The National Laboratory of the Rockies (NLR)
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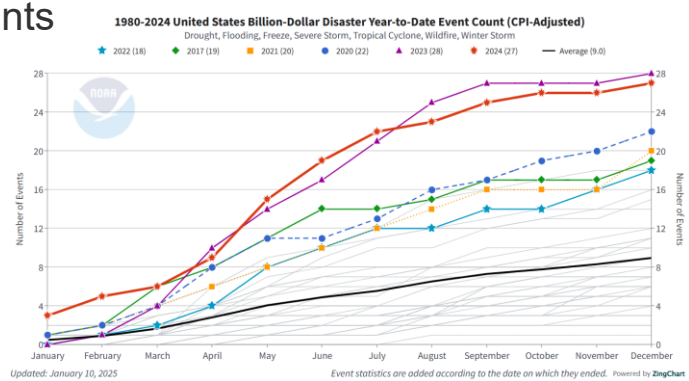
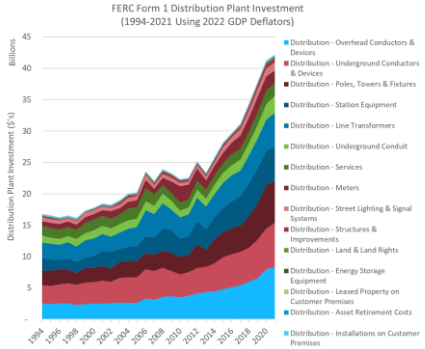
Planning Gap and Resilience Challenge

Utilities Operate in a Complex Planning Environment

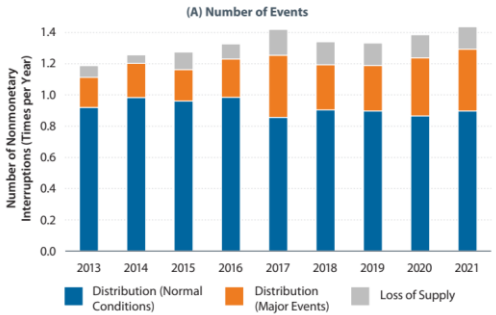
- More than 3,000 distribution utilities with different constraints
- Aging infrastructure and new load growth
- Multiple hazards affecting the same system
- High-cost, long-life investment decisions.

The challenge is making consistent decisions across this complexity.

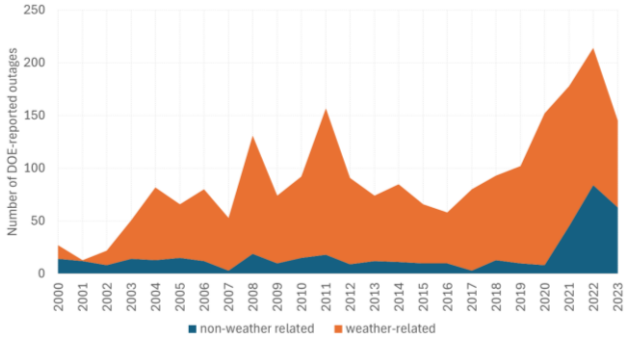




NLR, FERC Form 1 Analysis

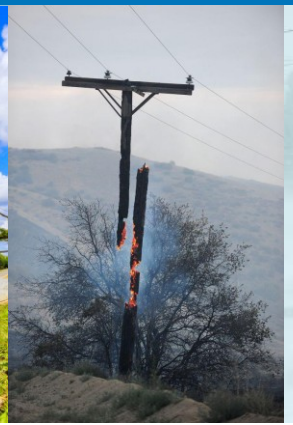


Climate Central



NLR, Explained: Reliability of the Current Power Grid, 2024

Why This Conversation Matters Now



- Extreme events are increasing in frequency and severity.
- Distribution systems drive the majority of outages.
- Utilities are investing at an unprecedented scale.
- Planning decisions now carry long-term cost and risk implications.

Utilities are making billion-dollar decisions under deep uncertainty.

Photos from Adobe Stock

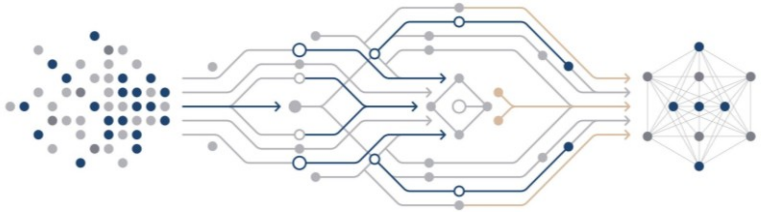
Where Current Planning Breaks Down

Today's Reality

- Hazard studies are siloed (e.g., flood, wildfire, wind).
- Results are hard to compare across interventions.
- Planning is often deterministic or scenario limited.

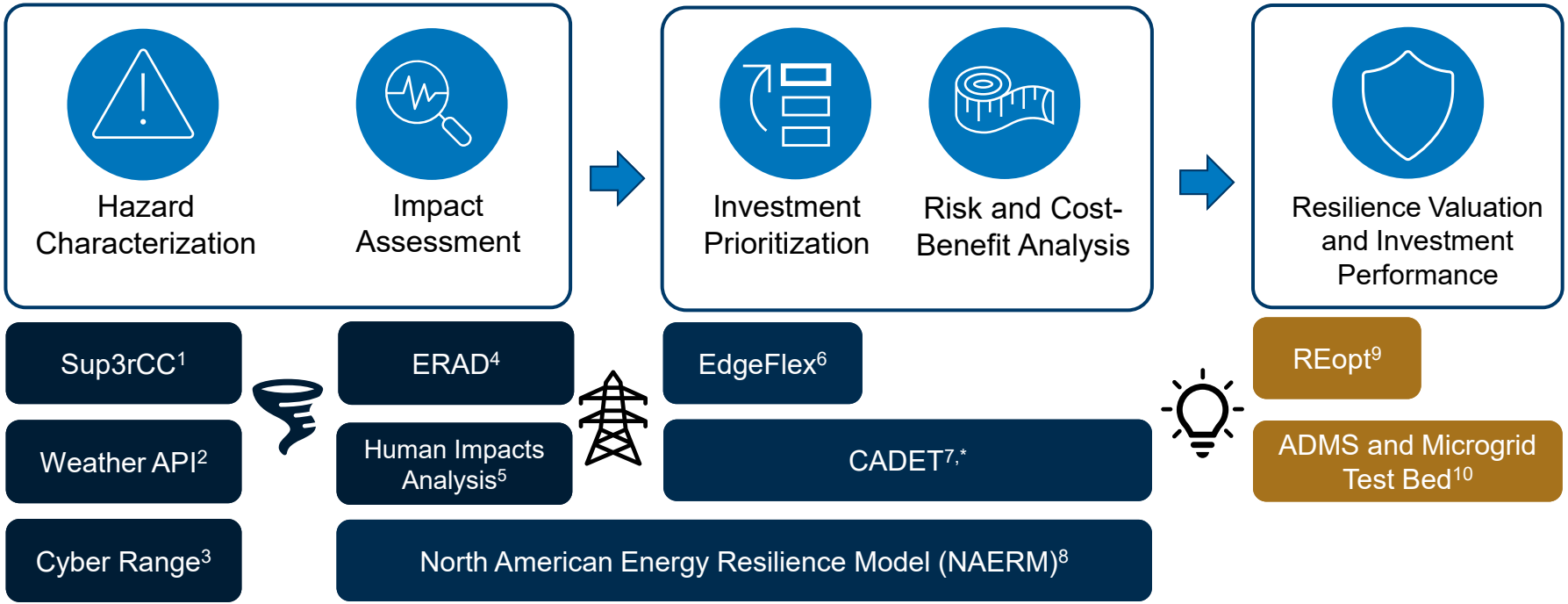
What Planners Actually Need

- Multihazard comparison
- Probabilistic risk understanding
- Direct link to investment decisions.



We don't have a modeling problem. We have a decision translation problem.

A Forward-Looking Resilience Planning Framework



under development

Sup3rCC = Super-Resolution for Renewable Energy Resource Data
API = application programming interface
ERAD = Energy Resiliency Analysis Tool for Distribution System

CADET = Capacity Expansion Decision Support for Distribution Networks
ADMS = advanced distributed management system

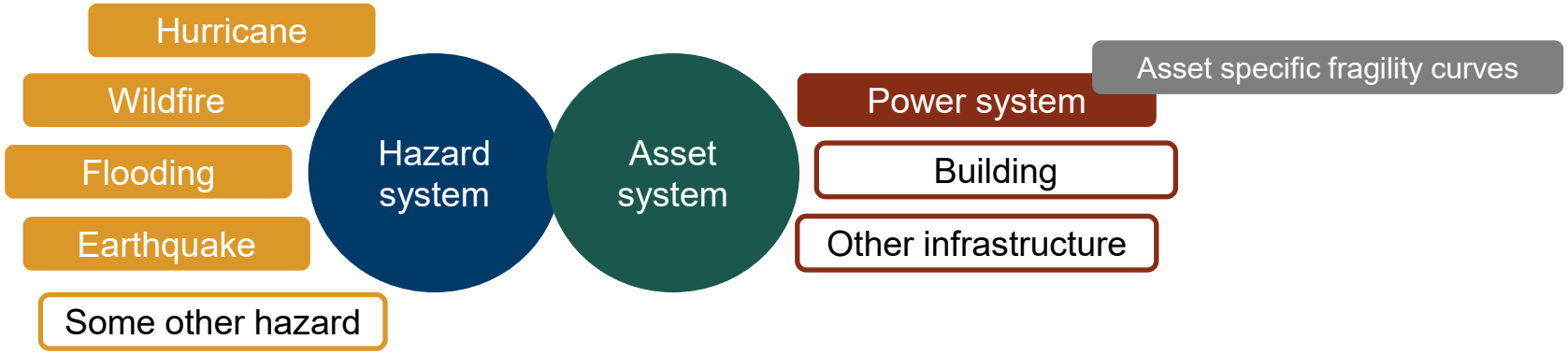
ERAD Fills the Gaps

- Existing studies are often hazard-specific and hard to compare across interventions.
- Distribution systems are most impacted by hazards and are the least studied.
- There is no consistent way to compare resilience investments across hazards, assets, and scenarios.

ERAD was built to bridge hazard modeling and investment decisions.

Intro to ERAD

ERAD Design Philosophy



Engine Capabilities

- Multi-hazard models (e.g., earthquake, wind/hurricane, flood, wildfire)
- Asset-centric simulation with configurable fragility curves
- Monte Carlo scenario generation for probabilistic planning.

Interoperability By Design

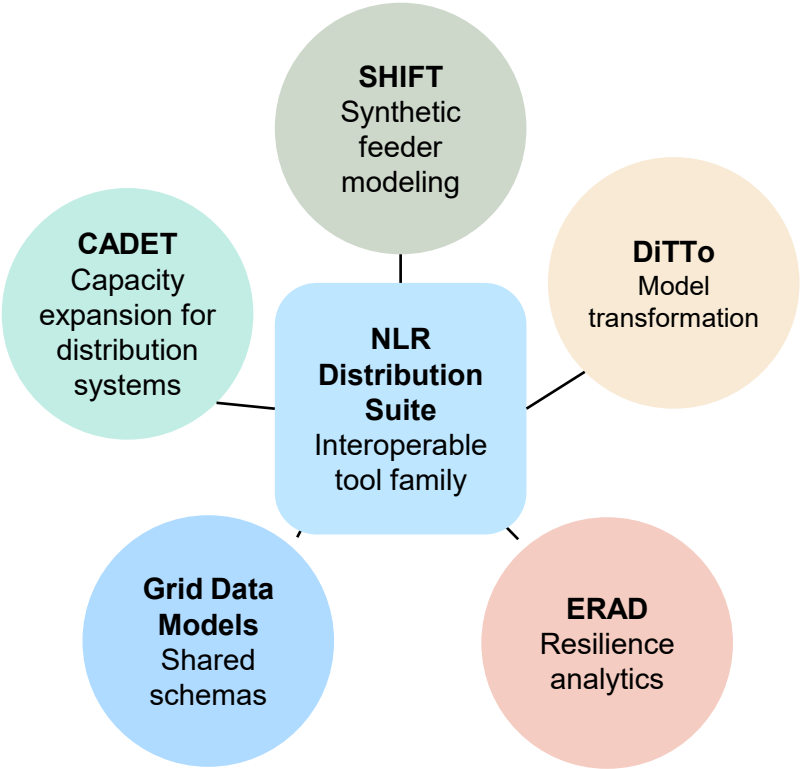
- Native alignment with grid data models (GDM) structures
- Artificial intelligence-native
- Supports integration with partner optimization, planning, and reporting stacks.

Extensibility Model

- The current asset library emphasizes electric power distribution systems.
- The data model and component system can be expanded to nonpower asset domains.

ERAD Ecosystem of Capabilities

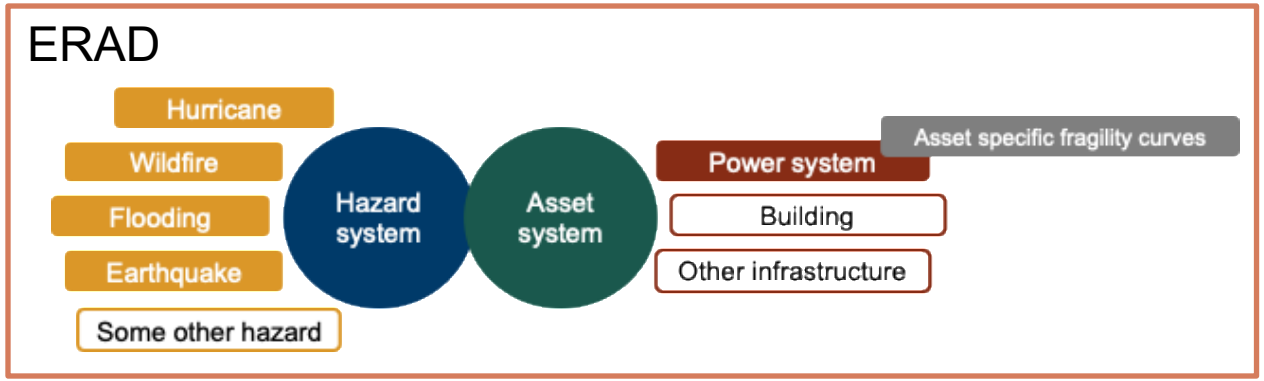
- ERAD is one module in an interoperable, open-source distribution planning ecosystem.
- Suite components and roles:
  - **SHIFT**: Builds synthetic distribution feeders from geospatial data (OpenStreetMap)
  - **DiTTo**: Transforms models across OpenDSS, CIM, CYME, and Synergi formats
  - **GDM**: Standardized, validated schemas for shared asset and network data.
- MCP and agent-ready interfaces allow multistep workflows across tools with fewer manual handoffs.
- **Result:** Faster scenario setup, repeatable studies, and better resilience decision support.



nlr-distribution-suite.github.io/distribution_software_suite/

SHIFT = Simple Synthetic Distribution Feeder Generation Tool
DiTTo = Distribution Transformation Tool
OpenDSS = Open-Source Distribution System Simulator
CIM = Common Information Model

What ERAD Is Not…



… A full-featured Hazard Engine

- Hazard models in ERAD are lightweight and often overly simplistic.
- They have been developed from literature.
- If high-fidelity hazard propagation models are needed, it is better to use third simulators.

… A tool to build fragility Models

- ERAD does not build fragility models.
- It enables users to define fragility curves at asset property level.
- Default curves mostly come from literature.
- External tools will be needed to build fragility curves.

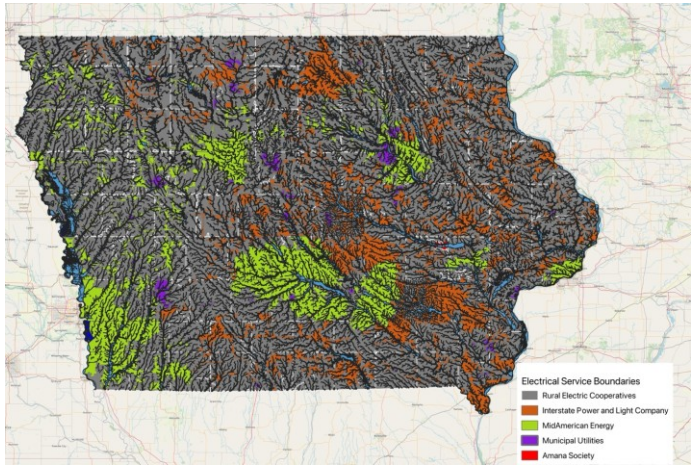
But you can use ERAD with external tools for these

Iowa Flood Resilience Assessment Using ERAD

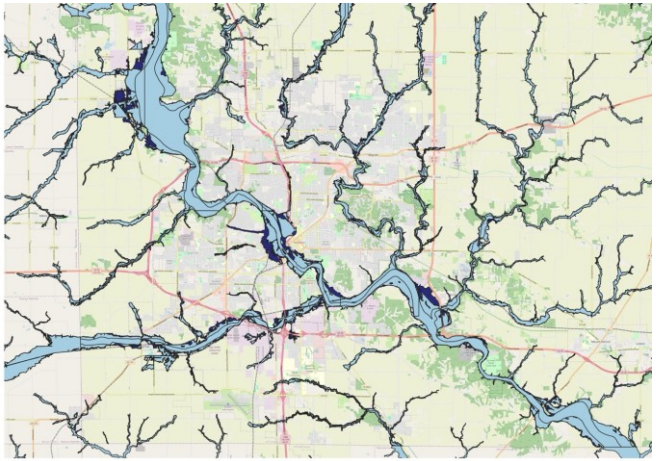
A planning workflow to translate flood risk into investment decisions

Where Is the Risk?

Federal Emergency Management Agency (FEMA) flood hazard zones overlapping with utility service territory in Iowa. Blue areas represent the 1% annual chance floodplain and the 0.2% annual chance floodplain.



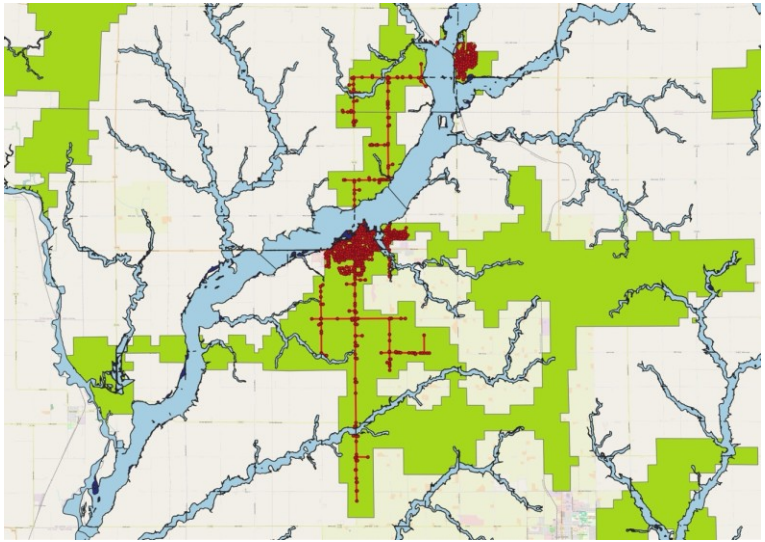
FEMA flood hazard map in Cedar Falls, Iowa. The light blue represents the 1% annual chance floodplain, and the dark blue represents the 0.2% annual chance floodplain.



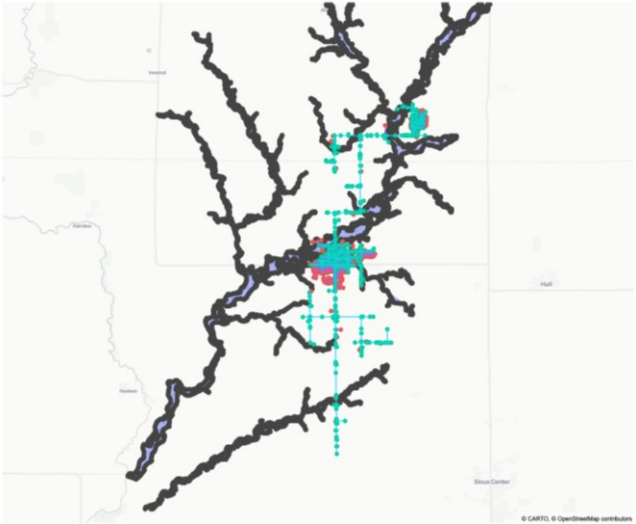
Flood exposure identifies **where** hazards occur, it does not tell us **what will fail**, **how likely it is to fail**, or **what to invest in**. Also, planning cannot rely on uniform assumptions across a service territory.

Spatial Risk Insight

FEMA flood hazard map in Rock Valley, Iowa, overlaid with electric utility infrastructure (red) and the utility service territory (green).



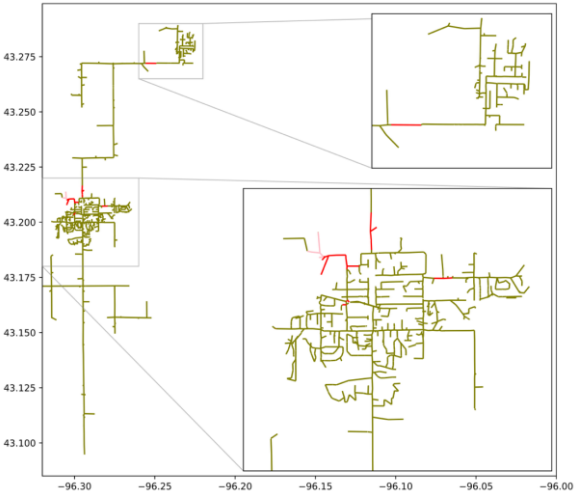
ERAD output showing the probability of damage to utility assets under the 2-year floodplain scenario.



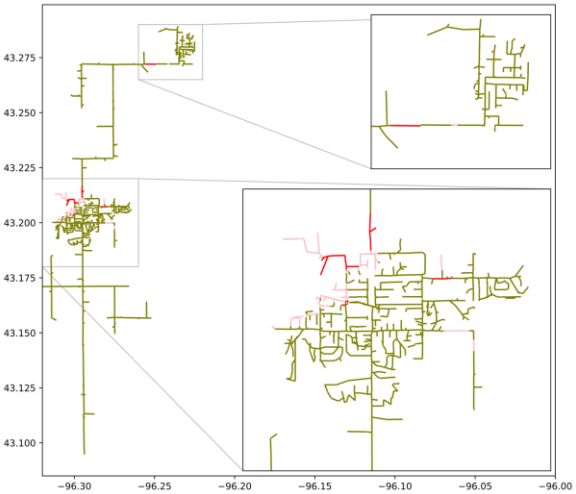
Not all assets in flood zones fail equally; risk is highly localized. This is why asset-level probabilistic modeling matters.

Investment Performance Depends on Scenario Severity

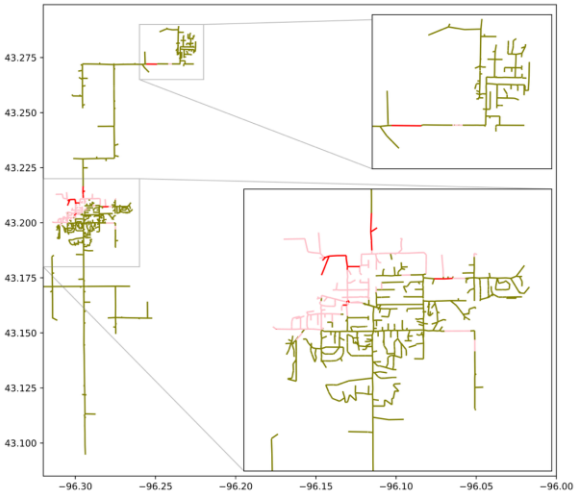
Pink represents the damaged assets and red represents the upgrades.



2-year flood



10-year flood



100-year flood

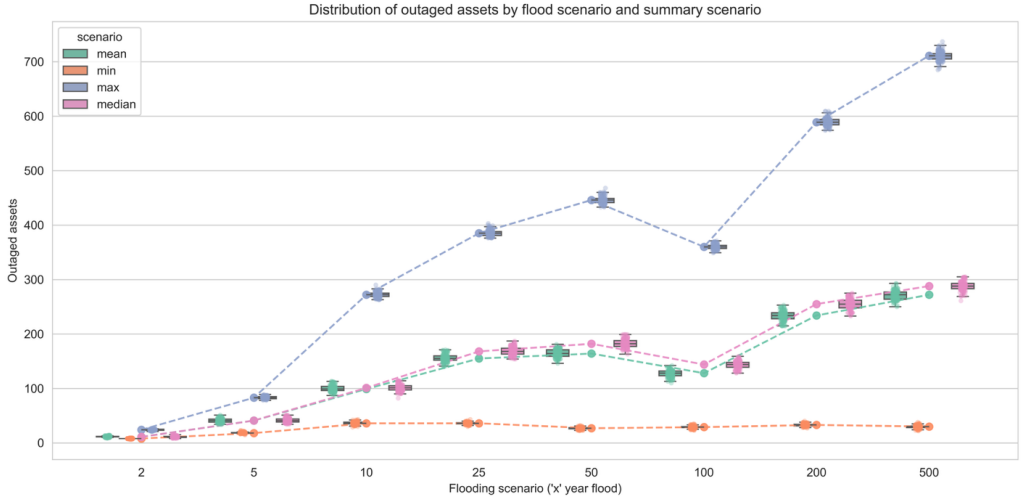
There is no single “best” investment without considering uncertainty.

What Actually Drives Resilience Value

Pole Upgrades
- Low cost and frequently selected
- Provide incremental resilience benefits.

Undergrounding
- Higher capital cost
- High benefit in severe scenarios.

Substations
- Critical points of failure
- Highest impact when protected.



Resilience planning requires targeted, data-driven investments across assets and scenarios.

Multihazard Simulation Using ERAD

Understanding compounding risks and their impacts

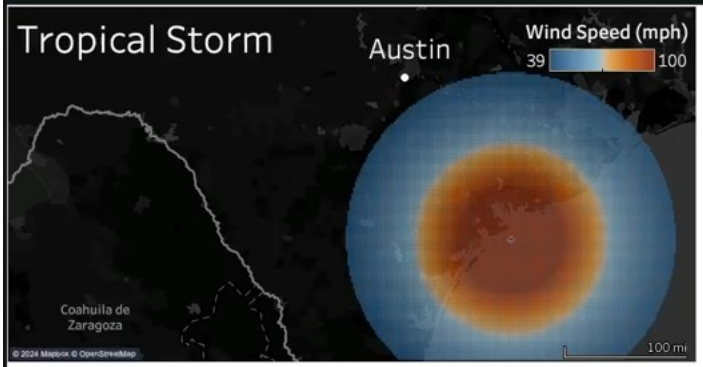
Why Multihazard Modeling Matters

Resilience planning requires understanding how multiple hazards interact and propagate through infrastructure and communities.

- Risks are compounding and interacting, not isolated.
- Single-hazard studies miss cascading impacts.
- Planning decisions must consider:
  - Multiple hazards
  - Infrastructure and community impacts.

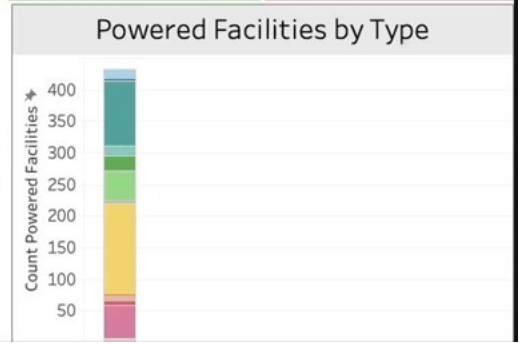
Photo from Pexels

Tropical Storm

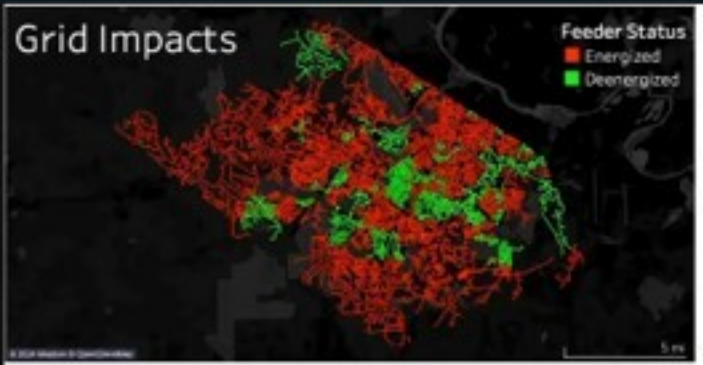


Critical Service Facility Types

Public Safety	Shelter
Fire & EMS	Library
Police Station	Place of Worship
	Shelter
Food & Fuel	**Healthcare & Medication**
EV Charging Station	Dialysis Center
Gas Station	Hospital
Grocery Store	Pharmacy
Hardware/Outdoor Store	Urgent Care



Restoration



ERAD Helps Utilities Prepare

ERAD: From Risk Modeling to Decision-Making Under Uncertainty

Helping planners and resilience teams make better decisions under hazard uncertainty

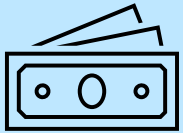
ERAD is an engine, not a one-off model:

- Built for interoperability through the NLR Distribution Suite ecosystem
- Designed to plug into existing analysis pipelines and partner tools
- Extensible by architecture
  - Hazard modules, fragility curves, and workflow interfaces are replaceable.

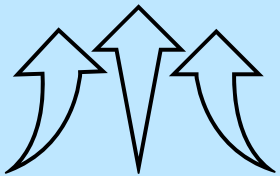
Current default asset system focuses **on electric power distribution assets**, but the same pattern can be extended to other domains (e.g., buildings, water, telecom, and community facilities).

Changing the Future of Resilience Planning

ERAD evaluates risk across hazards, assets, and scenarios in a way that unlocks…



Comparable, defensible investment decisions



Better alignment between cost, reliability, and resilience outcomes

The ability to plan for uncertainty, not just expected conditions

How To Access ERAD

Get Started Quickly

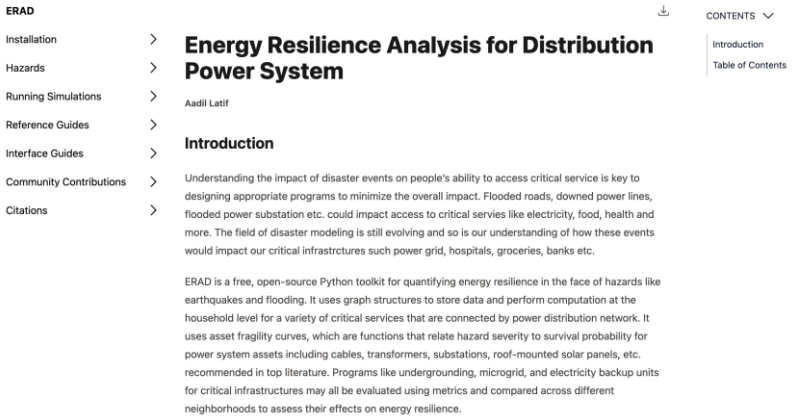
- **Core package:** pip install NLR-erad
- **Documentation:** nlr-distribution-suite.github.io/erad
- **Source and issues:** github.com/NLR-Distribution-Suite/erad.

Plugin Ecosystem

- github.com/NLR-Distribution-Suite/erad_plugins
- Install only what you need (climada, egsim, forefire, pywatershed).

Adoption Path

- Start with examples and notebooks.
- Move to command line interface for repeatable studies.
- Integrate Model Context Protocol tools for guided exploration and stakeholder Q&A.



Q&A

www.nlr.gov

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Forward-Looking Resilience Planning Framework Citations

1. Duwadi, Kapil, Bryan Palmintier, Aadil Latif, Kwami Senam Sedzro, and Sherin Ann Abraham. 2025. “ERAD: A Graph-Based Tool for Energy Resilience Analysis of Electric Distribution Systems.” Journal of Open Source Software 10 (116): 8782. https://doi.org/10.21105/joss.08782.
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