Dams as Systems

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(FERC)

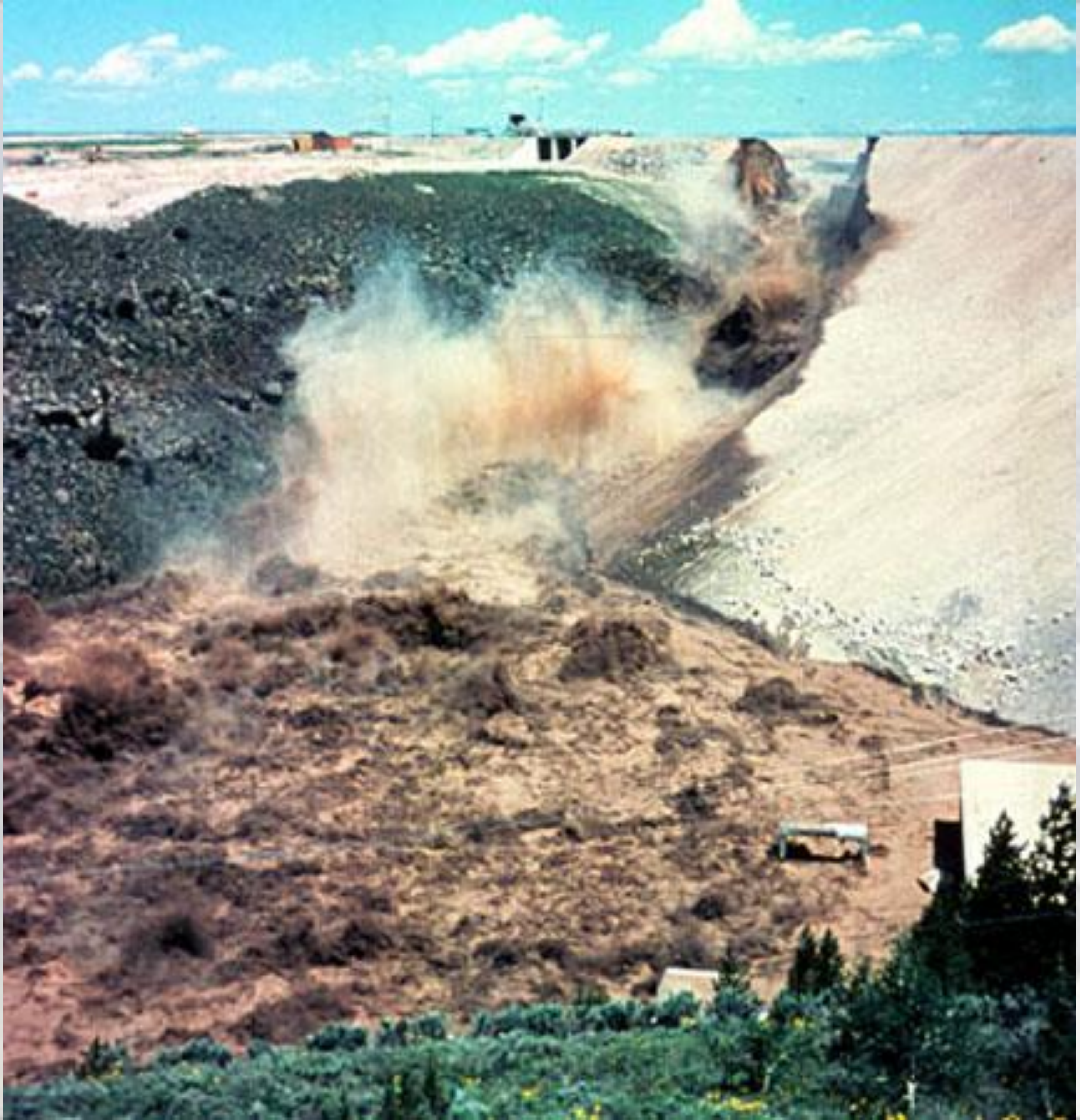
FERC

- >2,500 jurisdictional dams
  - 770 feet to 0.5 feet high
- Five Regions
  - Atlanta, Chicago, New York, Portland, San Francisco
- ~120 staff

A contemporary illustration of the broken South Fork Dam from Harper's Weekly.

Potential Energy

- A major dam like Grand Coulee or Oroville can store more than 100 times the energy released by the atomic bomb dropped on Hiroshima.
- The Sayano-Shushenskaya dam in Russia stores nearly 800 times the energy of the Hiroshima bomb.




WANTED
DAMN ENGINEER
DEAD OR ALIVE

Pre-Teton Dam (1976)

- **Strictly standards based**
- **Three loading conditions**
  - Static (normal)
  - Flood (unusual)
  - Seismic (extreme)
- **Defined minimum factor of safety**
  - Static (3.0*)
  - Flood (2.0*)
  - Seismic (1.3*)

* from FERC Engineering Guidelines, Chapter 3, 2002

Federal Guidelines for Dam Safety

- **Three categories of dams**
  - High Hazard Potential
    - Dams where failure or mis-operation will probably cause loss of human life. (one or more)
  - Significant Hazard Potential
    - Dams where failure or mis-operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns.
  - Low Hazard Potential
    - Dams where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses.

Post Teton

- Reclamation implemented a risk-based dam safety program
  - For the most part still only worried about the three loading conditions but included “piping”, the cause of the Teton failure
- Post Katrina, USACE is developing a risk-based program.
- Most states and the FERC are still in a deterministic world
  - FERC is in the process of developing a risk-informed approach


DEC 15 2005

Taum Sauk Report

- It is our conclusion that the **root cause** of "***the uncontrolled, rapid release of water from the Upper Reservoir"*** was the breach of the Rockfill Dike—a stability failure at the northwest corner of the Reservoir brought on by a rapid increase in the pore pressure at the Dike/foundation interface, stemming from the original design and construction which was flawed.

	Phase						
	Design	Initial Construction	Operation State 1 (1963-1990)	Operation State 2 (1990s)	"Remediation" (2004)	Operation State 3	Failure
Design	Location limited surface area of reservoir. Needed storage volume required 10' high parapet wall with 8' of water stored against wall Assumed clean rockfill No spillway included Emergency shut-off system includes high water alarm (alarm in PH) and high-high alarm (shuts off pumps at 1' remaining freeboard) Water level monitoring equipment placed near "morning glory" inlet-outlet works (shortest distance to PH)	Dirty Rockfill at best, rocky earthfill in some areas Instrumentation firmly fastened to concrete upstream face	Excessive settlement (~1' in 4.5 years) Water flow causes vortex development at inlet-outlet	Continuing settlement, up to ~2', results in cracking of concrete face slab and mis-alignment of parapet wall resulting in excessive seepage through dam	Geomembrane liner installed on upstream face to reduce seepage Penetration of liner not allowed. Instruments supported from top of dam to bottom by "suspension" system. Turnbuckle nuts not locked PVC conduit houses instruments Emergency shut-off system installed at "design" elevations (ignoring the 2' of settlement that had taken place)	Vibration from vortices loosens nuts on instrument support system PVC conduit bends due to vortices thereby giving erroneous water levels	On December 14, 2005, at about 0510 the dam overtopped during a pumping operation. The water level alarms did not sound because both alarms had to trigger to sound an alarm (after being rewired in parallel) and the high-high water alarm was about two feet higher than the lowest point on the wall (due to ignoring the settlement). Due to the lack of a spillway the parapet wall overtops. The water falls 10' onto the earthen embankment rapidly eroding the material and undermining the parapet wall. The wall overturns unleashing a 10' wall of water that rapidly erodes the remaining embankment. It took only about 12 minutes to drain the reservoir. Peak outflow was estimated at 289,000 cfs (more than the Mississippi River above its confluence with the Ohio River). Luckily a downstream park and campground was empty due the time of year and 5 people in a house survived even though the house was swept from its foundation.
Operation	1-2 pump cycles per week One unit used to pump		Experienced local operating staff Operations staff adjust water level controls to account for settlement	Profit driven operation Remote operation Pump-turbines replaced, 25% greater capacity (1999) Multiple pump cycles/day Two unit pumping		High water and high-high water level instruments re-wired in parallel to eliminate "false" readings Operators reprogram computer to "account" for deflection of conduits Overtopping events on Sept. 25 and 27, 2005	
Organization	No person designated to assure dam safety		Adjustment of water level controls not documents Arrogance - (letter to a FPC engineer) **"I told him there would be no structural damage if the pumps failed to shut down"**. (1968)	Retirement of experienced staff Loss of institutional knowledge No one considers impact of changed operation		Repair to water level conduits delayed until future planned outage to minimize impact on generation	
Societal Decisions	Rate of Return cost structure			Deregulation of electric industry (~1997). No guaranteed rate of return			

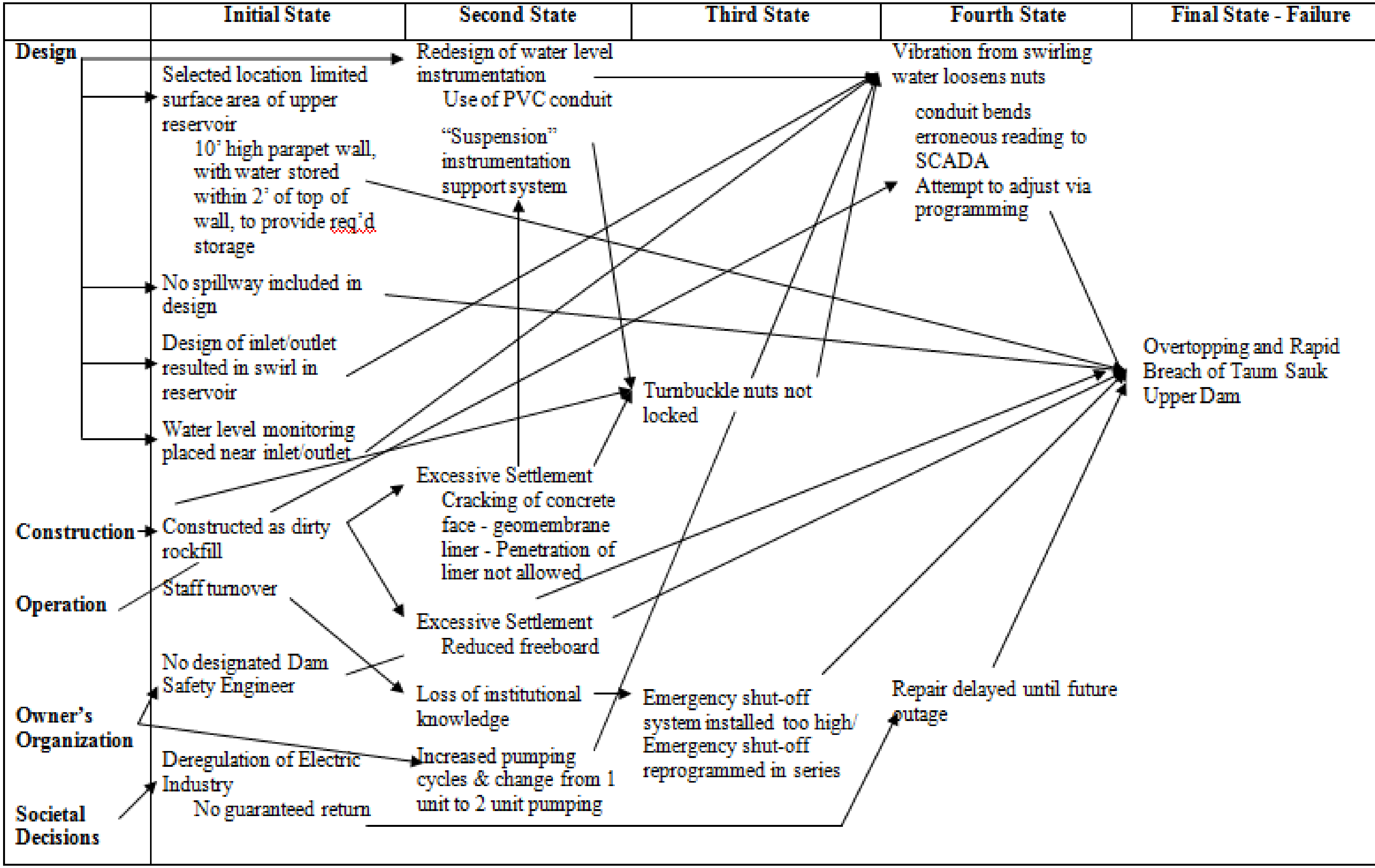
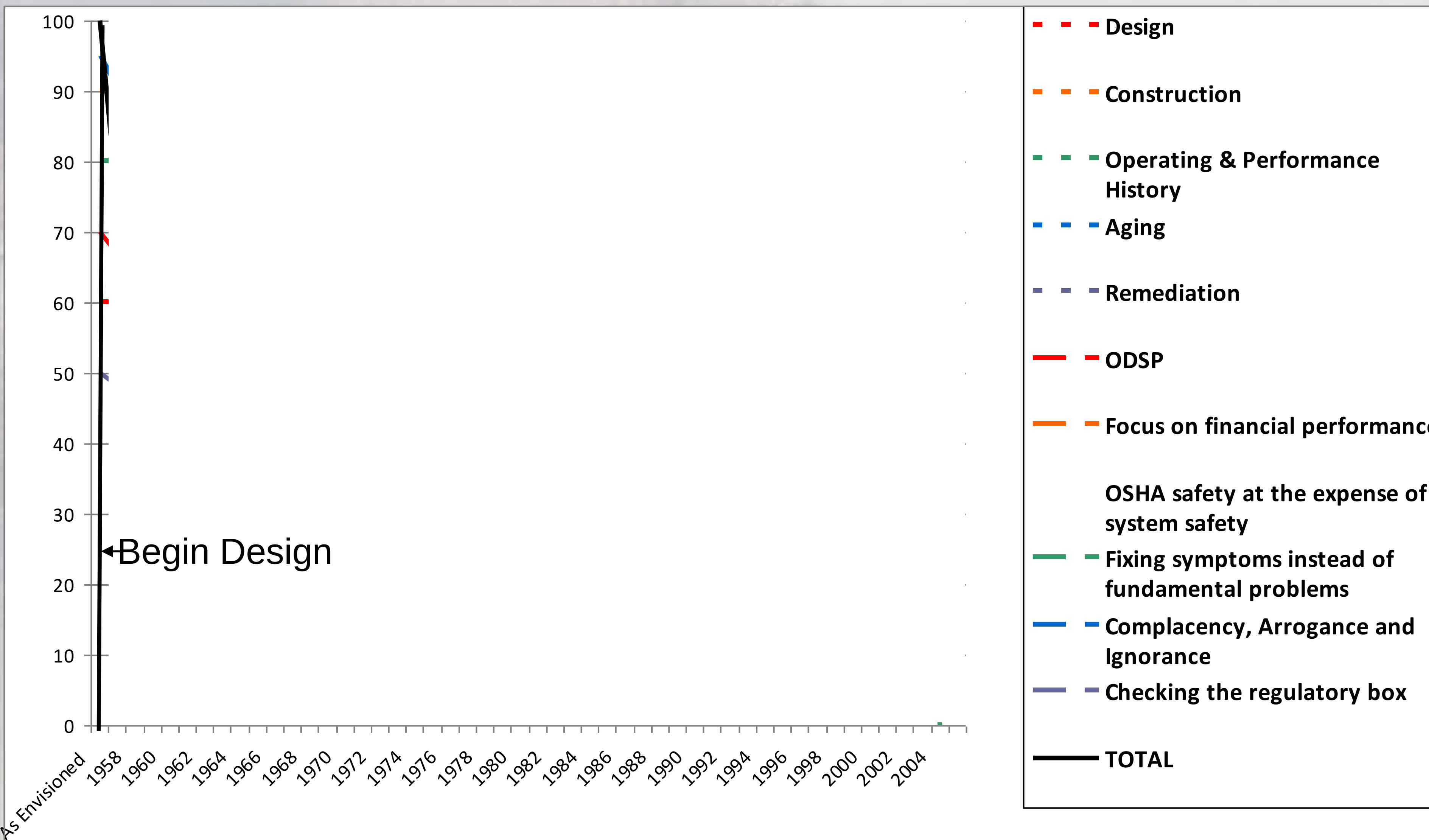
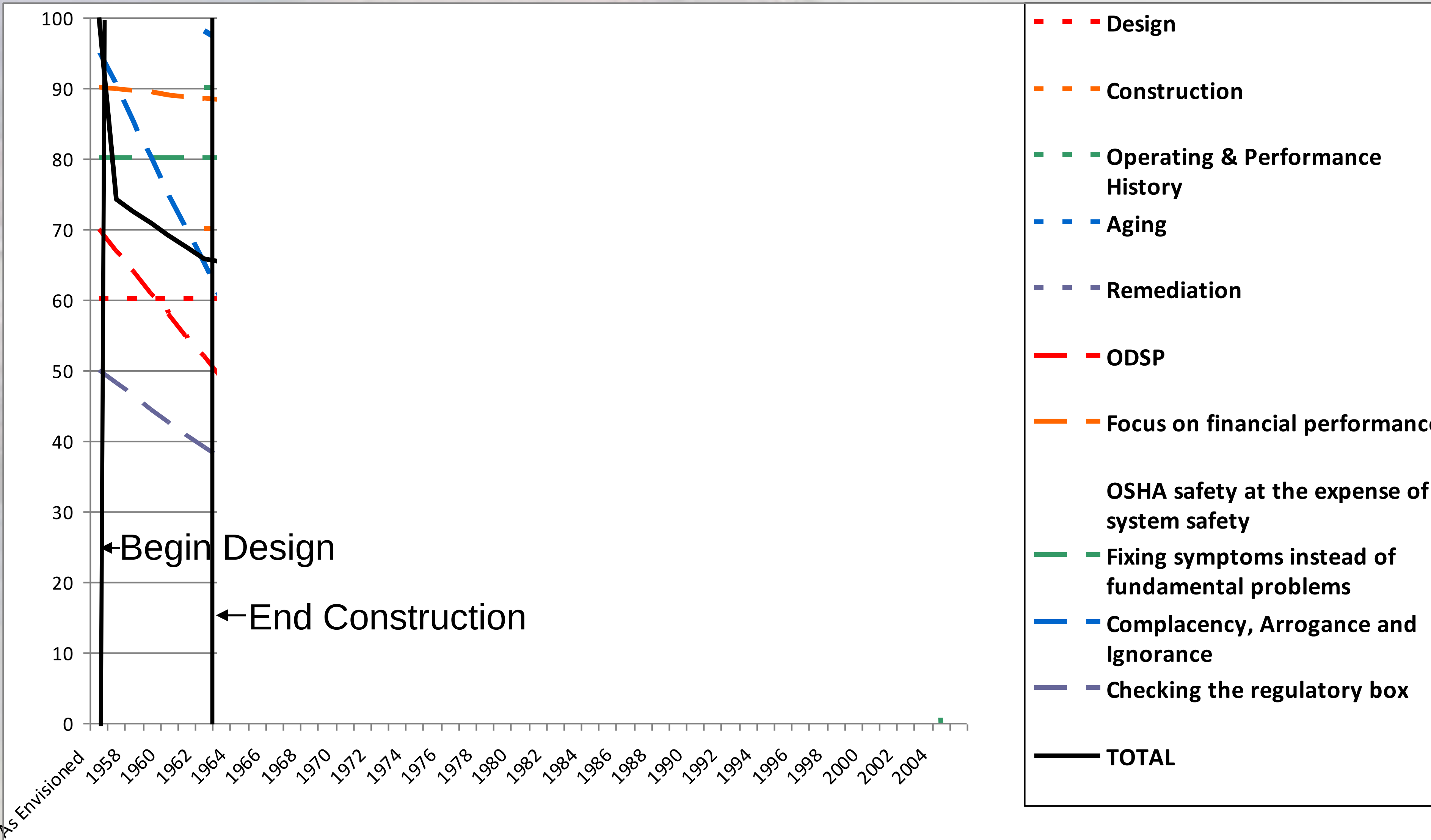


Figure 2 – Interaction Flow Chart – Taum Sauk Upper Dam Failure

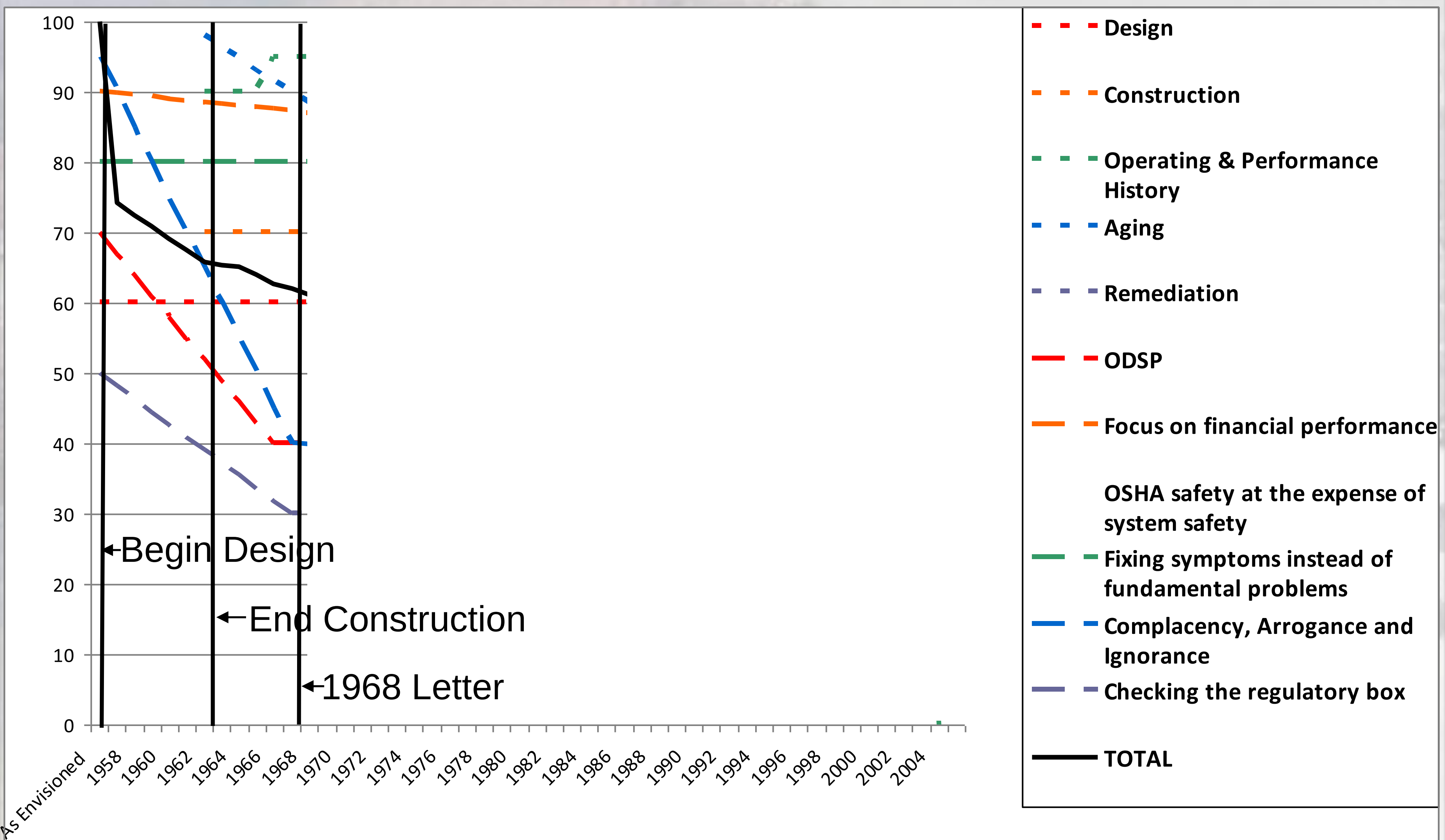
The March to Failure



The March to Failure



The March to Failure



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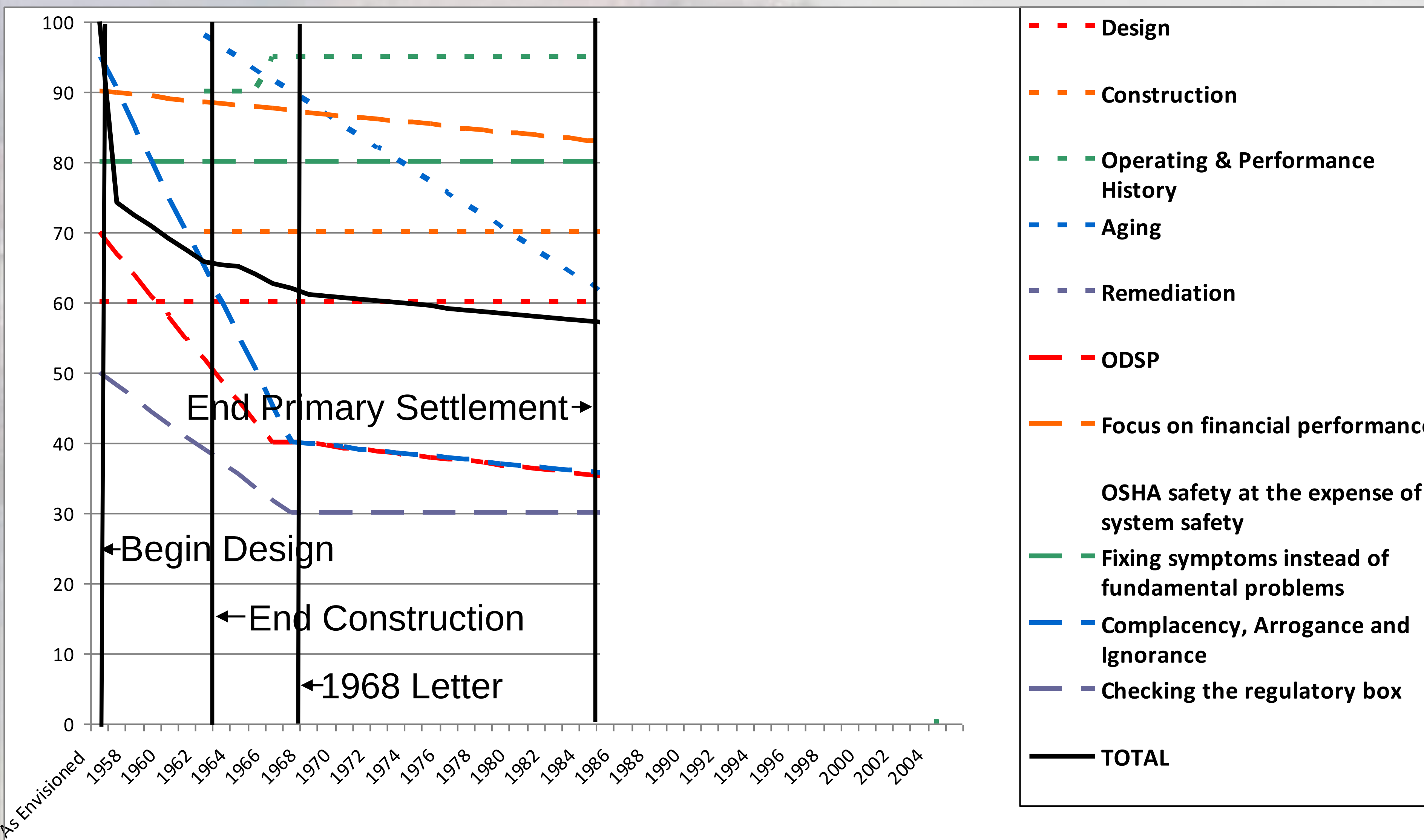

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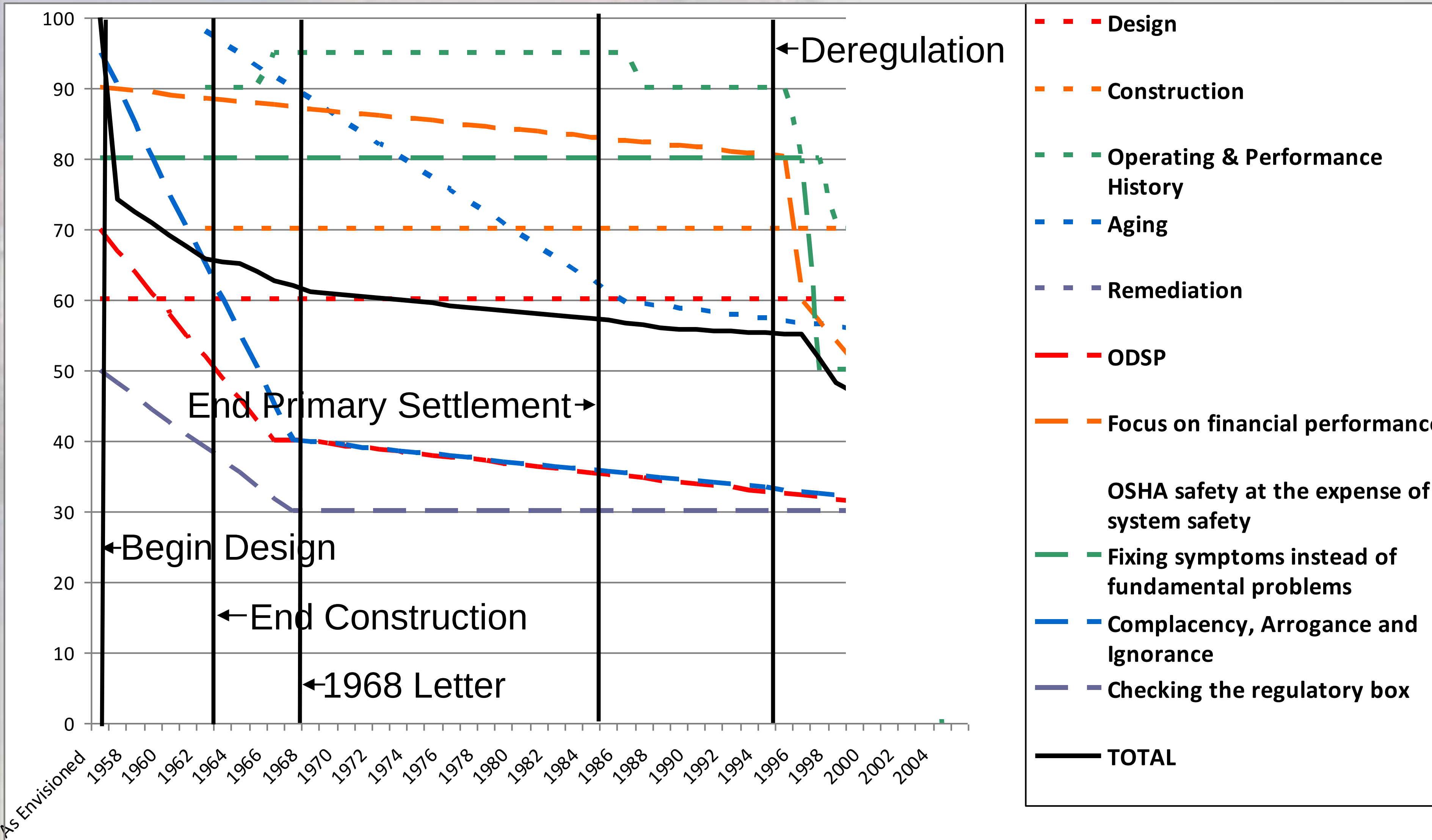

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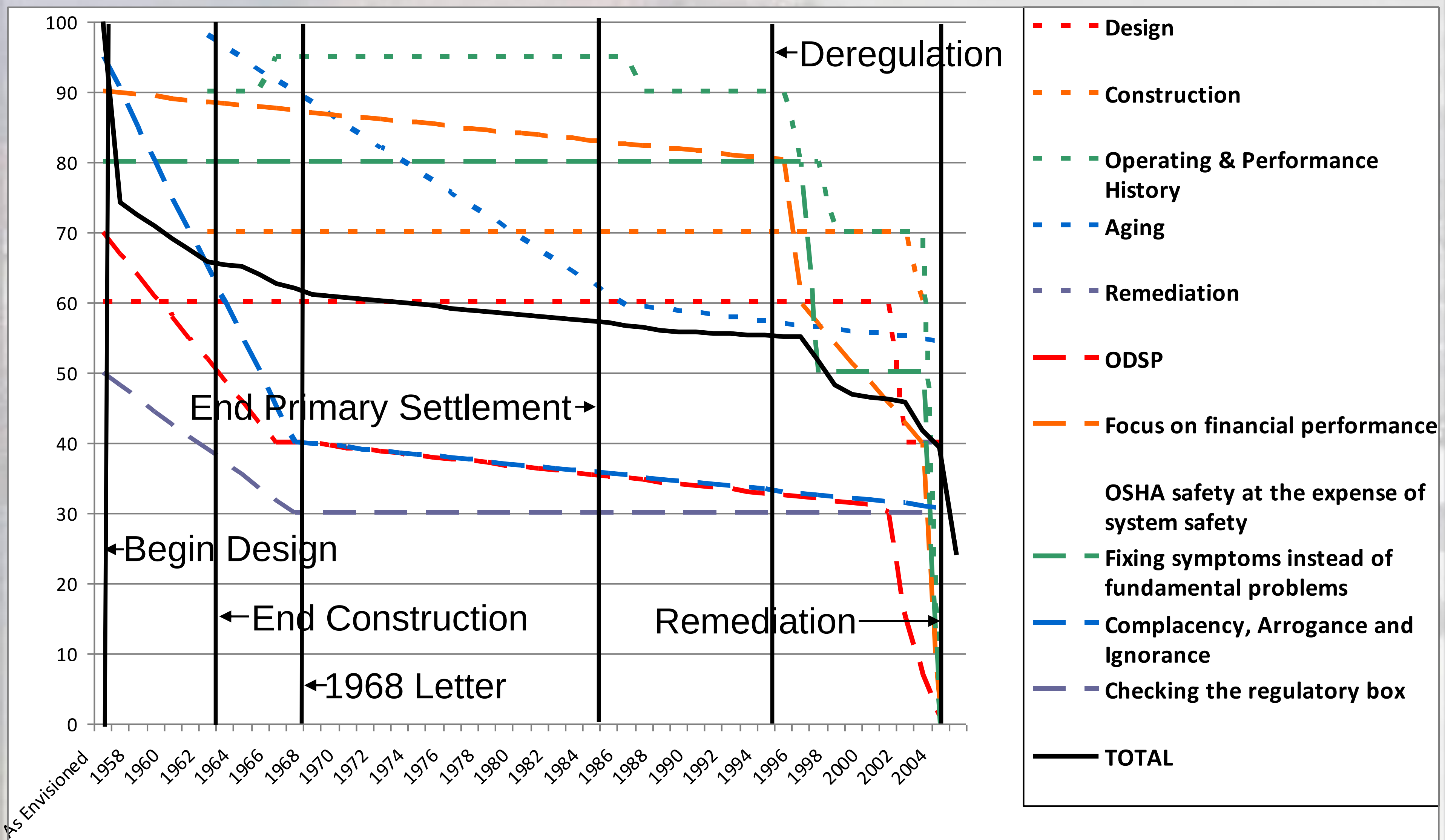

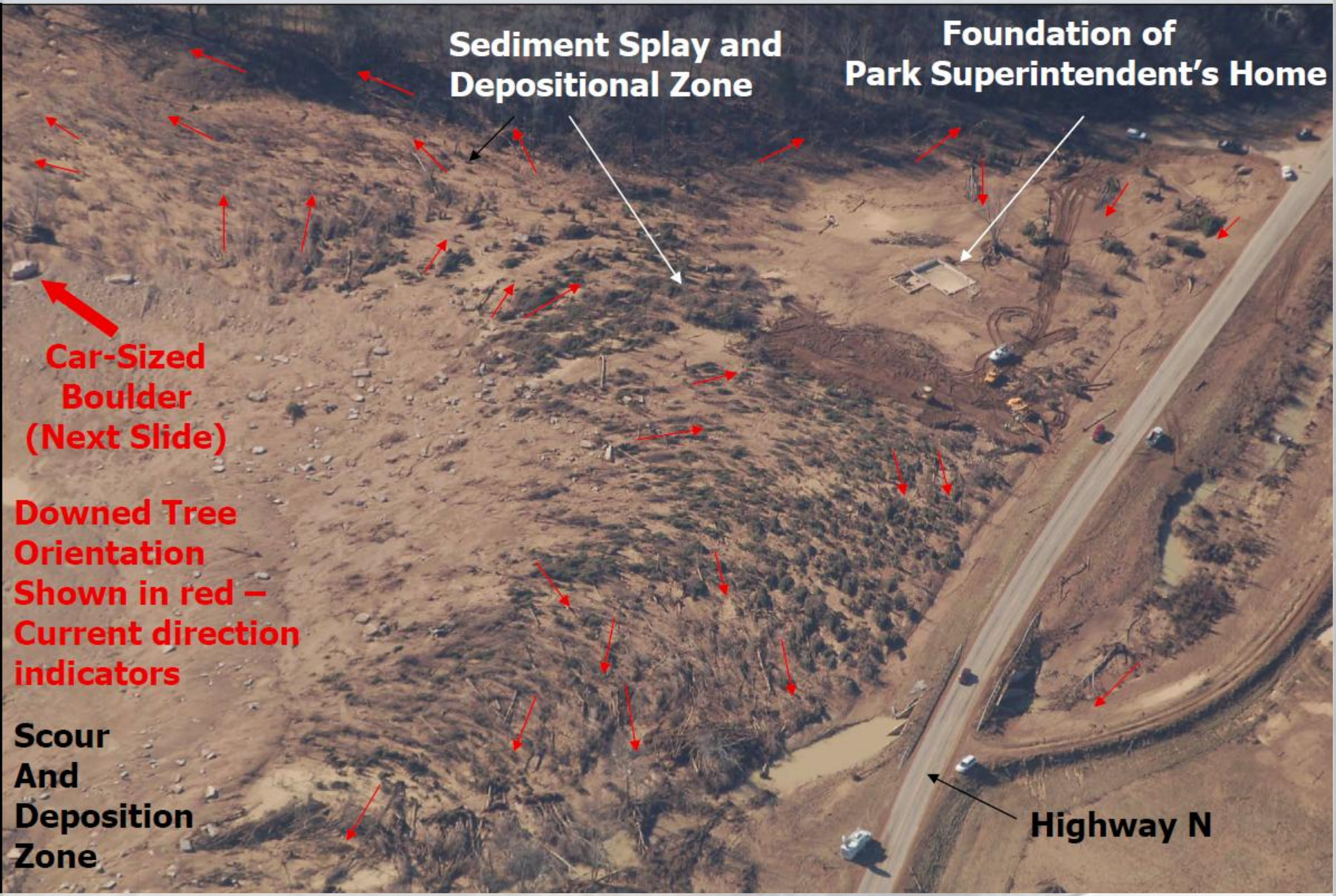
Sediment Splay and
Depositional Zone
Foundation of
Park Superintendent's Home
Car-Sized
Boulder
(Next Slide)
Downed Tree
Orientation
Shown in red –
Current direction
indicators
Scour
And
Deposition
Zone
Highway N

My Interests

- How can we use use systems engineering approaches to improve dam safety practices?
- How can we use systems engineering approaches to structure our approach to regulation?

My Interests

- Using Techniques and Practices built on STAMP to:
  - Guide Hazard Analysis
  - Guide Accident/Incident Causal Analysis and Understanding
  - Guide development of guidelines
  - Guide a study of the organizational structure of the FERC dam safety program