurate accounting of the location, size and carbon and nutrients inventory in both inland and coastal TAIs. An accurate global accounting of C stocks, fluxes, and transformations in the TAI is a basic but fundamental research need and a critical gap in the representation of these systems in models.

- What are the defining processes in TAI ecosystems and how do TAI state factors shift spatially and temporally in response to seasonal, engineered, and stochastic changes in hydrology? How do TAI ecosystems respond to forcing from other external drivers such as climate and land use? Which TAI characteristics render them more resilience or sensitive to perturbations?

- Local chemistries and the biological communities that catalyze chemical and geochemical reactions will change as hydrological perturbations affect the TAI, regardless of location: drought will increase water limitation and alter flow while sea level rise will introduce brackish and saline waters to typically freshwater ecosystems and river flooding will alter greenhouse gas emissions in adjacent floodplains and wetlands. An understanding of the effects of these chemical pressures on the core processes of the TAI, and the balance between C sources and sinks at the TAI is needed to improve the accuracy of predictive models of climate and carbon.

- The large-scale perturbations to these systems (sea level rise, drought, flooding) affect fine-scale ecosystem processes that result in important biogeochemical and hydrological transformations and fluxes through the TAIs. Scale-aware research is needed to predict the impacts of these perturbations on the relatively narrow zone of the interface. What will happen when the frequency of various events changes? Does the system become more primed to recover from more frequent events, or is the resiliency of the TAI diminished with each event?

Transdisciplinary science has the potential to reveal fundamentally new solutions, whether knowledge or models, synthesizing input from more than one discipline. This is in contrast to multidisciplinary science, wherein scientists collaborate but the disciplines remain compartmentalized, and interdisciplinary science, wherein some results are shared and integrated. It is clear that human systems will need to be considered in any study of terrestrial-aquatic ecosystems because of the immensity of their effects on key physical processes (e.g., Liu et al. 2015). Transdisciplinary science incorporates multiple stakeholders (Klenk et al. 2015), which for terrestrial-aquatic ecosystems would include the National Oceanic and Atmospheric Administration, U.S. Geological Survey, U.S. Department of Agriculture, the Environmental Protection Agency, and National Aeronautics and Space Administration among others. This report develops the technical basis and need for synthetic terrestrial-aquatic research. For these reasons, research into terrestrial-aquatic interfaces should be a national priority.