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

C.S. Magirl, R.H. Webb, and P.G. Griffiths
US Geological Survey, Tucson, Arizona

1923 Birdseye Expedition

Birdseye Expedition of Soap Creek Rapid. Kolb photograph 568-5137, courtesy of Special Collections, the Cline Library, Northern Arizona University.

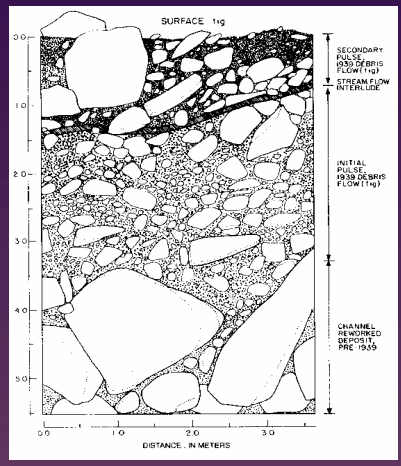
2000 LIDAR Over-flight

USGS science for a changing world

Techniques to Detect Debris Flows

Fresh debris-flow deposit at Lava Falls, 1995 (R.H. Webb, Stake 2964b).

- *Geochronology*
- *Direct observation*
- *Stratigraphy*
- *Repeat photography*



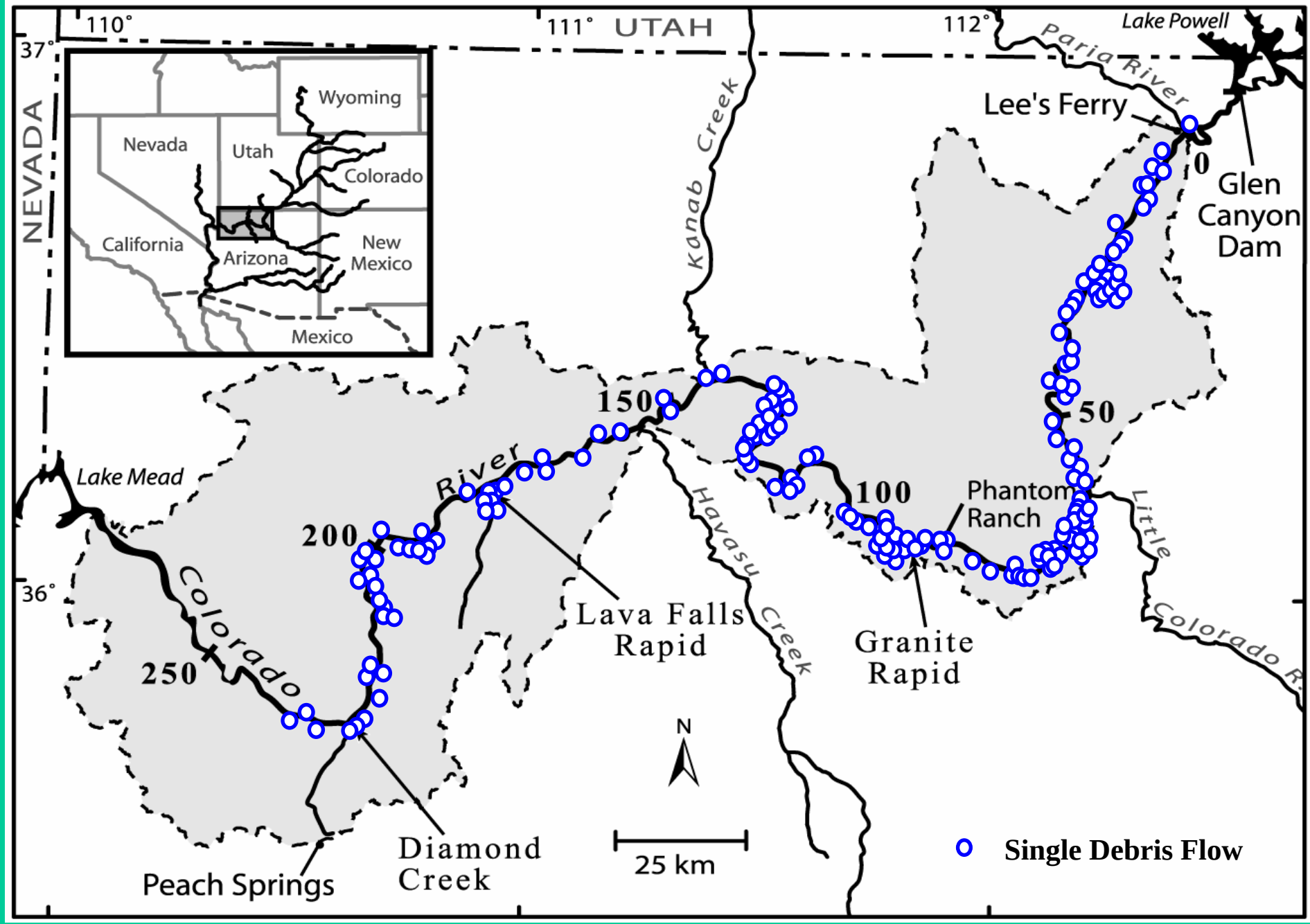
Typical debris flow stratigraphy from Prospect Canyon (Lava Falls Rapid).

1890 – 1990 Elf's Chasm

USGS science for a changing world

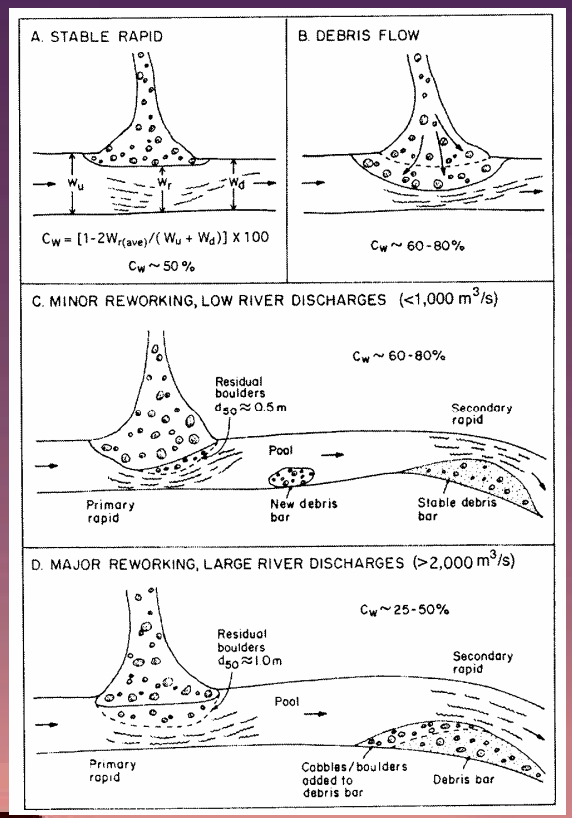
February 2003
C.S. Magirl, USGS

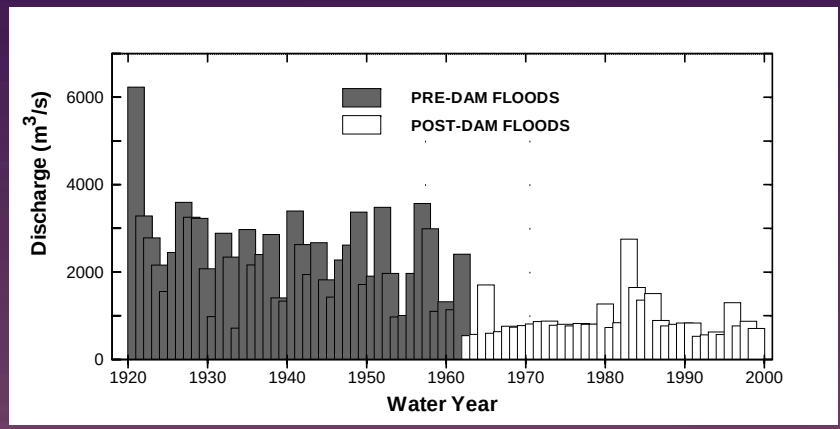
Distribution of Historical Debris Flows (1872-2002)



River Reworking

Debris flows add material to the river at a rate of 4-5 events per year.





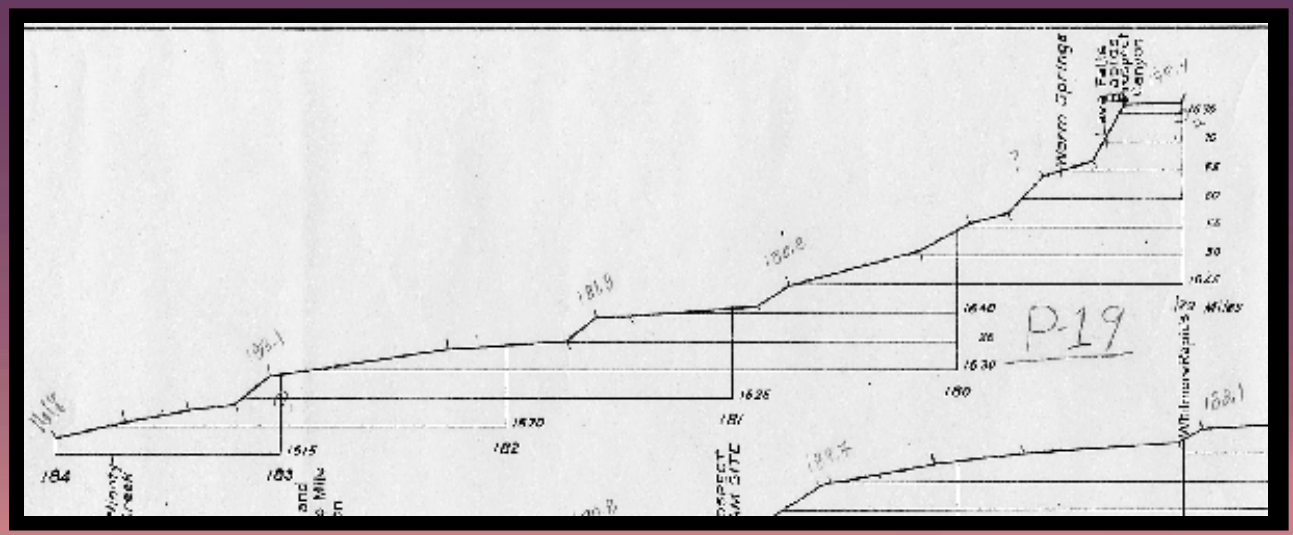
Historically, main-stem floods reworked debris flow deposits. Flood frequency in Grand Canyon drastically different in the post-Glen Canyon Dam era.

USGS science for a changing world

February 2003
C.S. Magirl, USGS

1923 US Geological Survey Expedition

- Led by Colonel Claude Birdseye
- Used stadia rod and theodolite survey technology
- Took four boats and one canvas canoe
- August 1, 1923 (Lee's Ferry, AZ) to October 19, 1923 (Needles, CA)
- Detailed survey along river corridor
- Published first comprehensive water-surface profile of Grand Canyon

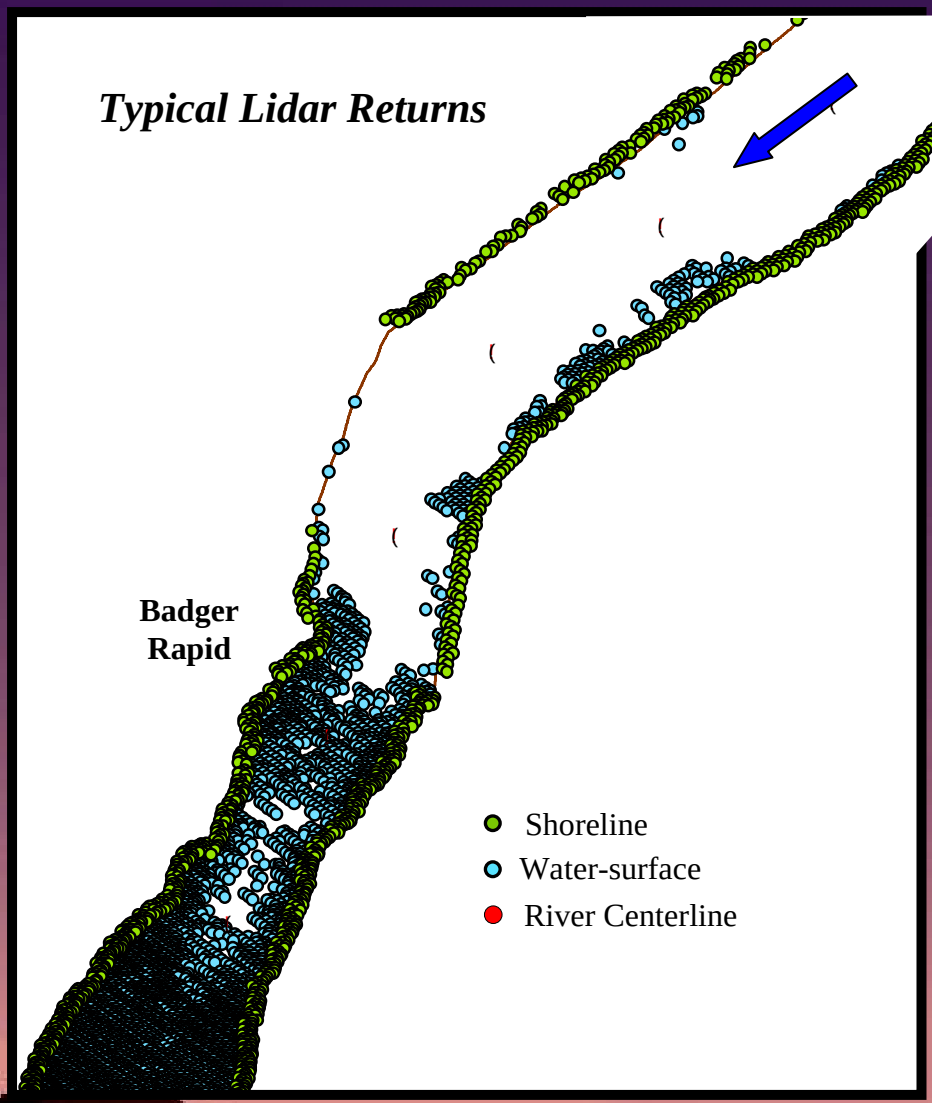


U.S. Geological Survey. 1924. Plan and profile of Colorado River from Lees Ferry, Ariz., to Black Canyon, Ariz.-Nev. and Virgin River, Nev.: U.S. Geological Survey, 21 sheets (A-U).

USGS science for a changing world

February 2003
C.S. Magirl, USGS

2000 GCMRC LIDAR Overflight

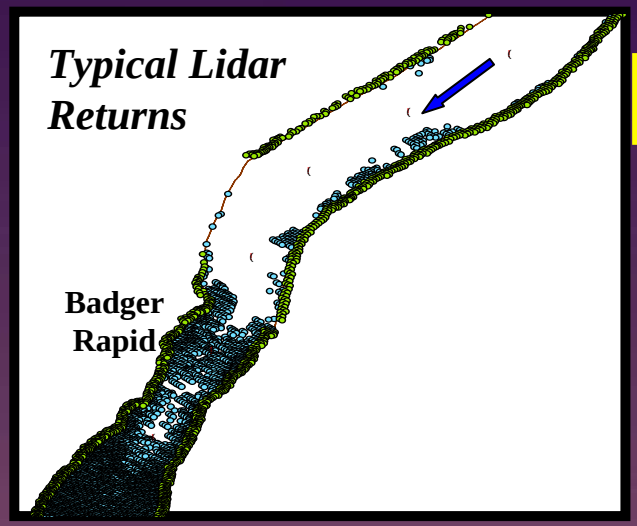


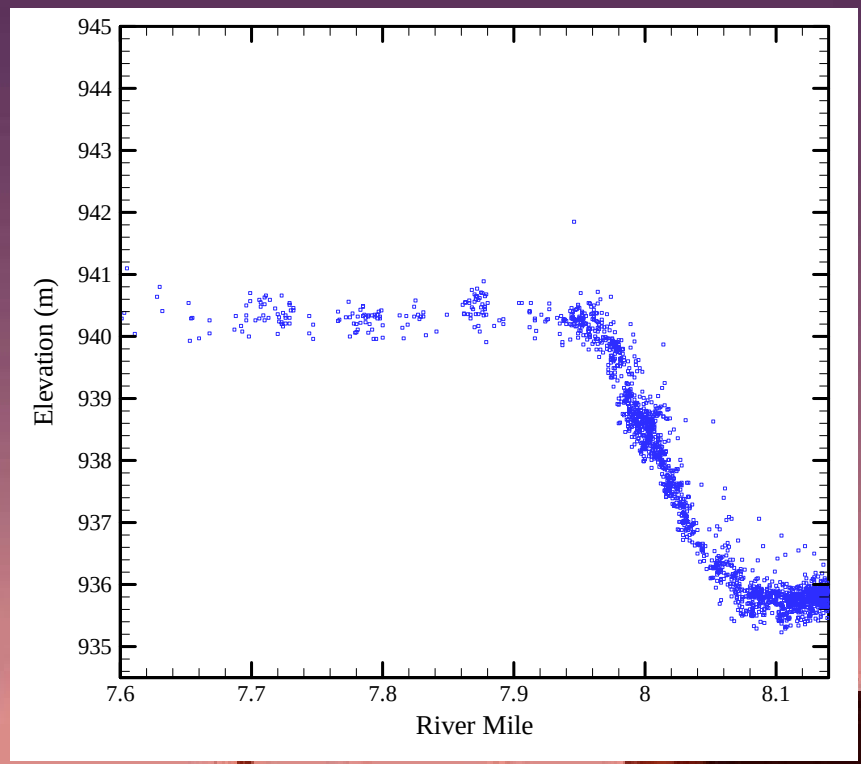
- Grand Canyon Monitoring and Research Center (GCMRC) coordinated remote sensing using LIght Detection And Ranging (LIDAR)
- Terrestrial topography was the focus--NOT water-surface profile
- Discarded returns from water used to construct new water-surface profile
- The first opportunity to create a comprehensive water-surface profile since Birdseye

USGS science for a changing world

February 2003
C.S. Magirl, USGS

Producing a Water-Surface Profile from LIDAR Data

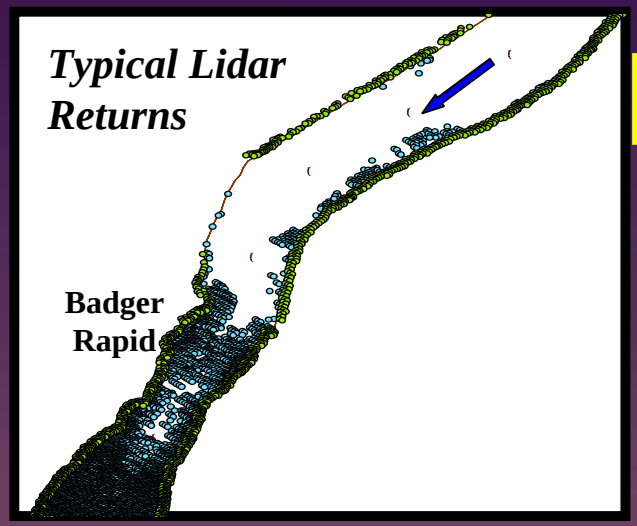


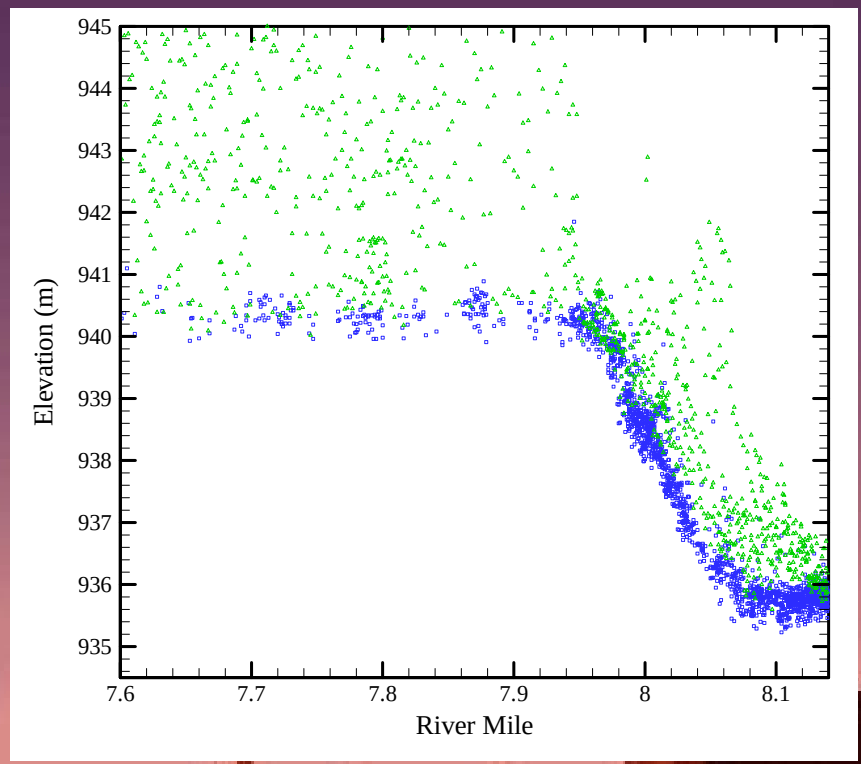


USGS science for a changing world

February 2003
C.S. Magirl, USGS

Producing a Water-Surface Profile from LIDAR Data

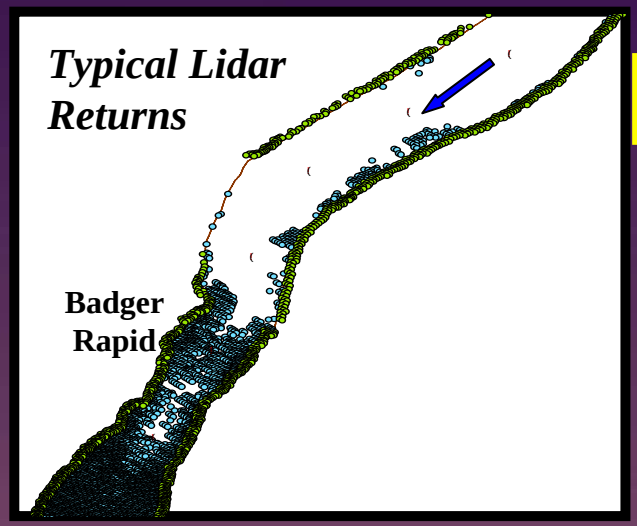


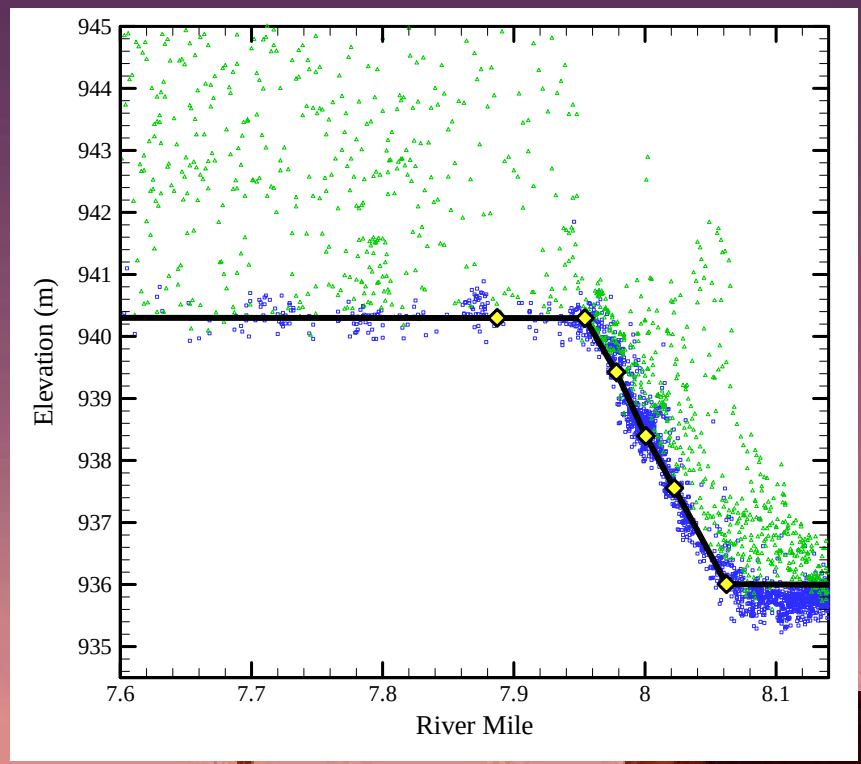


USGS science for a changing world

February 2003
C.S. Magirl, USGS

Producing a Water-Surface Profile from LIDAR Data

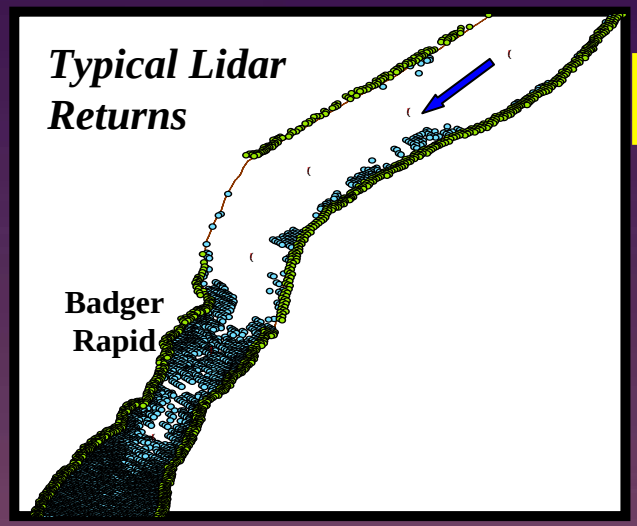


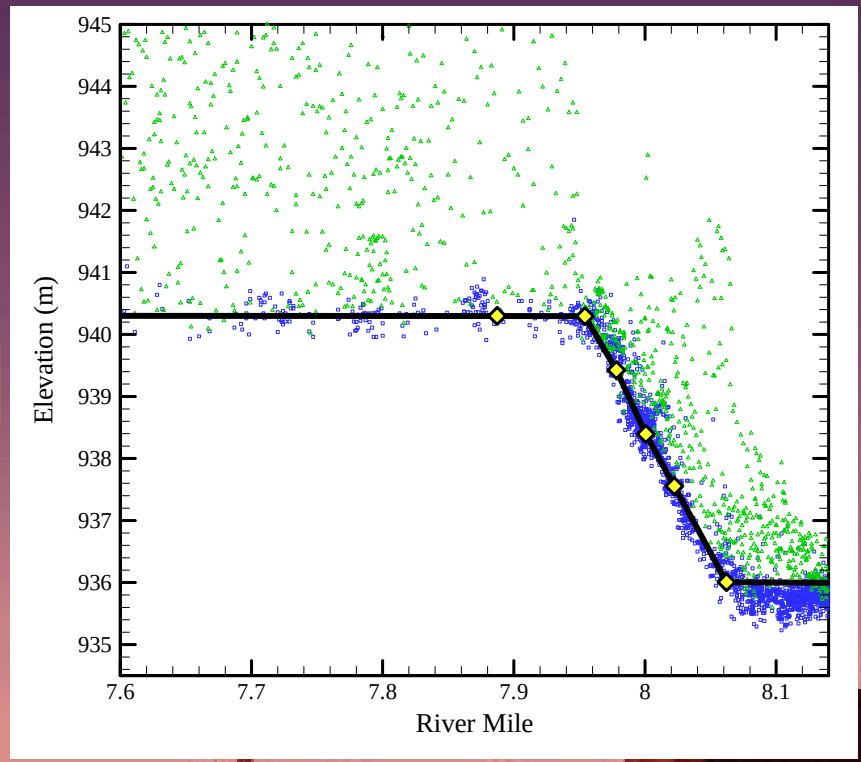


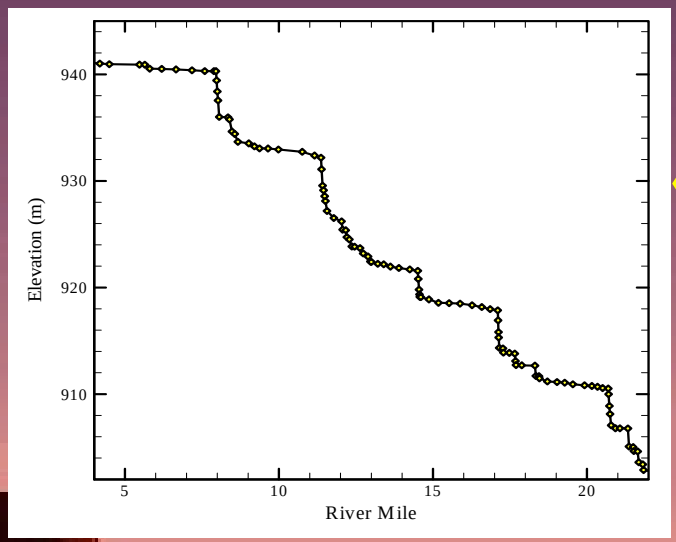
USGS science for a changing world

February 2003
C.S. Magirl, USGS

Producing a Water-Surface Profile from LIDAR Data







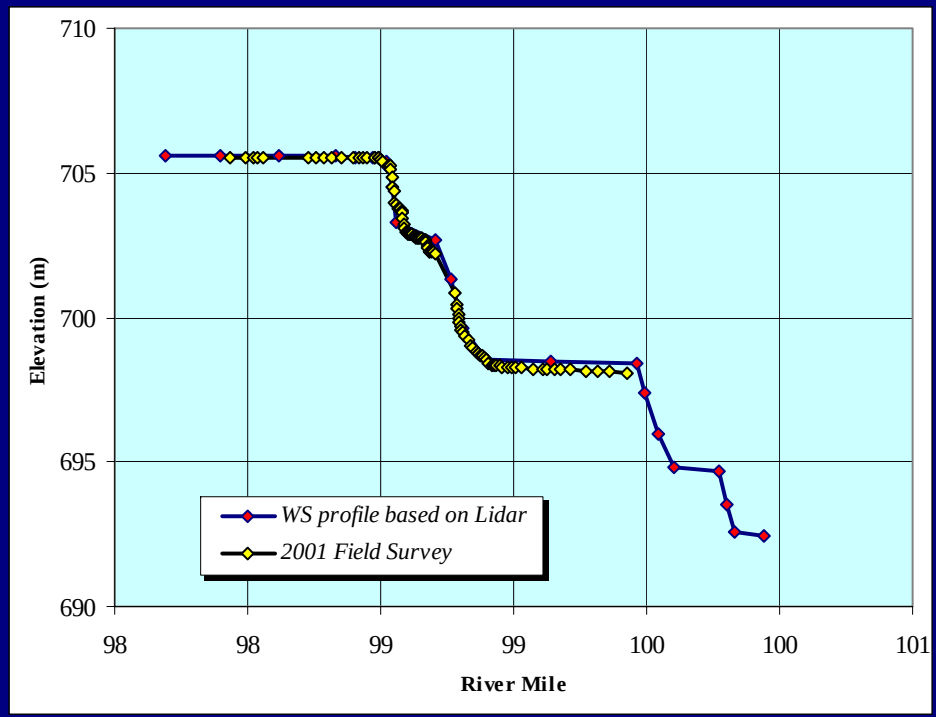
USGS science for a changing world

February 2003
C.S. Magirl, USGS

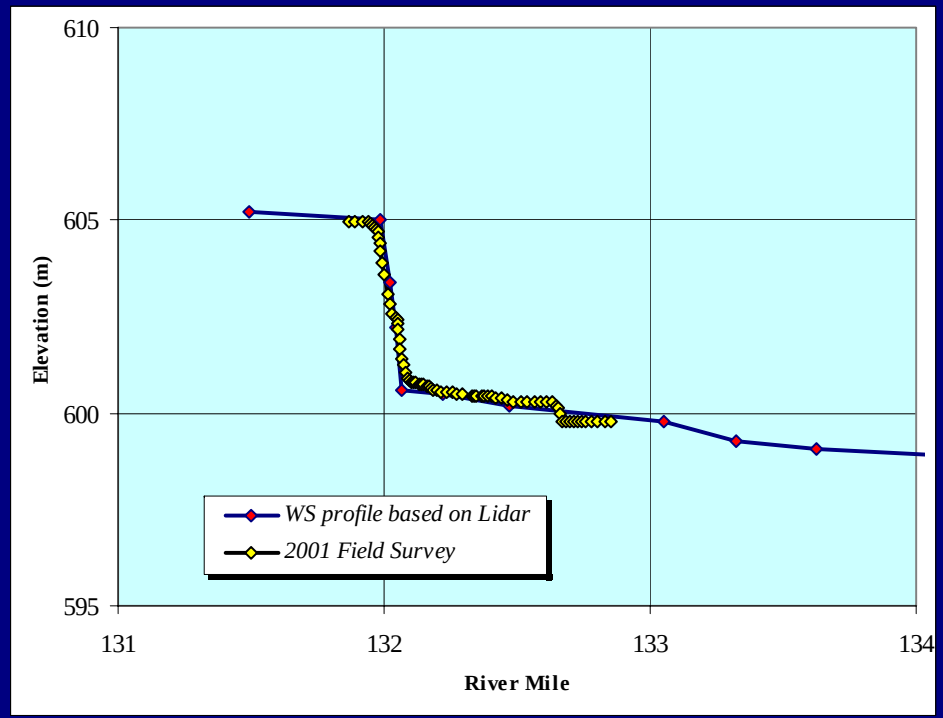
Verification of Lidar Profile with in-situ Survey

Survey data collected May 2002

Crystal Rapid



Dubendorff Rapid



USGS science for a changing world

February 2003
C.S. Magirl, USGS

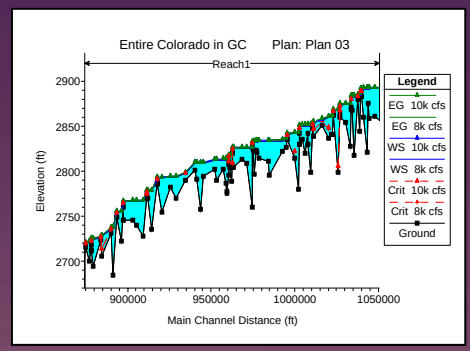
Comparison of 1923 Survey and 2000 LIDAR Data

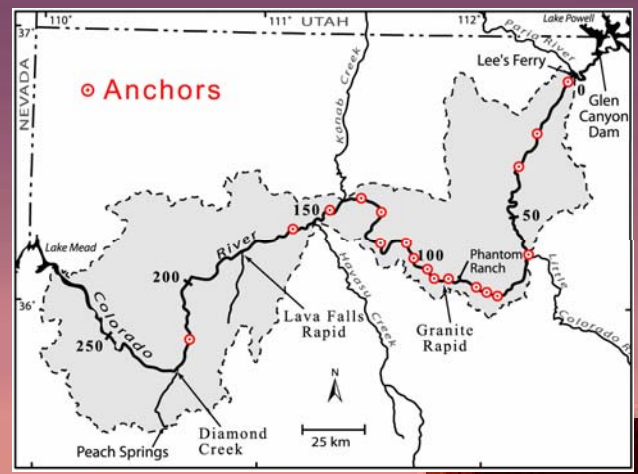
Issue

- Unique interpretations of river centerline—River mile position.
- 1924 Birdseye maps produced at 10,000 ft^3/s; 2000 LIDAR flown at 8,000 ft^3/s.
- Different global frames of reference: State plane vs. NAD27 coordinate systems

Solution

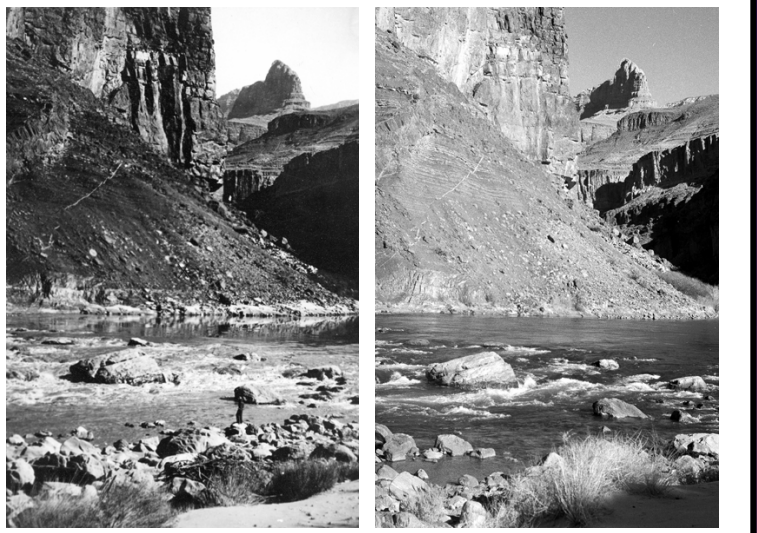
- ***Manually adjust Birdseye river miles***
- ***HEC-RAS simulation of water-surface profile***
- ***Anchor points***



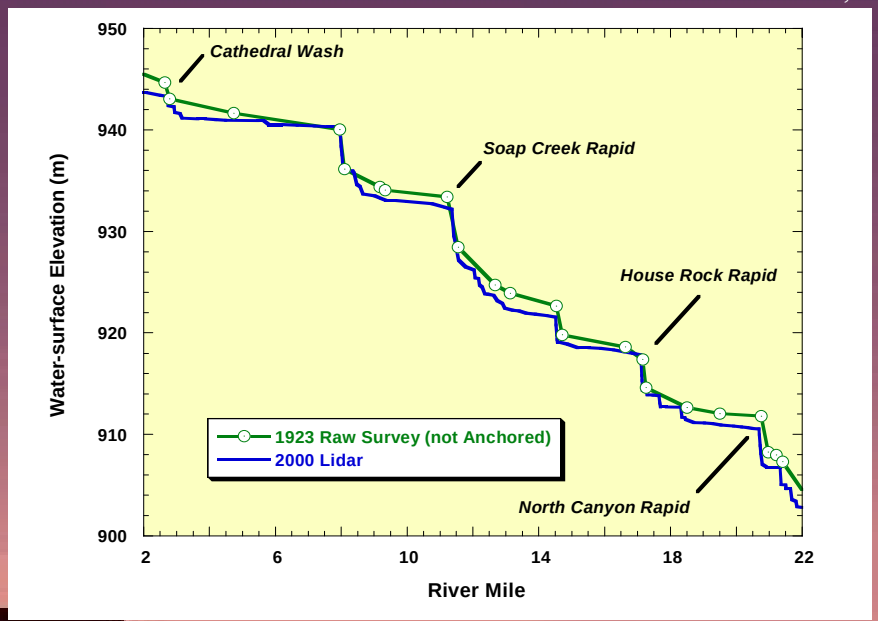


Anchor Points: Unchanged Rapids

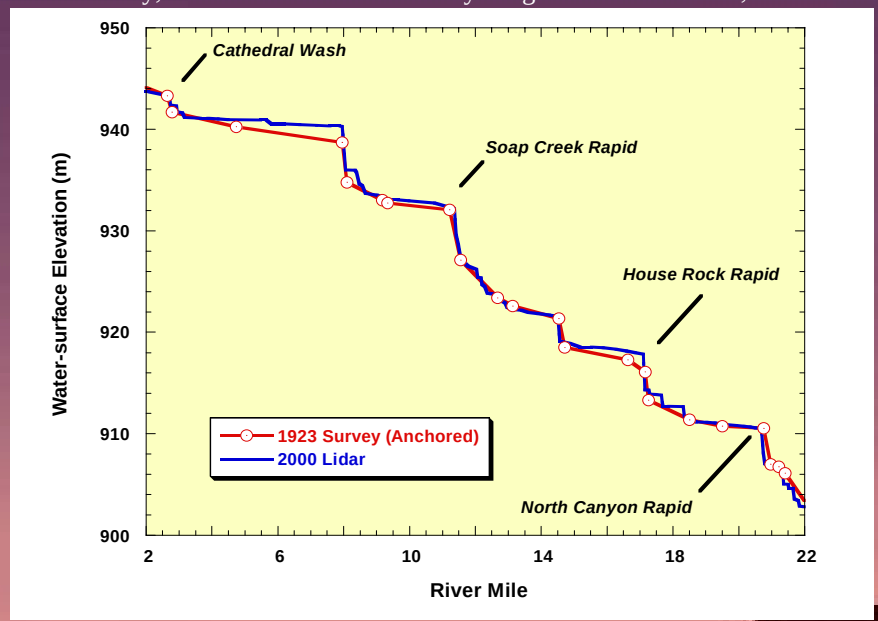
Using rapids that were not constricted by debris flows between 1923-2000 to tie together data sets



Hance Rapid unchanged form 1911 to 1990. Left: Kolb photograph 5834, courtesy of Special Collections, the Cline Library, Northern Arizona University. Right: Tom Brownold, Stake 1451



Marble Canyon; Before Anchoring

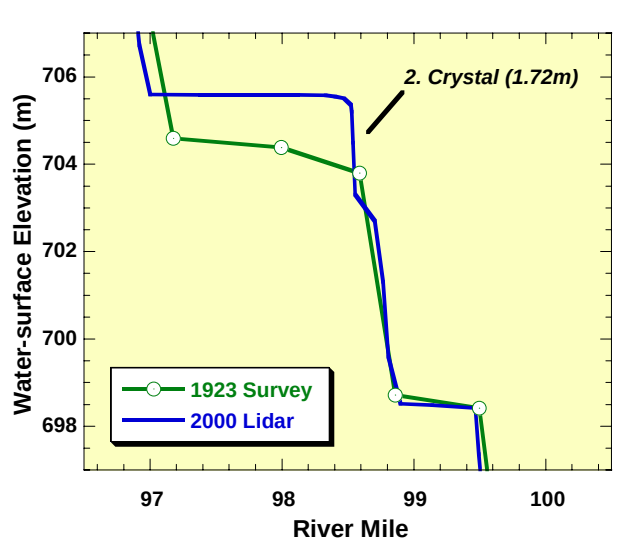


After Anchoring

USGS science for a changing world

February 2003
C.S. Magirl, USGS

Crystal Rapid



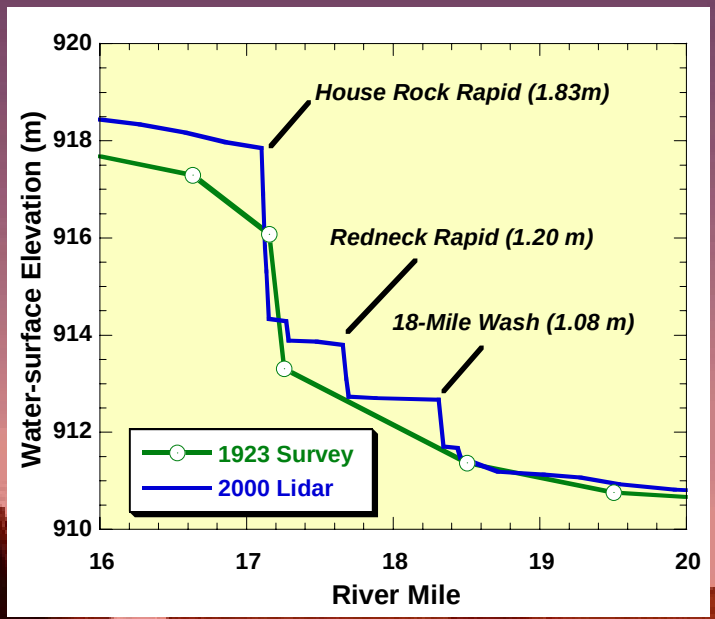
- 1966 Debris Flow
- Reworking in 1983

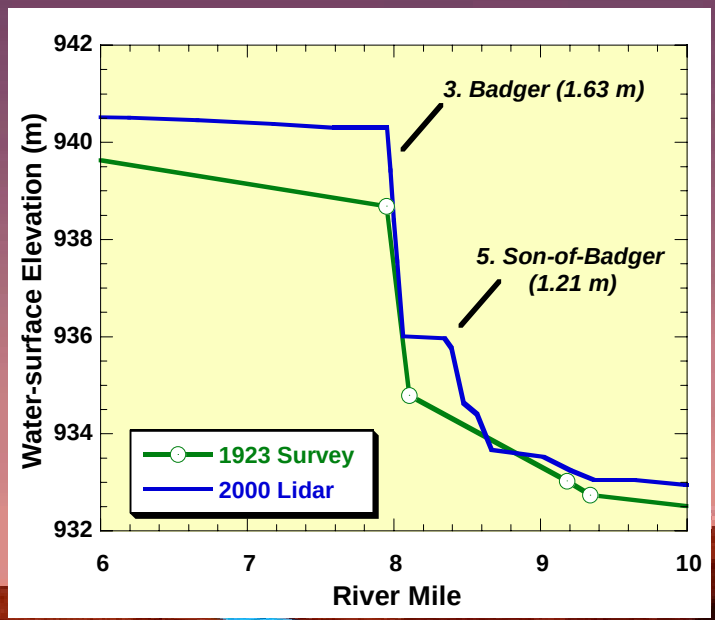
USGS science for a changing world

February 2003
C.S. Magirl, USGS

Top Ten Net Increases at the Heads of Rapids

	Rapid or Tributary	River Mile	WS rise (m)	Known Debris Flows ('23-'00)	Years	Reworking Floods
1	House Rock	17.1	1.83	1	1966-1971	1983
2	Crystal	98.8	1.72	2	1966, 1973-1986	1983
3	Badger	8.0	1.63	1	1994	1996
4	Doris (137.5 Mile)	138.3	1.29	0		??
5	son-of Badger	8.4	1.21	n/a	n/a	1996
6	Redneck	17.7	1.20	Rockfall	1973-74	1983
7	36.7R	37.0	1.16	0		??
8	Specter	129.7	1.13	1	1989	1996
9	18-Mile Wash	18.4	1.08	1	1987	1996
10	205- Mile	205.7	1.07	2	1937-56, 1998	several





USGS science for a changing world

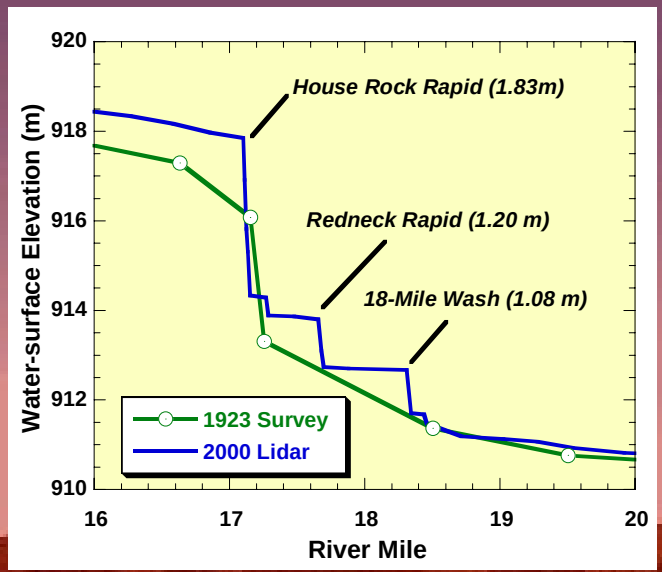
February 2003
C.S. Magirl, USGS

Largest Rise at Head of a Rapid

House Rock Rapid, mile 17.1

1923

1991



Net Rise: 1.83 m

USGS science for a changing world

February 2003
C.S. Magirl, USGS

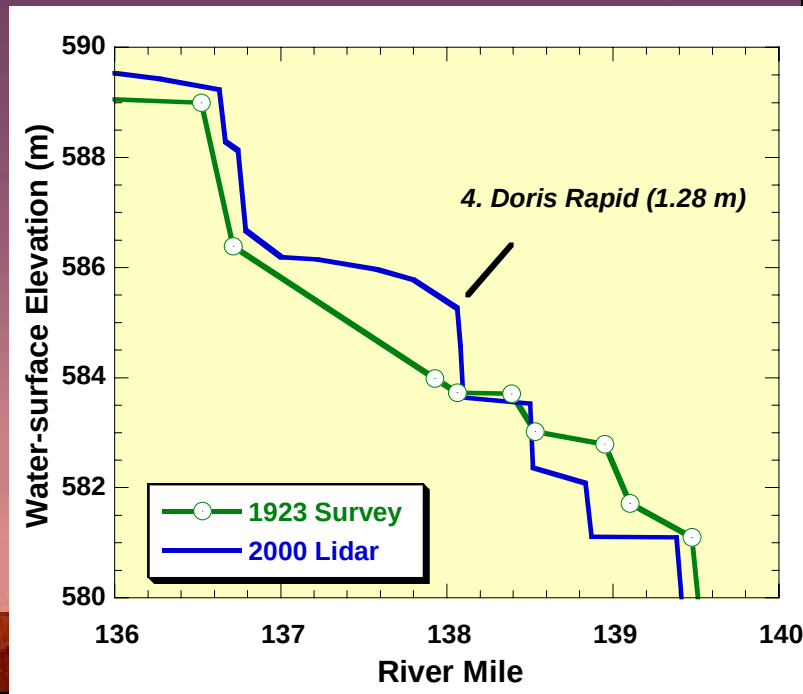
Detection of Previously Unknown Debris Flows

The riddle of Doris Rapid (mile 138.3):

- 1890: Stanton reports a 2.4-3.0 m drop
- 1923: Birdseye measures a 0.3 m drop
- 1940: Doris Nevills swims an enlarged rapid
- 2000: LIDAR measures a 1.62 m drop

Possible Explanation:

1. Debris flow occurs between 1884-1890
2. The 6,230 m^3/s flood in 1921 reworks the first deposit
3. A second debris flow occurs between 1923-1940

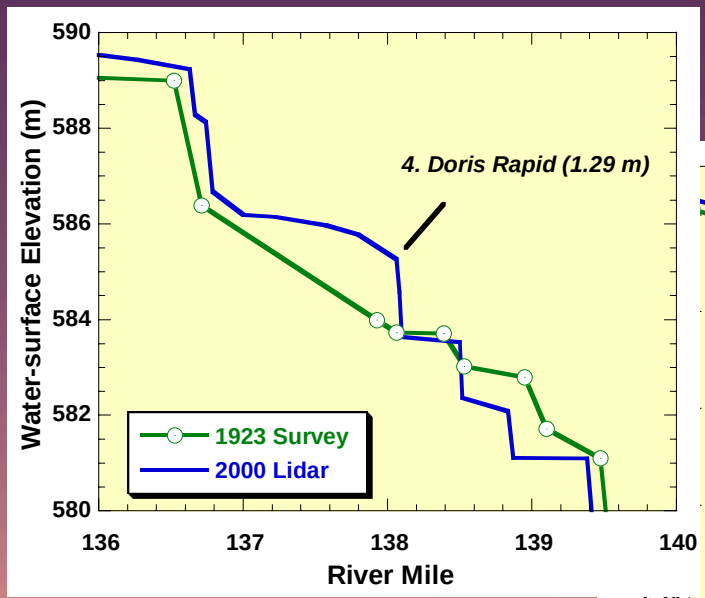


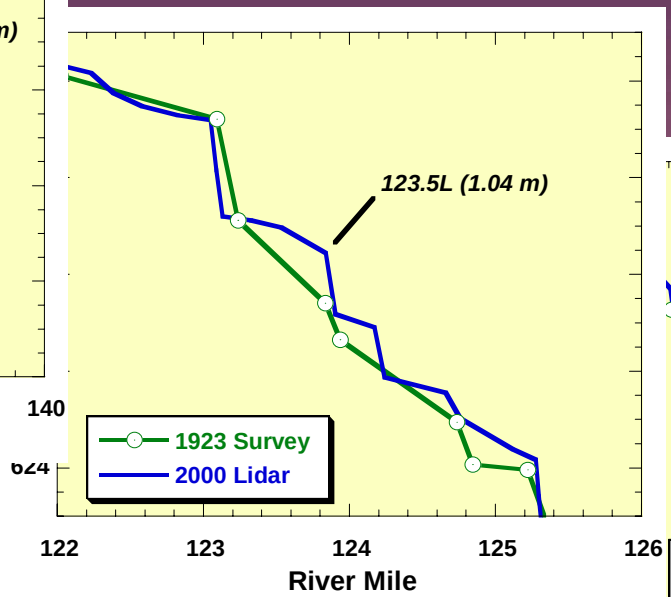
USGS science for a changing world

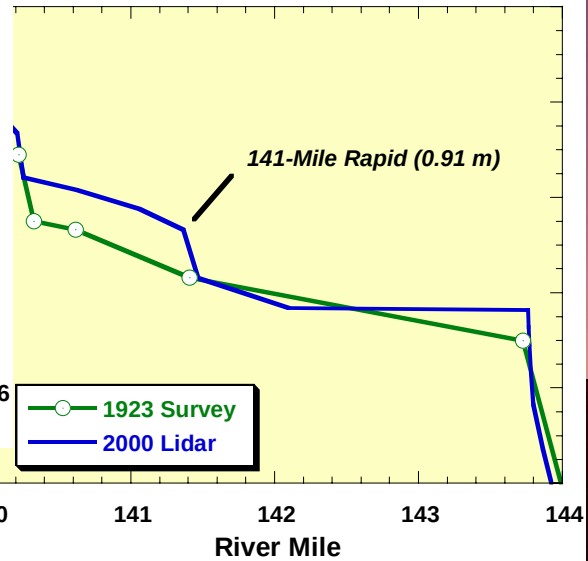
New Debris Flows Identified

The following rapids/riffles are new since 1923 and we have no record, based on repeat photography, of debris flows at these sites:

Doris Rapid (137.5-Mile Rapid)	[+1.29 m]
36.7 L (not shown)	[+1.16 m]
123.5 L	[+1.04 m]
141-Mile Rapid	[+0.91 m]



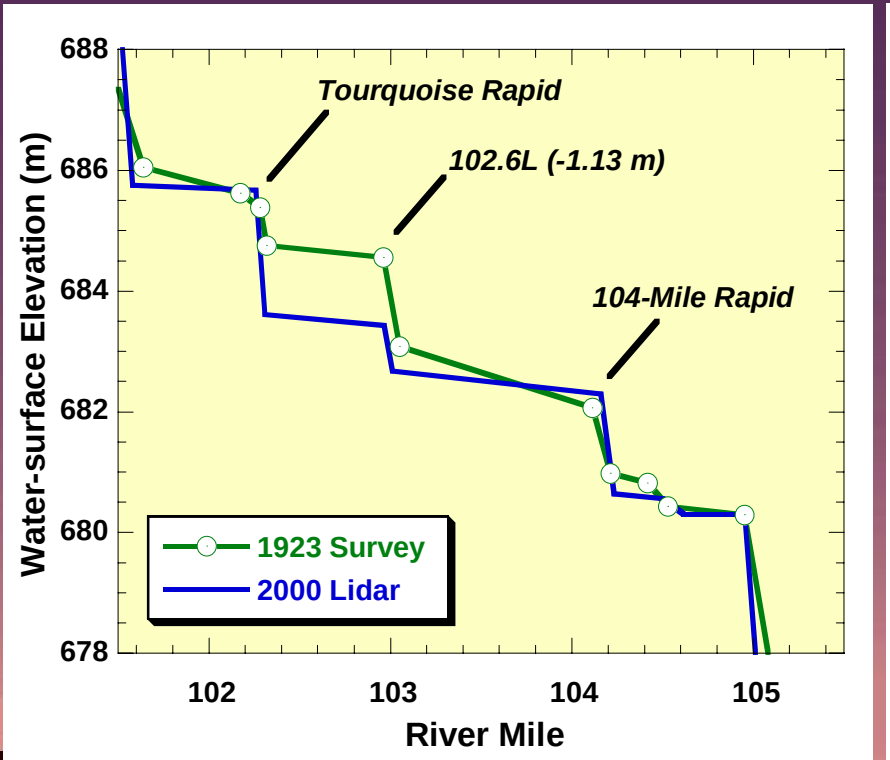


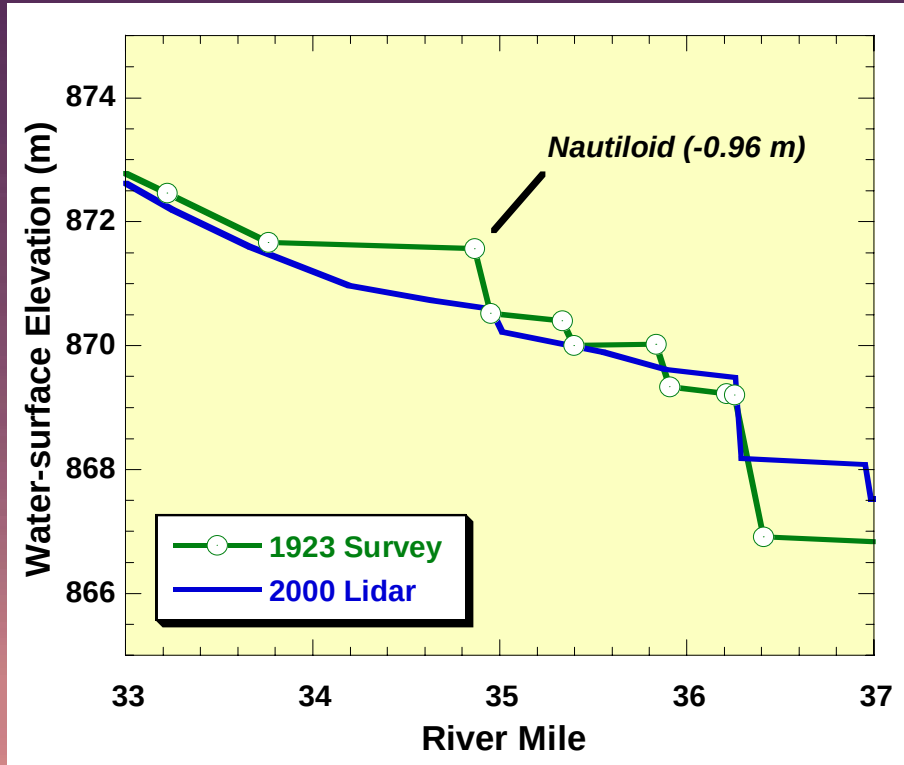


USGS science for a changing world

Largest Net Decrease at the Head of Rapids

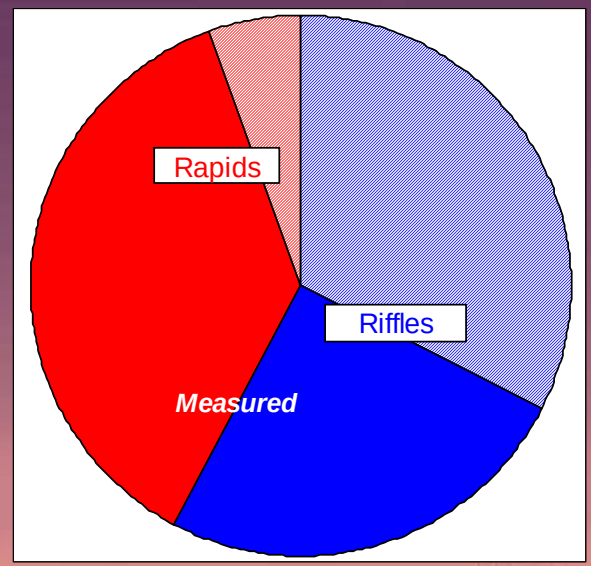
	Rapid or Tributary	River Mile	WS rise (m)	Known Debris Flows ('23-'00)	Years
145	102.6L	103.2	-1.13	1	1890-1990
144	79.4L	79.9	-1.02	0	
143	Nautiloid	35.0	-0.96	1	1980-1984





Success in Change Detection: Lee's Ferry (RM 0.0) to Diamond Creek (RM 226.0)

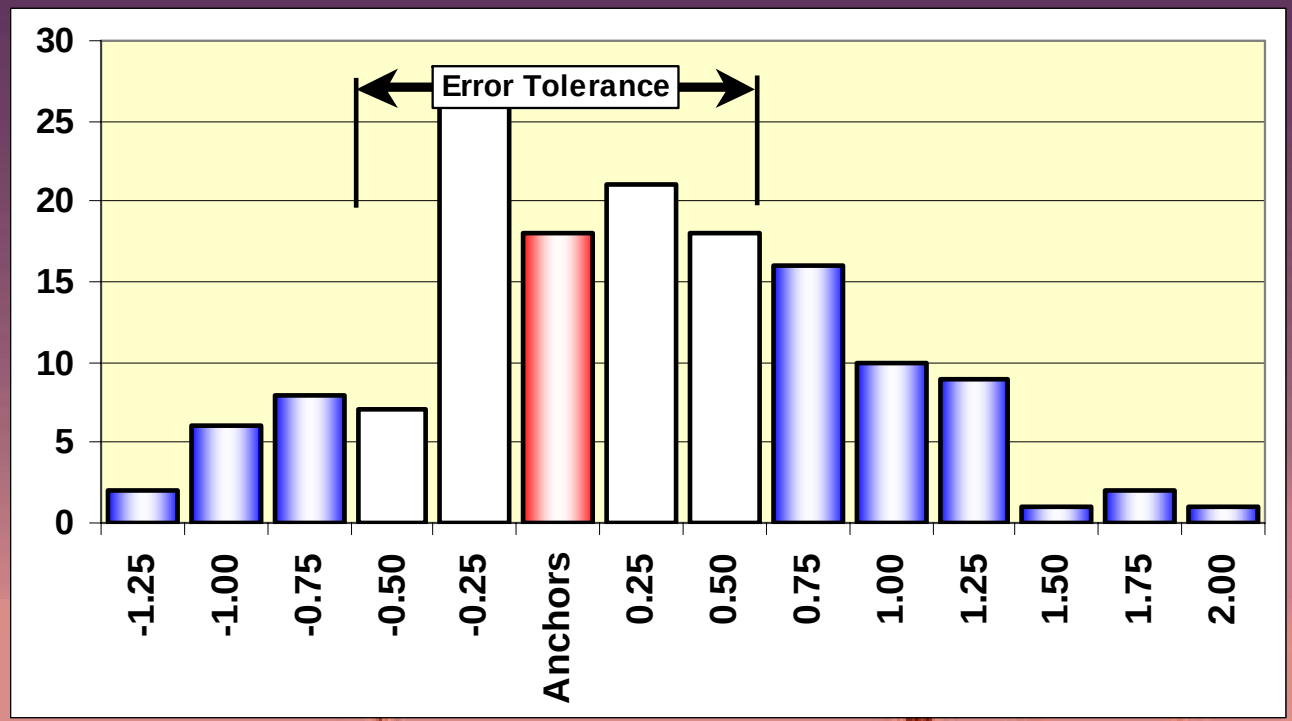
- 530 tributaries in this reach [Webb et al., 2000]
- 234 rapid/riffle drops by the 2000 Lidar Profile
- 145 rapids/riffles were compared with this technique
  - 62% of all riffles
- 99 named rapids [Stevens, 1983]
  - 87% of these rapids measured



USGS science for a changing world

Net Change in Rapids

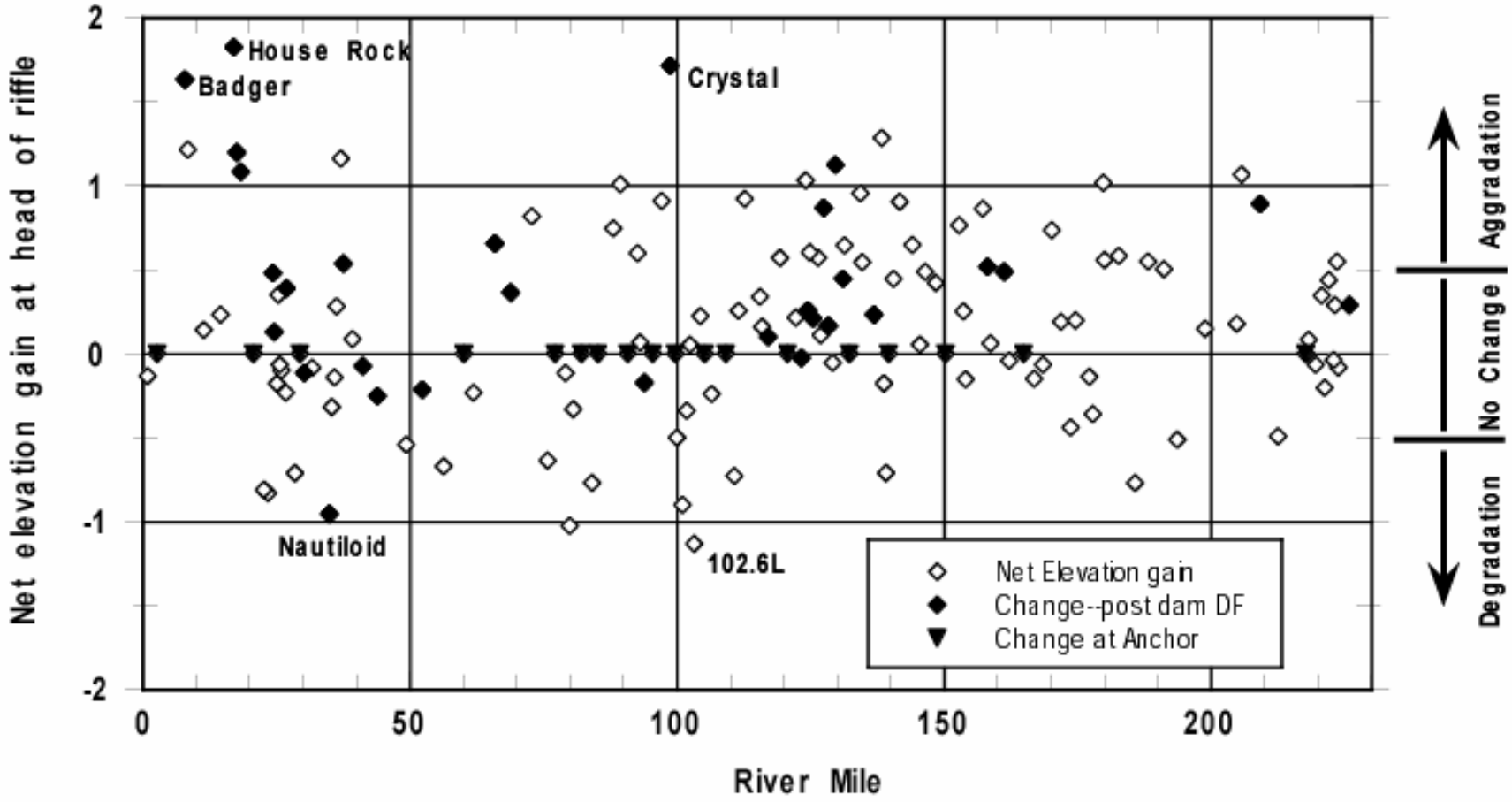
- 145 drops (18 anchors, 127 tributaries measured)
- Error tolerance in measurement roughly ± 0.5 meters
- 39 tributary mouths are aggraded
- 16 tributary mouths show degradation
- 72 saw net change less than 0.5 m
- Mean aggradation at 145 tributaries: +0.18



USGS science for a changing world

February 2003
C.S. Magirl, USGS

Net Change at riffle by river mile



- More aggradation than degradation
- No clear spatial signal

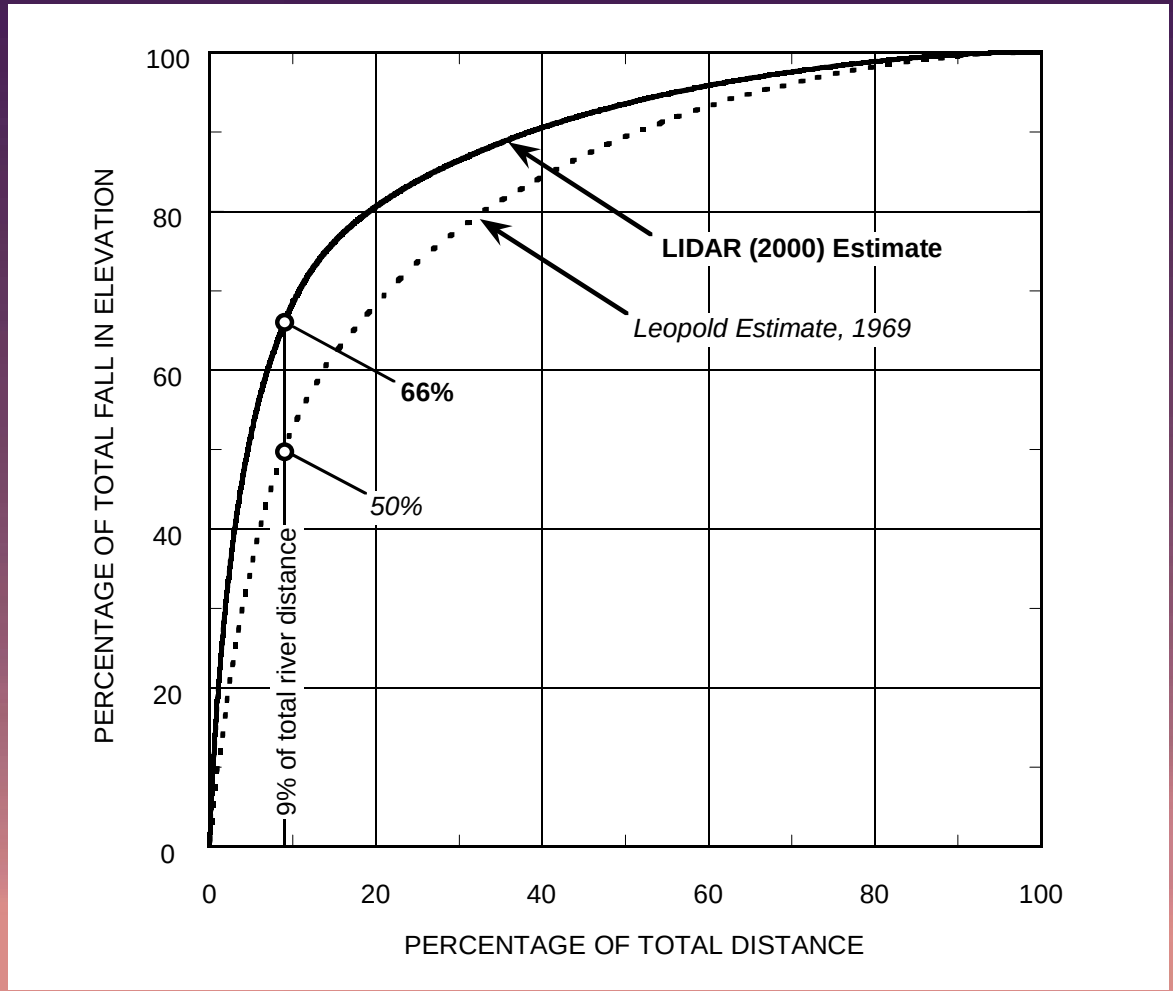
USGS science for a changing world

February 2003
C.S. Magirl, USGS

Geomorphology of the River

Luna Leopold (1969) stated …*50% of total decrease in elevation takes place in only 9% of the total river distance…*[based on Birdseye profile]

New estimate, based on 2000 LIDAR profile: 66% of drop in 9% of distance



Ref: Magirl et al., in preparation

USGS science for a changing world

Conclusions

- With work, remote-sensing data (LIDAR) can be directly compared to 1923 survey data to assess net geomorphic change in Grand Canyon over 77 years.
- Significant aggradation is occurring throughout the river corridor, in part related to operations of Glen Canyon Dam.
- As predicted by Howard and Dolan (1981), the pool-rapid morphology in Grand Canyon is enhancing.
- Though useful, the LIDAR data from 2000 is imperfect: noisy data from the water prevents complete characterization of water-surface profile.
- We recommend LIDAR overflight specifically targeted at mapping the water surface to A) generate a better comparison of 1923 verses modern data and B) establish a modern baseline to compare future overflights against.

Acknowledgements:

We greatly appreciate the support of the professionals at Grand Canyon Monitoring and Research; particularly Ted Melis, Michael Breedlove, Stephanie Wyse, and Steve Mietz. We also thank Diane Boyer for her photo archival support.

USGS science for a changing world

February 2003
C.S. Magirl, USGS