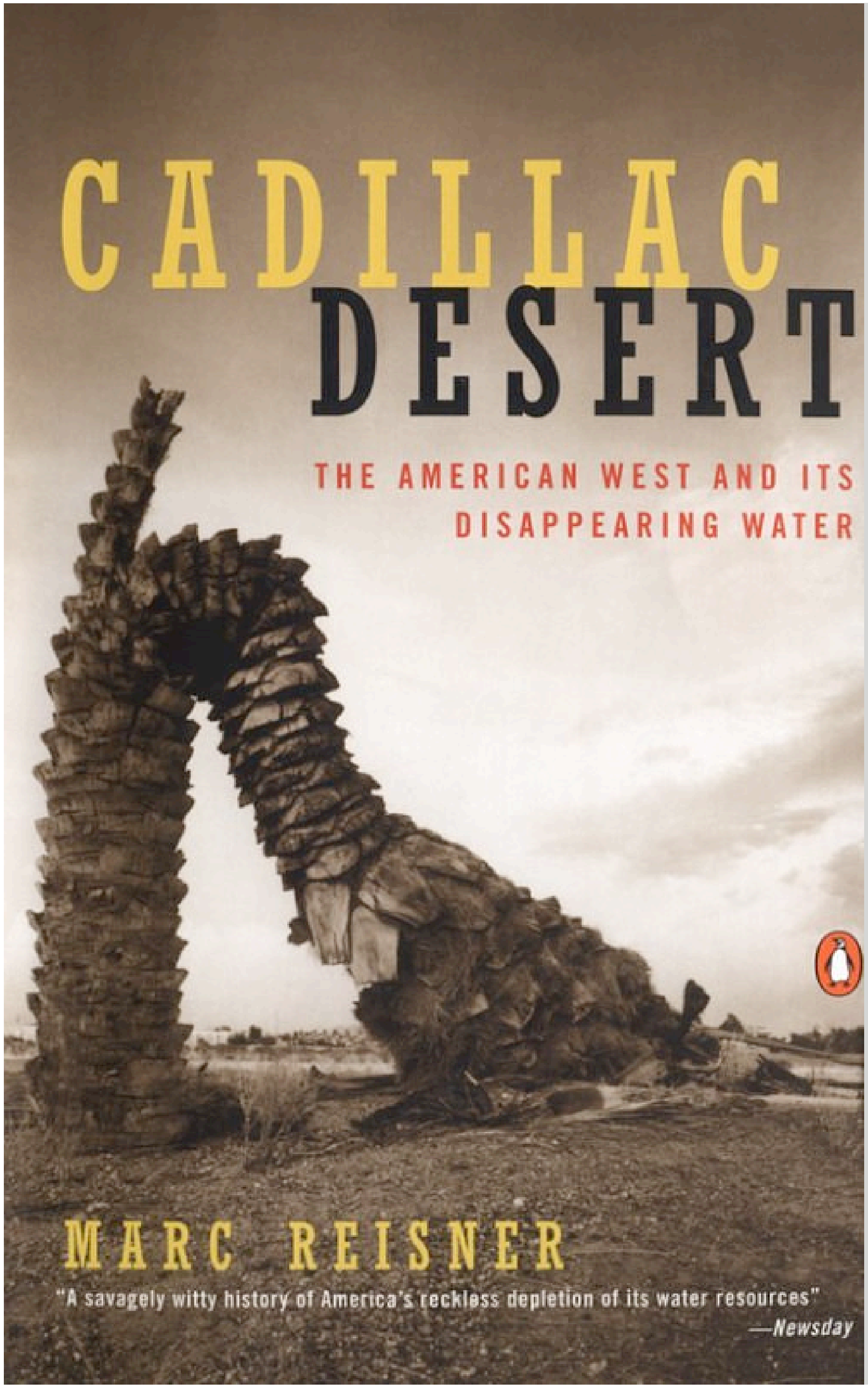
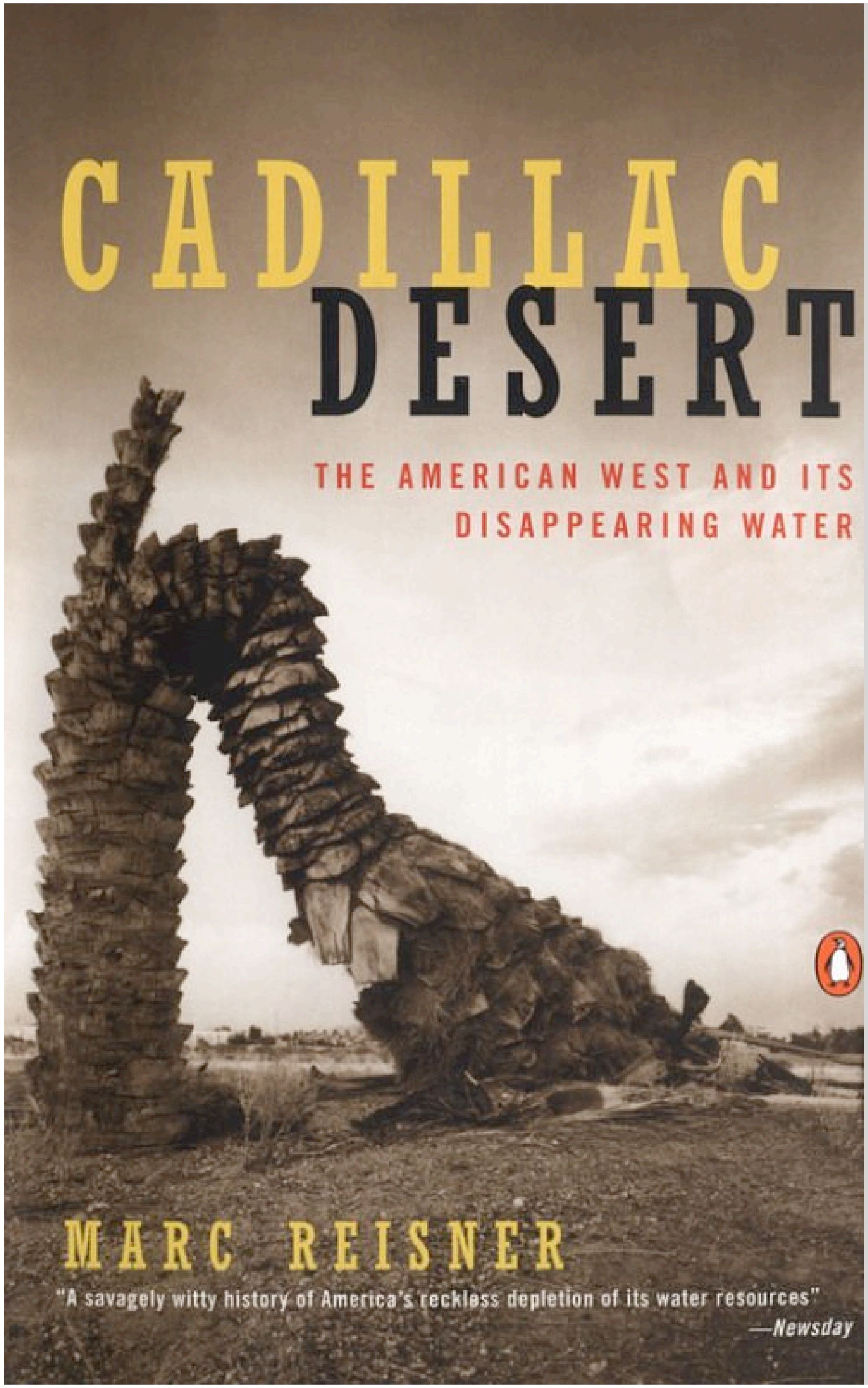
Rapid Changes in Water Level and Reservoir-Induced Seismicity

David Simpson
IRIS

IASPEI, Cape Town
January 2009


CADILLAC
DESERT
THE AMERICAN WEST AND ITS
DISAPPEARING WATER
MARC REISNER
"A savagely witty history of America's reckless depletion of its water resources"
—Newsday



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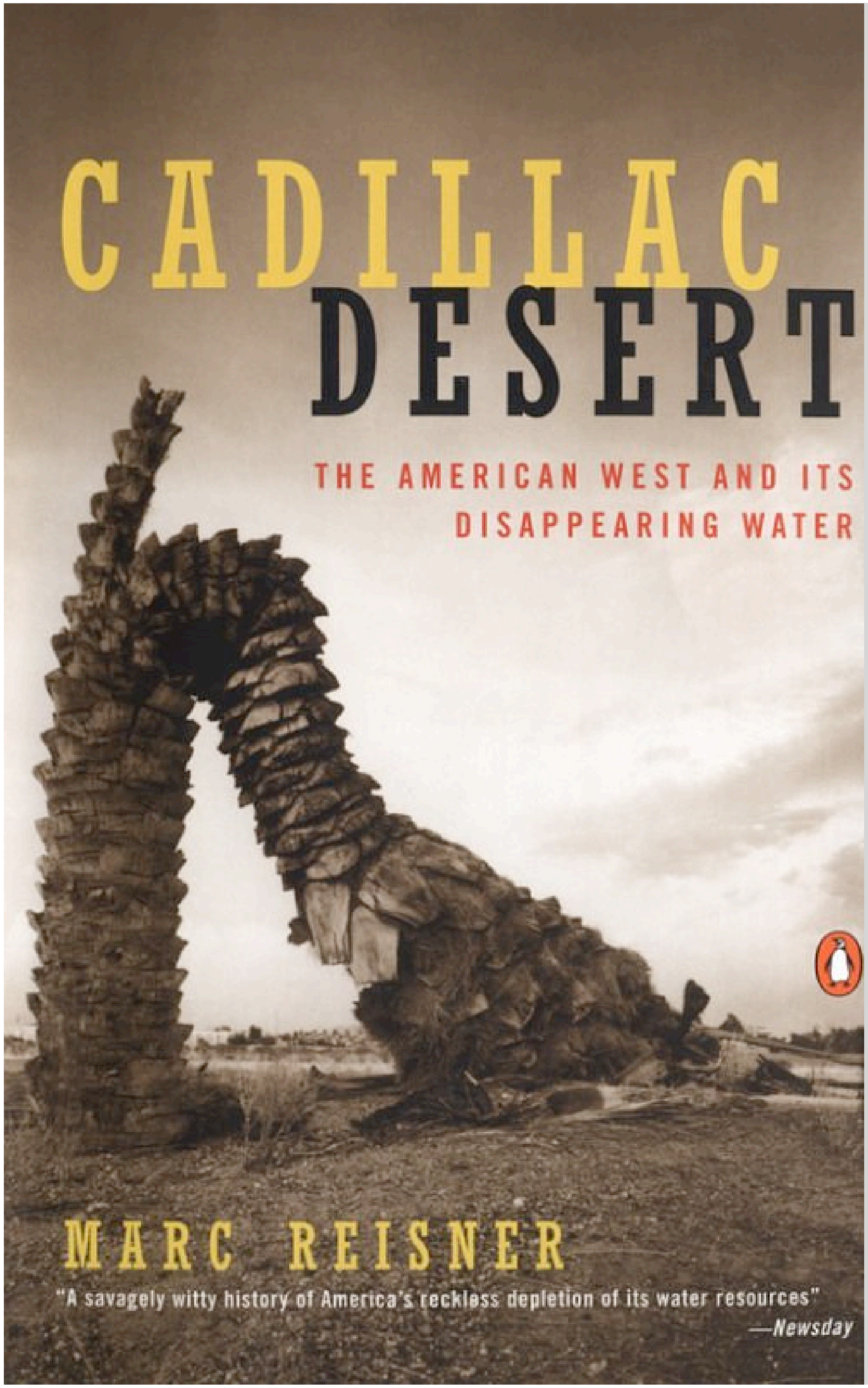
"***Those Who Refuse to Learn***"

discussing the filling of the reservoir behind Teton Dam.



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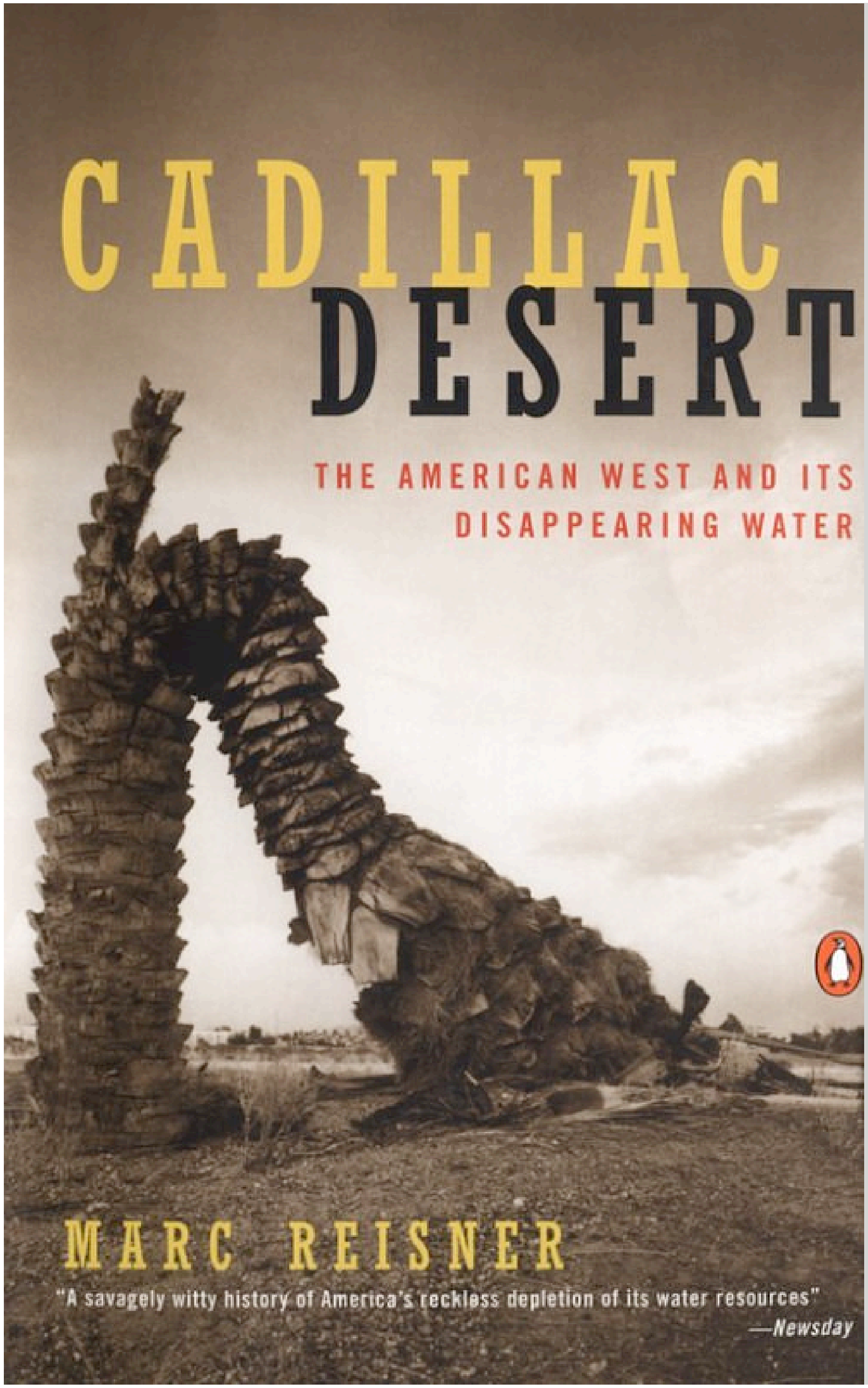

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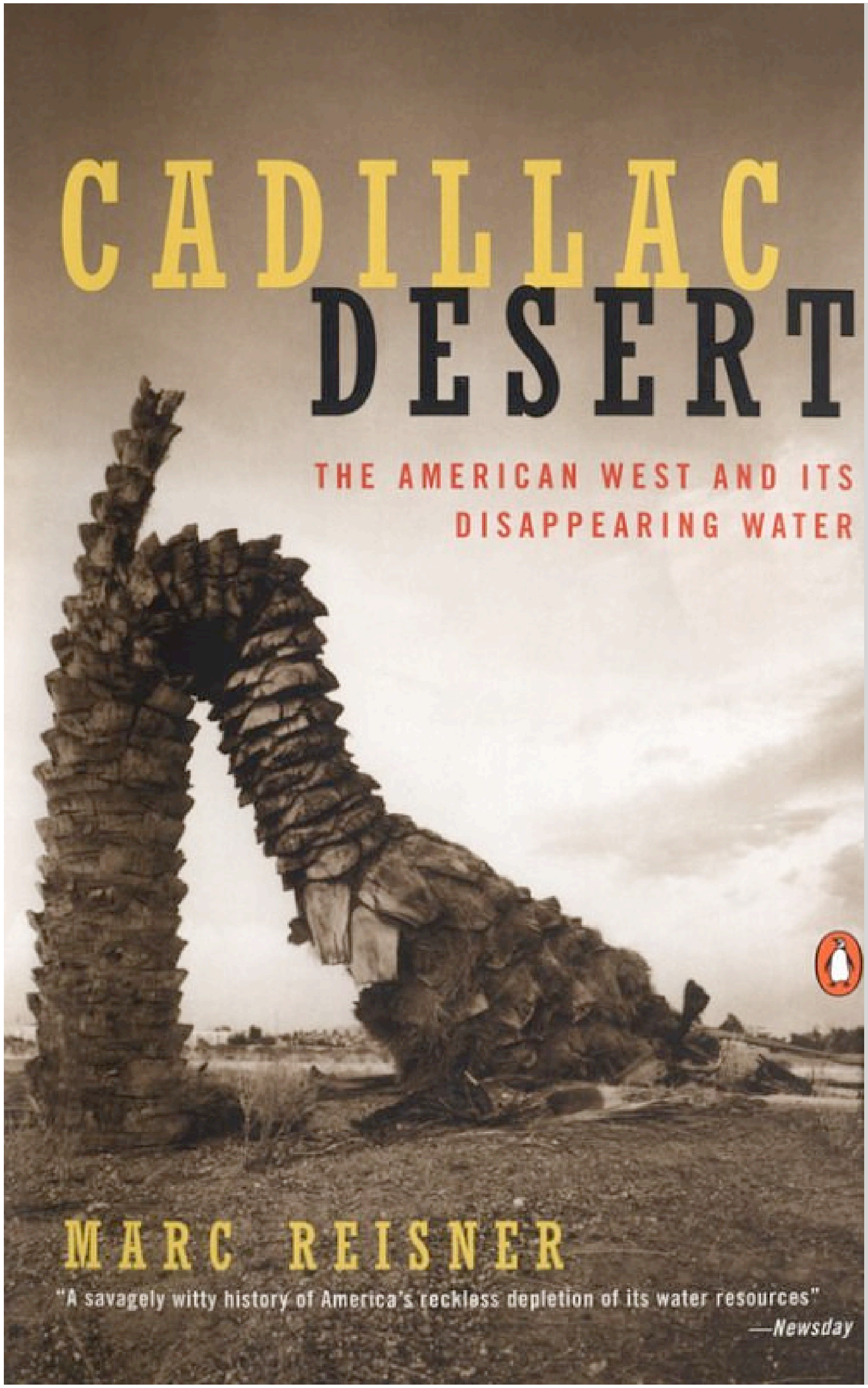

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That way, if problems develop with the dam or abutments, or back along the reservoir itself - where rising water sometimes loosens rock and causes landslides, or **causes the bedrock to shift under it weight**, producing the same result - they can be dealt with.

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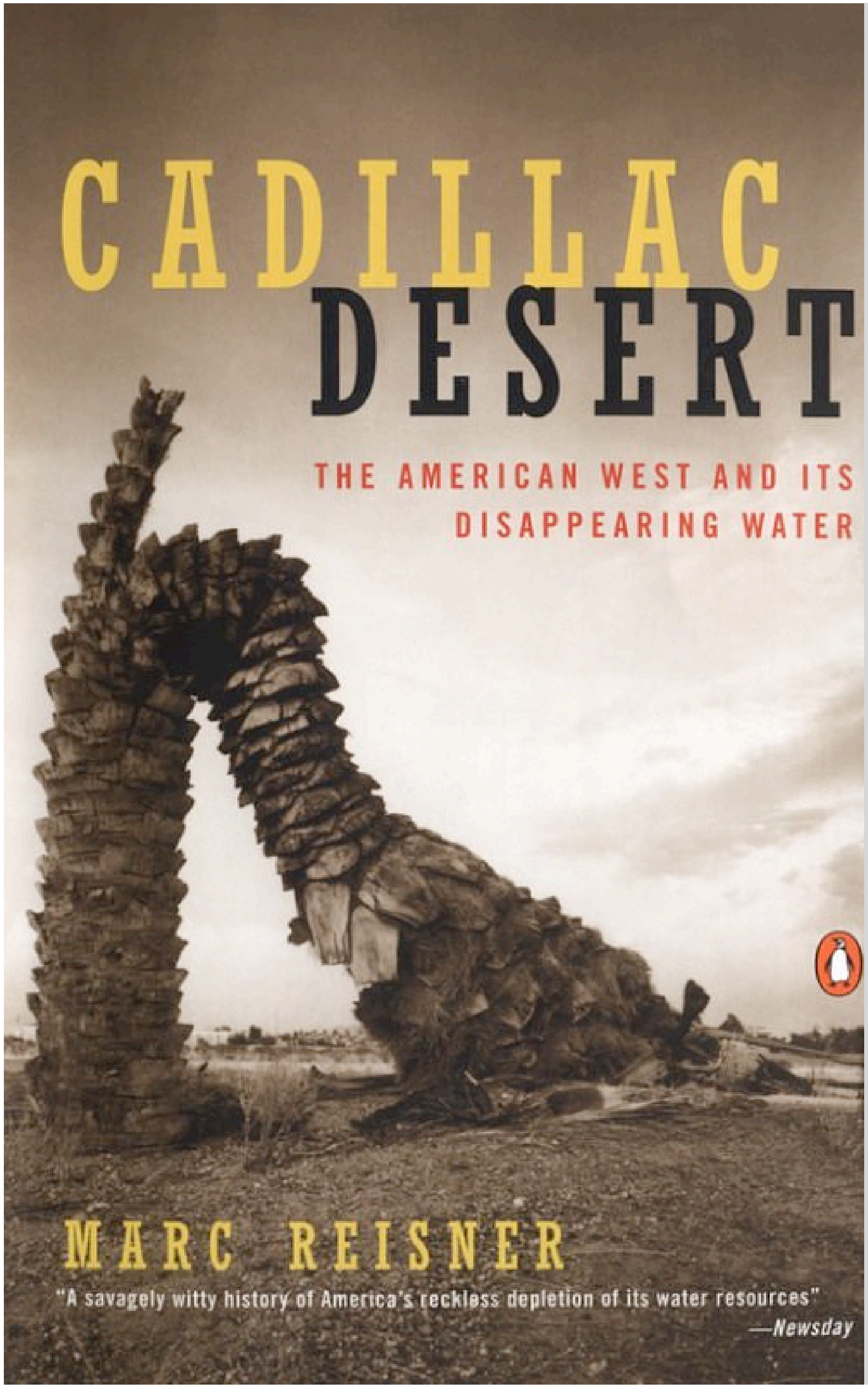

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Why not dispense with it again . . . ."

Cadillac Desert, Penguin Press, 1986, 1991 pg 398

Failure of Teton Dam
southeastern Idaho
June 5, 1976

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Mechanisms for triggered and induced seismicity

- Debate and some consensus concerning:
  - "Diagnostic" criteria
  - Probability of triggered earthquakes and maximum magnitude

  - Significance of:
    - Elastic load, pore pressure and coupled response
    - Water level history - "Kaiser effect" (Nurek and Koyna)
    - Rapid and delayed response
    - "Triggered" and "induced" seismicity

Induced seismicity *- "the causative activity can account for either most of the stress change or most of the energy required to produce the earthquake."*

Triggered seismicity *- "the causative activity can account for only a small fraction of the stress change or energy associated with the earthquake - in this case, tectonic loading plays the primary role."*

McGarr and Simpson, 1997

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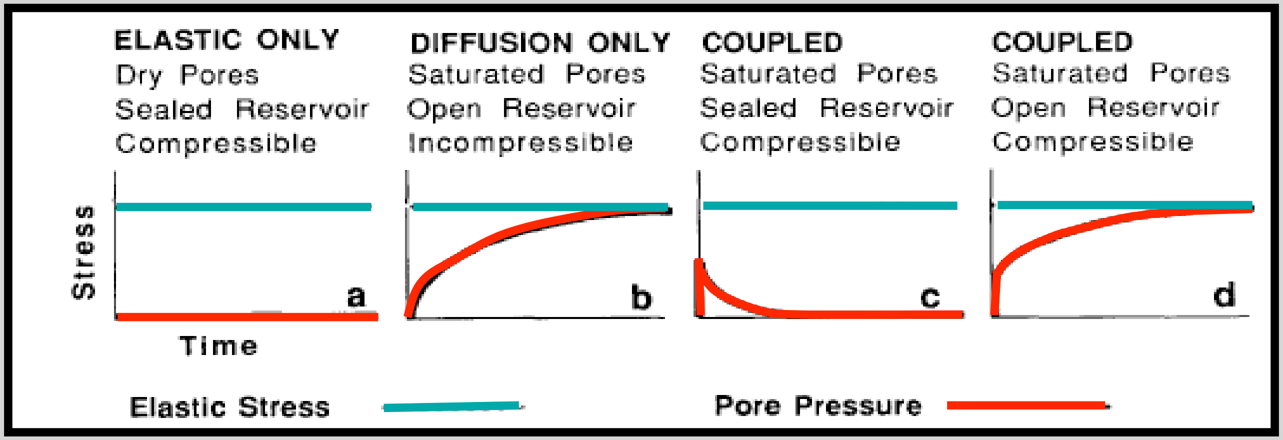
    - "Triggered" and "induced" seismicity

- Enigmatic issues
  - Why are triggered earthquakes relatively rare in the United States?
  - Why does Koyna continue to trigger earthquakes after 40+ years?
  - Why do most maximum earthquakes occur soon after a maximum in water level?
  - Why are changes in rate of filling important in triggering?

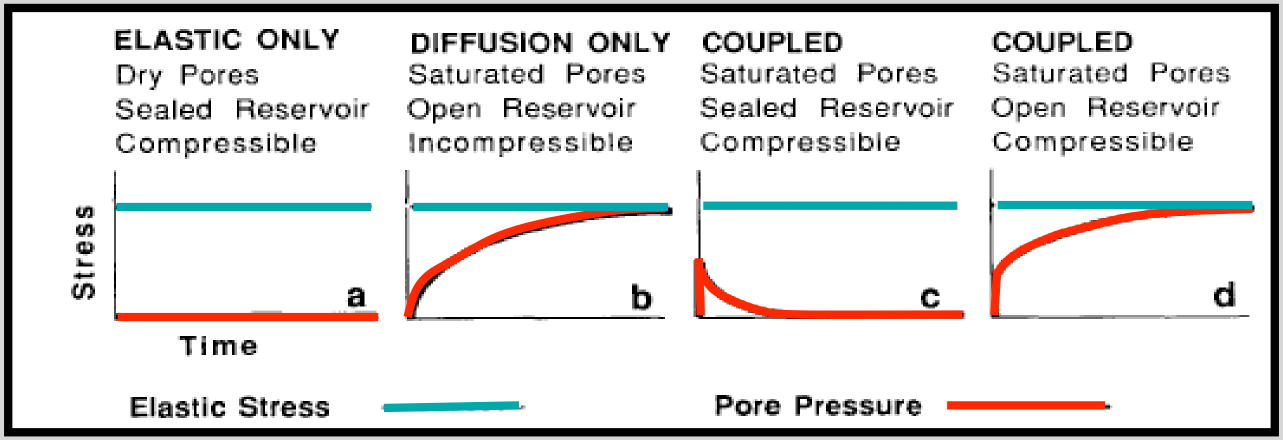


Simpson, Leith and Scholz, 1988

Two types of Reservoir Induced Seismicity

Rapid Response

Delayed Response



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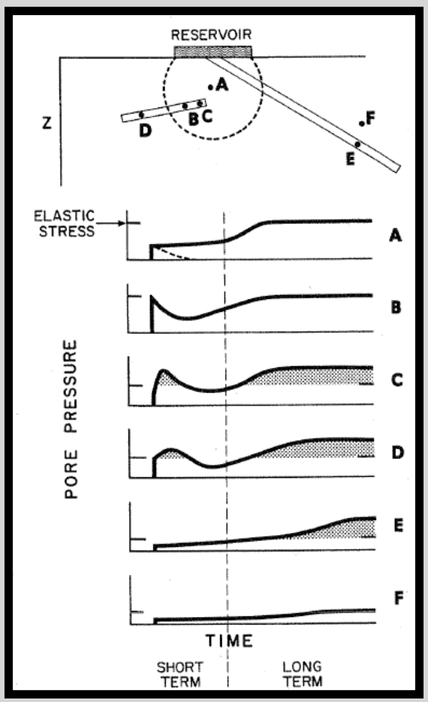
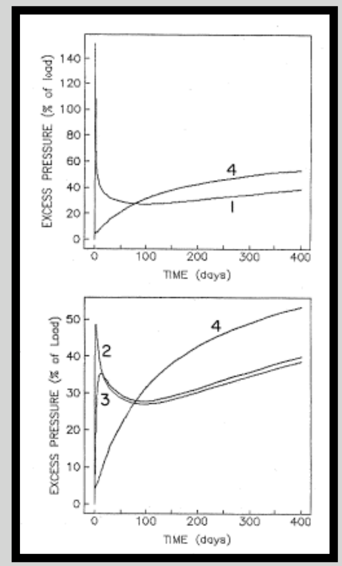
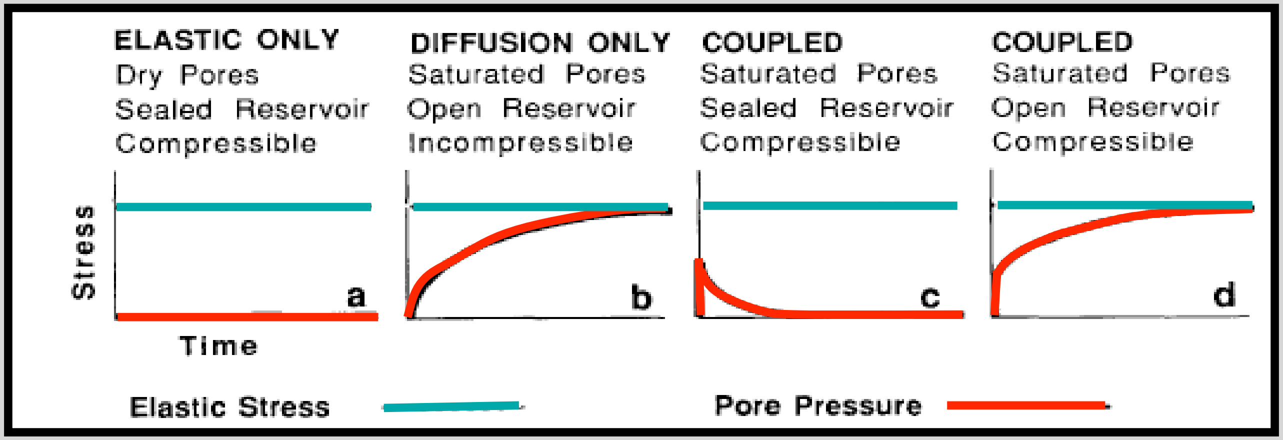




Simpson and Narasimhan, 1990



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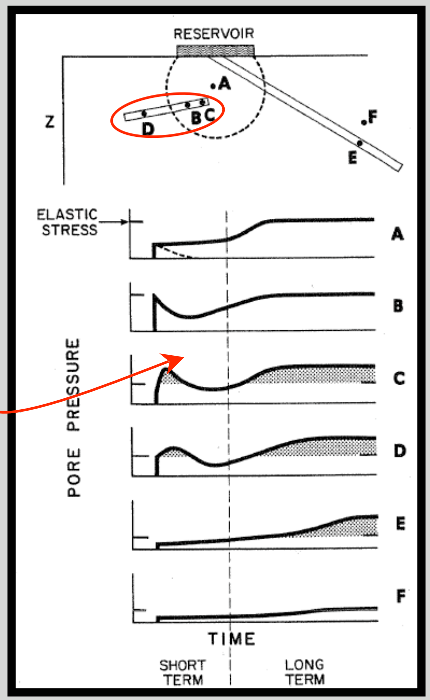
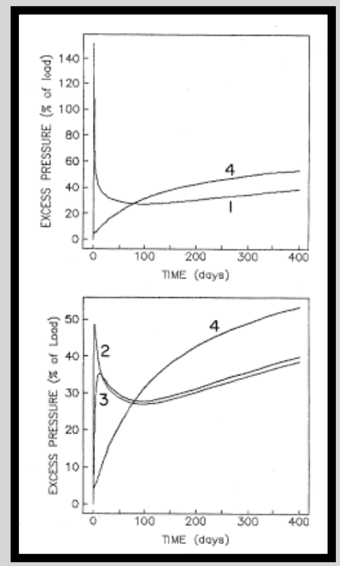
Rapid

Coupled response

Diffusion time constant related to internal fault scales





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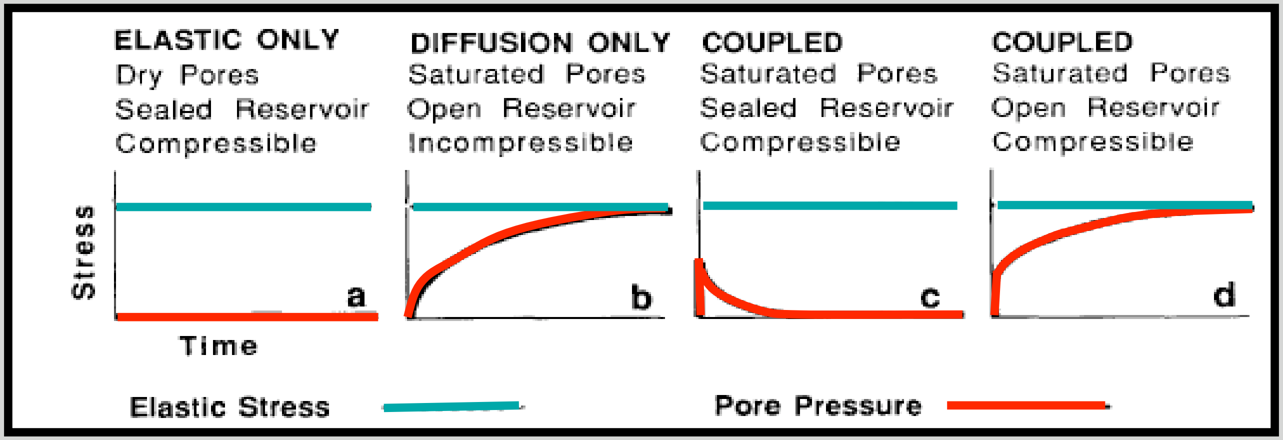

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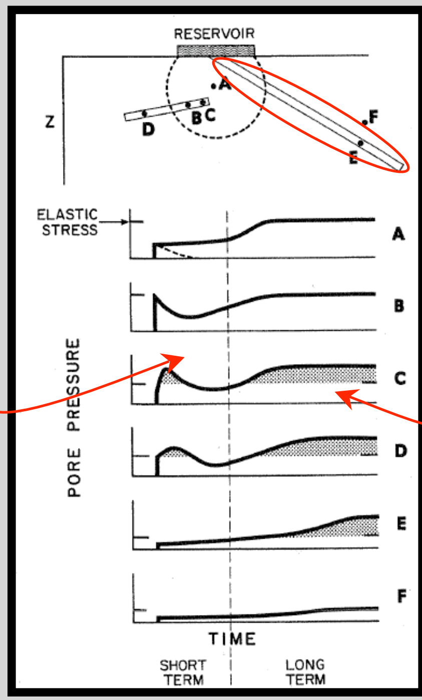
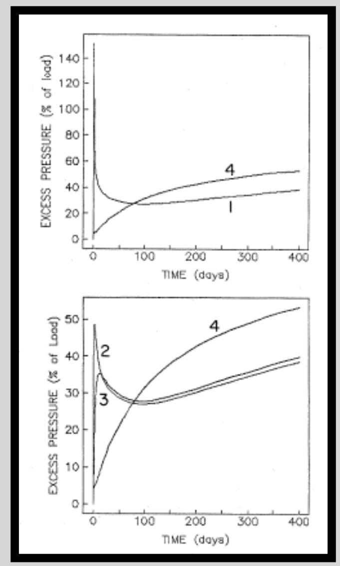


Delayed

Diffusion dominant

Diffusion time constant related to distance from reservoir

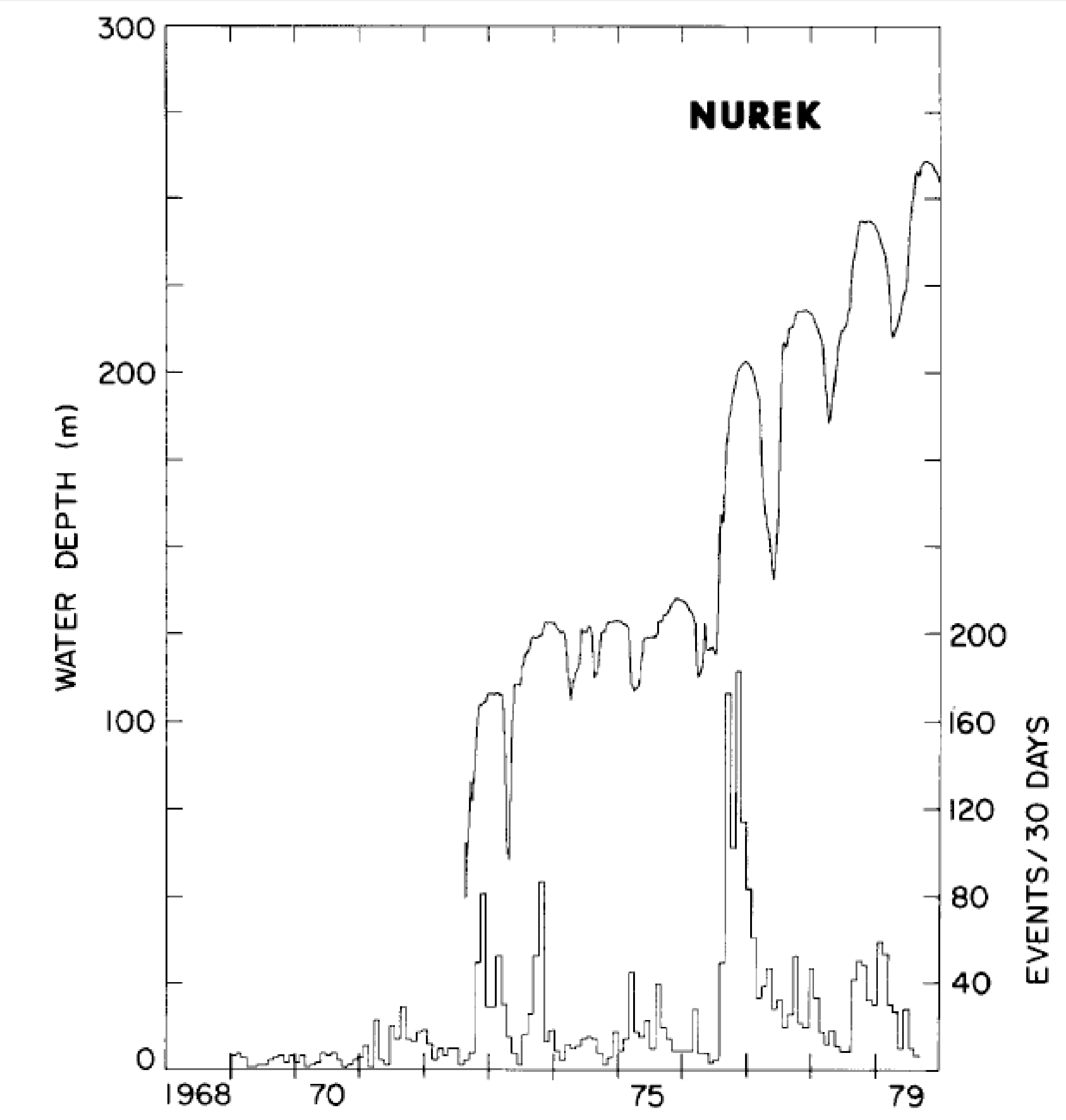


Simpson and Narasimhan, 1990

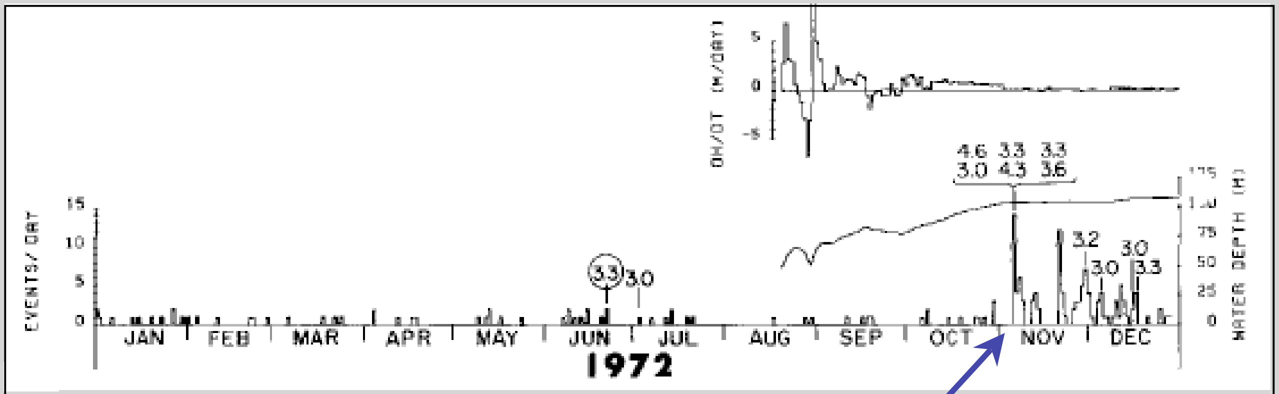
Rapid Response

Nurek Reservoir, Tadjikistan

Increases in seismicity related to rapid changes in water level *and* changes in water level *gradient*



Simpson and Negmatullaev, 1981



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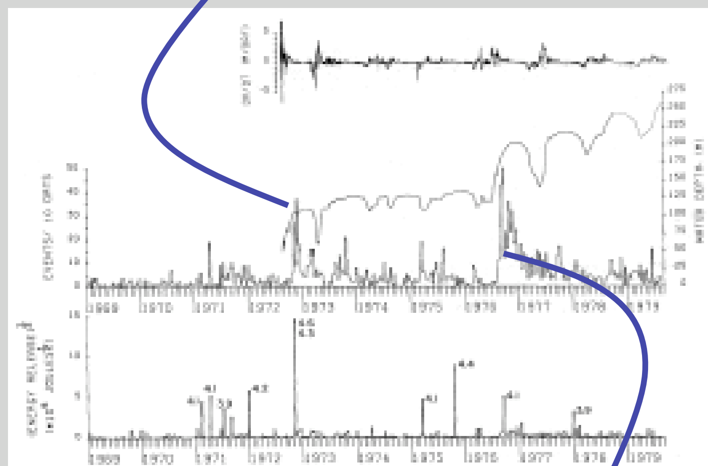

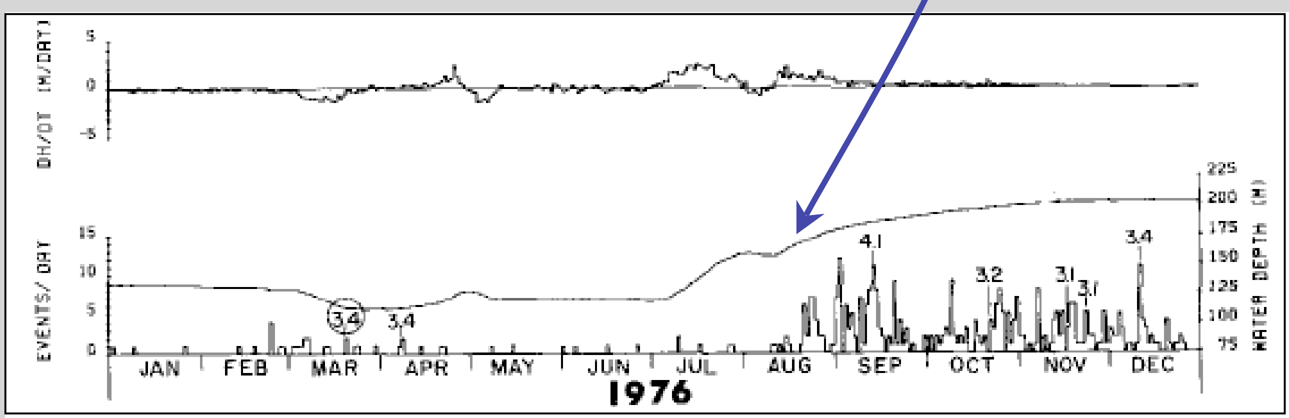

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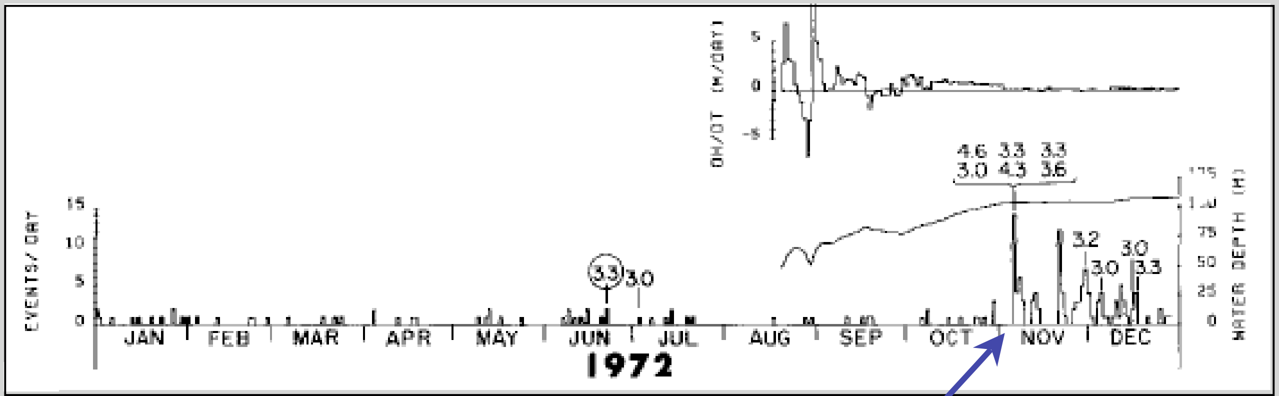

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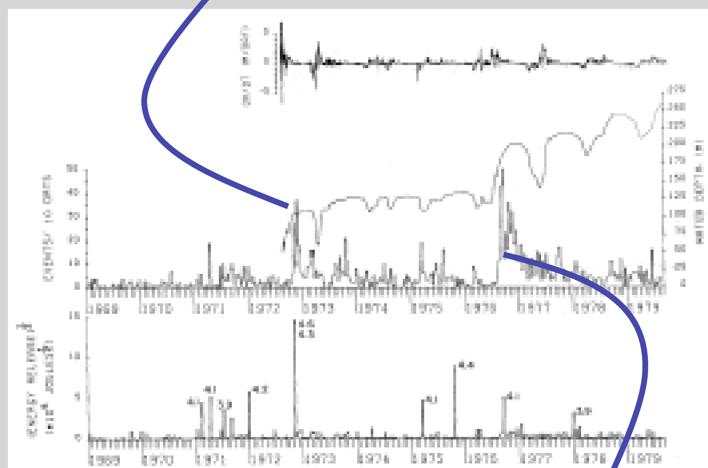
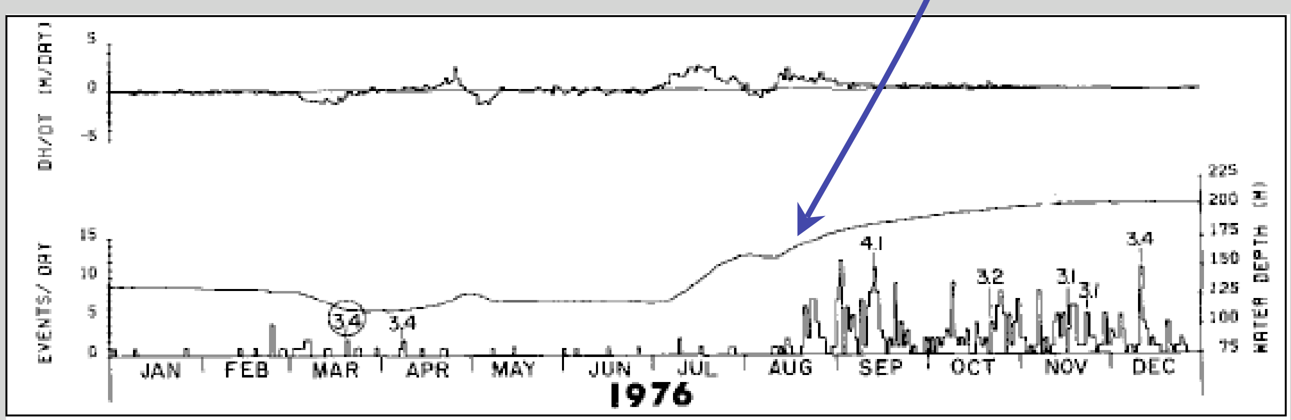


Filling rate > 1 m/day
Annual cycles > 20 m
m_{max} = 4.6
V = 10 km^3

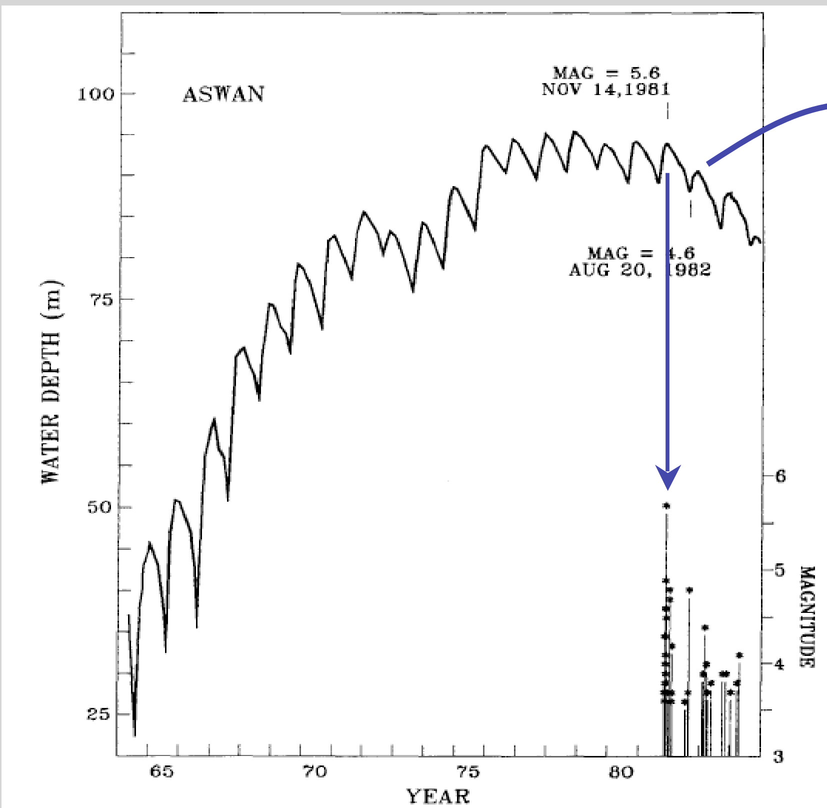


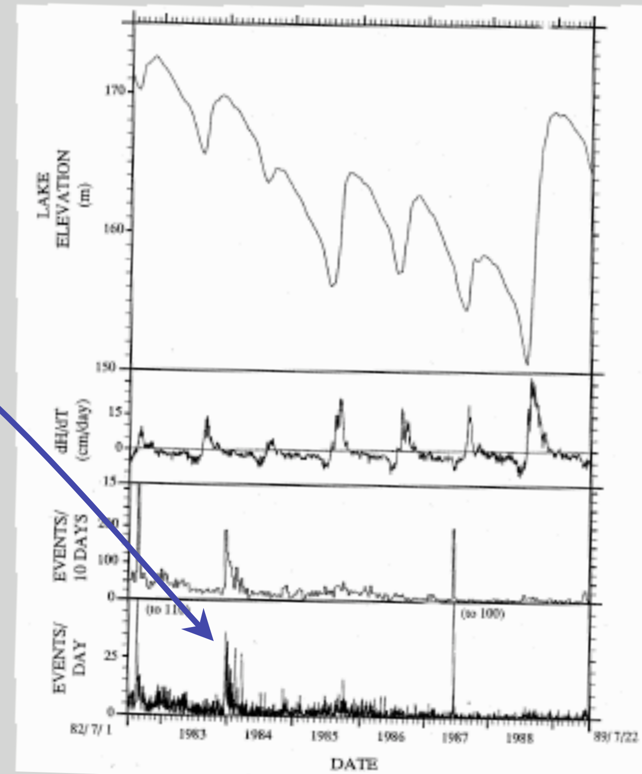
Simpson and Negmatullaev, 1981

Delayed Response

Aswan reservoir, Egypt

Triggered seismicity related to flooding
of Nubian sandstone





Simpson, Gharib and Kebeasy , 1990

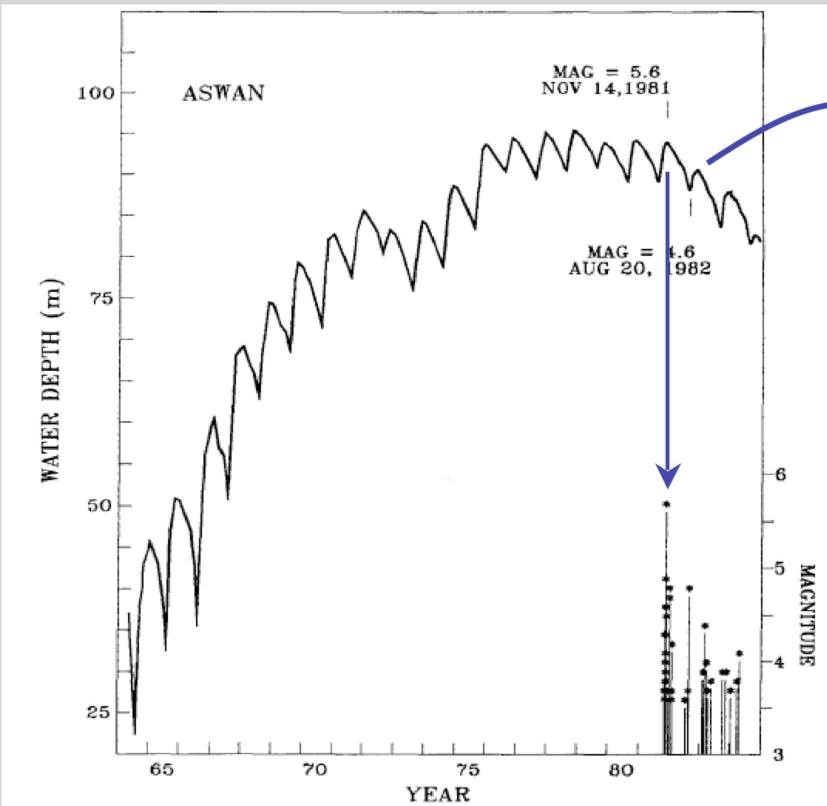
Delayed Response

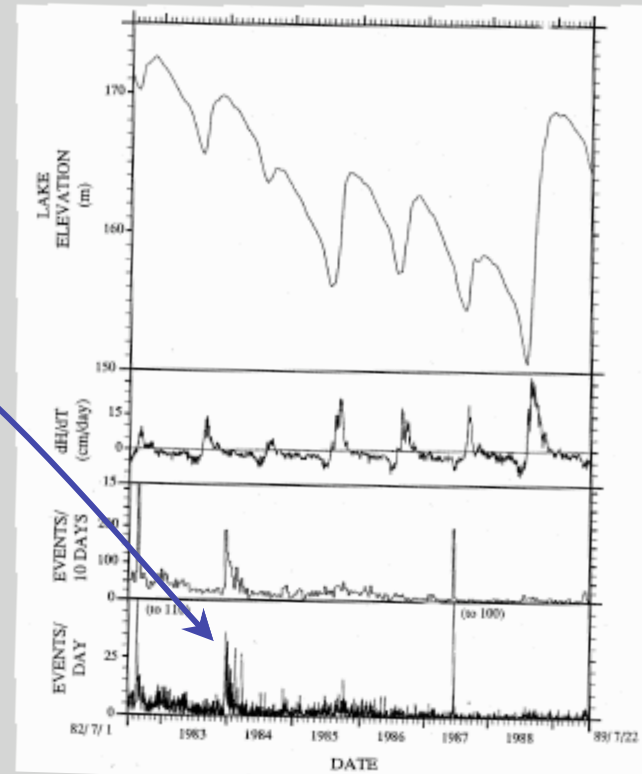
Aswan reservoir, Egypt

Triggered seismicity related to flooding of Nubian sandstone

Filling rate < 0.1 m/day
Annual cycles < 10 m
m_{max} = 5.6

V = 160 km^3





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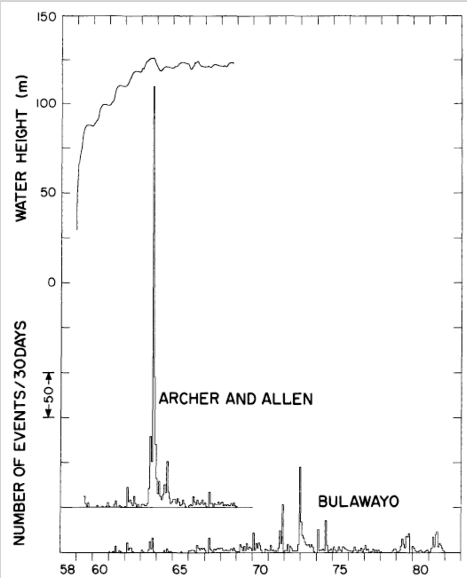
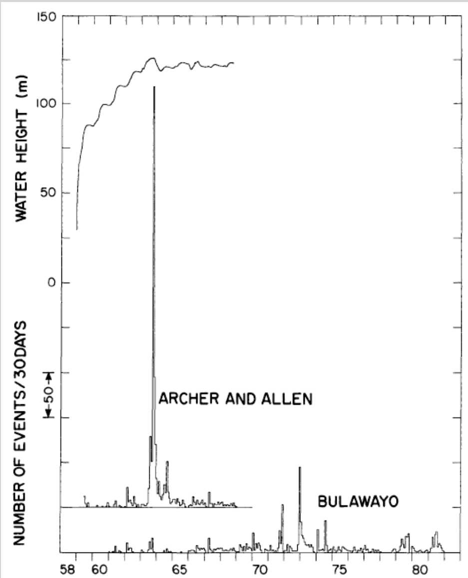
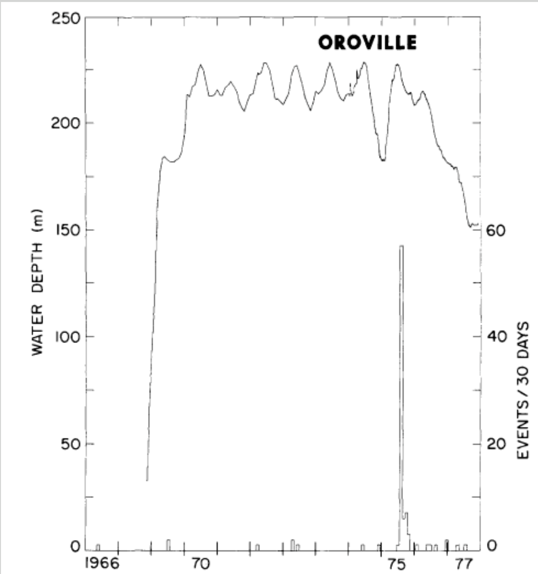


Kariba

Filling rate ~ .05 m/day
Annual cycle < 10 m ?
m_{max} = 5.8
V = 160 km^3

Simpson, Leith and Scholz, 1988





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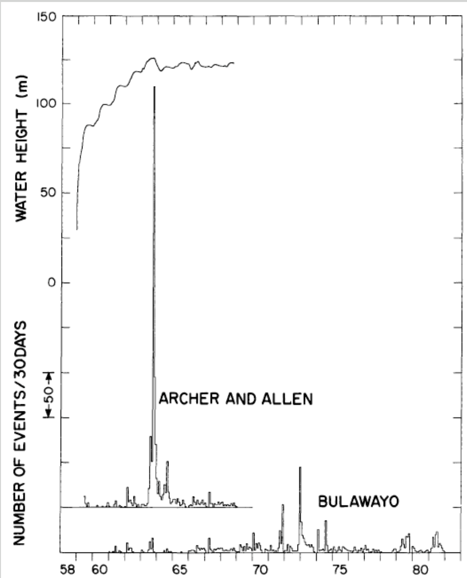
Oroville

Filling rate ~ 0.2 m/day
Annual cycle ~ 20 m

1975
Filling rate ~ 0.3 m/day
Annual Cycle ~ 50 m
m_{max} = 5.7
V = 4 km^3

Simpson, Leith and Scholz, 1988



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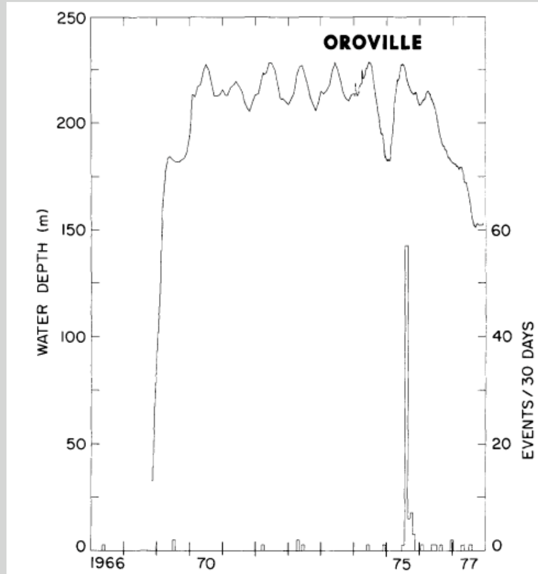

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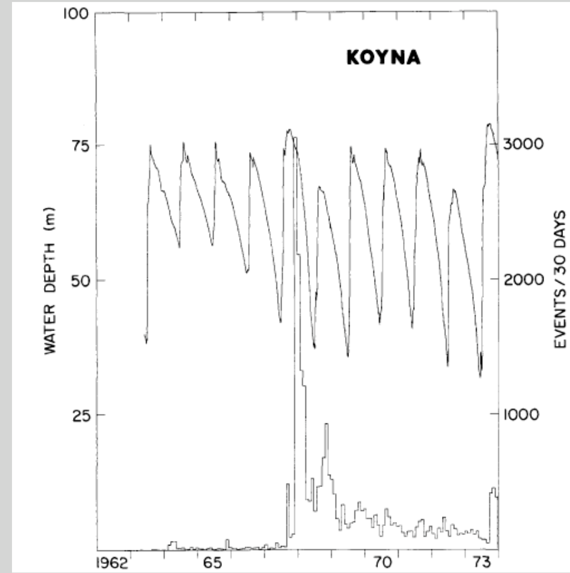
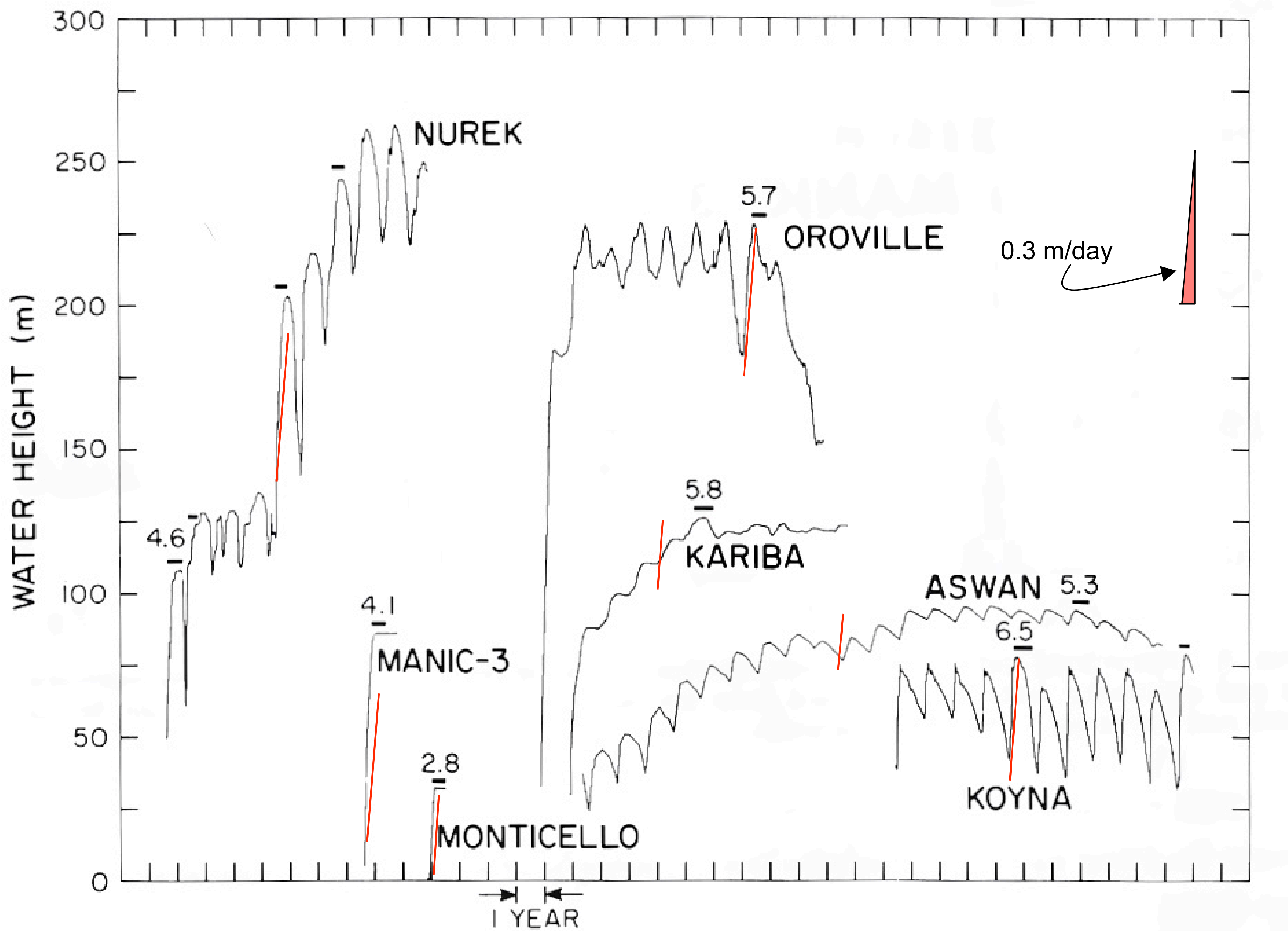


Koyna

Filling rate **~1.5 m/day**
Annual cycle **~ 40 m**
m_{max} = 6.5
V = 3 km^3

Simpson, Leith and Scholz, 1988



Simpson, Leith and Scholz, 1988 - Two types of Reservoir Induced Seismicity

Conclusions

Rate of filling of large reservoirs is an important factor in controlling the timing of triggered and induced earthquakes.

Rapid filling can enhance the development of excess pore pressure, weaken faults and lead to triggering.

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(Slow and smooth filling can decrease the likelihood of triggering)

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Recommendations

Systematic review of filling history at large reservoirs - both seismic and aseismic.

Collect accurate and frequent (daily) water level data in all future reservoir studies.

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