



Floods and Rivers in a Non-stationary World

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Colorado Floods: Response and Planning for the Next One

- Assessing Risk in a Non-Stationary World
- Structural and Non-Structural Adaptation
- Rebuilding for the future



Times-Call



Times-Call



Times-Call

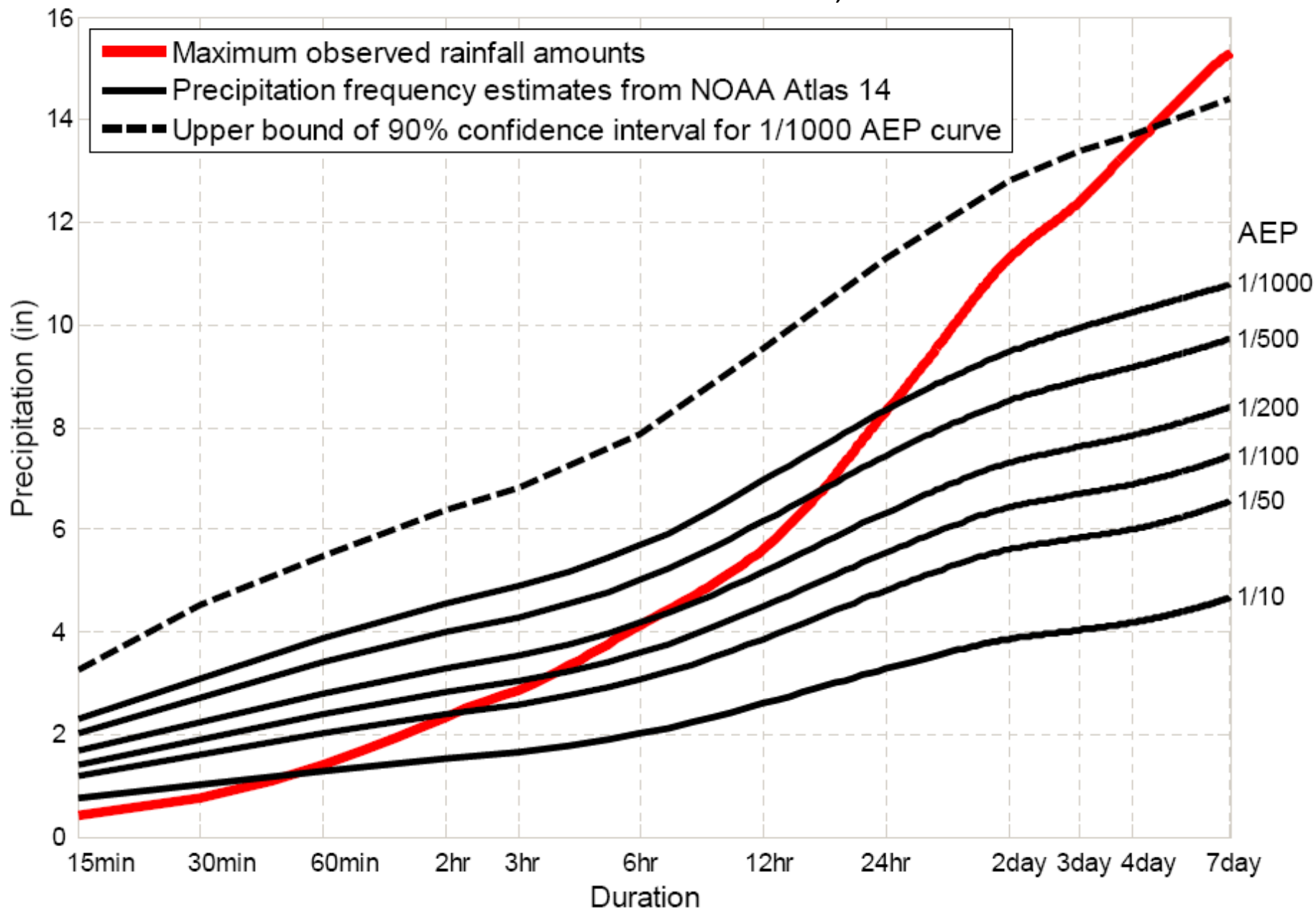
Calculating Risk

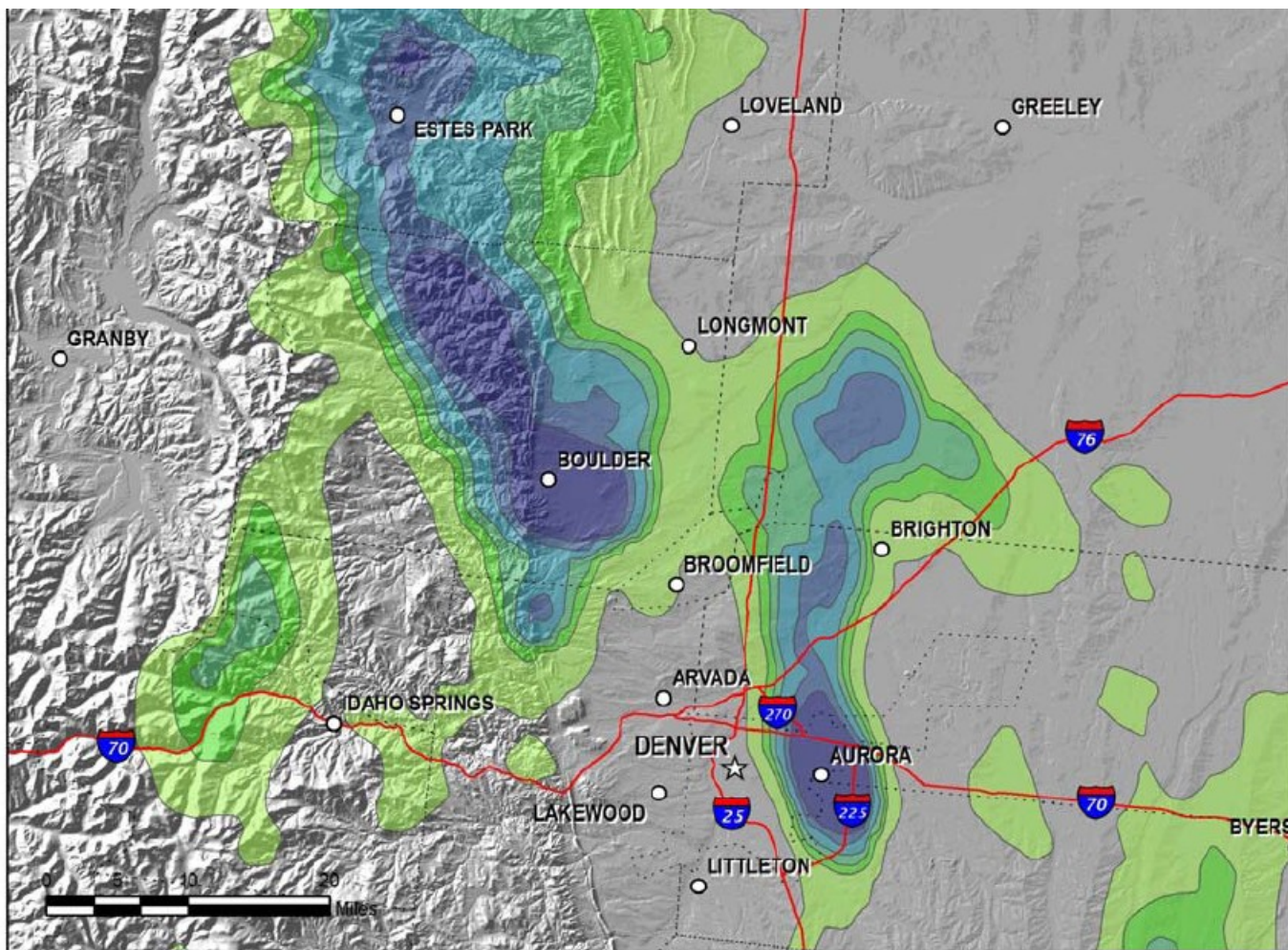
- Classic Definition:

$$\text{Risk} = \text{Probability} * \text{Consequence}$$

- Probability of an event with a given severity may be changing
- The consequence of the event is only increasing with development

NOAA – NWS Data From Boulder, CO





Colorado Flood Event, 9-16 September 2013
Annual Exceedance Probabilities (AEPs) for Worst Case 24-hour Rainfall

Hydrometeorological Design Studies Center
 Office of Hydrologic Development, National Weather Service
 National Oceanic and Atmospheric Administration

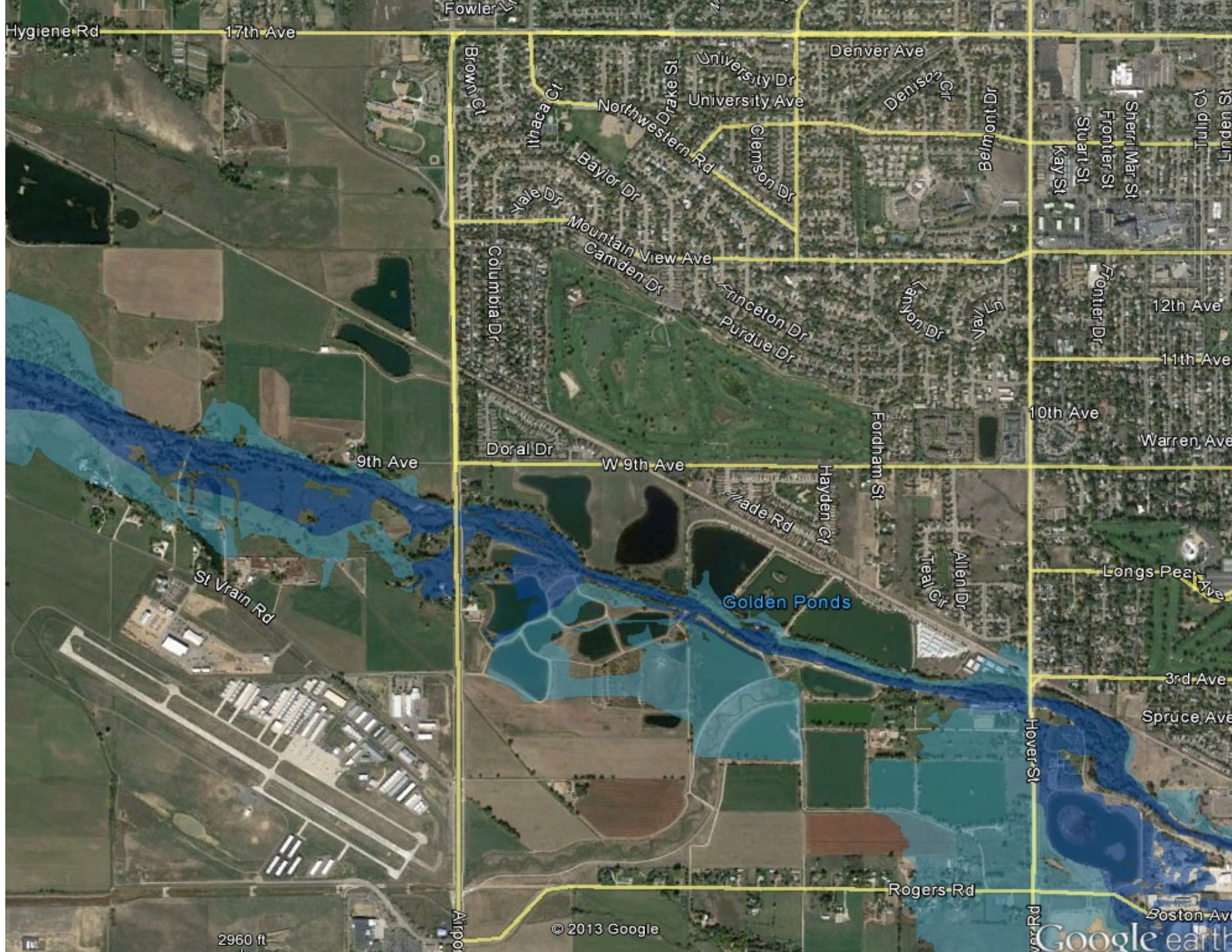
<http://www.nws.noaa.gov/ohd/hdsc/>

Created 17 September 2013

Precipitation frequency estimates are from NOAA Atlas 14, Volume 8, Version 2.
 Rainfall values come from 6-hour multi-sensor data.

-  > 1/10
-  1/50 - 1/10
-  1/100 - 1/50
-  1/200 - 1/100
-  1/500 - 1/200
-  1/1000 - 1/500
-  < 1/1000





Hygiene Rd 17th Ave

Fowler
Brown Ct
Ithaca Ct
Northwestern Rd
University Dr
University Ave
Denver Ave
Denison Ct
Belmont Dr
Sherri Mar St
Frontier St
Stuart St
Kay St

Yale Dr
Baylor Dr
Mountain View Ave
Camden Dr
Princeton Dr
Purdue Dr
Forsyth Dr
Valley Ln
Frontier Dr
12th Ave
11th Ave
10th Ave
Warren Ave

9th Ave
Doral Dr
W 9th Ave
Fordham St
Hayden Ct
Made Rd
Teal Ct
Allen Dr
Longs Peak Ave
3rd Ave
Spruce Ave

St Vrain Rd
Rogers Rd
Hover St
Boston Ave
2960 ft
© 2013 Google
Golden Ponds



Flooding along St. Vrain River near Airport Road

Longmont, Colorado
40.172642N 105.148429W



St. Vrain river channel

Twin Peaks Golf Course

approximately
1 mile

West 9th Avenue

Longmont Vance
Brand Municipal
Airport

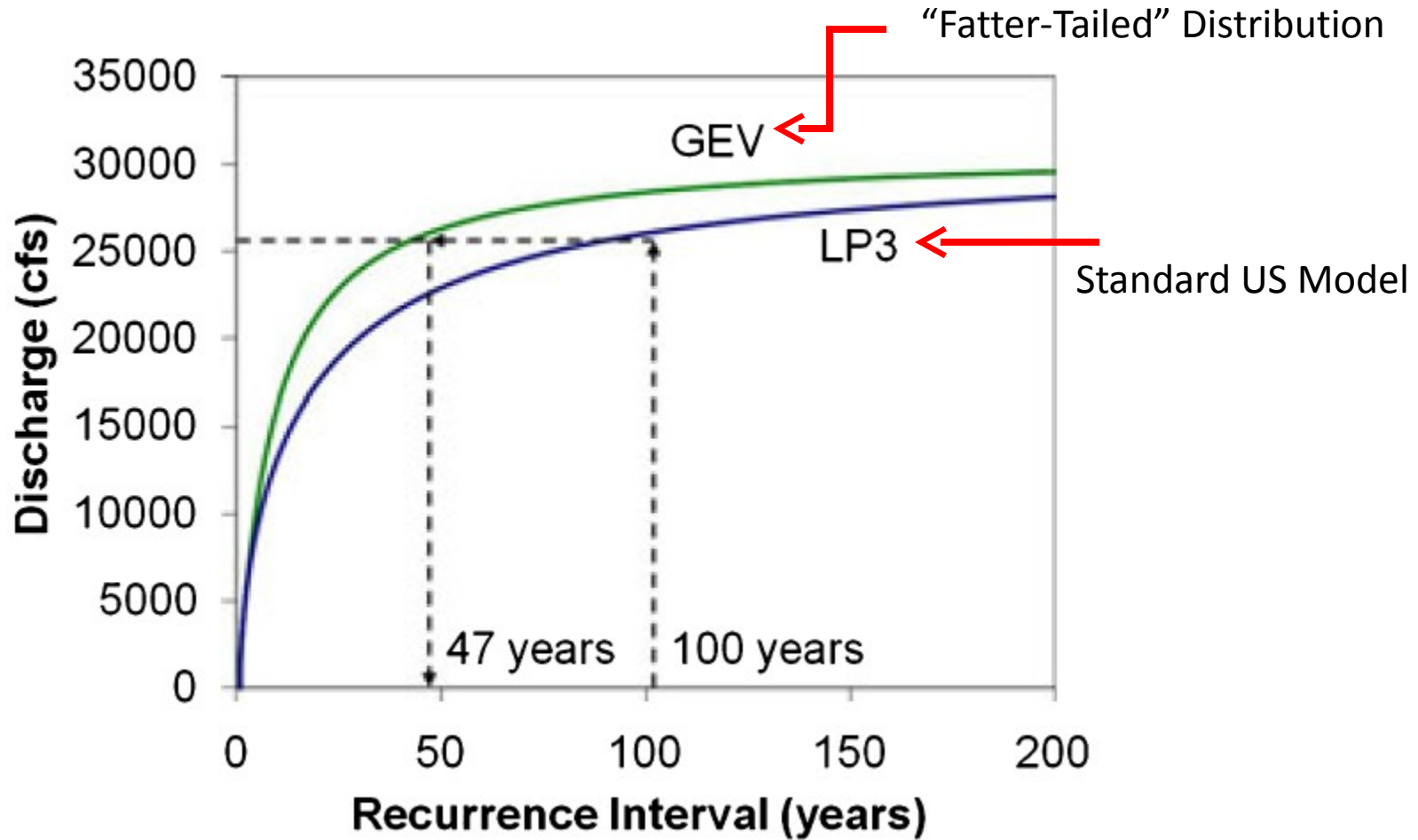
Airport Road

Hover Street

Recurrence Intervals for Floods

- 100 yr flood has a 1 % chance of occurring in a given year, and a 100% chance of occurring in 100 years.
- Estimates of the magnitude of the 50 yr, 100 yr, 500 yr floods all depend on the previous record.
 - With each new flood, that record changes
 - With environmental change (climate and land use) the record may not be stationary
- Dependent on Statistical Assumptions
 - Which Probability Distribution Function (PDF) best represents extreme events?

Recurrence Interval for Floods



Non-Stationary Flood Record

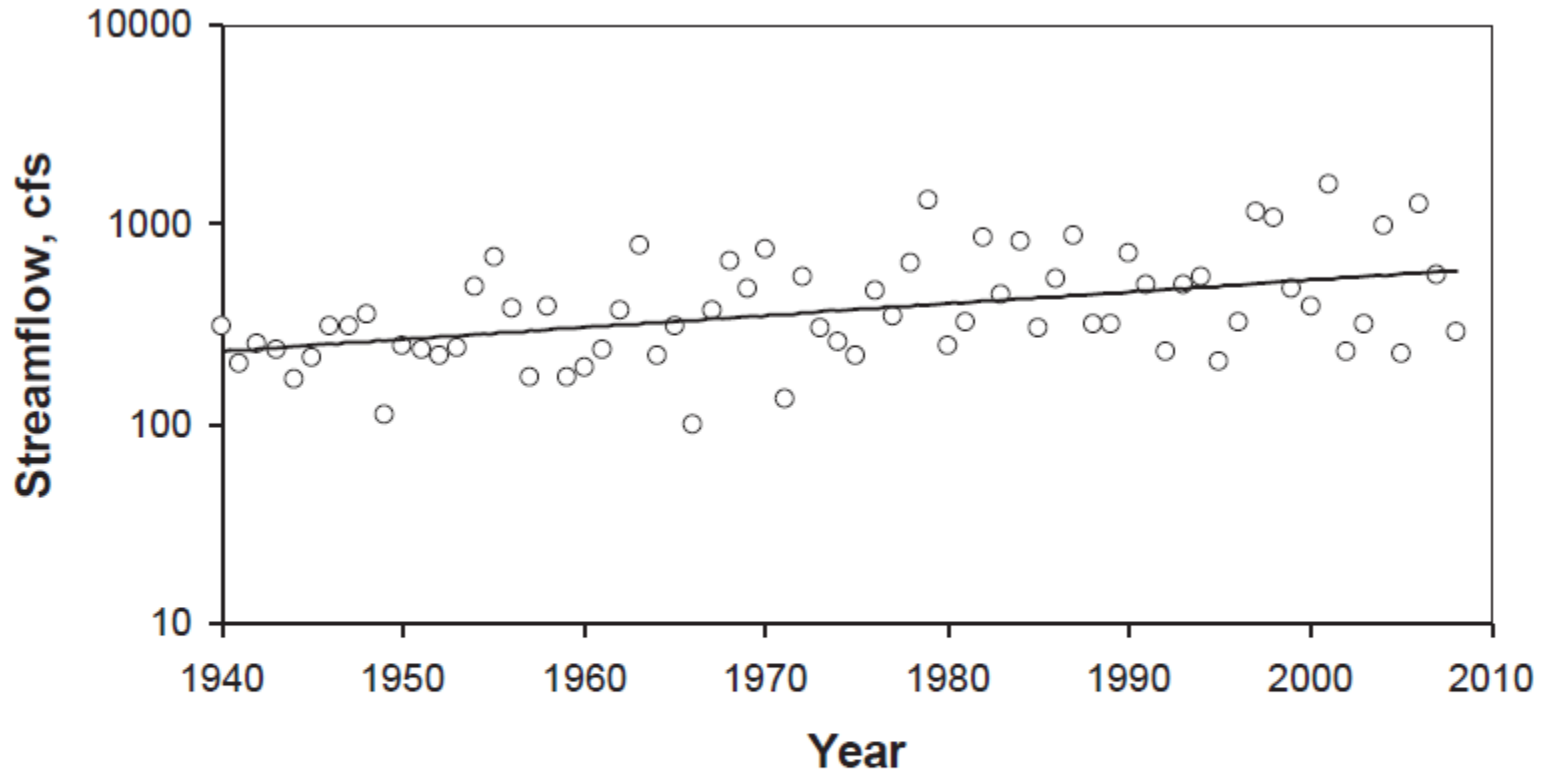


FIGURE 2. Example of Trend in the Logarithms of the Annual Maximum Streamflows for the Aberjona River in Massachusetts ($\hat{\beta} = 0.0146$).

Increasing Magnitude of Floods

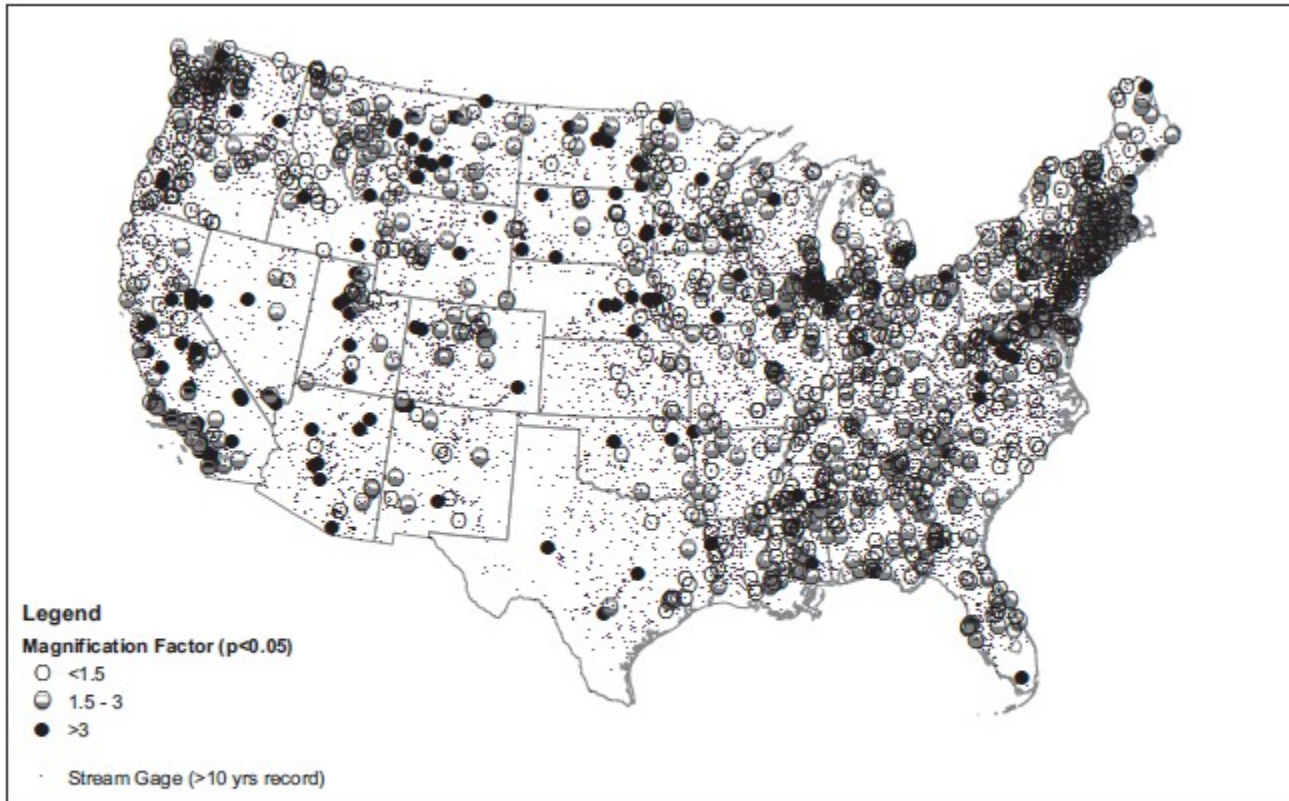
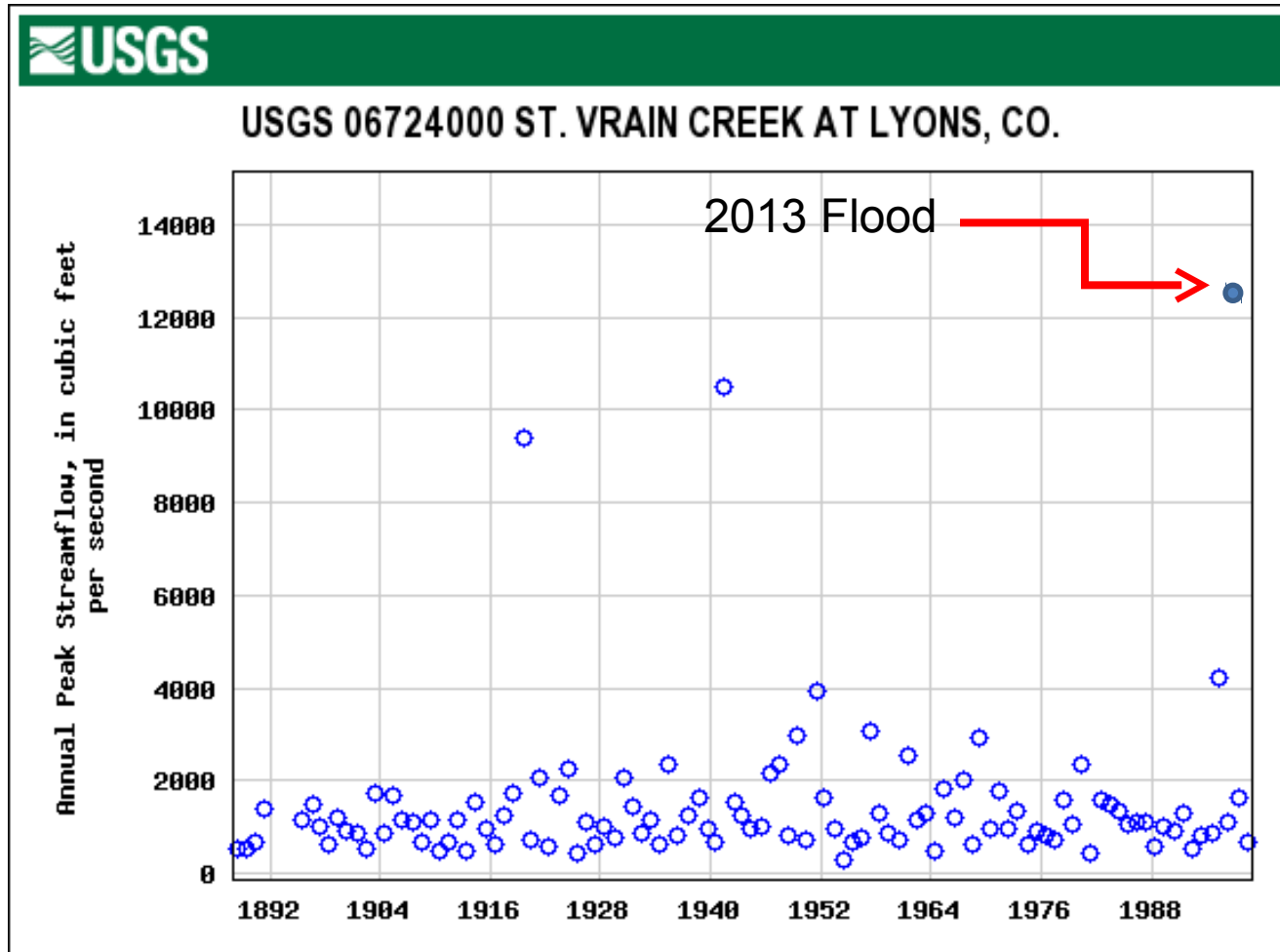


FIGURE 3. Location of 14,893 Stations in the “No Regulation” Group and the Decadal Magnification Factors Associated With the 1,642 (11%) Stations Which Exhibited Positive Trends.

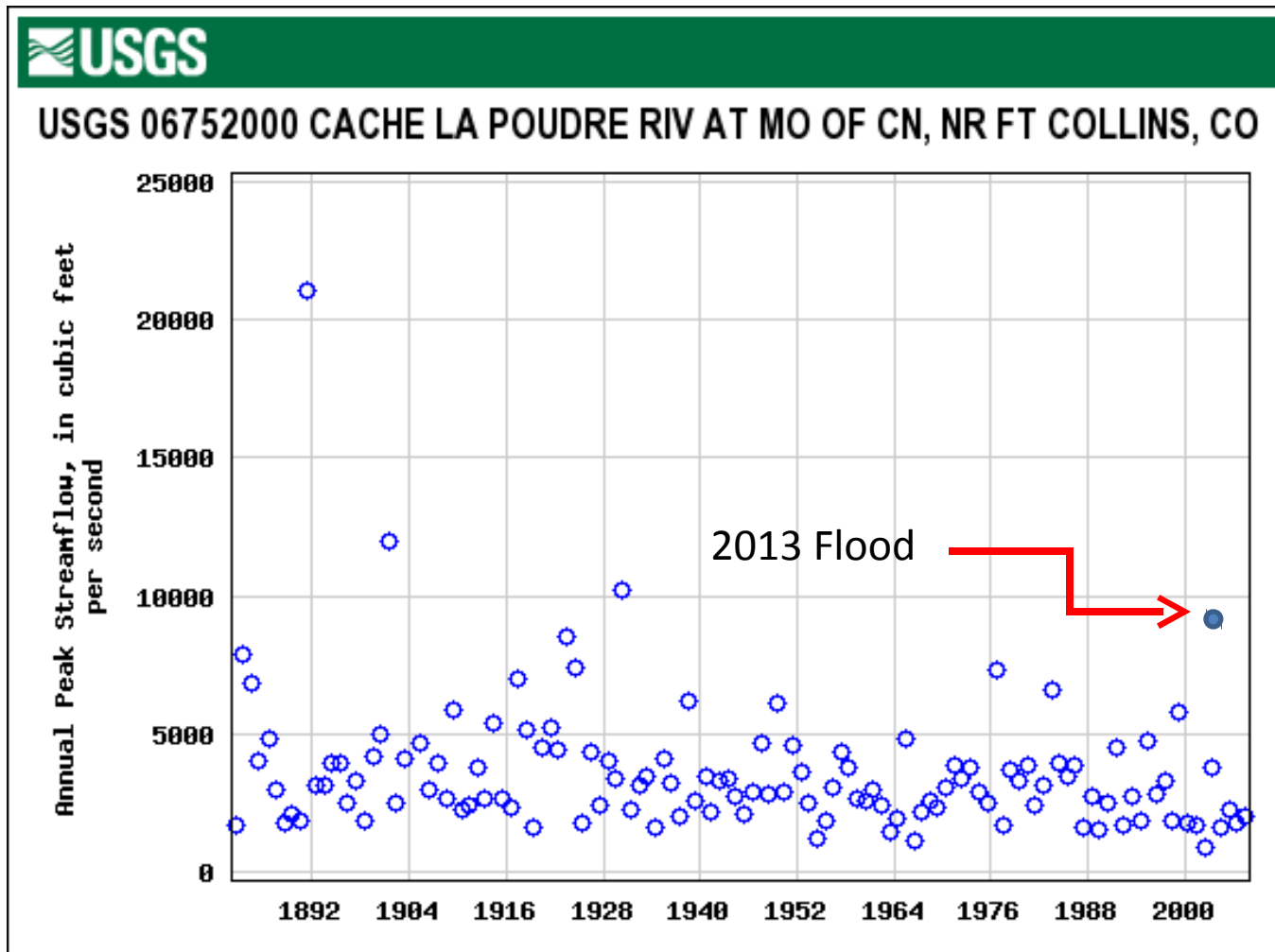
Nonstationarity in Front Range Record?

Flood



Nonstationarity in Front Range Record?

Flood



Is this the new norm in Colorado?



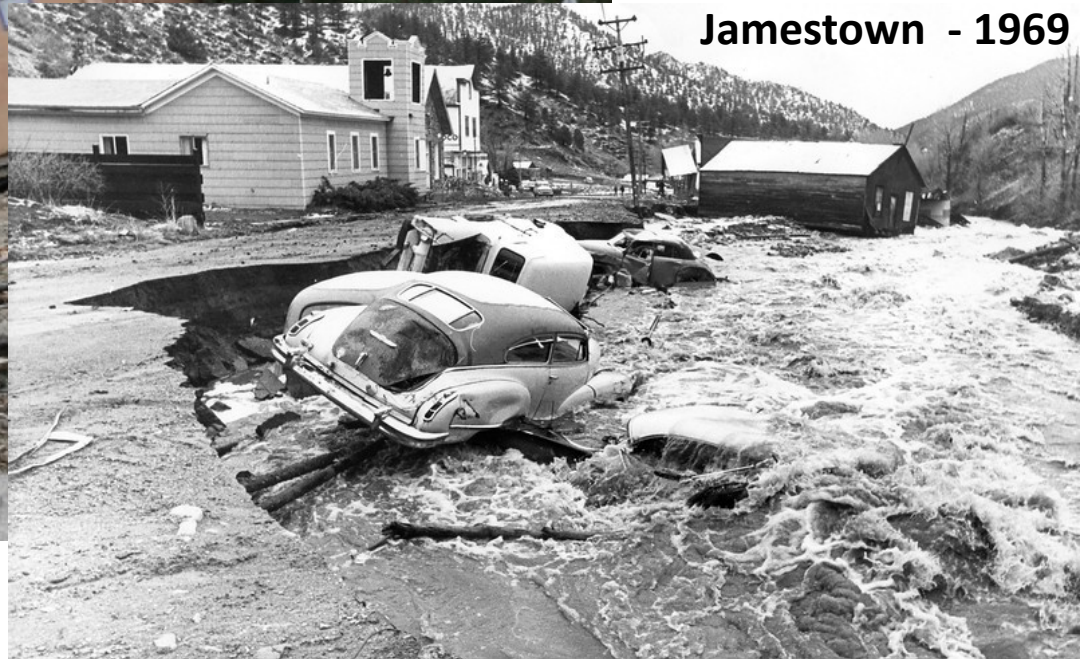
Jamestown - 2013

Is this the new norm in Colorado?

- I would suggest that it **is** the norm



Jamestown - 1969



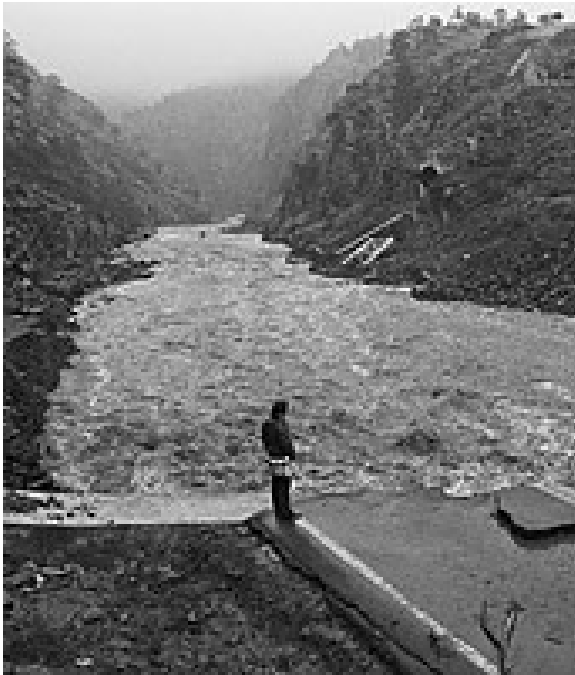
Jamestown - 2013

The new norm? Or just normal...



Big Thompson - 1976

The new norm? Or just normal...



Big Thompson - 1976



Big Thompson - 2013

Calculating Risk

- Classic Definition:

$$\text{Risk} = \text{Probability} * \text{Consequence}$$

- Probability of an event with a given severity may be changing
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Consequences

- A function of what we build and where we build.





Times-Call



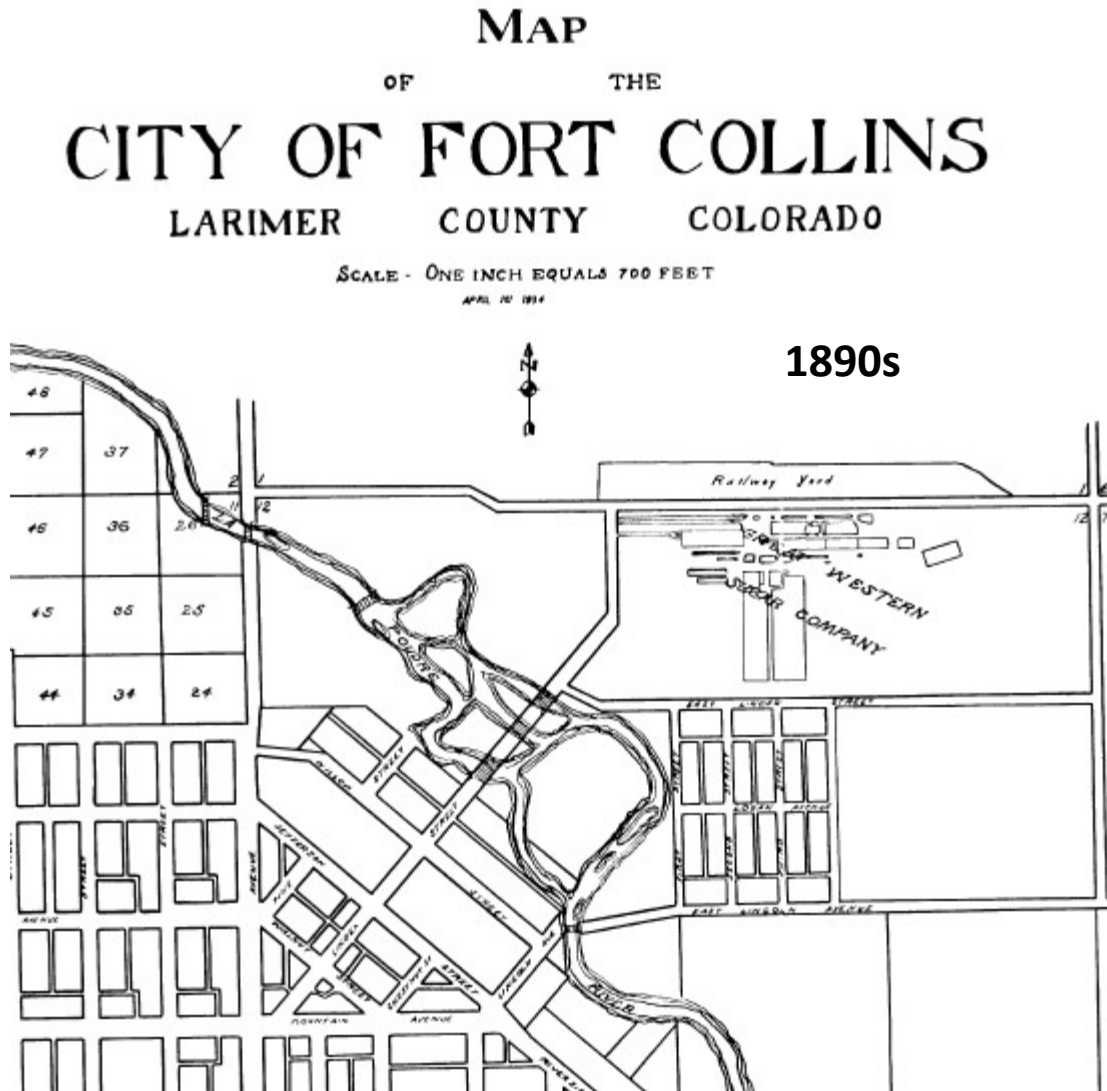
Structural Lessons from Vermont

- Design for the future: Changing FEMA's reimbursement rules



<http://www.leahy.senate.gov/press/fema-agrees-to-funding-for-flood-resistant-culverts>

Non-structural Lessons



A wide, rocky river channel with a large gravel bar in the middle, surrounded by trees and hills under a blue sky. The river is brown and turbulent, flowing through a rocky bed. The banks are covered in green trees and shrubs. In the background, there are hills and a clear blue sky.

These rivers need space

Build less, and less vulnerably in the floodplain

To what future do we design for?

- We will never accurately quantify risk.
- Do we just re-build stronger? Stouter?
- Can we build resiliency into our human-river interfaces (aka the floodplain)?

Spectrum of Responses

Build it Stout
Never Doubt

Flexible Structures &
Non-Structural
Mitigation



Calculating Risk

- Engineering Definition: $R = 1 - (1 - p)^n$
 - For RI of 100 yr, $p = 0.01$ in a given year
 - $n = \textit{number of years}$
 - Probability of five heads in a row = $(1/2)^5$
 - BUT... p may be changing: $p(t)$

$$R(t) = 1 - \prod_{t=1}^n (1 - p_t)$$

Salas et al. 2013