Rock Erosion *Initiation* In Unlined Emergency Spillways

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Recent Emergency Spillway Erosion Event

Resulting Regulatory Response

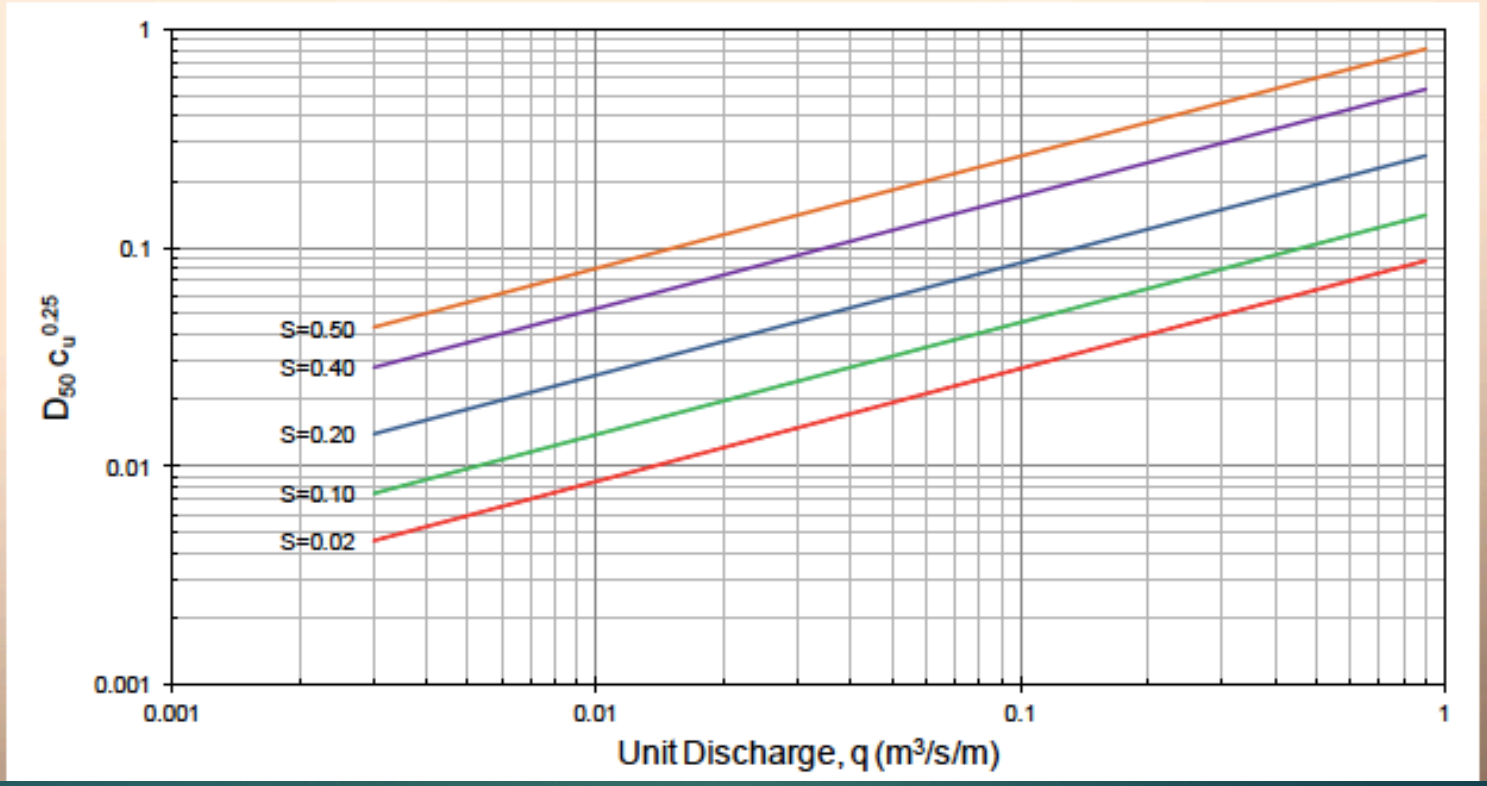
"93 California dams need reassessment before next flood season, state agency says"

Los Angeles Times, July 30 2017

"These assessments may require acquiring additional information to adequately evaluate the spillway's ability to perform satisfactorily during a flood event"

Rip-Rap/Rockfill Erosion Initiation Chart

(Frizzell *et al, 1998*)



From COE-Bureau Best Practices

Rock Erosion

- Many of the methods used currently to analyze rock were developed for mining applications, or used data from these methods.
  - Barton's Q-System characterized rock for tunneling.
  - Kirsten's ripability index established relationships between strength of rock and size of excavation equipment.
  - Annandale's erodibility index threshold line compares stream power against a headcut erodibility index.
  - Wibowo's uses logic regression to develop threshold probability lines that approximate the Annandale index.

From COE-Bureau Best Practices

Soil Erosion

There are multiple variables to be considered when looking at erosion of soils:

- Flow Depth
- Shear Stress
- Flow Velocity

Stream Power

- Soil Material Type
- Geometry
- Armoring
- Vegetation
- Soil Properties (cohesion, particle size, etc…)

Soil mass properties may control erodibility

From COE-Bureau Best Practices

Numerical Modeling Methods for Soil and Rock Erosion

SITES – Developed by USDA from observed Performance of Spillways to simulate headcut erosion in earthen spillways.

WINDAM B – Developed by the USDA from research conducted at the Agricultural Research Service in Stillwater, Oklahoma. Incorporate spillway erosion from SITES and includes algorithms for dam breach simulation.

.....cannot account for flow concentrations, variations in geometry(bends, cross slopes, changes in widths, etc.

For *Initiation* considerations.....

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Team Approach

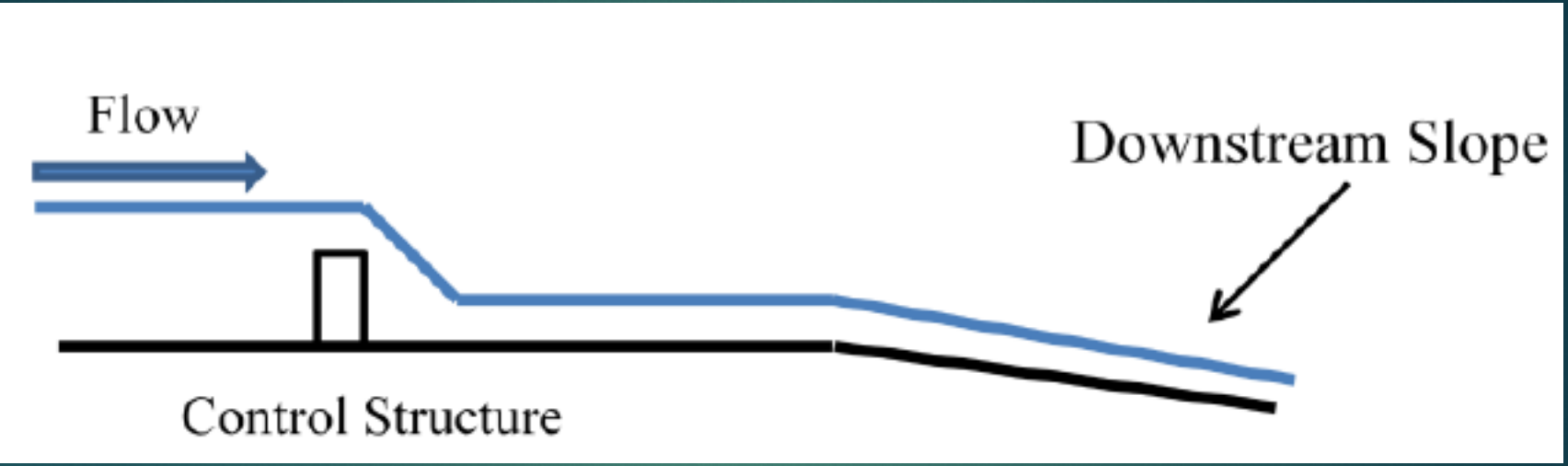
- Engineering Geologist
- Geologic-Geotechnical Engineer
- Hydraulic Engineer

Holistic consideration of factors must consider more than:

- Hydraulics
- Block Theory
- Vegetation cover
- *In many cases a qualitative or semi-quantitative approach may be useful*

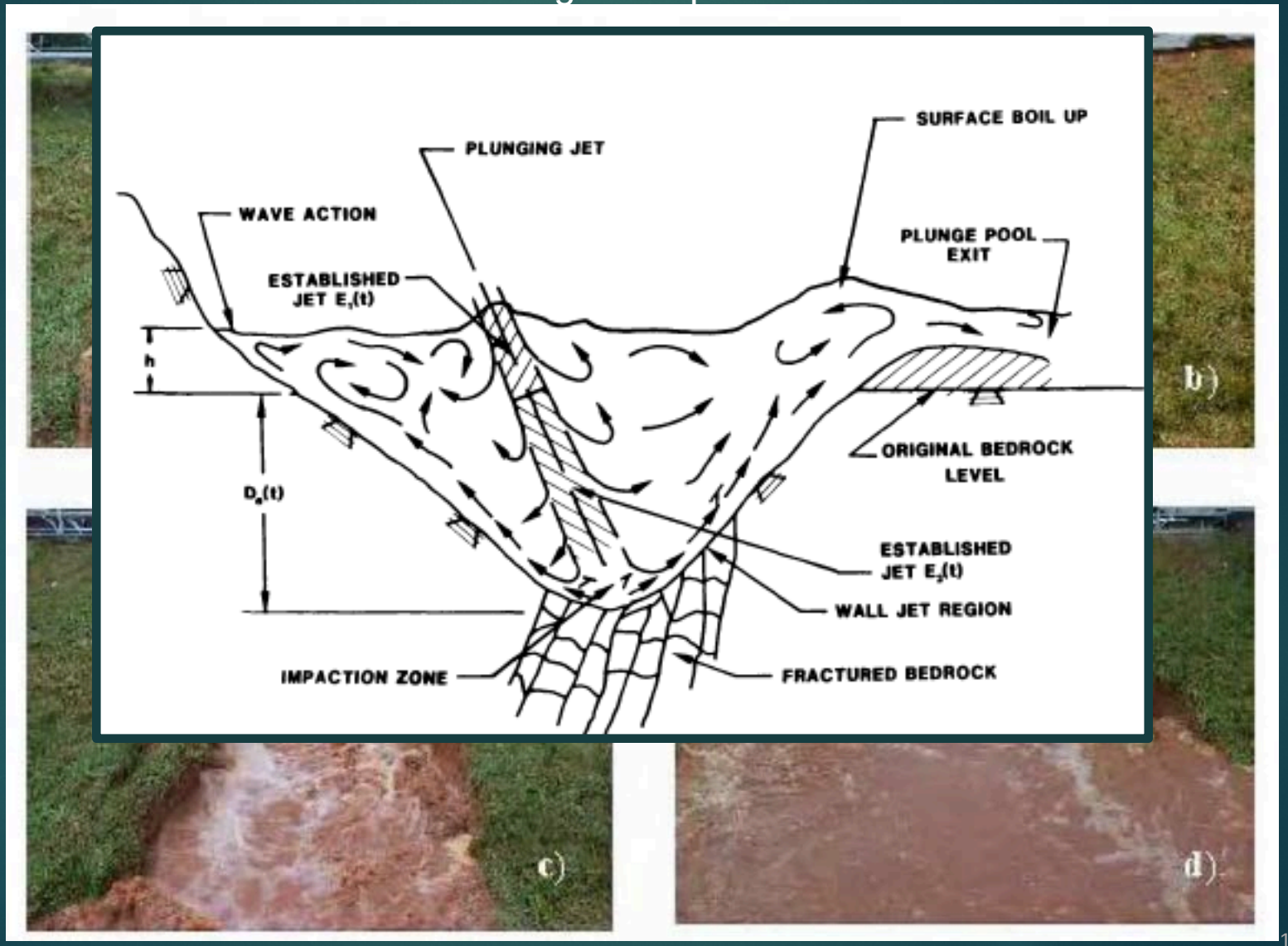
Geomorphology
Geology
Hydraulics

Geometry of Slope



Flow Concentrations or Perturbations

- Vegetation variation
- Presence of existing knickpoints



Geologic Factors

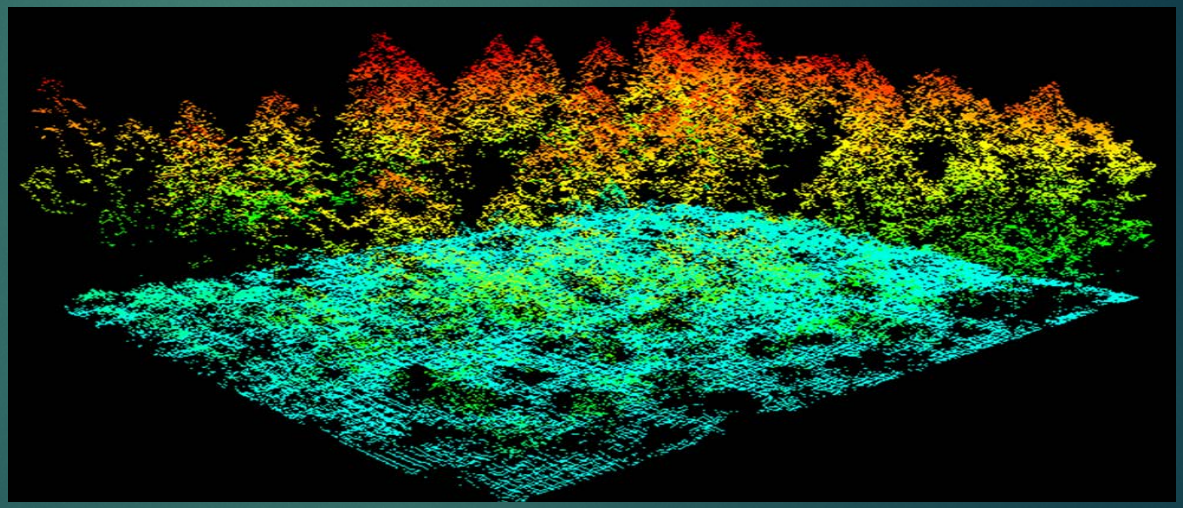
- Presence of discontinuities with shears may concentrate erosion
  - often the most continuous features at a site

- Regolith thickness may control erosion depth

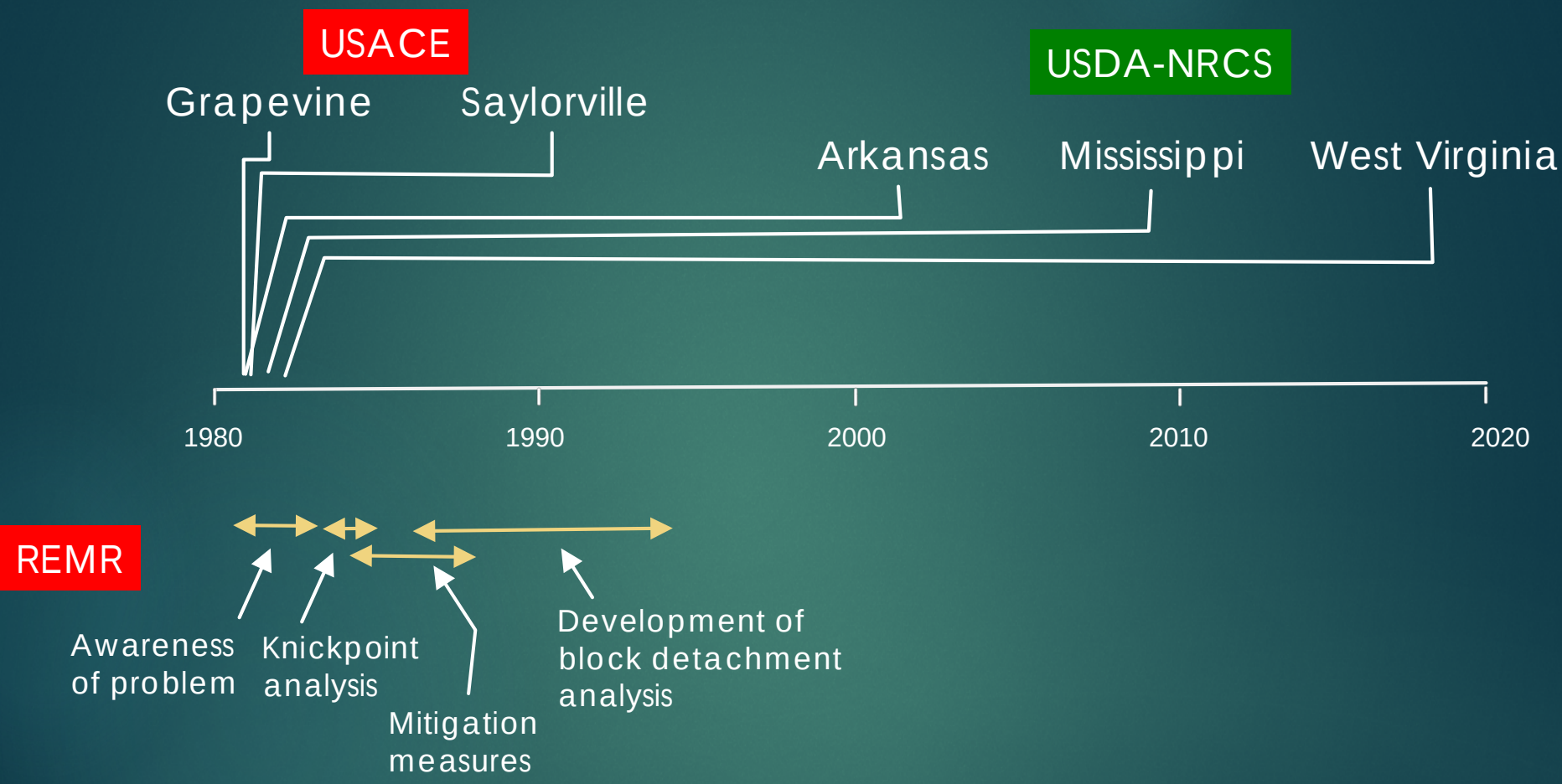
Other Factors

- Use of drones
- Media & social media

Point Cloud Data Created from drone photography



Earlier emergency spillway erosion studies



Corps of Engineers

Grapevine Spillway - 1981

- 5 volumes, 1986 – 1990
- Nationwide survey of COE erosion events
- Qualitative case history descriptions
- Analysis of knickpoint erosion
- Remediation
- Geotechnical issues

Conclusion

- Semi-qualitative holistic analysis of the spillway system
  - Can predict areas where erosion may initiate
  - Facilitates obtaining data for more site specific block analyses
- Multi-discipline team approach helps
- Use of drones to obtain aerial imagery, and use of imagery analysis software is cost effective and yields the best detail of site features