A Case for Resilience and Systems Thinking

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(Opinions expressed represent those of the author and not necessarily those of the Bureau of Reclamation).

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RESILIENCE:

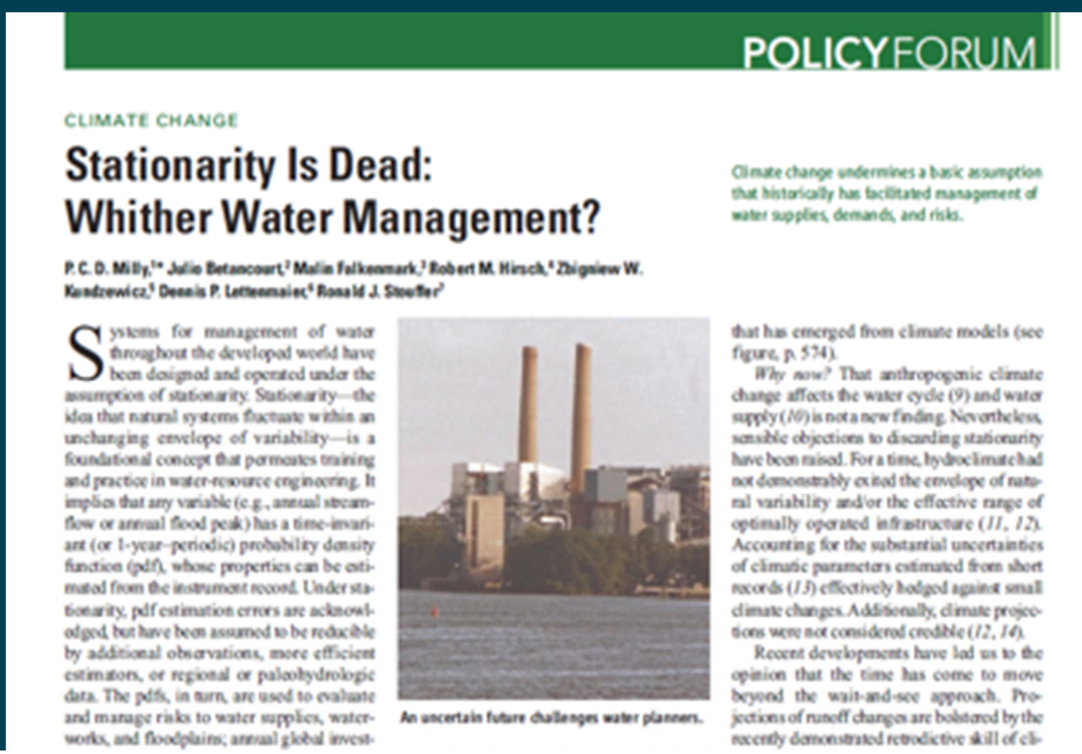
"The capacity of a system to absorb a spectrum of disturbances and reorganize so as to retain essentially the same function, structure, and feedbacks—to have the same identity." (Walker and Salt 2012).

Flooding by Richard, Flickr Creative Commons

Forest Wildfire by Project LM, Flickr

Traditional Engineering is based on the concept of Stationarity

Stationarity assumes that the statistical properties of hydrologic variables in future time periods will be similar to past time periods



POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global invest-

An uncertain future challenges water planners.

that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (9) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of cli-

"Climate change **undermines a basic assumption** that historically has facilitated management of water supplies, demands, and risks."

Traditional engineered structures are designed to be stable, and resistant to disruptions and change

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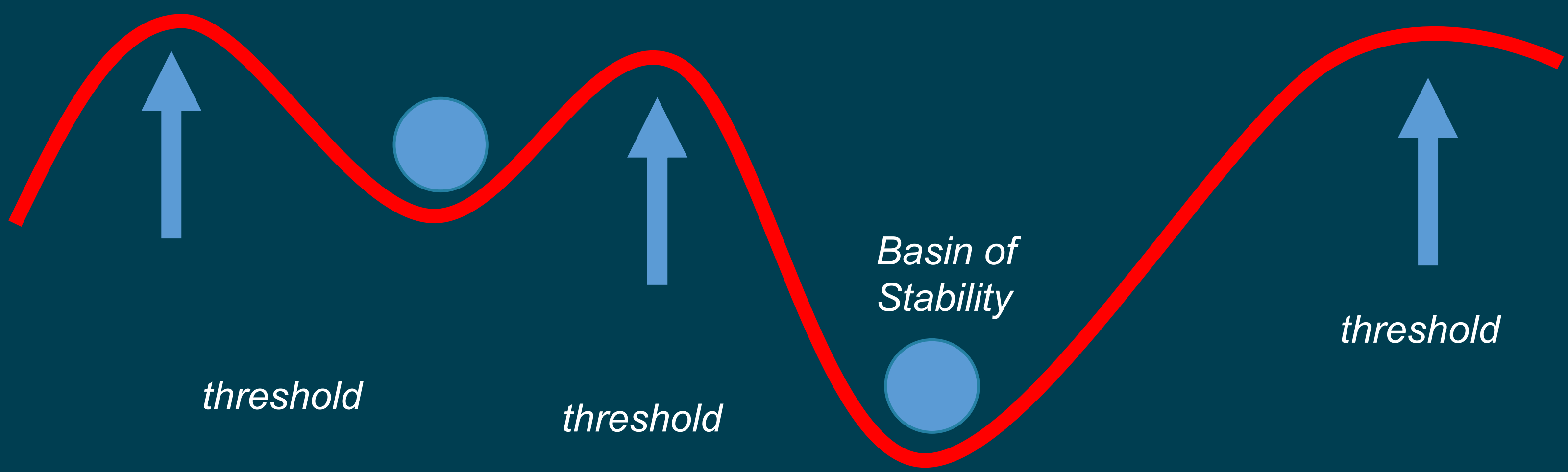
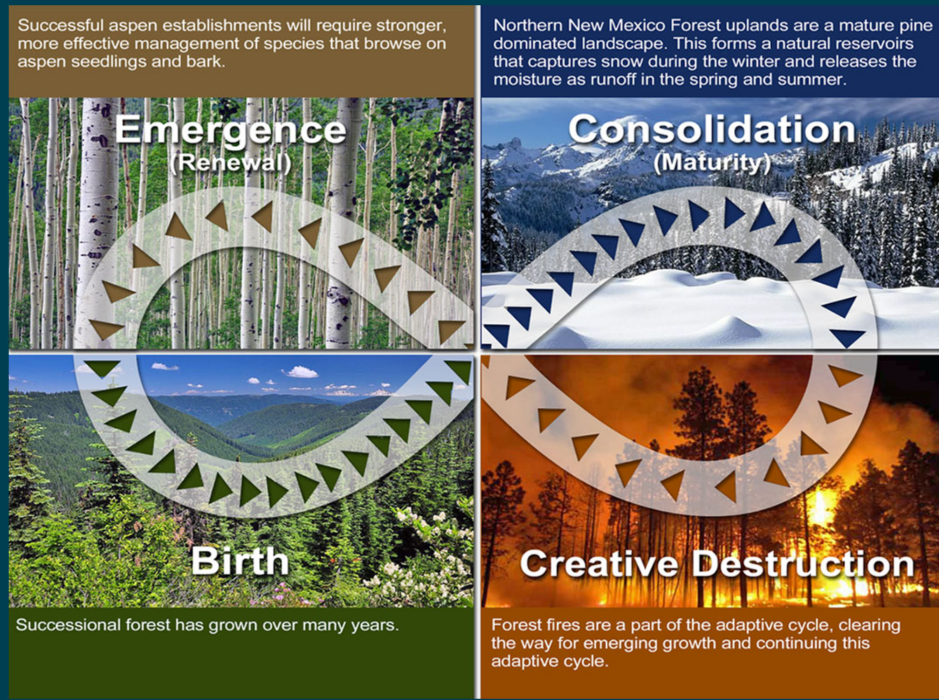


There are limits to how much a self-organizing system can be disturbed and still recover. Beyond those limits it functions differently because some critical feedback process has changed. These limits are known as:

thresholds

Healthy adaptive cycle in a natural system



Disturbance

Transformation!

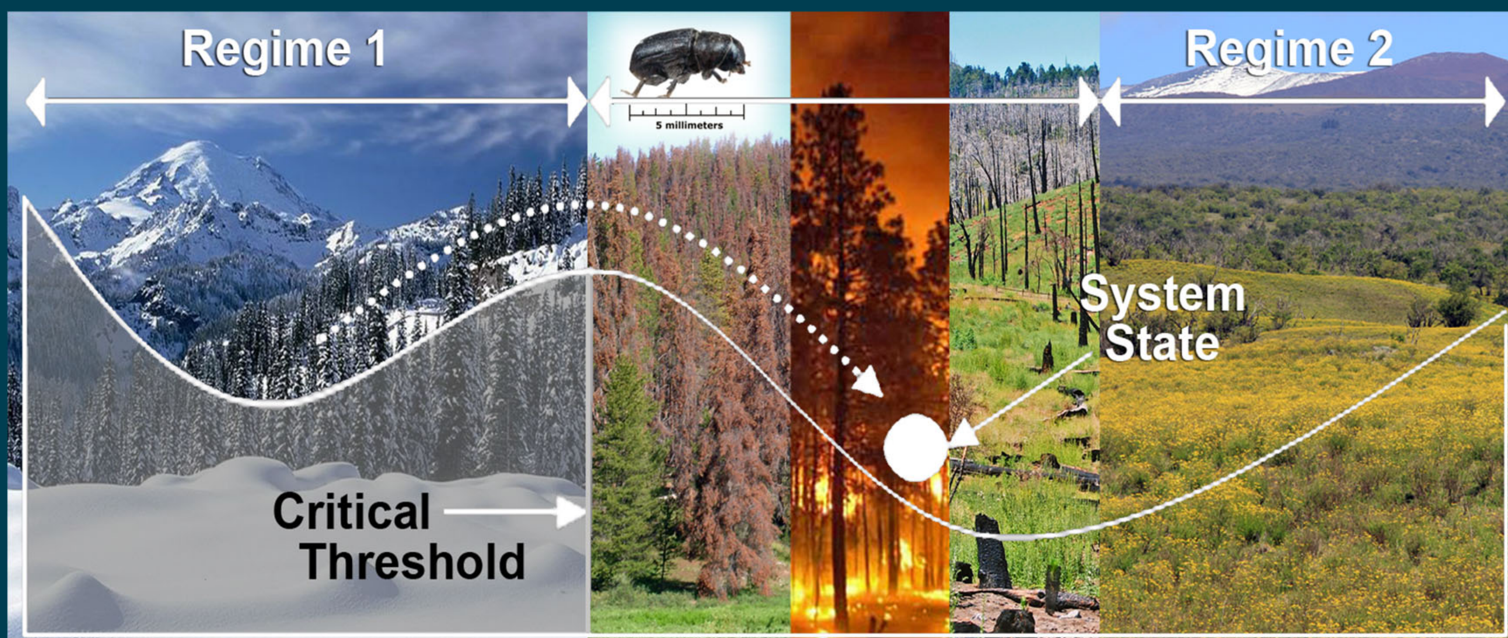


Image source: Bureau of Reclamation

Low Resilience

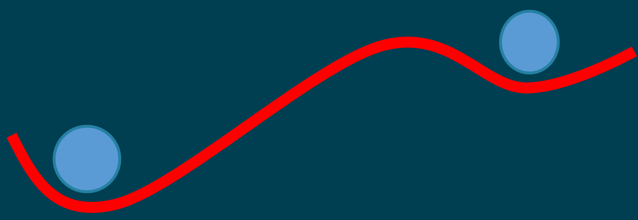
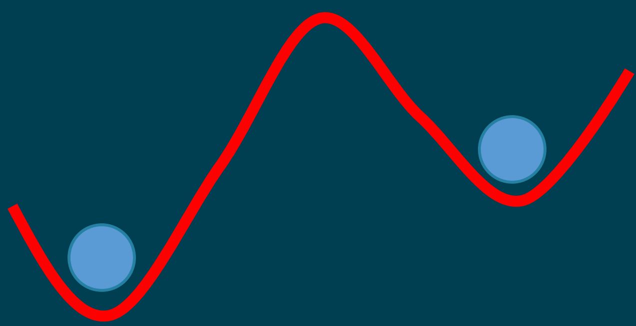


Photo by: Karen MacClune



High Resilience

This system is more likely to maintain its structure and function after a disturbance, but if it crosses a threshold, it's hard to go back to the previous system.

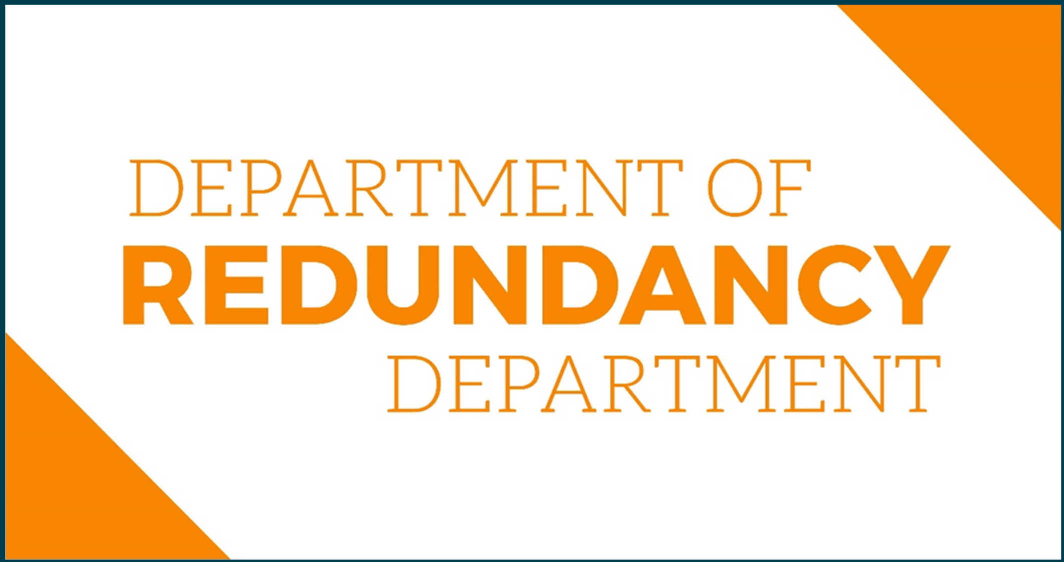
Characteristics of Resilient Systems

- Ability to Fail Safely

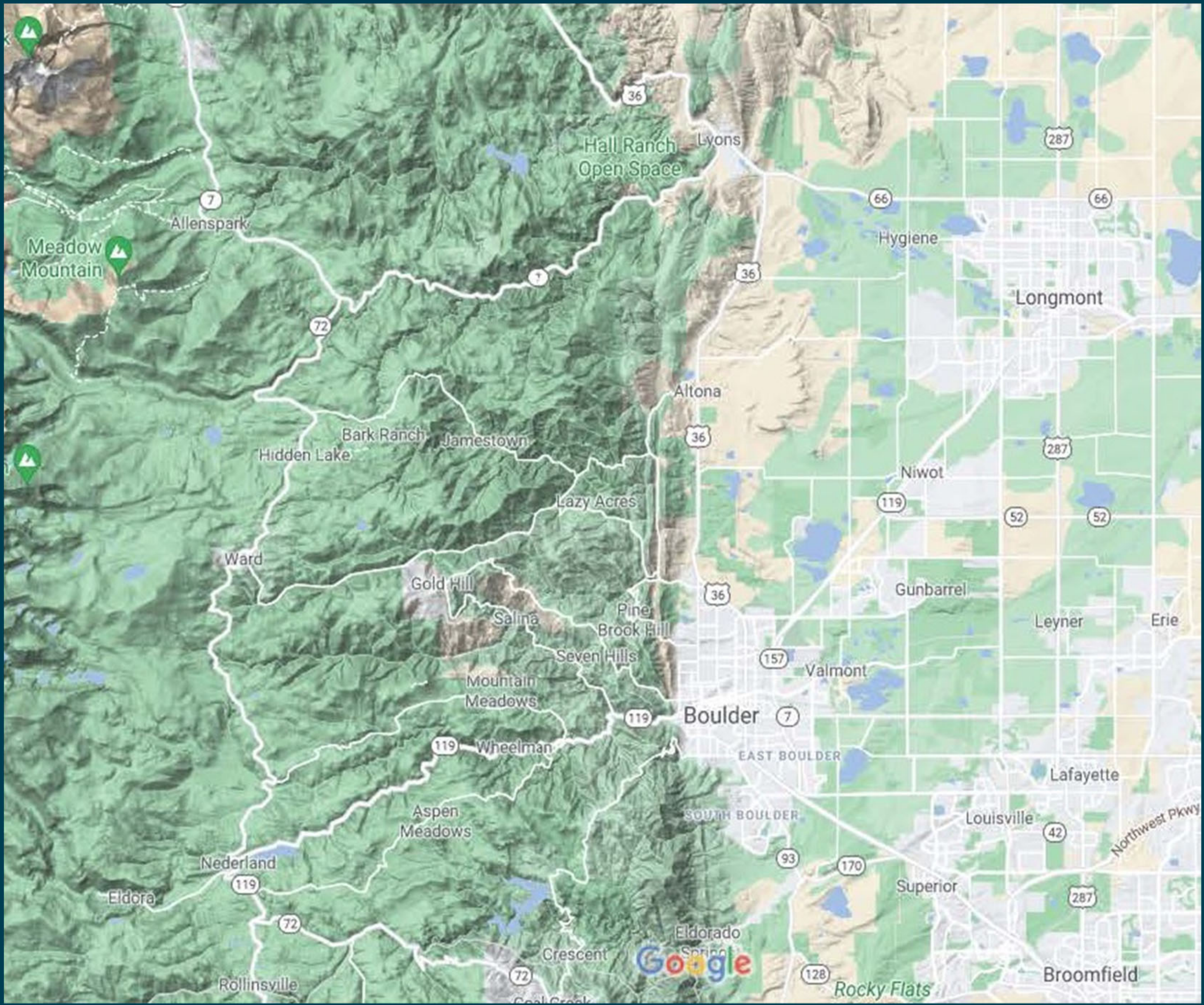
Credit: Beyond Resilience; I-S-E-T International, 2015

Characteristics of Resilient Systems

- Redundancy

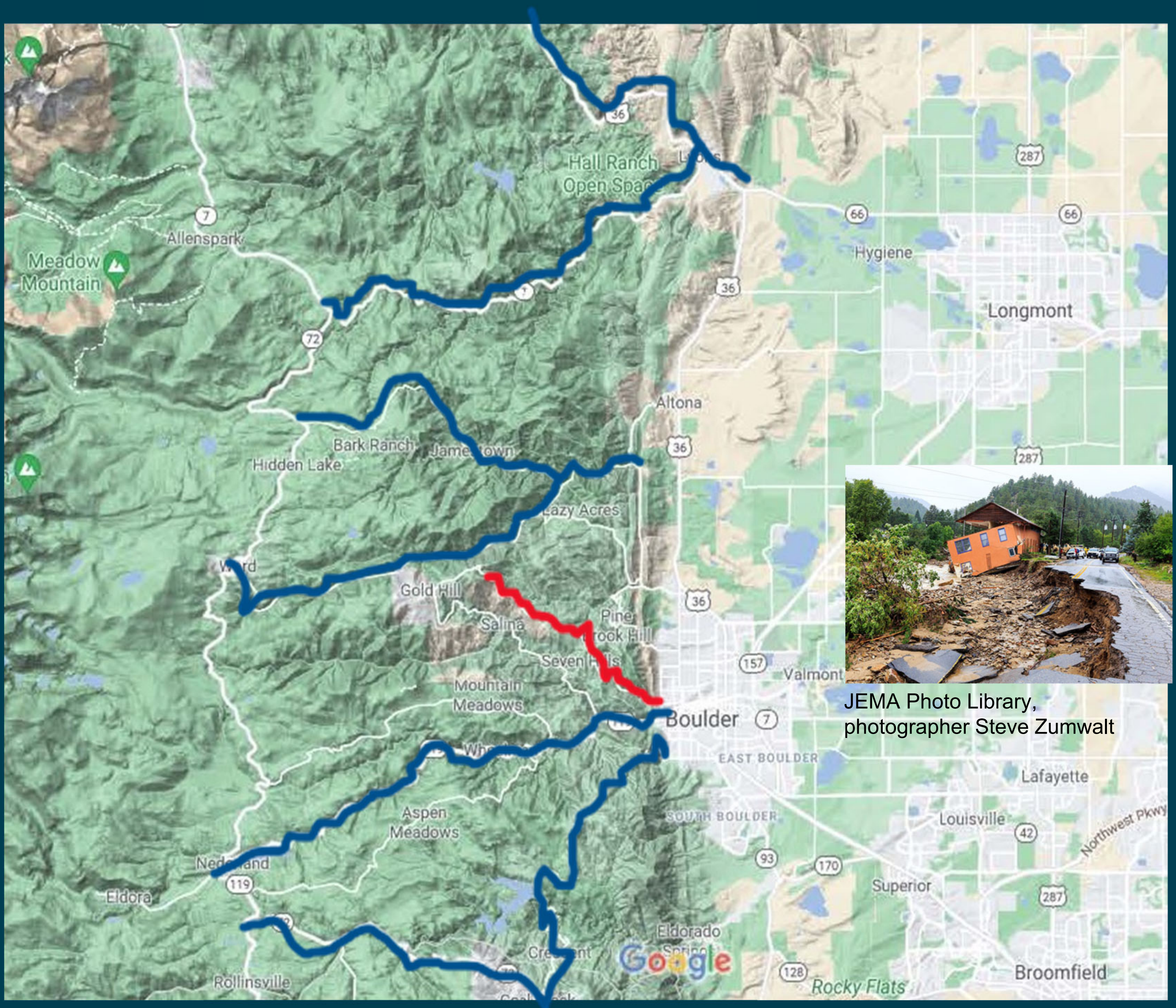


Credit: Beyond Resilience; I-S-E-T International, 2015



Transportation network Redundancy

2013 floods, Boulder Colorado



JEMA Photo Library,
photographer Steve Zumwalt

Flood Failure
Mode

Characteristics of Resilient Systems

- Diversity

Credit: Beyond Resilience; I-S-E-T International, 2015

Characteristics of Resilient Systems

- Modularity

Wikipedia commons hyperloop
1024px-Na19-Apr-Hyperloop.jpg

Credit: Beyond Resilience; I-S-E-T International, 2015

Characteristics of Resilient Systems

- Flexibility

Credit: Beyond Resilience; I-S-E-T International, 2015

Key Takeways

1. Humans and their infrastructure are part of highly interconnected socio-ecological systems.
2. In a constantly changing climate, a key concept underlying engineering design – stationarity, or the concept of "normal" – is becoming less viable.
3. As we experience more weather extremes, systems that would have had adequate safety factors in the past will fail more frequently. We want to make sure those failures are safe, and don't lead to catastrophic impacts and loss of life.
4. Rather than just make our structures more resistant to ever-changing conditions, we need to build for system resilience through redundancy, modularity, flexibility, and diversity and planning for graceful failure.

Thanks for your attention!

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