De-risking Energy Infrastructure and Improving Energy Resilience through Nature-based Solutions

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Motivation and Introduction

- The Department of Energy (DOE) Office of Cybersecurity, Energy Security, and Emergency Response (CESER) leads efforts to strengthen the security and resilience of US energy infrastructure against all threats and hazards.
- PNNL, with support from CESER, has partnered with states and territories on energy security planning efforts, in which most mitigation strategies focus on gray infrastructure.
- States and territories are well positioned to consider Nature-based Solutions (NbS) in their hazard mitigation plans as longer-term, multi-benefit strategies.

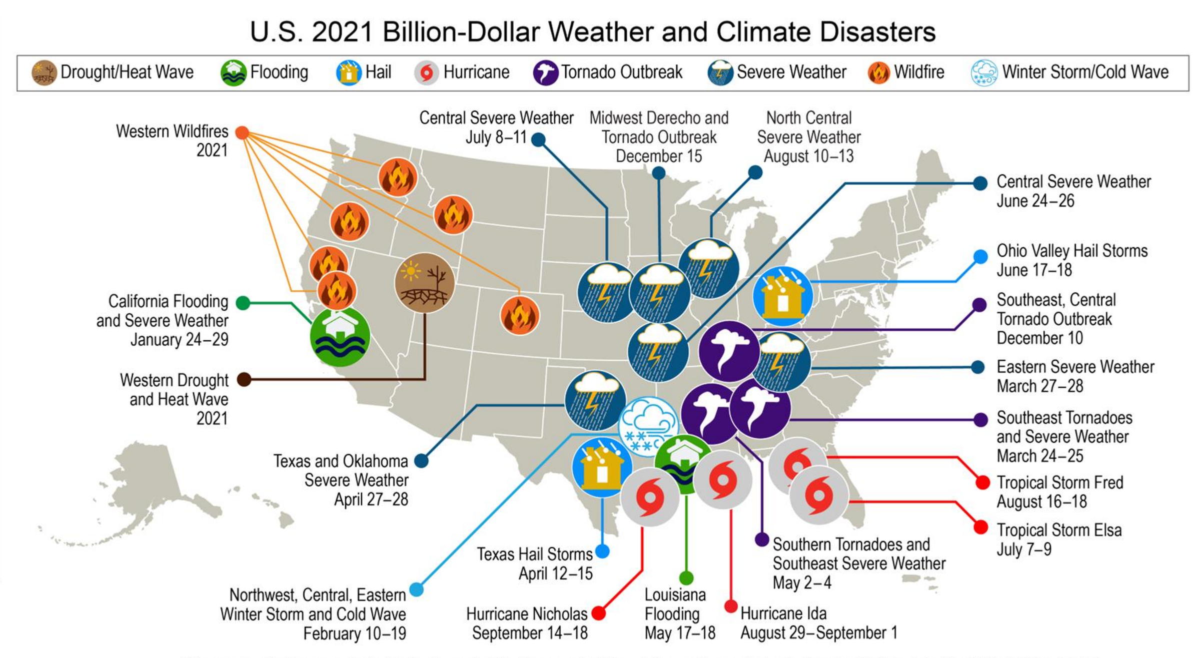


Fig 1. Map to show weather and climate disasters that impacted US in 2021, (Source: https://www.climate.gov/media/13976).

NbS: Definitions and Mechanisms

- NbS are actions that protect, manage, and restore natural or modified ecosystems to address societal and environmental challenges [1].
- Gray infrastructure, such as levees, dams, and drainage systems, focuses on controlling, diverting, or containing hazard impacts through structural and mechanical means.
- While gray infrastructure offers immediate and predictable protection, it often lacks adaptability and co-benefits beyond hazard control. NbS, in contrast, provide "blue-sky" co-benefits, such as , biodiversity, recreation, and improved air and water quality.

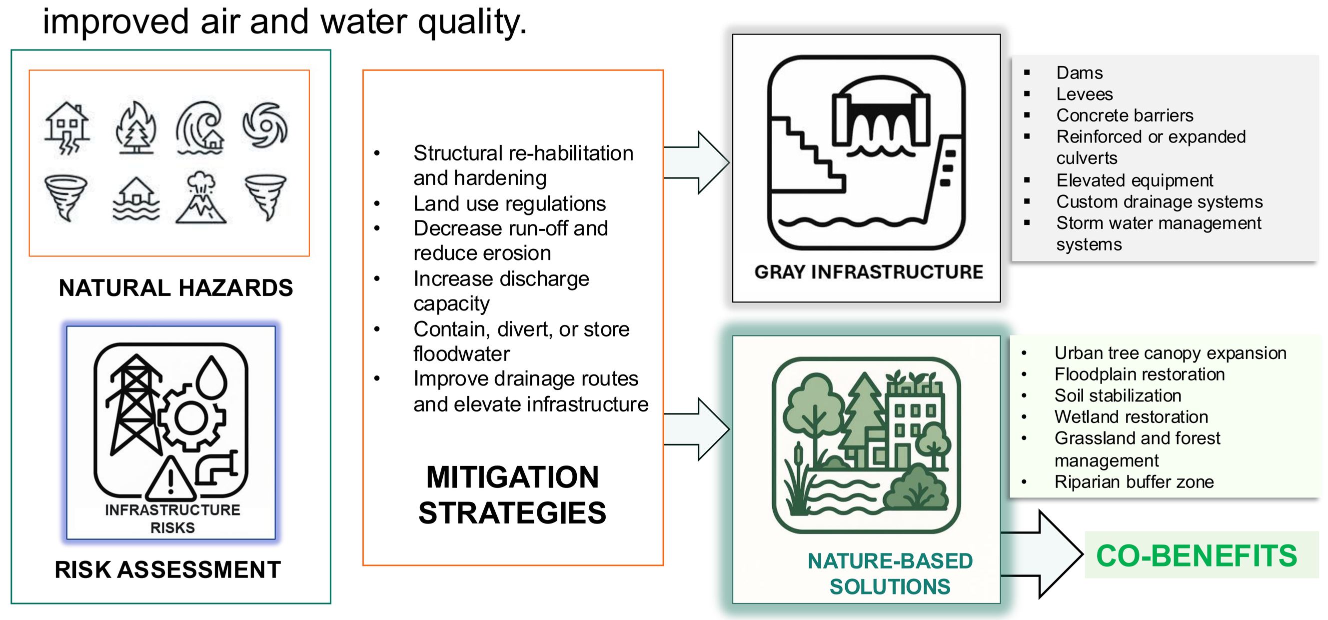
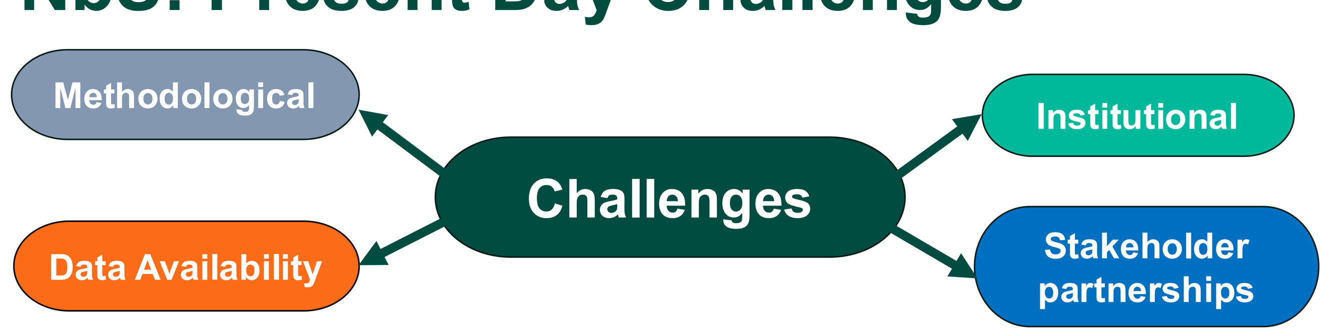


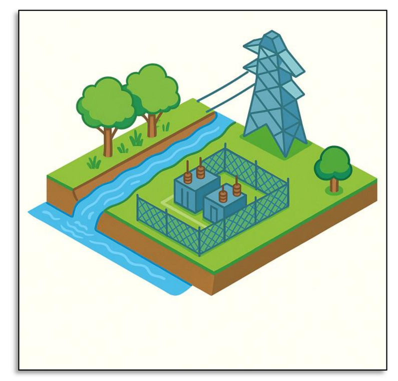
Fig 2. Contrasting gray infrastructure and NbS for infrastructure risk mitigation against different types of natural hazards (e.g., earthquakes, hurricanes, floods, etc.).

NbS: Present Day Challenges



[1] International Union for Conservation of Nature (IUCN). (2016). *Nature-based solutions to address global societal challenges.* Gland, Switzerland: IUCN. https://doi.org/10.2305/IUCN.CH.2016.13.en

Examples of NbS for Energy Risk Mitigation



RIPARIAN BUFFERS

- **Blue-sky benefit:** Riparian buffers enhance habitat connectivity and carbon sequestration while improving local microclimate and water quality.
- **Infrastructure risk mitigation:** They shield substations and transmission corridors from flood-induced erosion, debris impact, and foundation instability.
- **Grid-level relevance**: Most effective at the transmission and sub-transmission interface, where floodplains and waterways intersect critical infrastructure.

FOREST MANAGEMENT AND AFFORESTATION

- **Blue-sky benefit:** Forest management and afforestation enhance carbon sequestration, biodiversity, and local climate regulation through increased canopy cover.
- **Infrastructure risk mitigation:** Managed vegetation reduces wildfire fuel loads and limits heat exposure to transmission lines and substations.
- **Grid-level relevance:** Most impactful at the transmission corridor and distribution-feeder interface, especially in wildfire-prone or high-temperature regions.

URBAN CANOPIES AND GREEN INFRASTRUCTURE

- **Blue-sky benefit:** Urban canopies and green infrastructure improve air quality, reduce urban heat islands, and enhance community livability.
- **Infrastructure risk mitigation:** They lower ambient temperatures, reducing transformer and cable overheating while mitigating stormwater flooding near substations.
- **Grid-level relevance:** Most effective at the distribution and urban microgrid level, where dense load centers and localized heat stress occur.

Proposed Analytical Framework

- **Eco-physical modeling:** Captures spatio-temporal dynamics of natural systems, such as hydrology, vegetation, and land processes under baseline and NbS scenarios.
- **Energy system modeling:** Represents interdependent generation, transmission, and distribution networks alongside market and policy layers influencing grid operations.
- **Risk analytics:** Links ecological and energy domains to evaluate how NbS implementation modifies infrastructure risk, resilience metrics, and system-level performance.

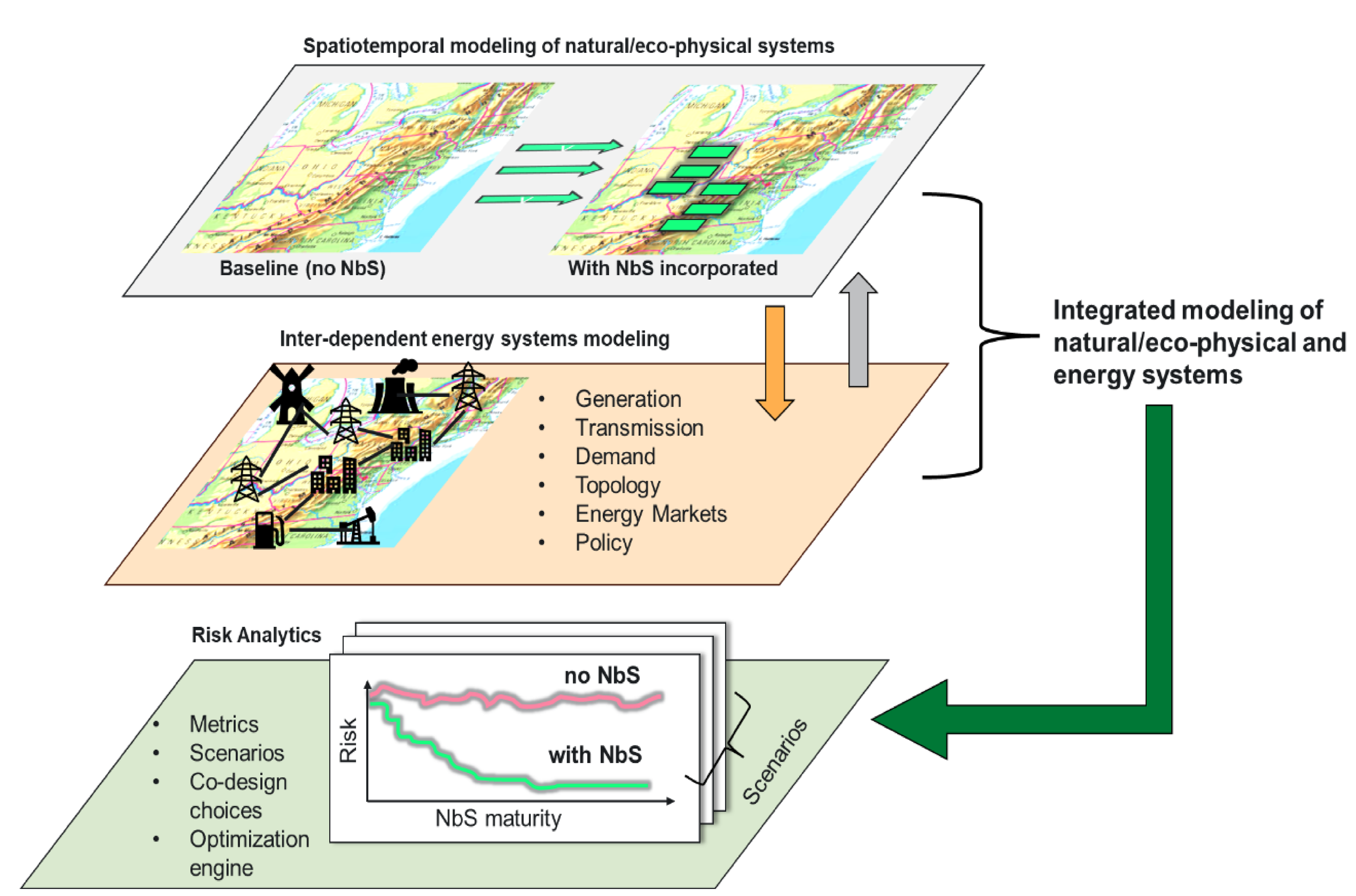


Fig 3. Proposed analytical framework for understanding how NbS can address energy infrastructure risks.

Illustrative Example

- IEEE 9-bus network overlaid on a hypothetical flood-prone riverine topography.
- We perform plausible scenario analysis for exploratory modeling.
  - Lines 4–5, 5–6, 9–4 cross high-risk zones.
  - Considered a 10-day period in which days 4, 5 and 6 are impacted by severe flooding.
  - Flooding causes *derating* and reduced power transfer capability in affected lines.
  - Performed an optimization-based dispatch to minimize load shed for the 10-day window.
  - Watershed buffers mitigate flood severity near transmission assets.
  - Buffers preserve capacity and enhance grid reliability during floods.

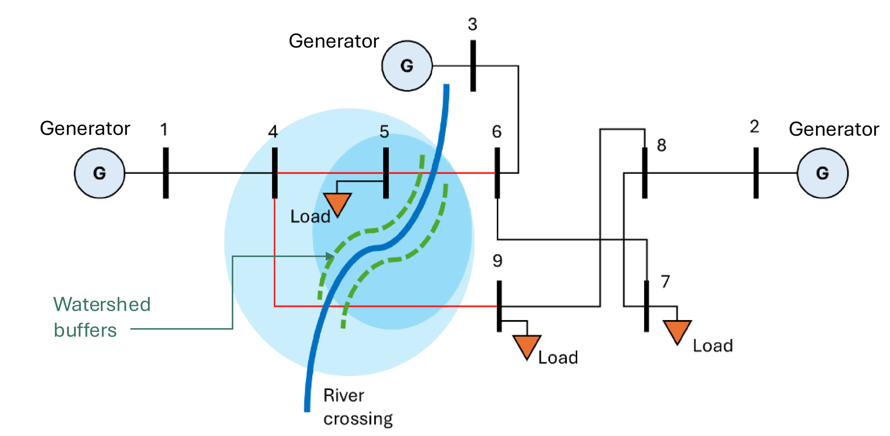


Fig 4a. IEEE 9 bus system overlaid on flood-prone topography. Blue zones represent high risk of flooding and red lines are affected by floods. Green dotted lines represent watershed buffers.

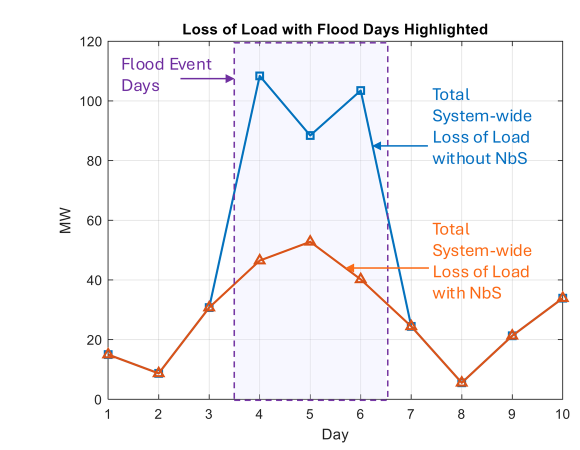


Fig 4b. Watershed buffers reduce loss of load across the whole system during event (flood) days.

Existing Programs that Support NbS

- ***The Floodplains by Design (FBD) Program from Bonneville Environmental Foundation (BEF):***
  - A public-private partnership among the WA state Department of Ecology and NGO Bonneville Environmental Foundation (BEF) supporting collaboratives of local governments, Tribes, NGOs, utilities, special service districts, and communities.
  - Provides large capital grants and capacity support to plan and implement projects that reduce flood risk, restore habitat and support agricultural resilience, often through integrated green-gray infrastructure.
  - Implementers often leverage a "dig once" approach to also address energy infrastructure at risk and minimize disruption, reduce costs, and maximize efficiency.
- Example actions that increase energy system resilience include:
  - Relocation of power transmission lines out of high flood risk areas.
  - Protection or relocation of jet fuel lines and oil/gas pipelines.
  - Integration of measures to understand and manage post-fire debris flows that threaten energy and other infrastructure.

Fig 5. Yakima County's Cowiche Creek levee setback project, in conjunction with the City of Yakima's Nelson Pipeline project will install a pump station on the landward side of the levee powered from the power pole (bottom left), and power to the Naches Cowiche Canal Company shop will be rerouted to higher ground. (Kory Graafstra, Yakima County).

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