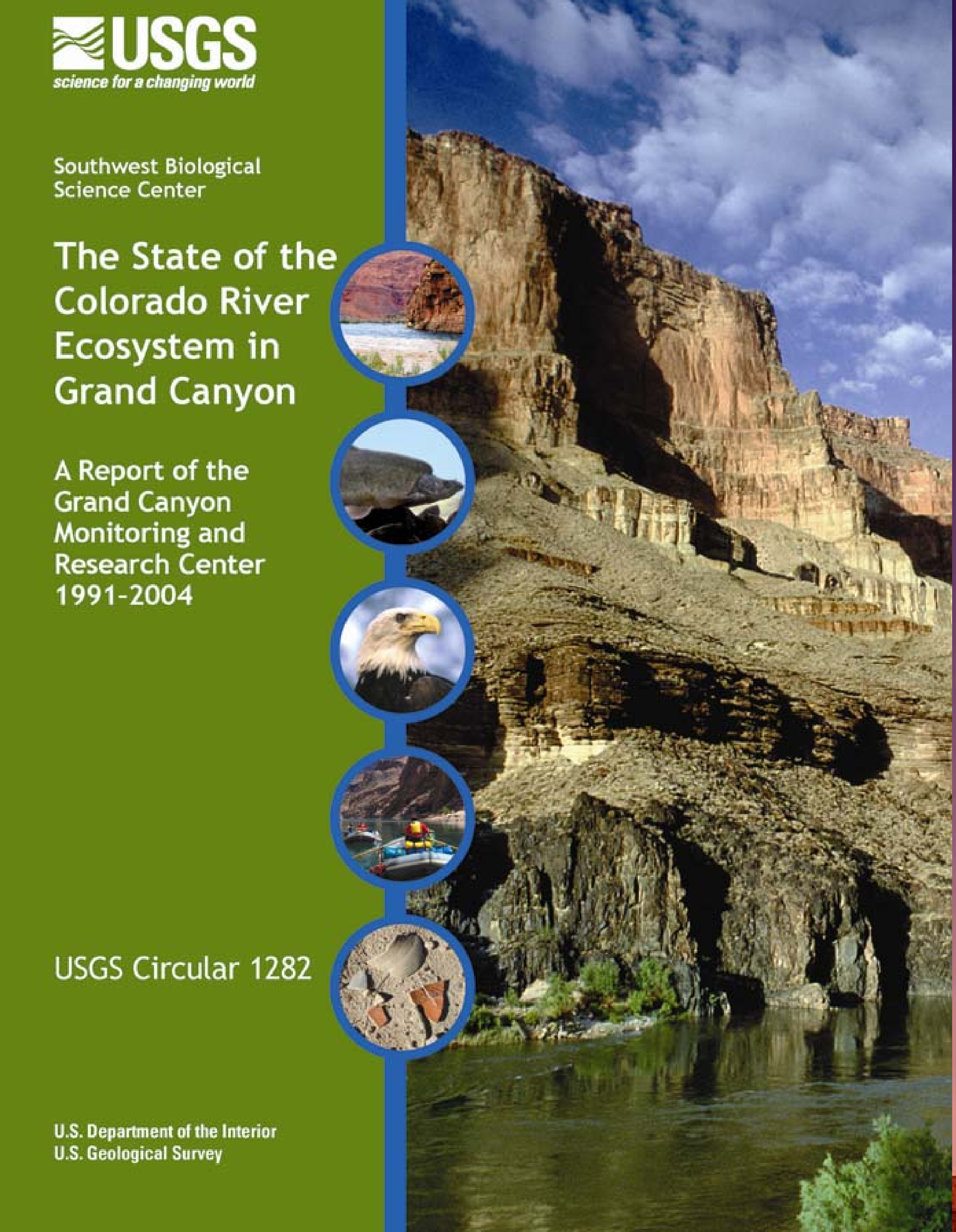

DEBRIS FLOWS IN GRAND CANYON AND THE RAPIDS OF THE COLORADO RIVER

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Debris-flow Effects on the Colorado River

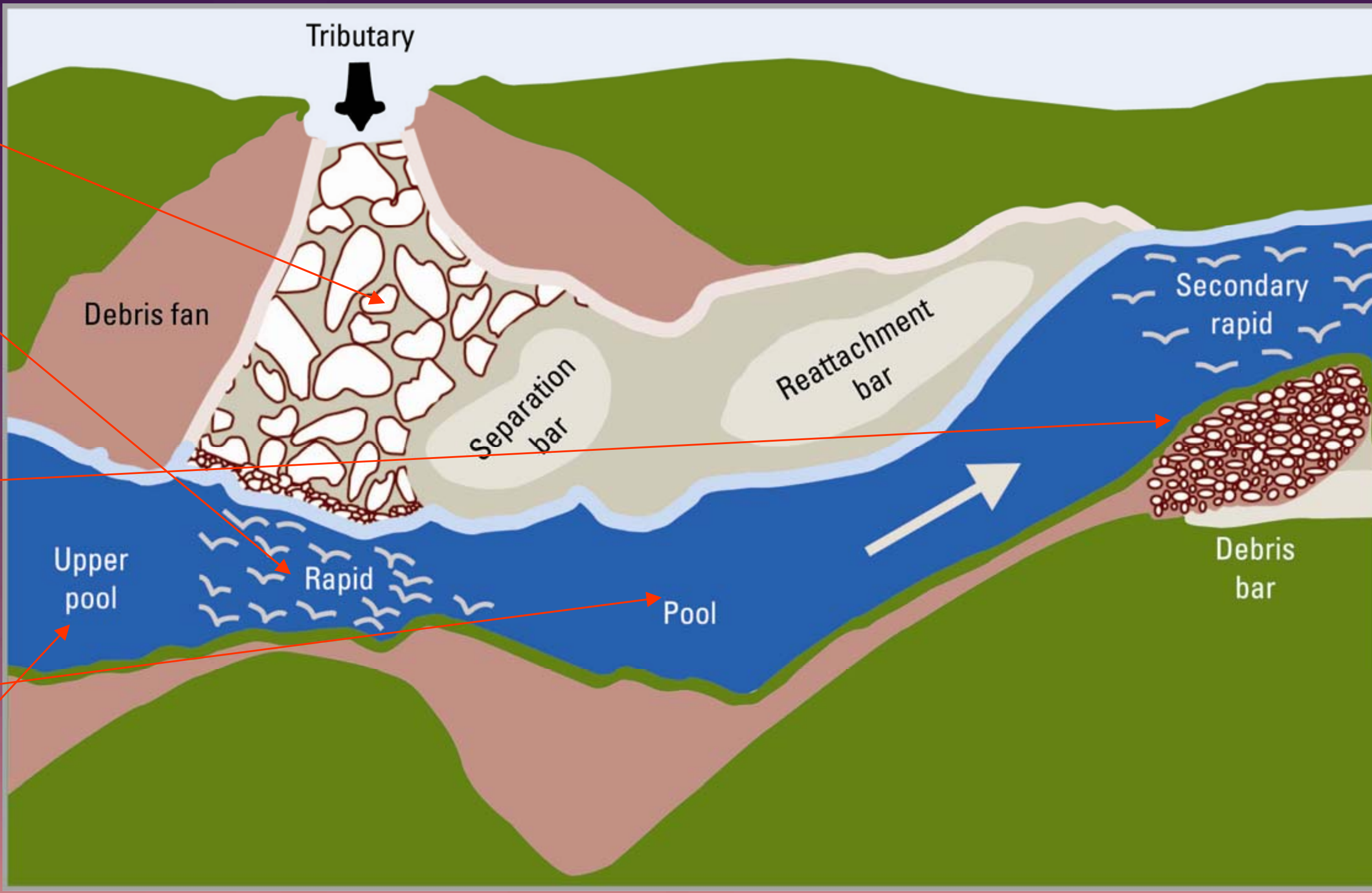
1. Debris flow occurs in tributary

2. River is constricted, bed elevation rises

3. Reworked debris accumulates downstream

4. Pool forms, allows sand deposition in eddies

5. Sediment accumulates in upper pool as well



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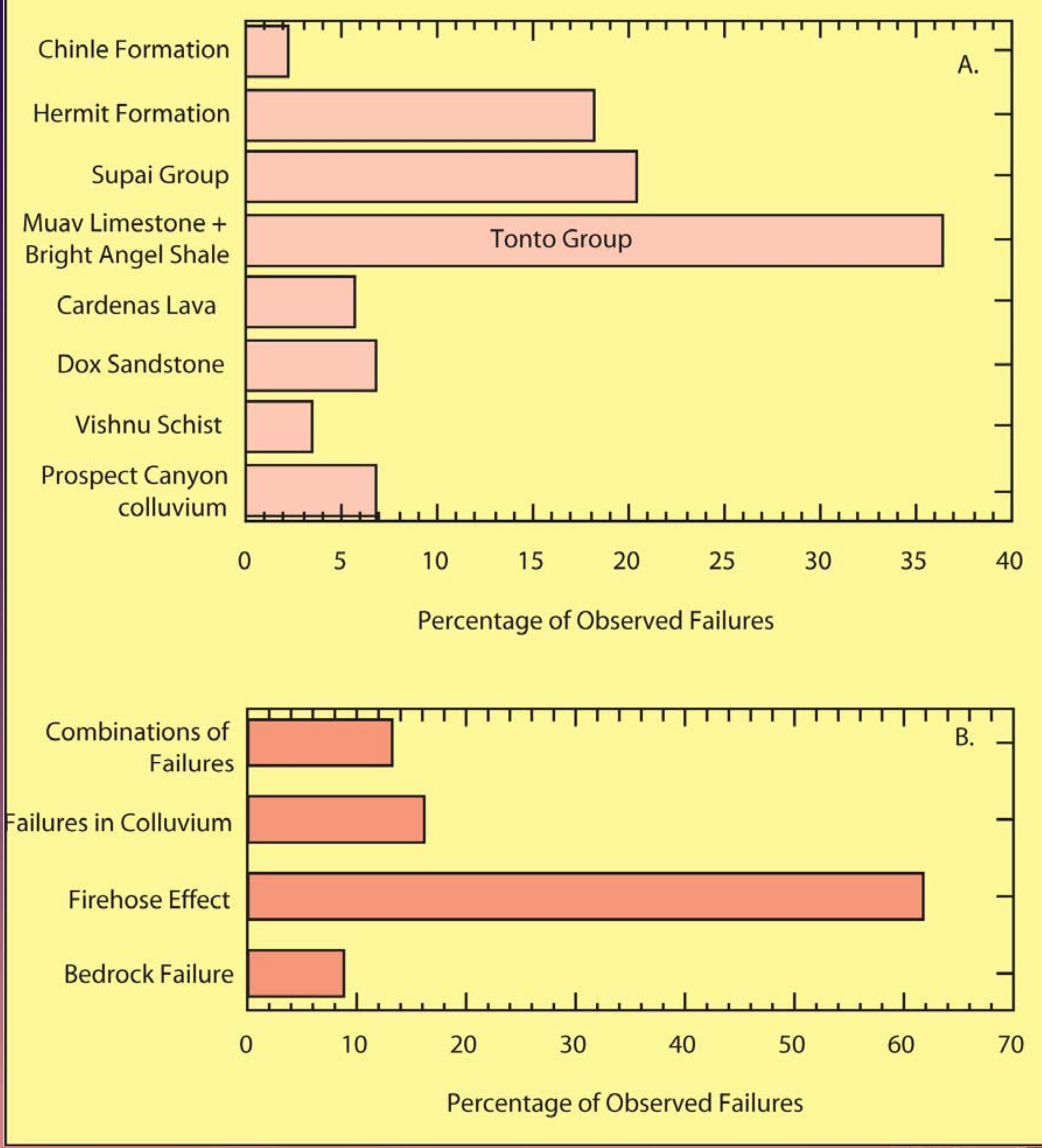
Debris Flow Initiation and Frequency



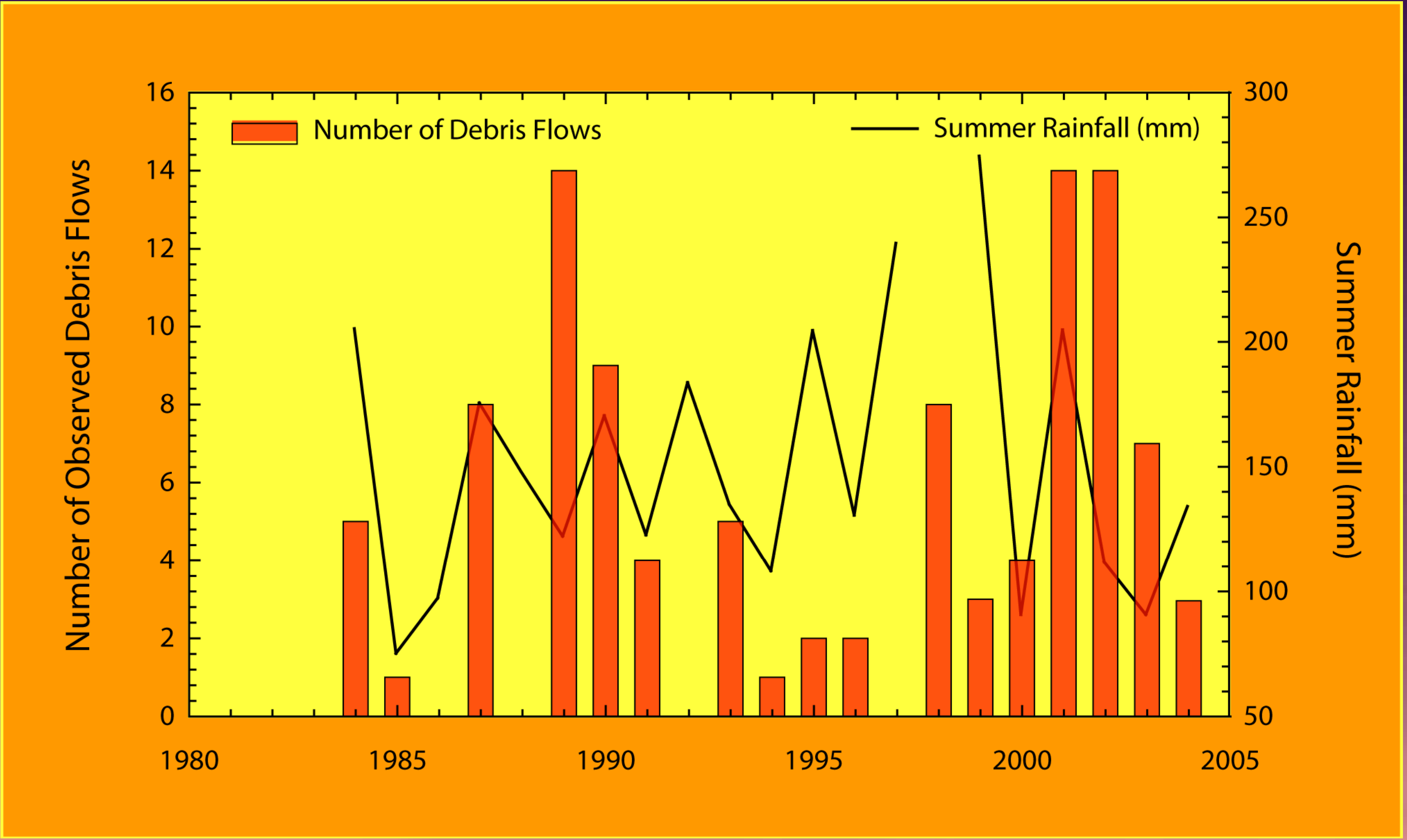
Ref: Griffiths et al. (2004)

Repeat Photography and Debris Flows

- Matched 1,365 photos showing debris-flow evidence at 147 debris fans.
- Earliest photo: 1871. Most useful group: 1890.
- We documented 93 debris flows in 84 tributaries (1890-1983).
- Extrapolation: 5.0 debris flows per year (1890-1983).

Ref: Webb (1996), Webb et al. (1999a)

Observed Debris Flows, 1984-2004



Ref: Griffiths et al. (2004)

Debris Flow Frequency

- From 1890-1983, the reconstructed frequency of debris flows is 5.0 events/yr.
- From 1984-2004, a total of 104 debris flows from 88 tributaries were observed in Grand Canyon (4.9/yr).
- From 1984-2004, 12 increased the severity of existing rapids, 8 changed existing riffles into rapids, and 3 created new riffles.

Ref: Griffiths et al. (2004)

Logistic Regression

- Photography records at least one debris flow in 84 of 160 tributaries (57%) from 1890 through 1990.
- We analyze debris-flow occurrence as “yes/no” categorical data with 22 geologic and morphologic variables.
- We calculate debris-flow probabilities with 5-7 significant variables (e.g., drainage area, lithology, aspect).

Ref: Webb et al. (2000), Griffiths et al. (2004)

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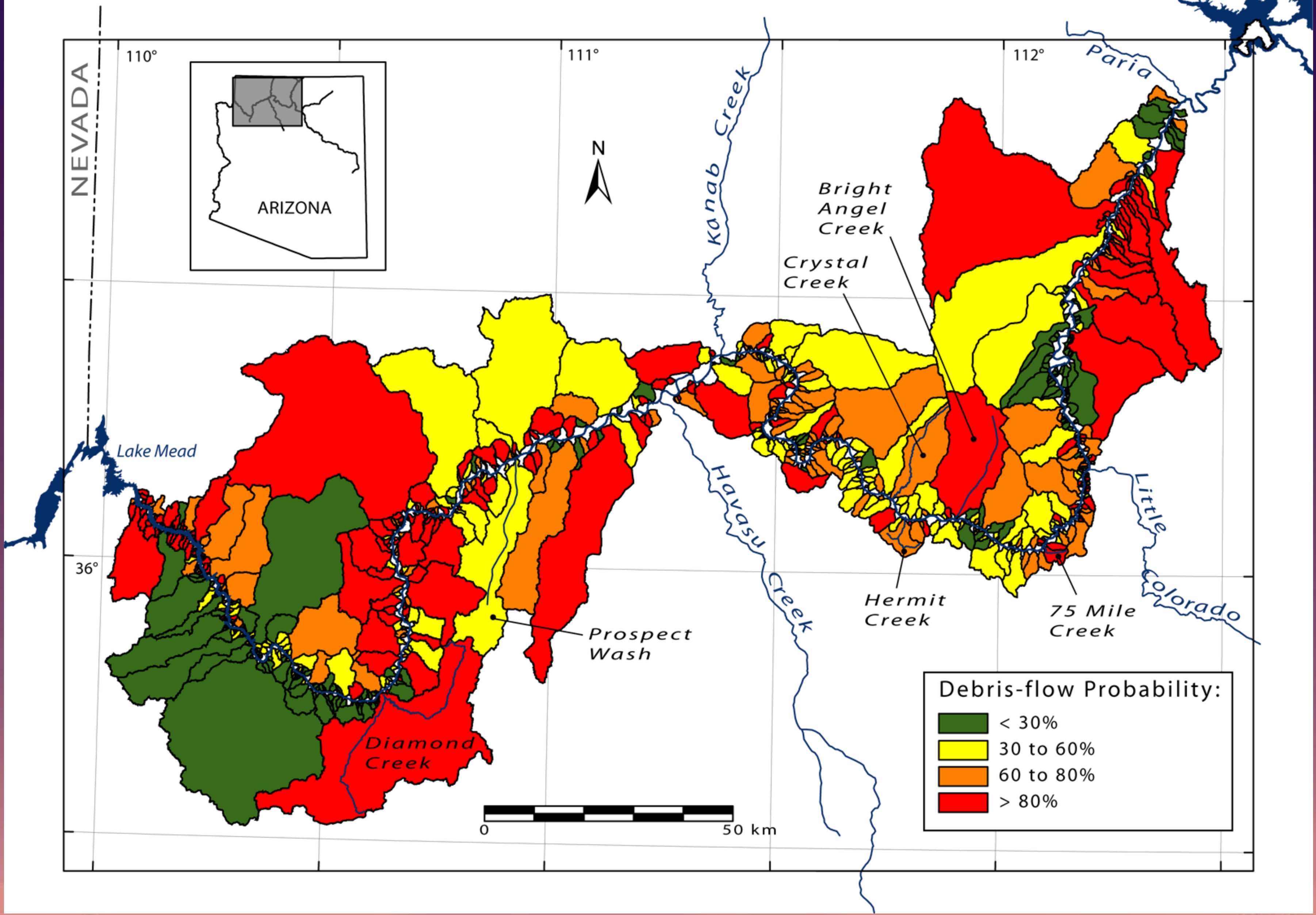


Ref: Griffiths et al. (2004)

Boulder-Delivery Model

- Model form is:

$$Q_b = \Sigma\,(0.769 \cdot E\{PS_b\} \cdot F[\pi(x)] \cdot V\,(A)),$$

where Q_b = boulder delivery (m^3/ka), $E\{PS_b\}$ = 0.138, $F[\pi(x)]$ = frequency factor from logistic regression, $V\,(A)$ = expected debris-flow volume, and the summation occurs over a thousand years.

- Deposition area in river, A_d, is:

$$A_d = W_u \cdot L_r + A_{df}\,,$$

where W_u = width of unconstricted river, L_r = length of rapid, and A_{df} = area of modern debris fan (all measured at 227 m^3/s).

- Bed rise (m/ka), $H = Q_b / A_d$.

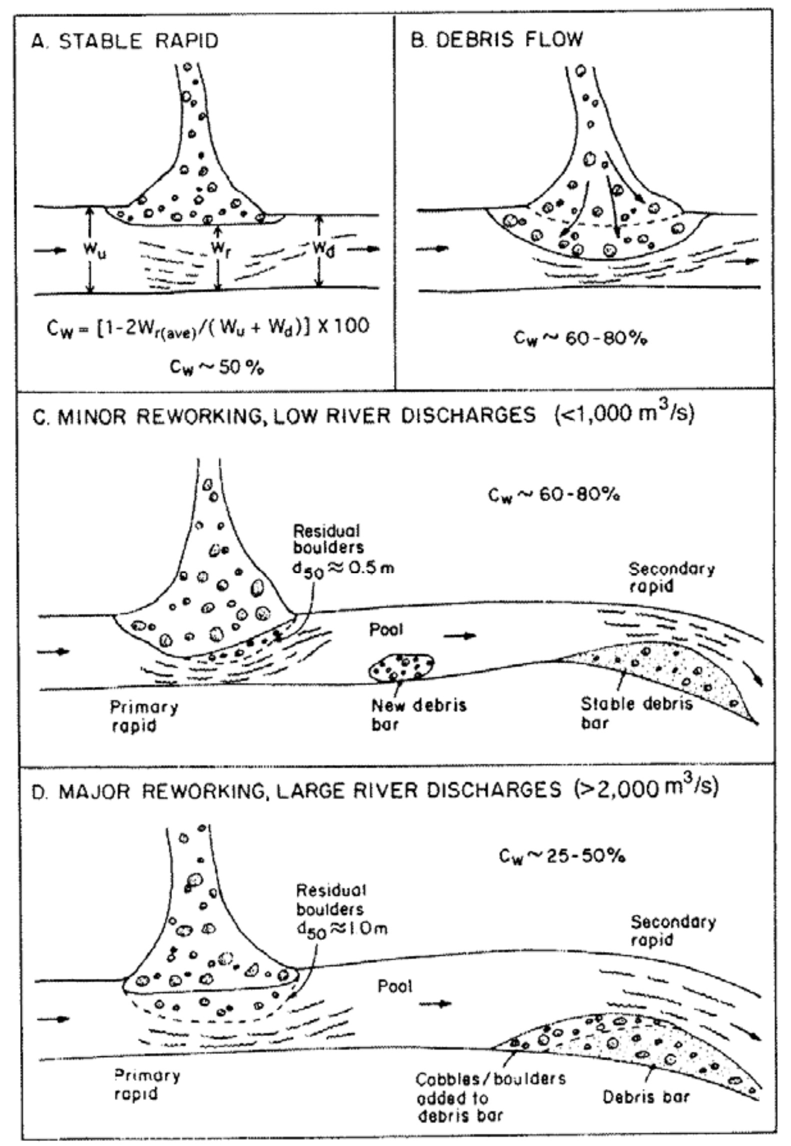
Ref: Webb et al. (2000)

Largest Rapids Versus Predicted Bed Rise

- Realistic: Lava Falls has 4.3 m drop, is predicted to have a 2.75 m drop.
- Questionable: Bright Angel Creek Rapid has a 5.9 m drop, is predicted to have a 12.5 m drop.
- Unrealistic: South Canyon has a 1.2 m drop, is predicted to have a 13.0 m drop.

Ref: Webb et al. (2000, 2004)

River Reworking



- Glen Canyon Dam completed in 1963.
- Pre-dam floods (to 8,500 m^3/s) removed all particles <1-2 m (b-axis diameter).
- Post-dam floods (< 2,720 m^3/s) move smaller particles up to 1.5 m in diameter.
- Particles now end up in the pool instead of the secondary rapid.

Ref: Melis (1997), Webb et al. (1999a, 1999b, 2000)

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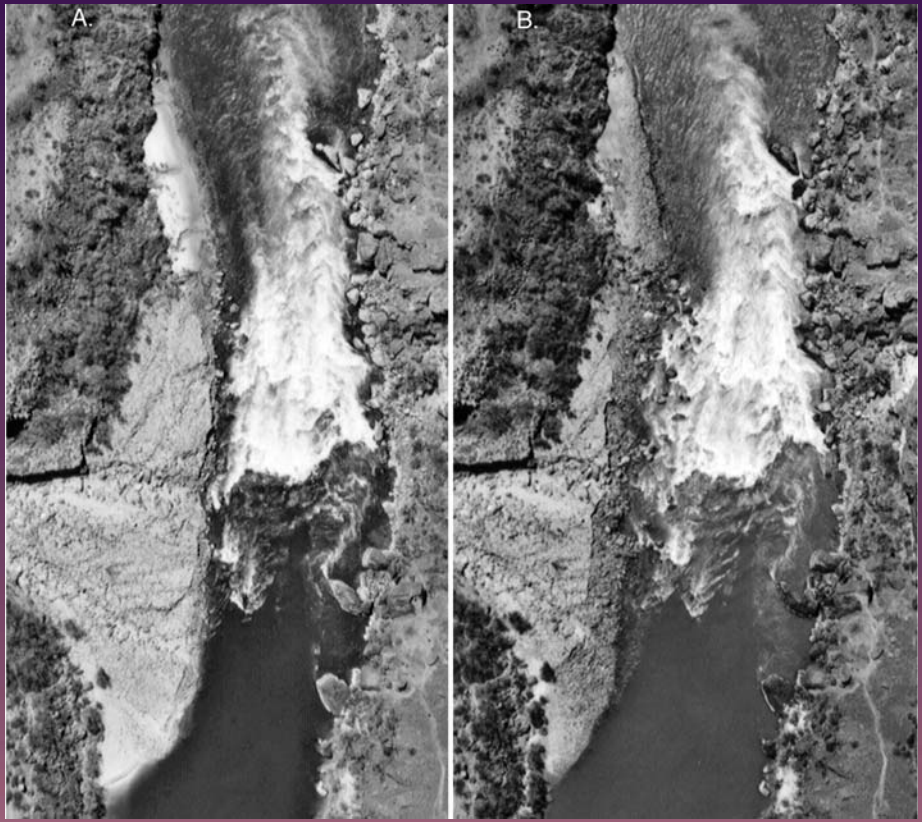
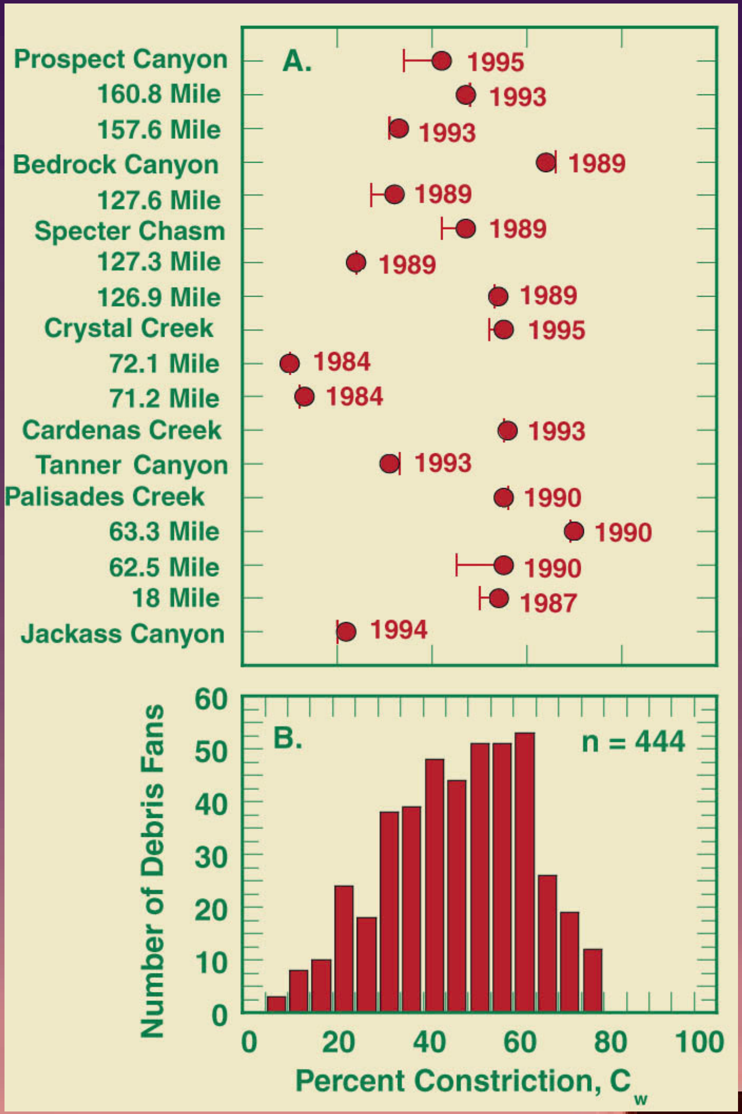
Reworking of Aggraded Debris Fans (the 1996 Flood)



Lava Falls Rapid. A. March 25, 1996. B. April 6, 1996. The rapid widened by about 20 m by reworking of 1995 debris-flow deposits.



Ref: Webb et al. (1999b), Pizzuto et al. (1999)

Geomorphic Change Detection in Grand Canyon: Comparison of 1923 Survey and 2000 Lidar Data

1923 Birdseye Expedition

2000 Lidar Overflight

The water-surface profile in Grand Canyon has been measured twice:

1. Directly surveyed by the USGS expedition in 1923.
2. Extracted from Lidar data collected in 2000.

Ref: Magirl et al. (2005)

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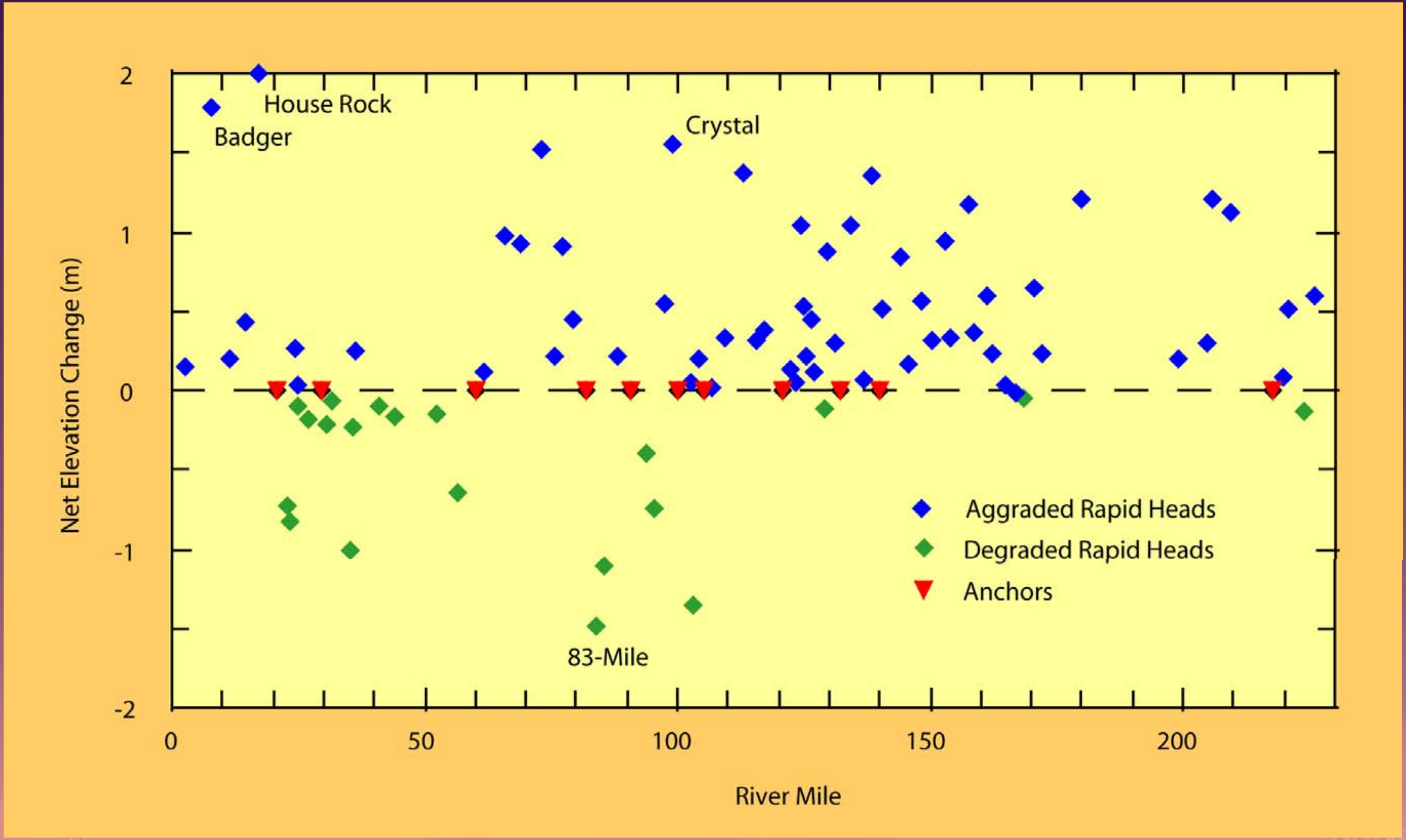
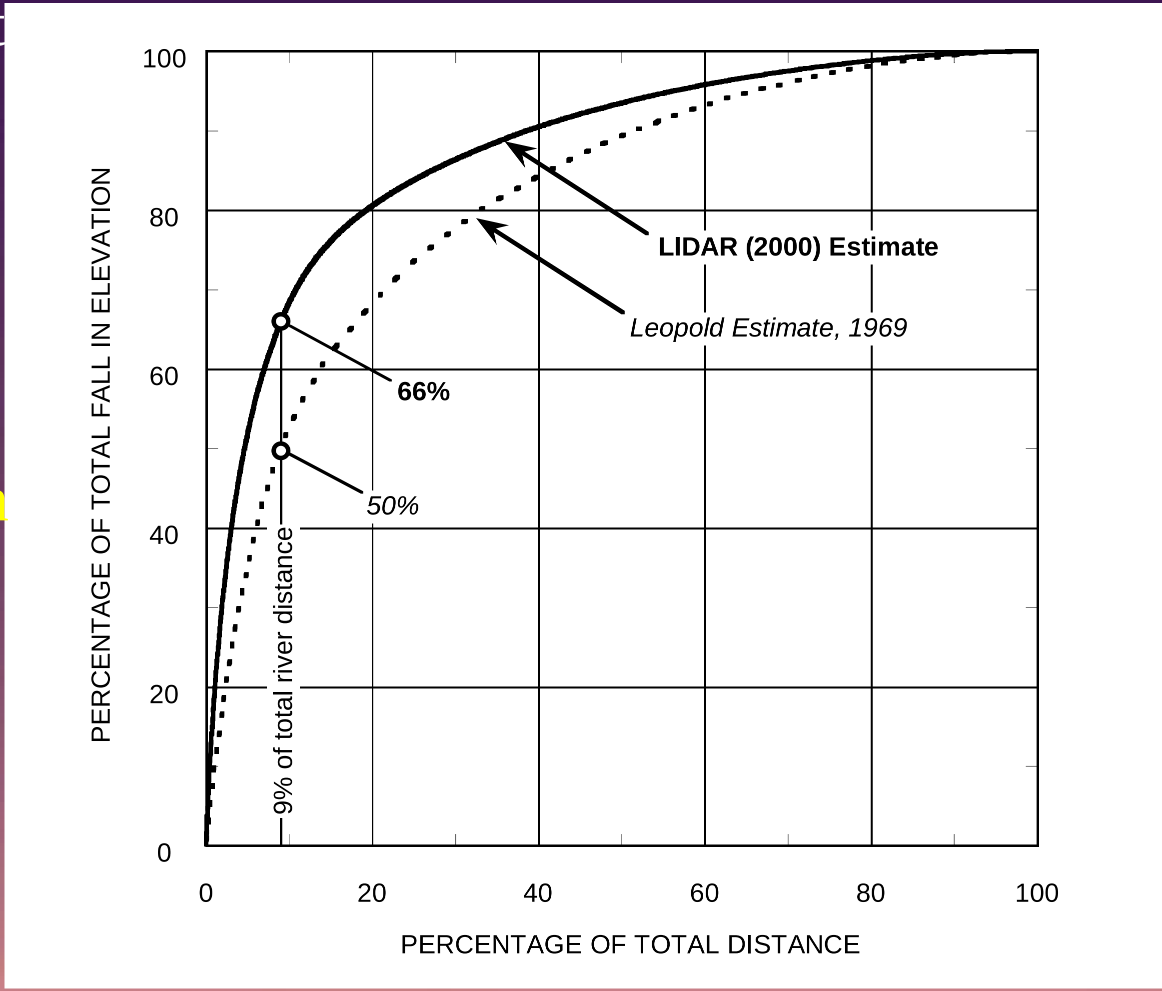
Changes in Rapids, 1923-2000



Ref: Magirl et al. (2005)

Interpretation of Profile Change

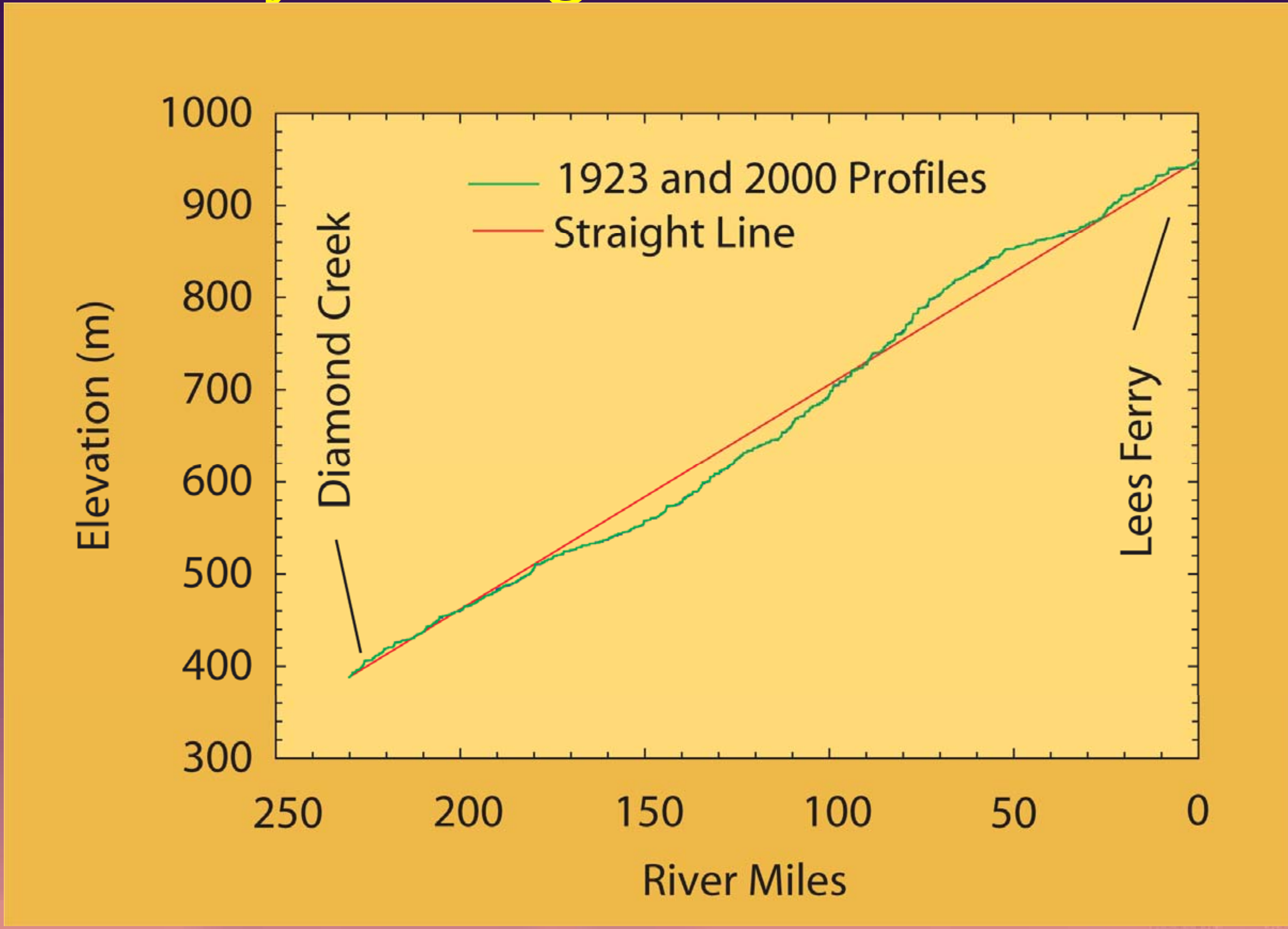
- Leopold (1969) found that 50% of total decrease in elevation takes place in only 9% of the total river distance (1923 profile).
- 2000 Lidar data indicates that 66% of drop occurs in 9% of distance.
- Lack of imagery from ~ 1963 precludes definitive comparison of effects of Glen Canyon Dam operations



Ref: Magirl et al. (2005)

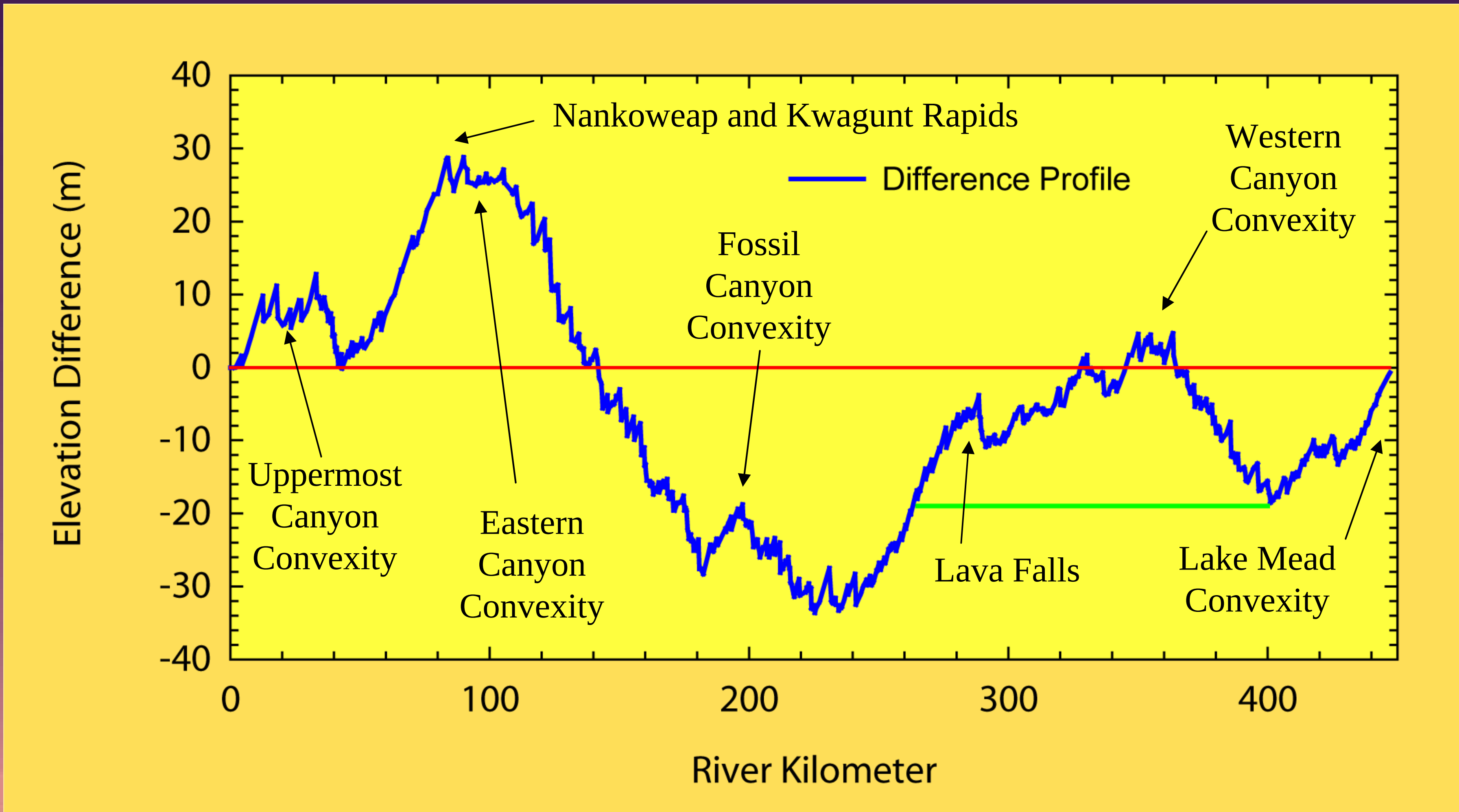
Grand Canyon Longitudinal Profile

The profiles measured in 1923 and 2000 do not show differences at the scale of the full length of the canyon.



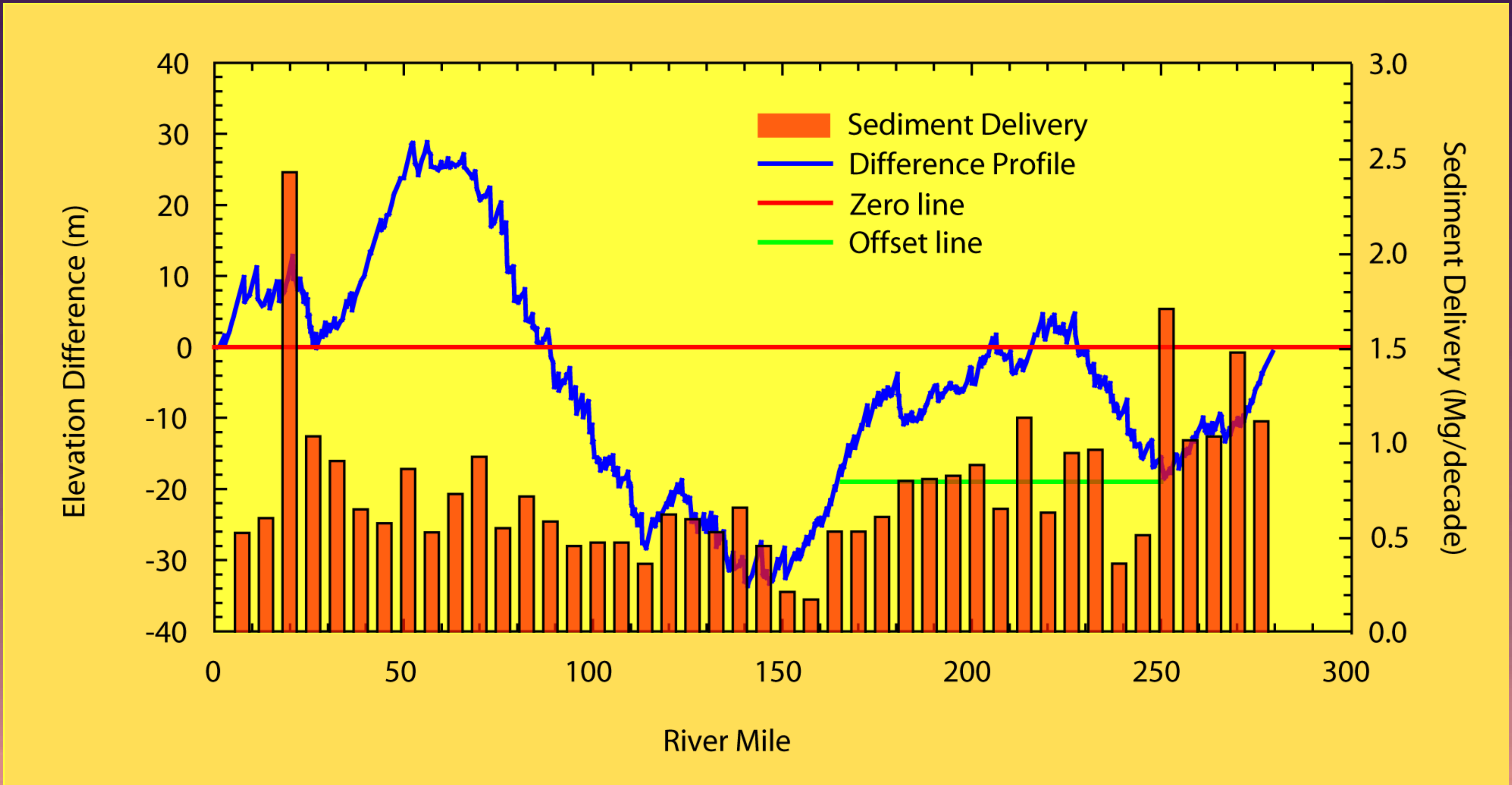
Refs: Hanks and Webb (submitted)

Difference Profile Reveals Convexities



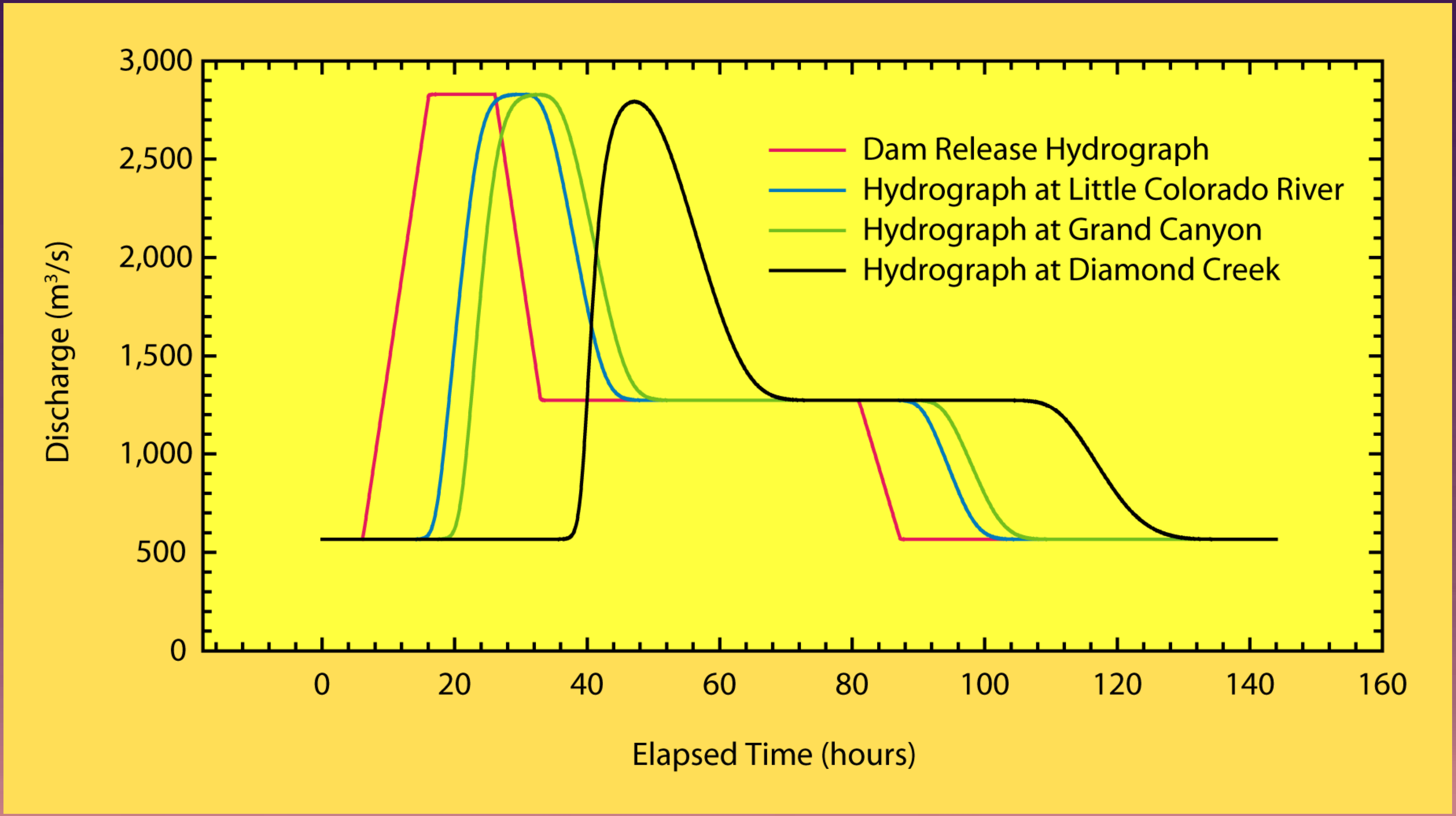
Ref: Hanks and Webb (submitted)

Difference Profile and Debris-Flow Sediment Yield



Ref: Hanks and Webb (submitted)

Future Controlled Flood Release



Ref: Wiele (unpublished data)

Conclusions

- From 1984-2004, an average of 4.9 debris flows has occurred each year. From 1890-1983, 5.0 debris flows occurred each year.
- Logistic regression shows that debris-flow frequency varies among the geomorphic reaches of Grand Canyon.
- Frequency modeling is the basis of a sediment yield model for debris flows that may be able to explain small- and large-scale variation in the river’s longitudinal profile.

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Conclusions

- Howard and Dolan (1981) predicted that the longitudinal profile through Grand Canyon is becoming an enhanced pool-drop profile as a result of operations of Glen Canyon Dam. Owing to minimal data from about 1963, this is difficult to demonstrate conclusively.
- For selected rapids monitored in the last 21 years, aggradation is occurring with local and reach-scale effects on the Colorado River ecosystem.