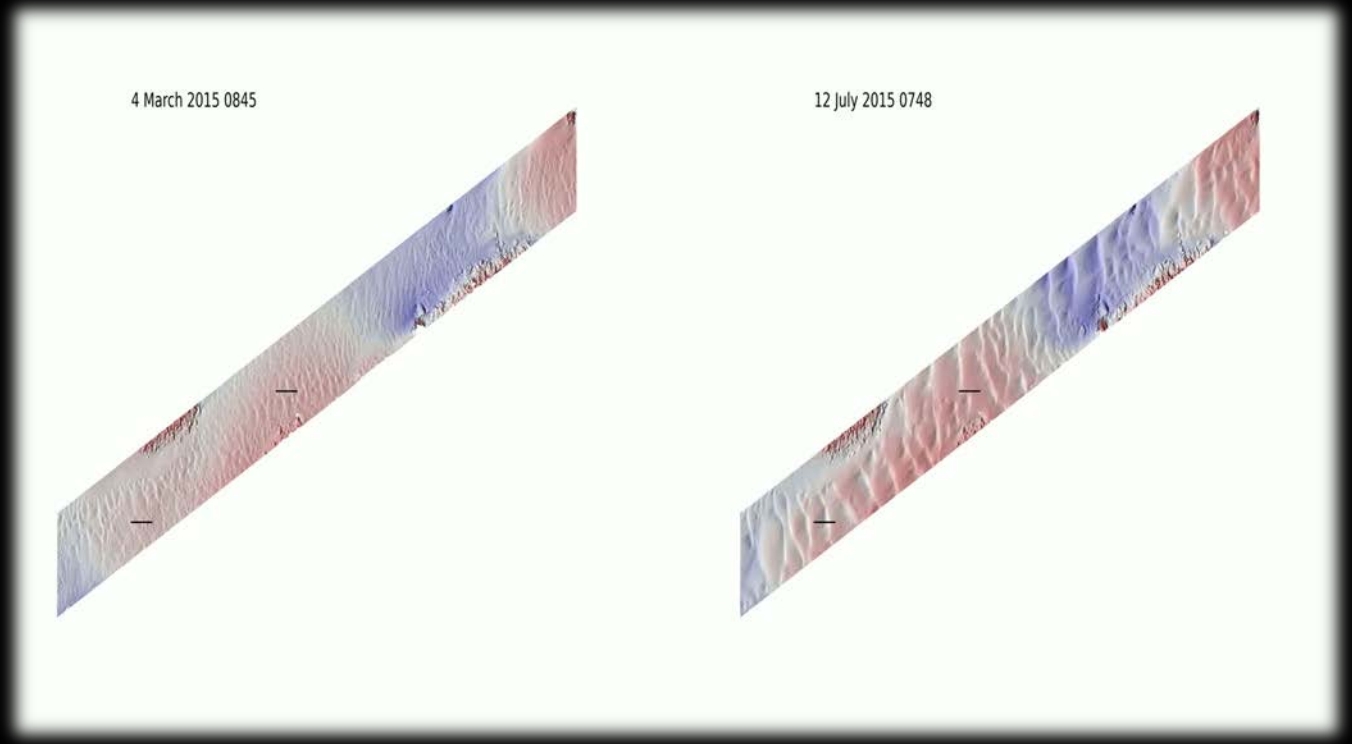
Observations of sand dune migration on the Colorado River in Grand Canyon using high-resolution multibeam bathymetry



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[3] University of Wyoming, Laramie, WY.

Funded by Glen Canyon Dam Adaptive Management Program, USGS Grand Canyon Monitoring and Research Center

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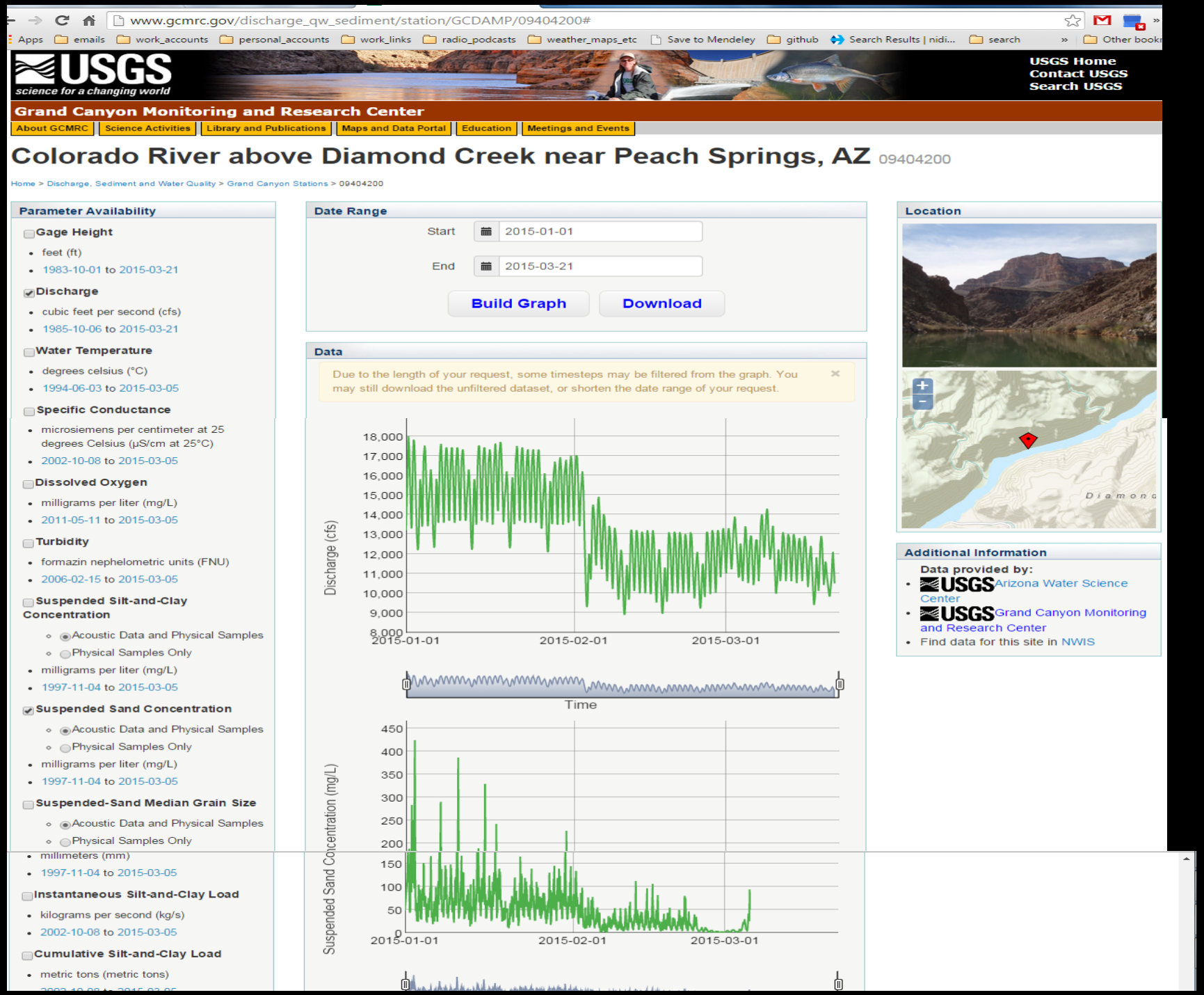
BACKGROUND

Continuous monitoring of suspended sediment concentration, grain size, and flux

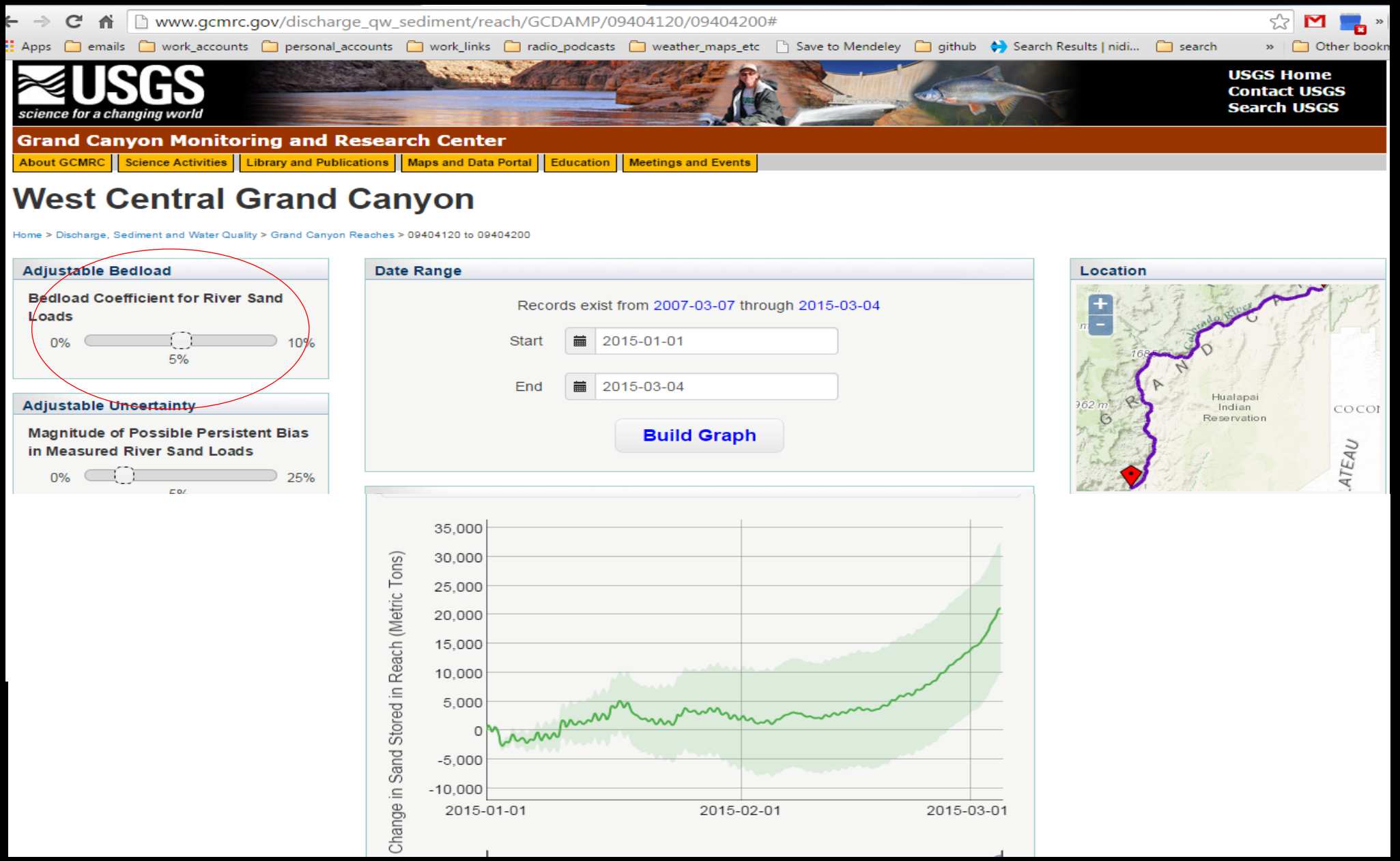


USGS

BACKGROUND

Total sediment flux = suspended flux + bedload flux

Bedload expressed as a constant proportion of suspended load



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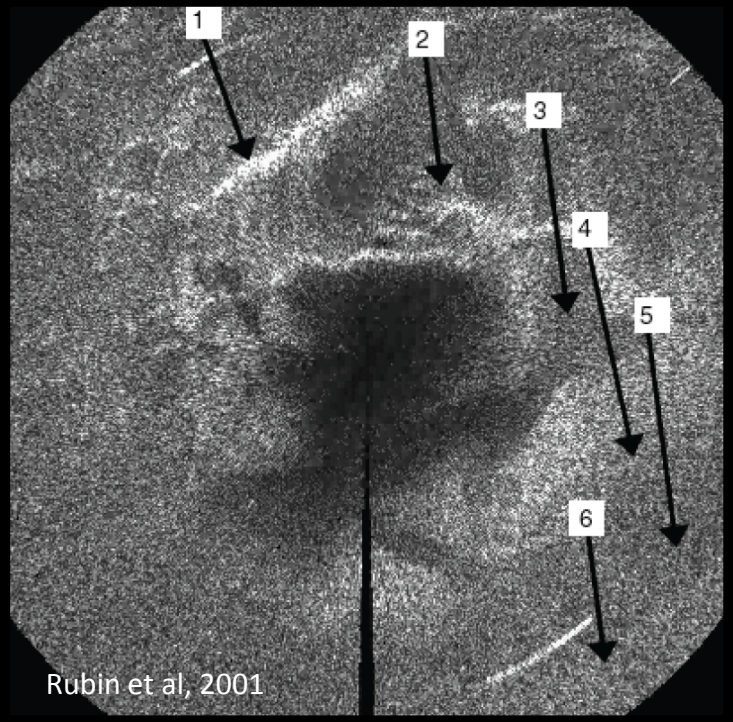
BACKGROUND

Based on measurements of bedform migration made at one discharge (595 m^3/s) using rotating side-scan sonar (Rubin et al, 2001)



Rubin et al, 2001

Dunes in Colorado River, Grand Canyon,

Features to note:
(1) Dune size increased as discharge increased.
(2) Superimposed dunes.
(3) Spurs are oriented obliquely to dune crests.
(4) Scour pits present in dune troughs.

Scale: 20 m diameter
Duration of observation: 8 hours, 10 minutes, with 2 gaps of approximately 20 minutes each
Time between images: 2 minutes 4 seconds
Date: September 25-26, 1998

Sonar data collected by Dave Rubin, George Tate, and Roberto Arima
Image processing by Dave Rubin
US Geological Survey

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A NEW APPROACH

Over the past 15 years, GCMRC scientists have developed a suite of technologies that enable us to:

- Rapidly produce 3D maps large areas of the bed using multibeam bathymetry
- Simultaneously map bed sediments using multibeam sonar backscatter
- Measure sand grain size distribution using images acquired with a specialist underwater microscope
- Continuously measure of suspended sand concentration and grain size with increasing sophistication and accuracy
- Accuracy measure flow velocities using acoustic Doppler profilers

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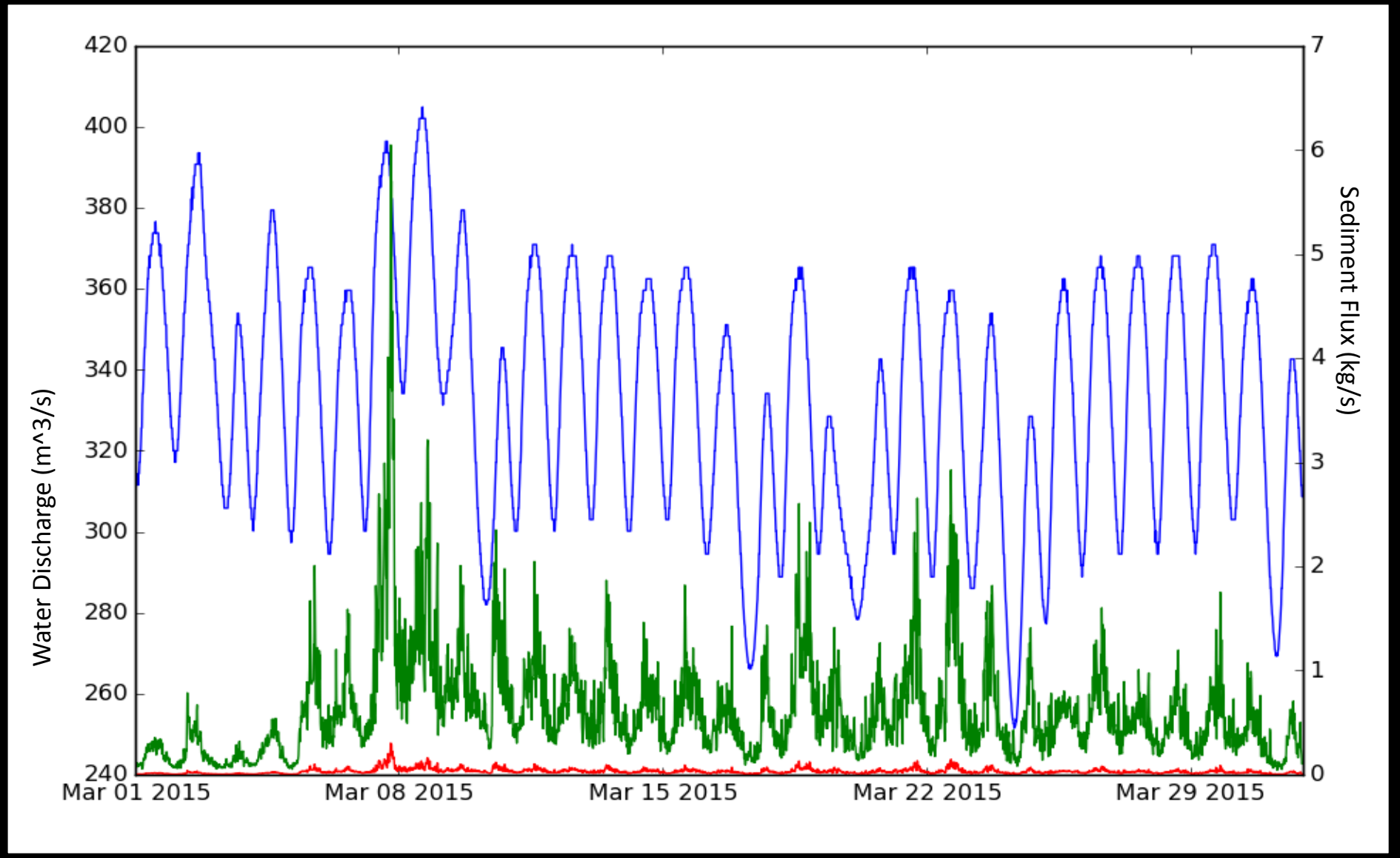

Can we develop relationships between measured discharge, suspended sediment flux, and bedload flux …

… that better predict bedload flux?

Objective: bedload flux as a function of routinely measured quantities

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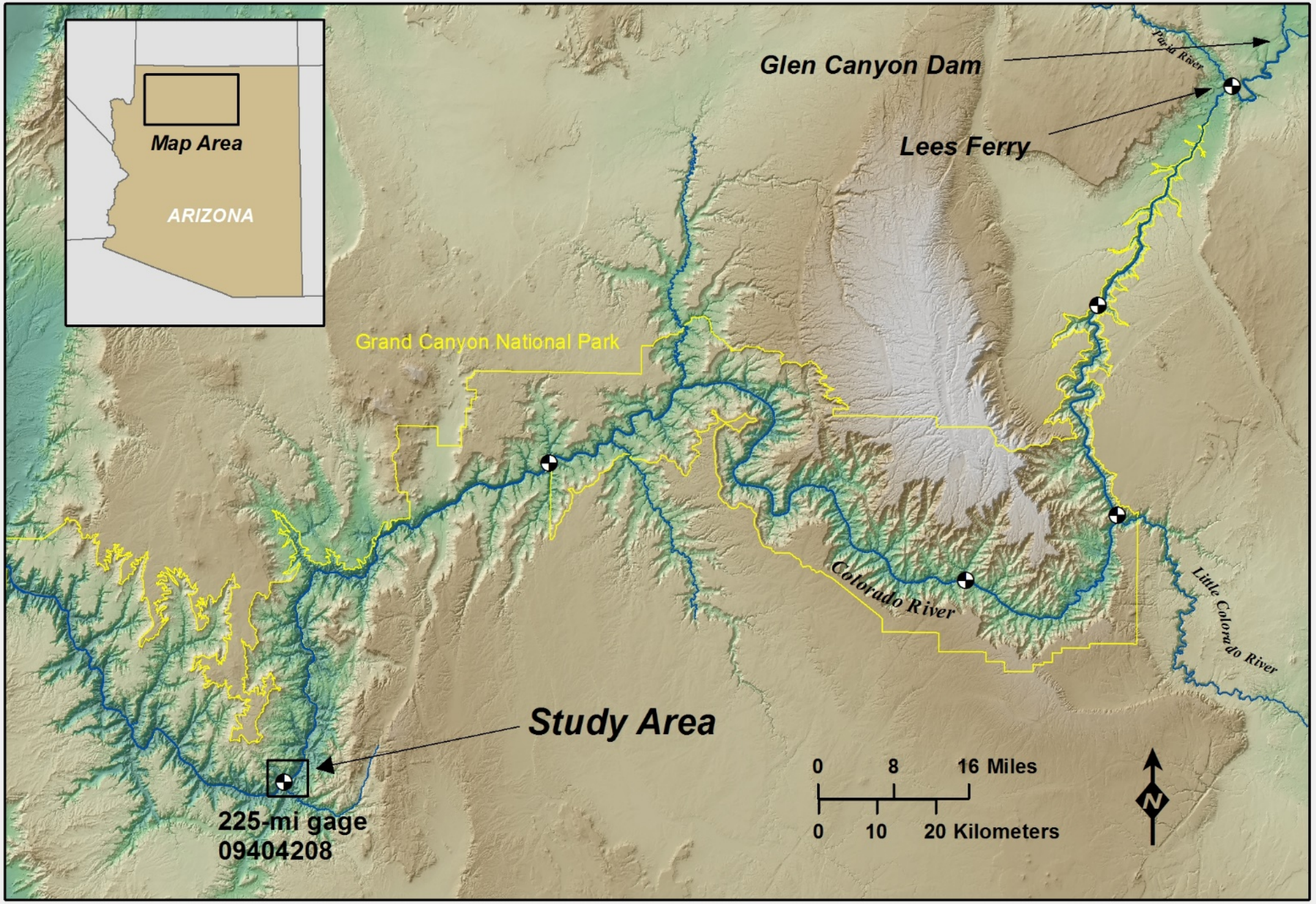

Map Area
ARIZONA
Glen Canyon Dam
Lees Ferry
Paria River
Grand Canyon National Park
Colorado River
Little Colorado River
Study Area
225-mi gage
09404208
0 8 16 Miles
0 10 20 Kilometers
N

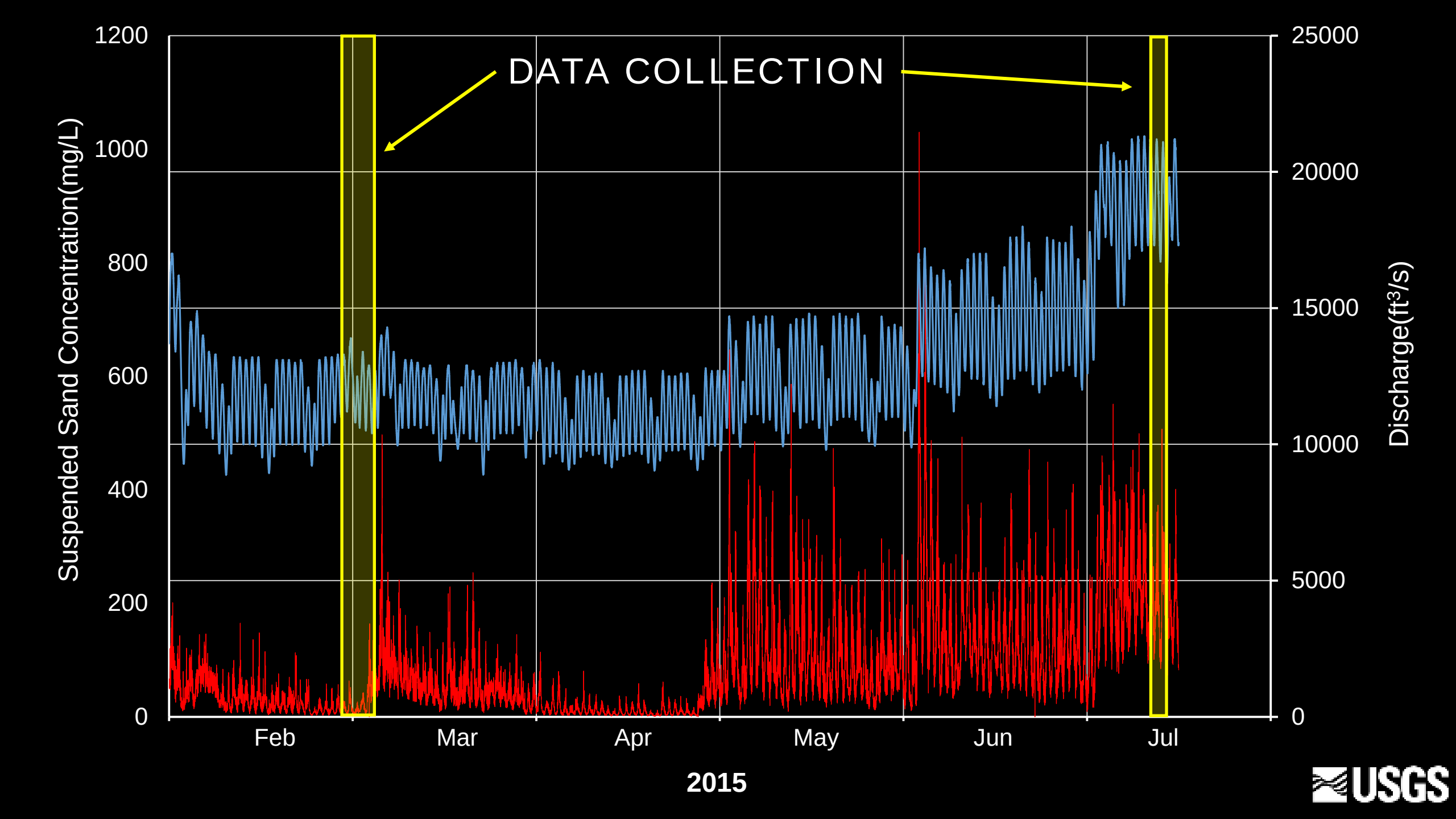
DATA COLLECTION

Bathymetry - Multibeam Sonar (Reson 7125, IxSea hydrins IMU &Heading, Trimble SPS930)

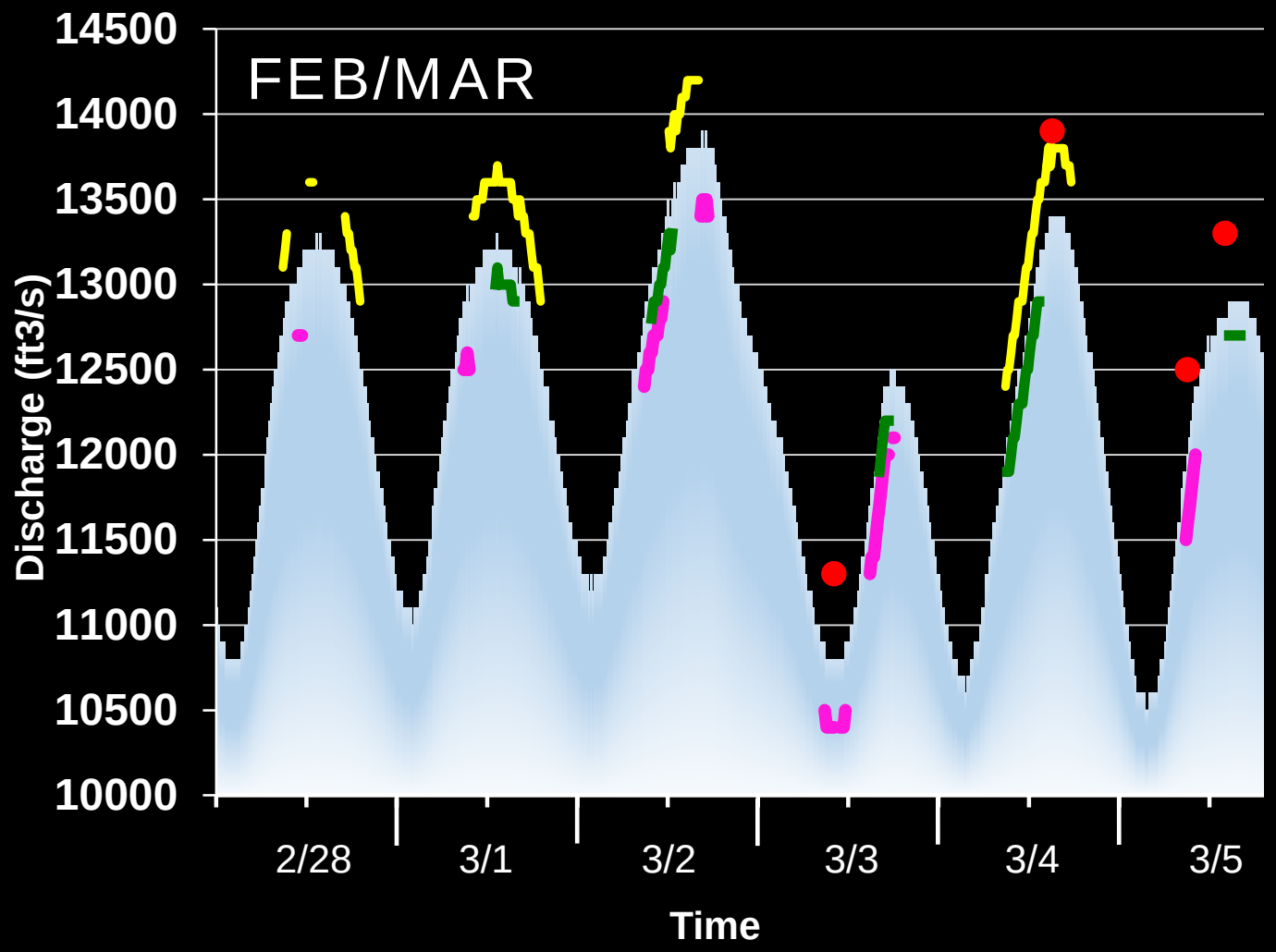
Current Velocity - ADCP (RDI workhorse)

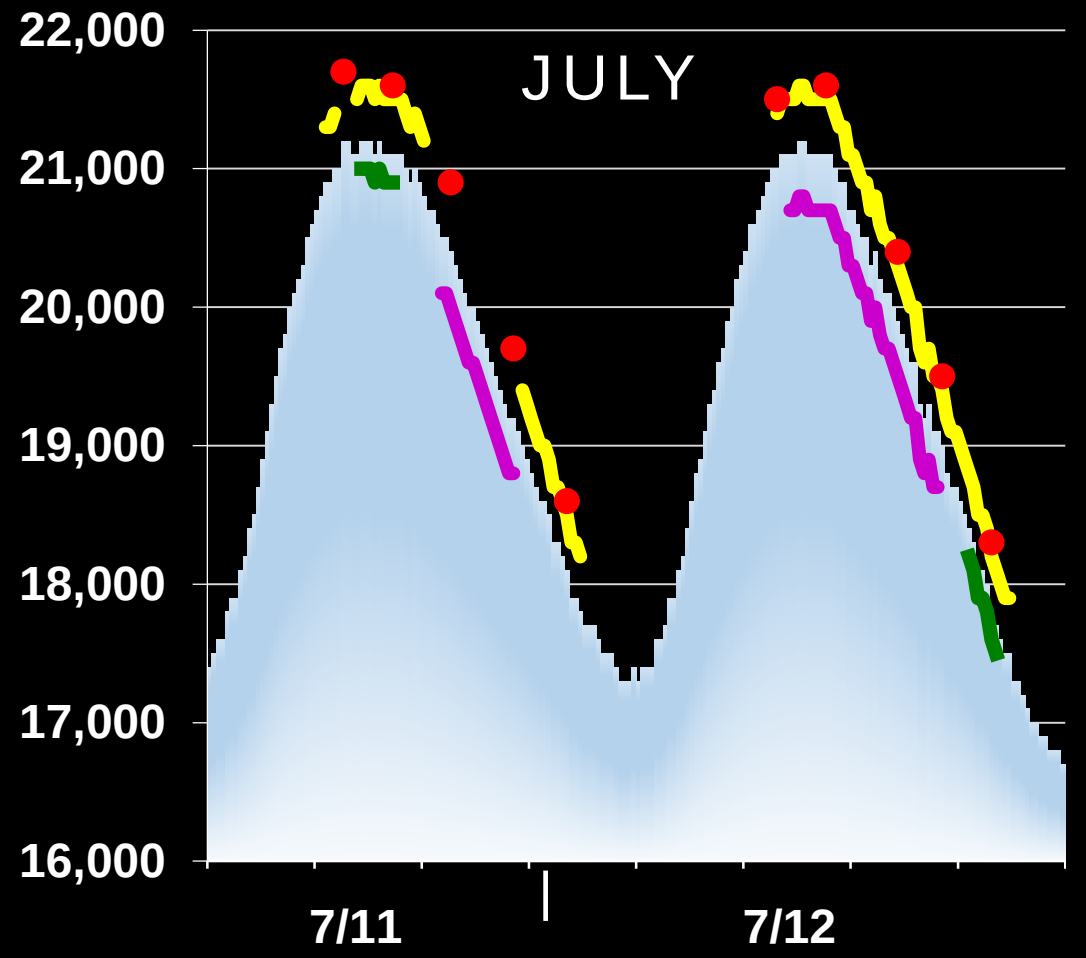
Bed Grain Size - Underwater Camera (Buscombe et al., 2013)

Suspended Sediment – Acoustics samples @ 15 minute intervals, calibrated with D96 & P61 point samples from cableway


DATA COLLECTION
Suspended Sand Concentration(mg/L)
Discharge(ft³/s)
1200
1000
800
600
400
200
0
25000
20000
15000
10000
5000
0
Feb
Mar
Apr
May
Jun
Jul
2015
USGS

DATA COLLECTION





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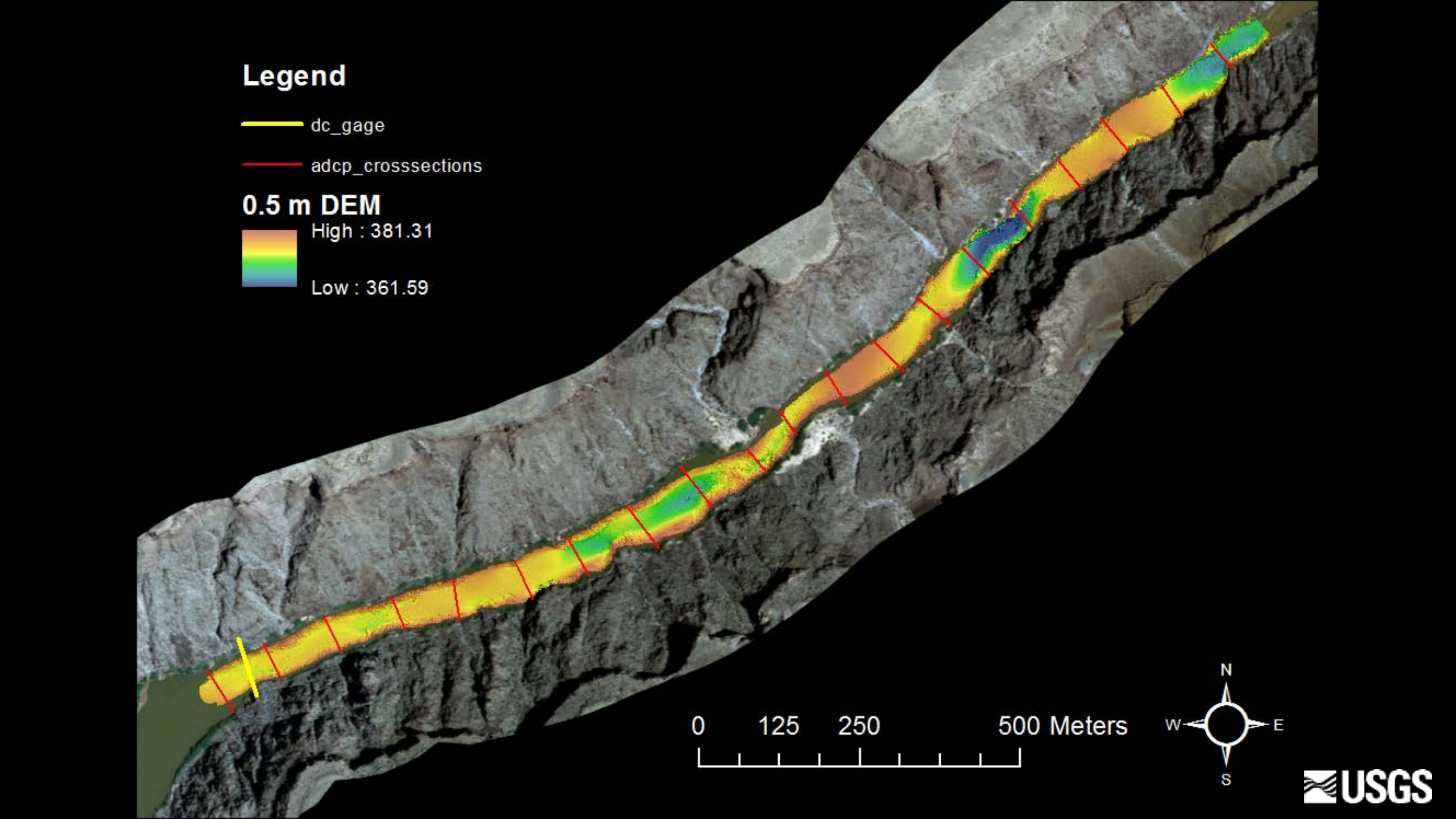
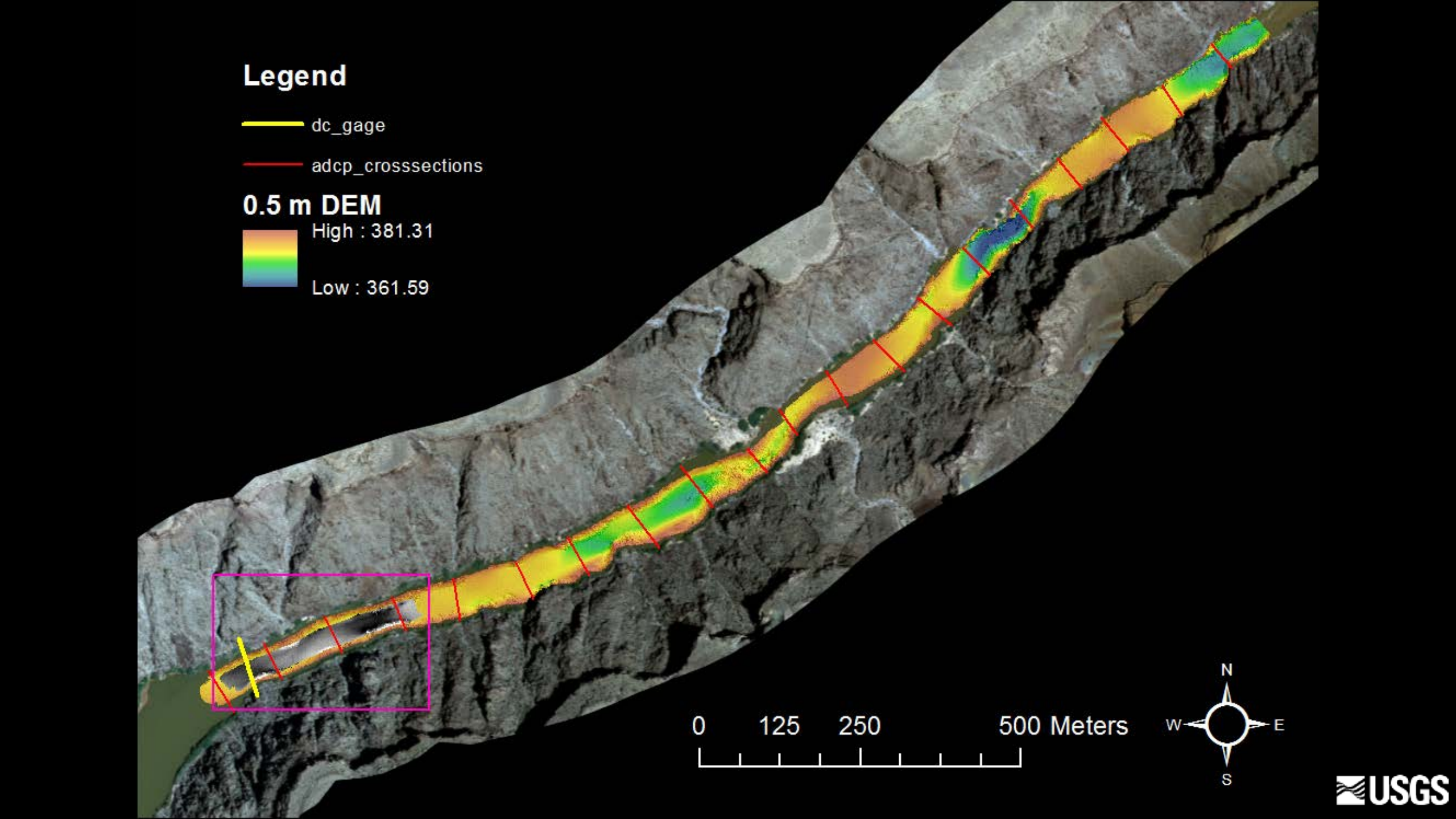
Multibeam Surveys

ADCP Surveys

Grain-Size Surveys

Suspended Sediment Samples


Legend
dc_gage
adcp_crosssections
0.5 m DEM
High : 381.31
Low : 361.59
0
125
250
500 Meters
N
W
E
S
USGS


Legend
dc_gage
adcp_crosssections
0.5 m DEM
High : 381.31
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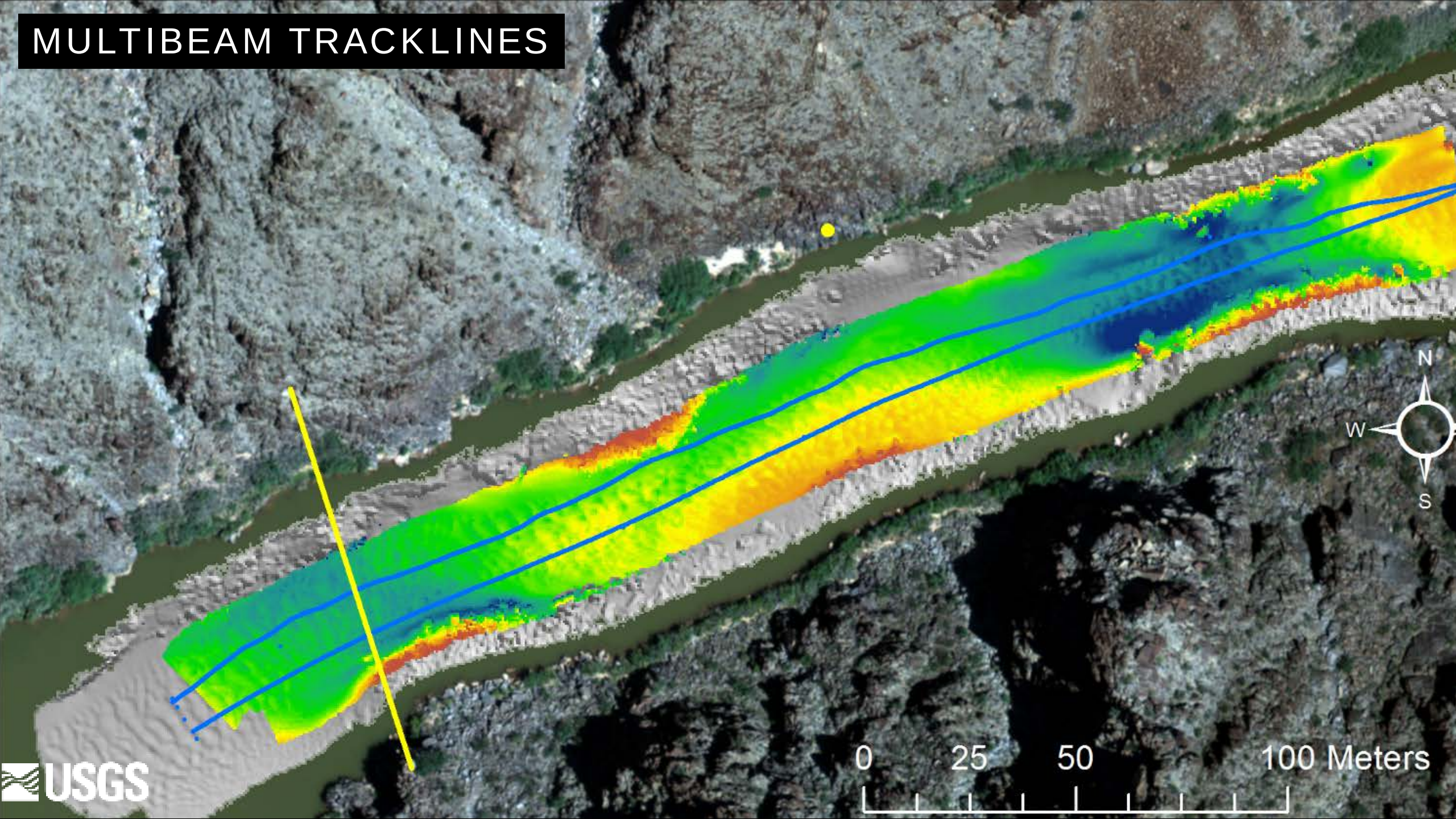
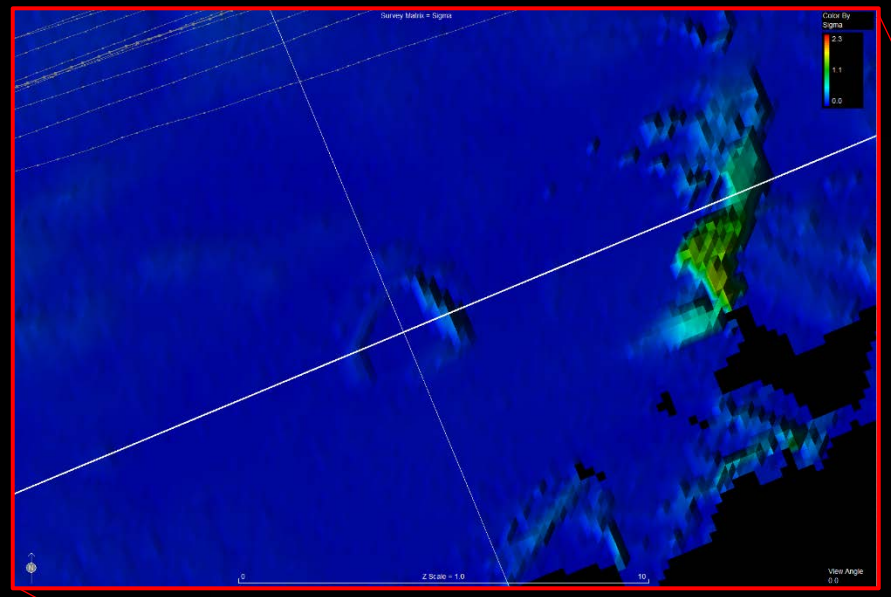
0
125
250
500 Meters
N
W
E
S
USGS


MULTIBEAM TRACKLINES
N
W
S
0
25
50
100 Meters
USGS

DATA COLLECTION

MULTIBEAM UNCERTAINTY



July 12, 2015 survey
20 survey lines
0.10 m cell size
20-30 soundings/cell
30-60 degrees beam angles
Mean cell standard deviation = **0.015m**
Cell Count = 119

Color By
Elevation
377.7
374.2
370.7

USGS

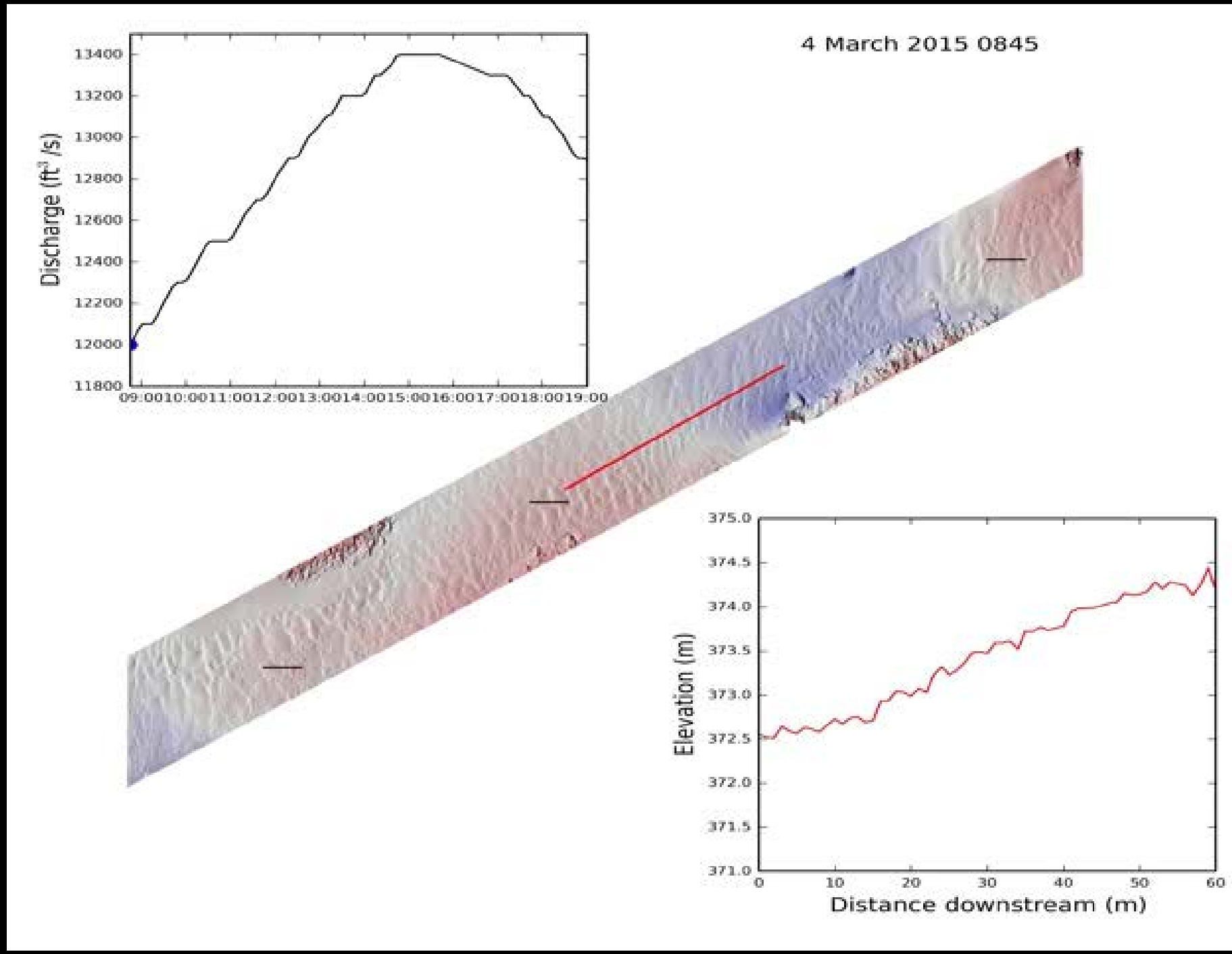
MARCH 4, 2015

Dune height: 30 and 50 cm
Dune length: 5 m

Migration rate: ~1 m / hour

Fully capture dune migration

using data collected at unprecedented temporal and spatial resolutions

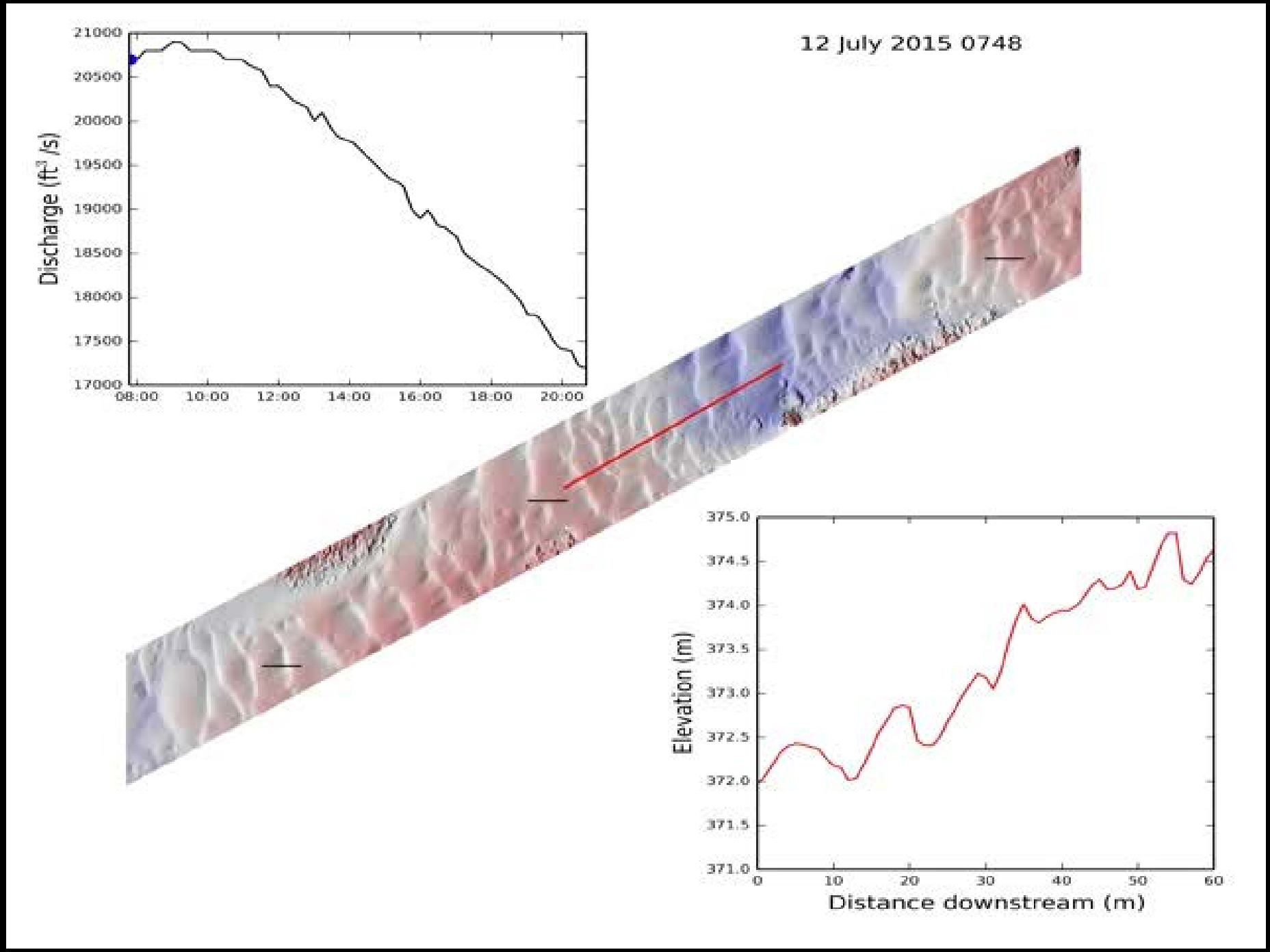


USGS

JULY 12, 2015

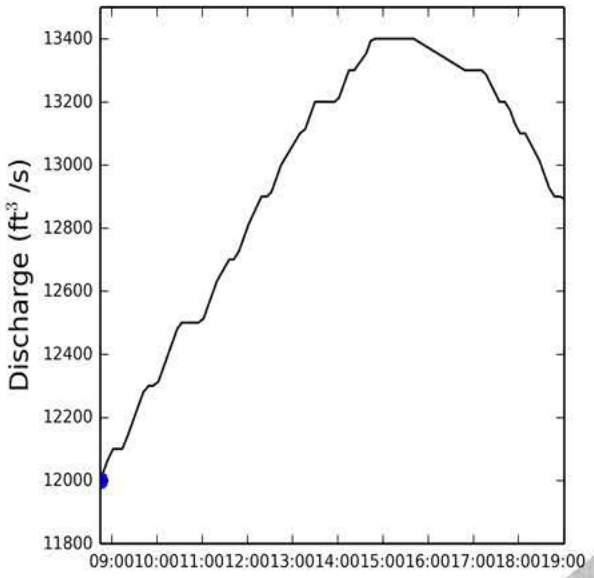
Dune height: 75 and 130 cm
Dune length: 10-15 m

Migration rate: ~2 -5 m / hour

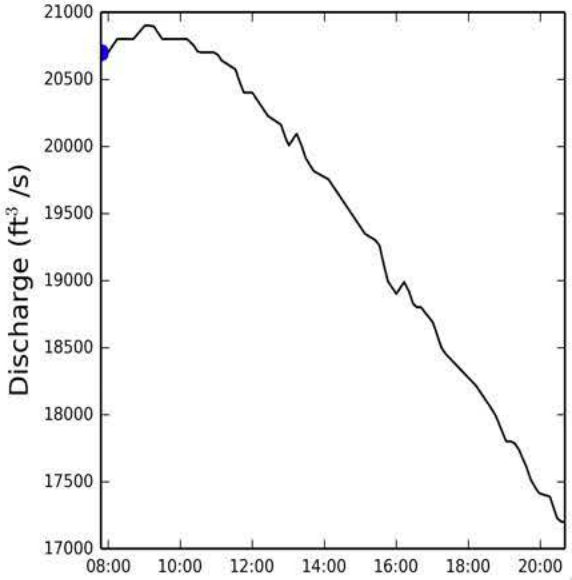


USGS

4 March 2015 0845



12 July 2015 0748



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BEDLOAD CALCULATIONS

Bedload flux calculations:

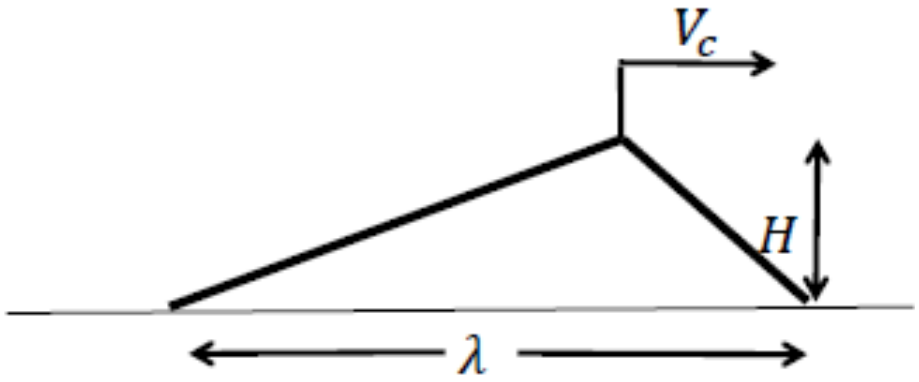
Translation only

1D only

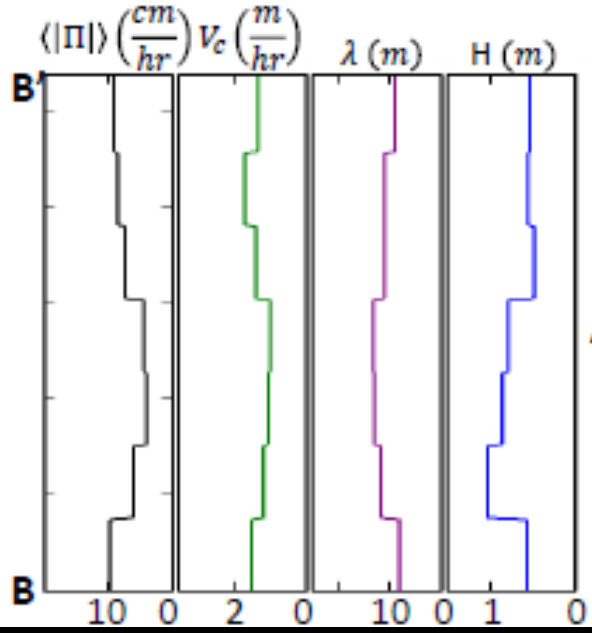
Averaged over field of dunes (not calculated per dune)

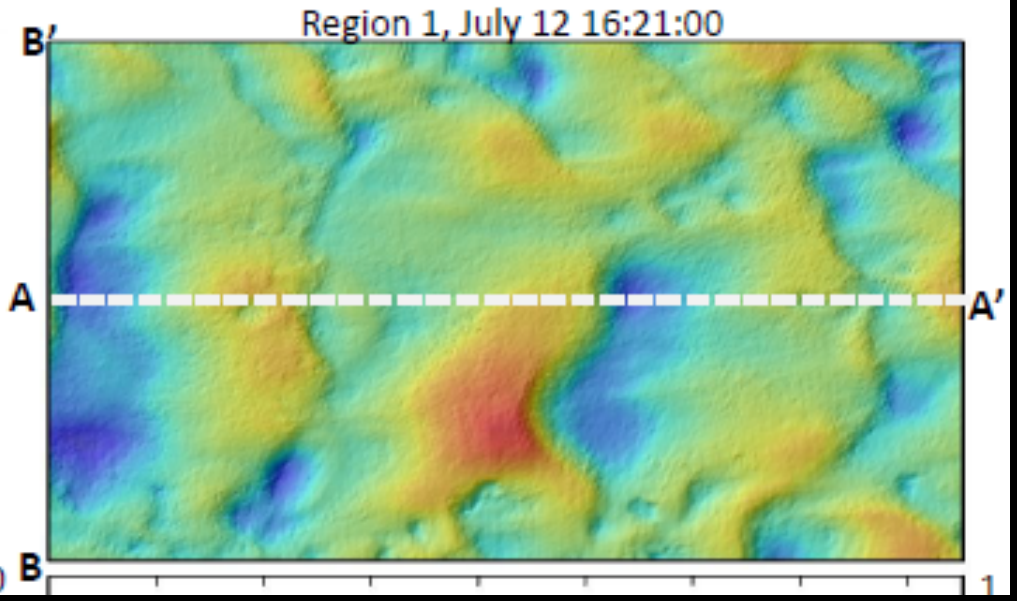
Simons et al (1965) - mean sediment flux per unit bedform length

q_0 is a constant of integration (here set to 0 but a topic of research)

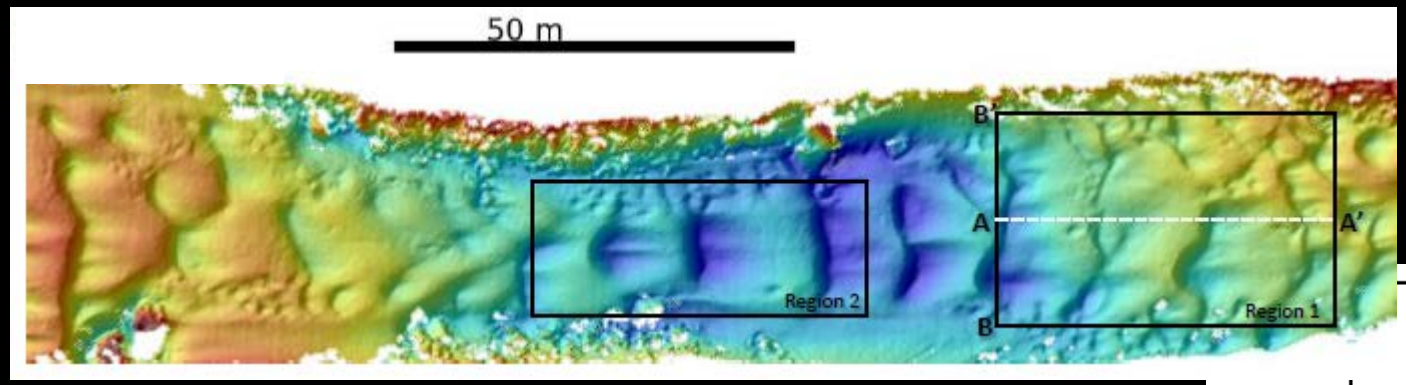


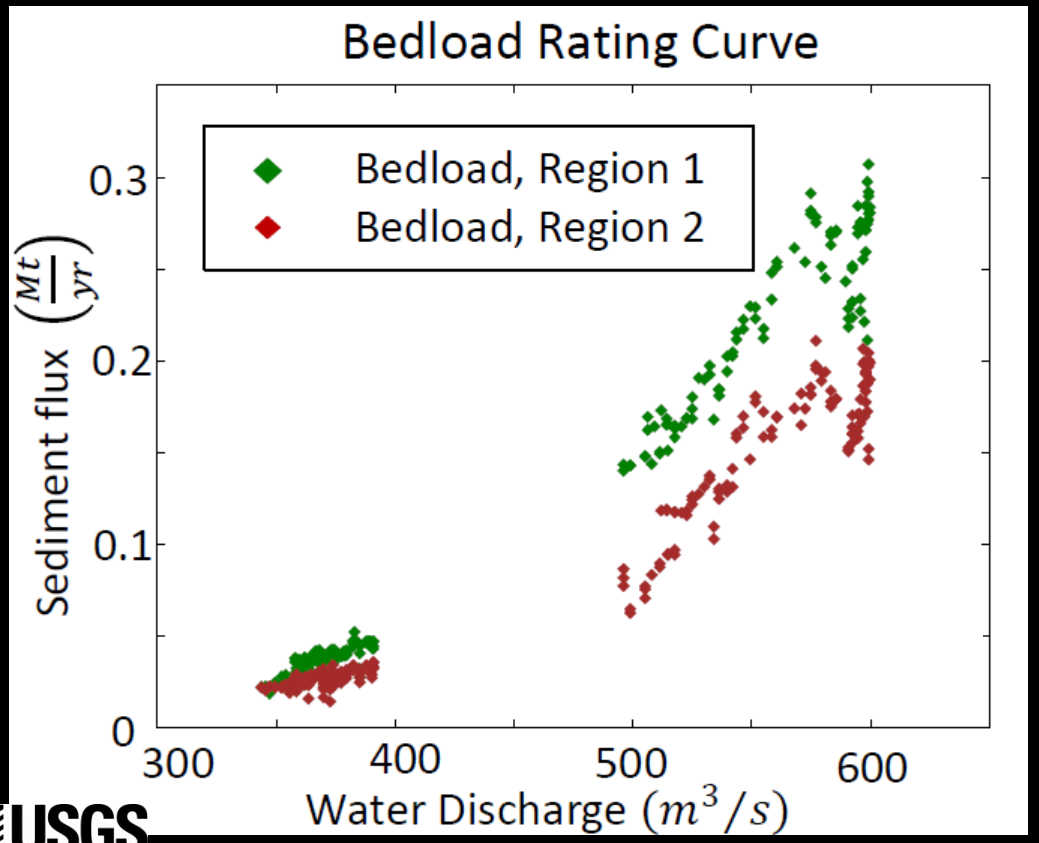
$$\langle q_b \rangle = \frac{1}{\lambda}(1-p)V_c\frac{H\lambda}{2} + q_0$$

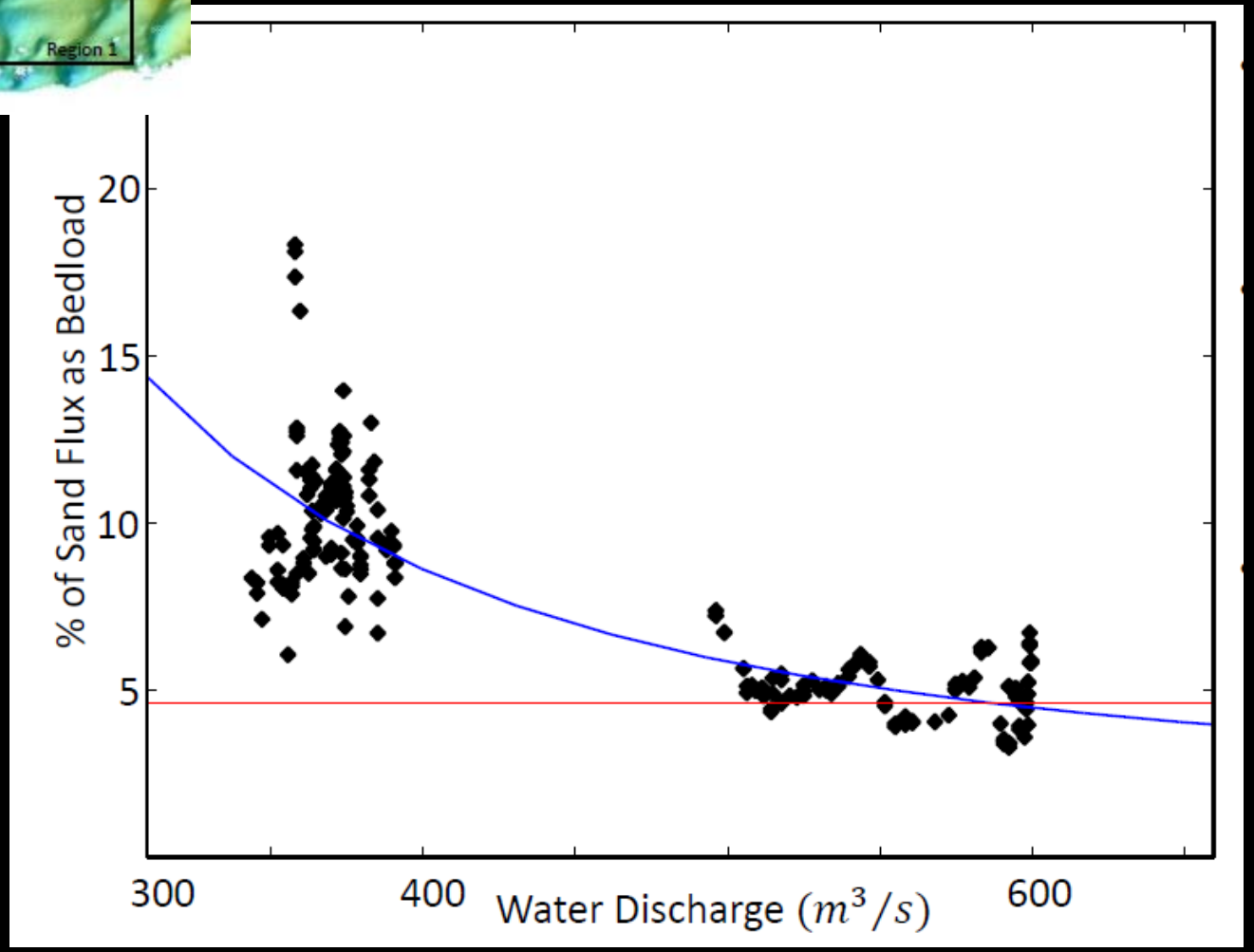




BEDLOAD CALCULATIONS







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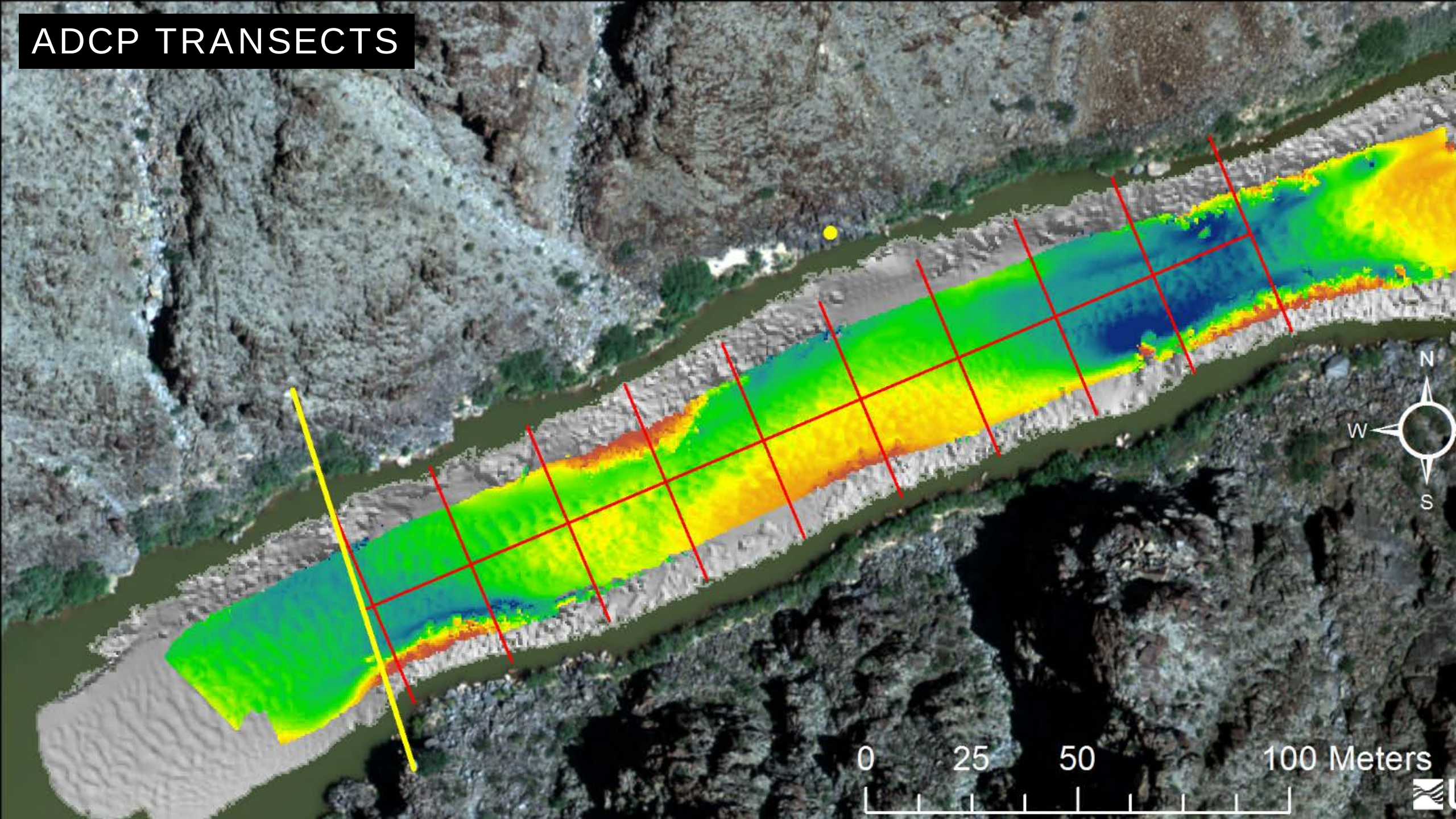
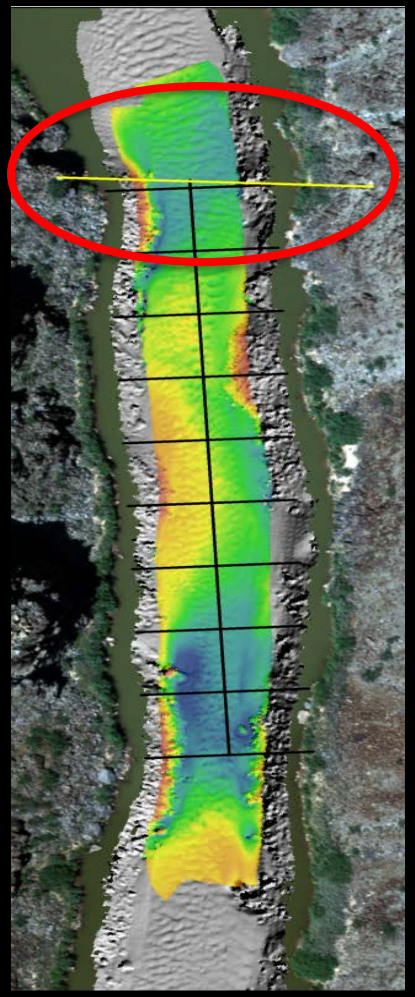

ADCP TRANSECTS
N
W
S
0
25
50
100 Meters

ADCP SURVEYS



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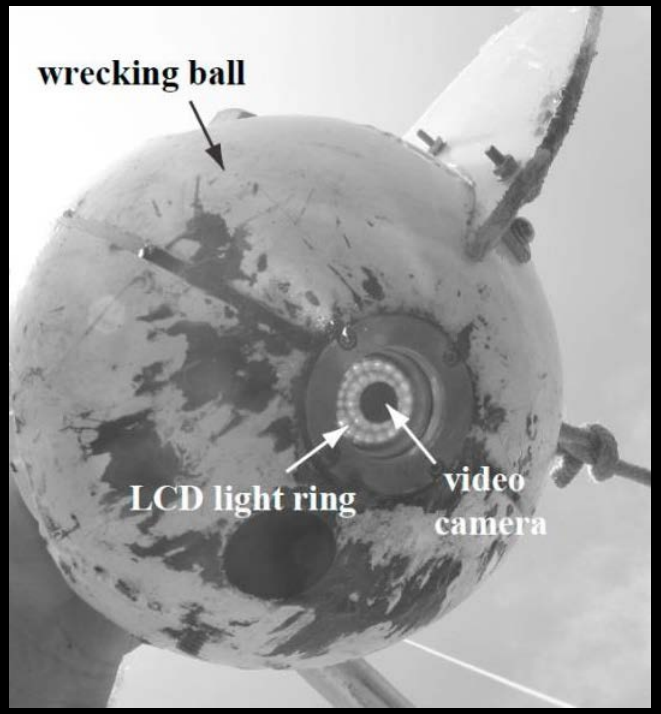
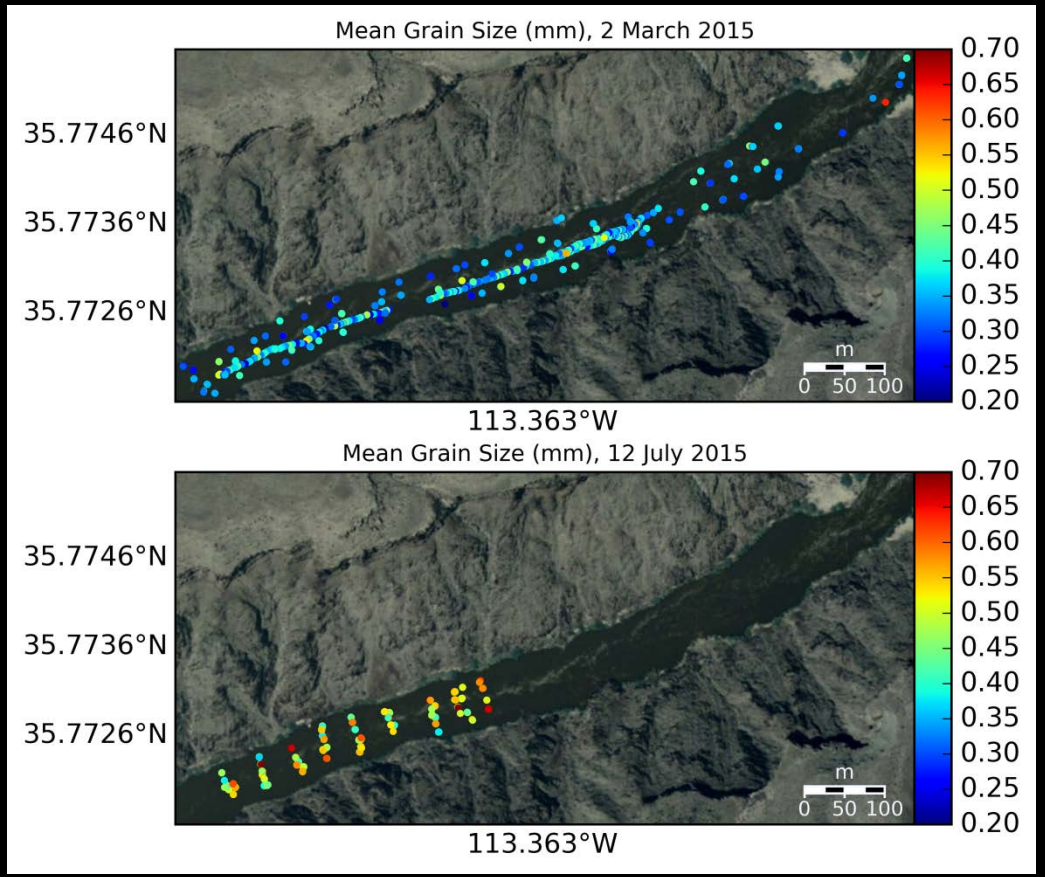
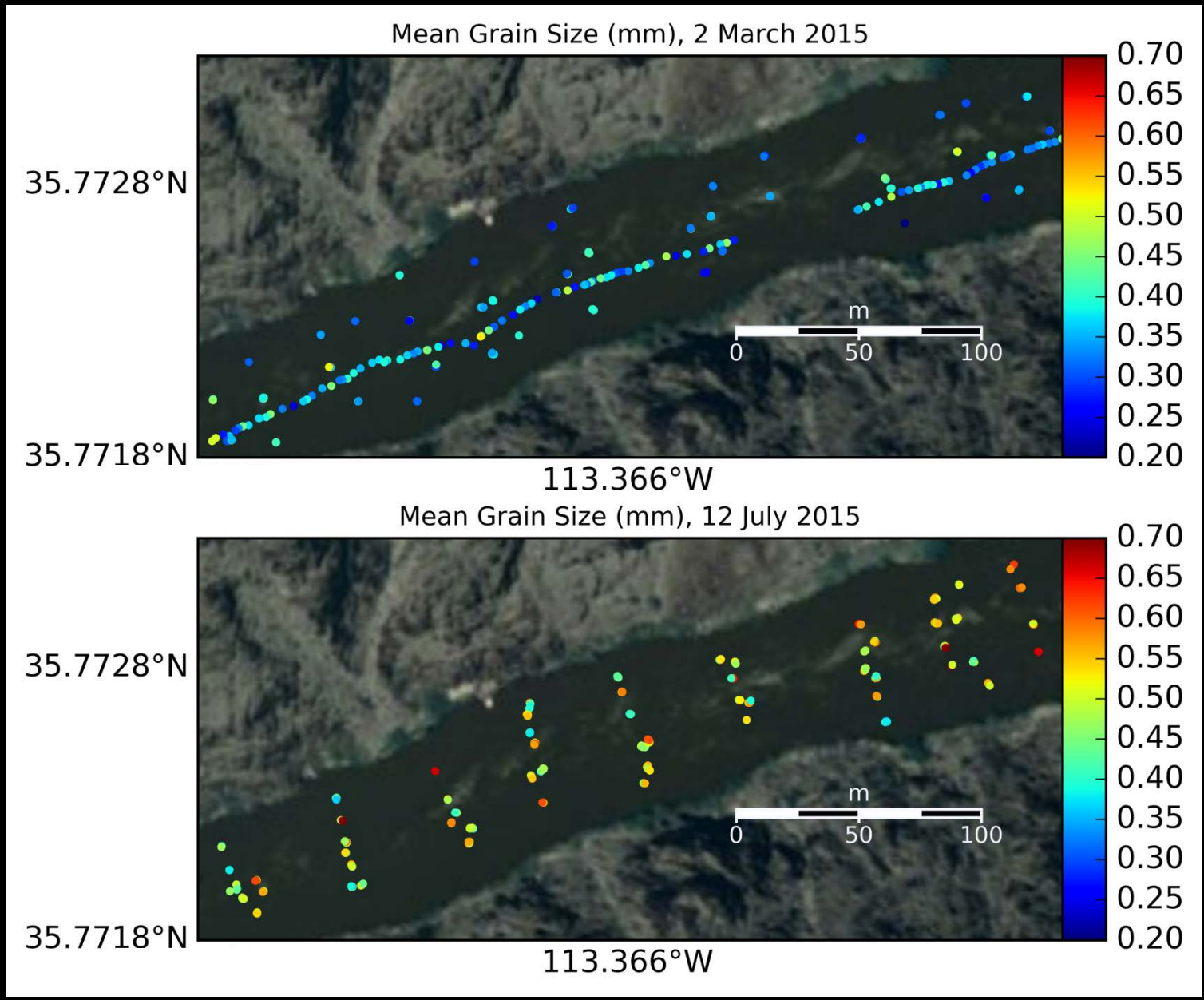
		streamwise	backscatter	
13000 cfs	2015-02-28 11:00:00 48.81 ft 13000 cfs			33.9 mg/L (silt/clay) 1.62 mg/L (sand)
12800 cfs	2015-03-01 09:00:00 48.72 ft 12800 cfs			135 mg/L (silt/clay) 3.76 mg/L (sand)
13300 cfs	2015-03-02 11:00:00 48.85 ft 13100 cfs			54.9 mg/L (silt/clay) 4.65 mg/L (sand)
13700 cfs	2015-03-02 16:30:00 49.11 ft 13700 cfs			185 mg/L (silt/clay) 7.2 mg/L (sand)
10800 cfs	2015-03-03 08:45:00 47.85 ft 10800			43.6 mg/L (silt/clay) 2.54 mg/L (sand)
10700 cfs	2015-03-03 11:15:00 47.83 ft 10700 cfs			125 mg/L (silt/clay) 2.19 mg/L (sand)
13200 cfs	2015-03-04 16:15:00 48.91 ft 13200 cfs			112 mg/L (silt/clay) 19.3 mg/L (sand)
12100 cfs	2015-03-05 09:45:00 48.45 ft 12100 cfs			132 mg/L (silt/clay) 33.1 mg/L (sand)

‘FLYING EYEBALL’ BED SEDIMENT CAMERA



BED SEDIMENT MEAN GRAIN SIZE WAS SLIGHTLY COARSER IN JULY





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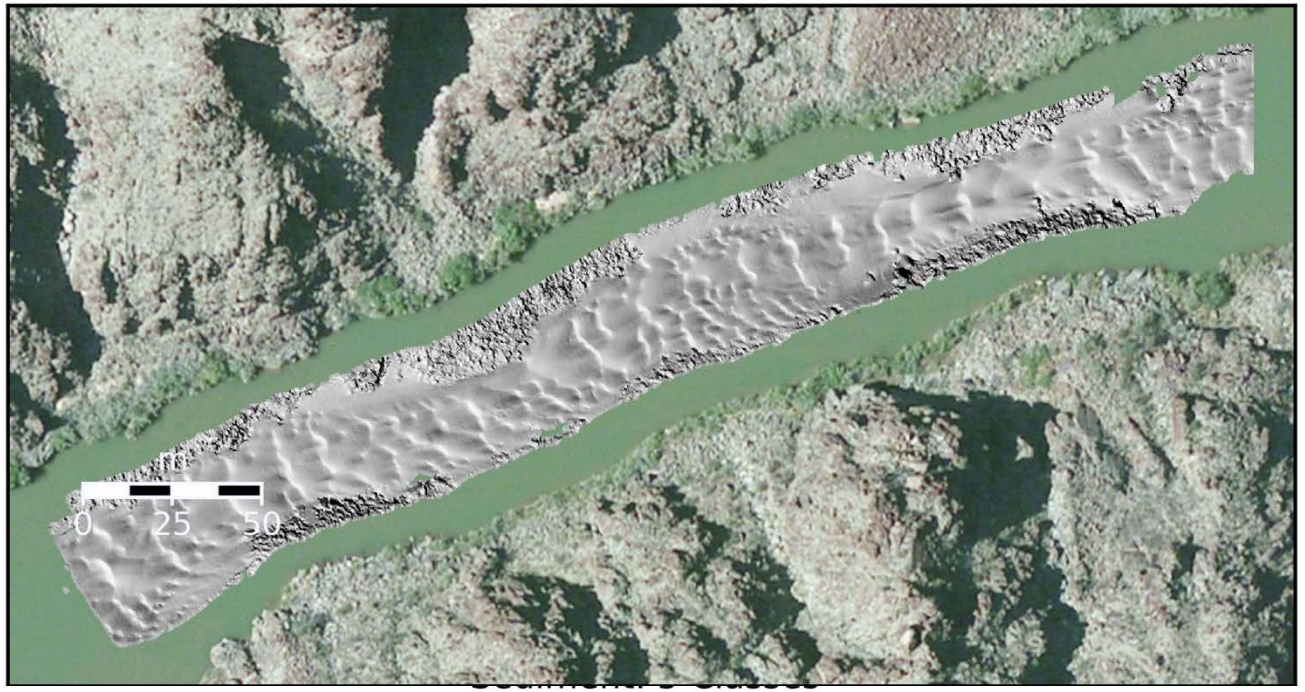
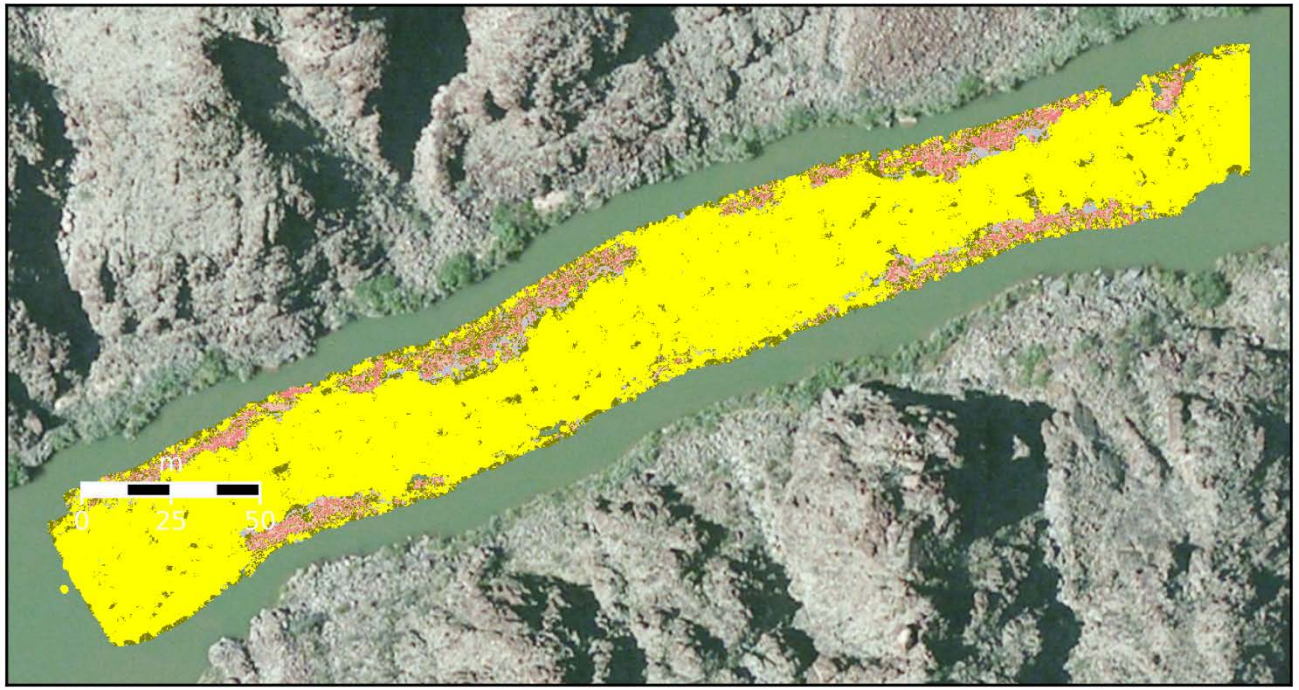
BUT LITTLE EVIDENCE OF GRAVEL IN TROUGHS

Hillshaded bathymetry



Acoustic backscatter sediment classification (Buscombe et al 2014)

Yellow = sand



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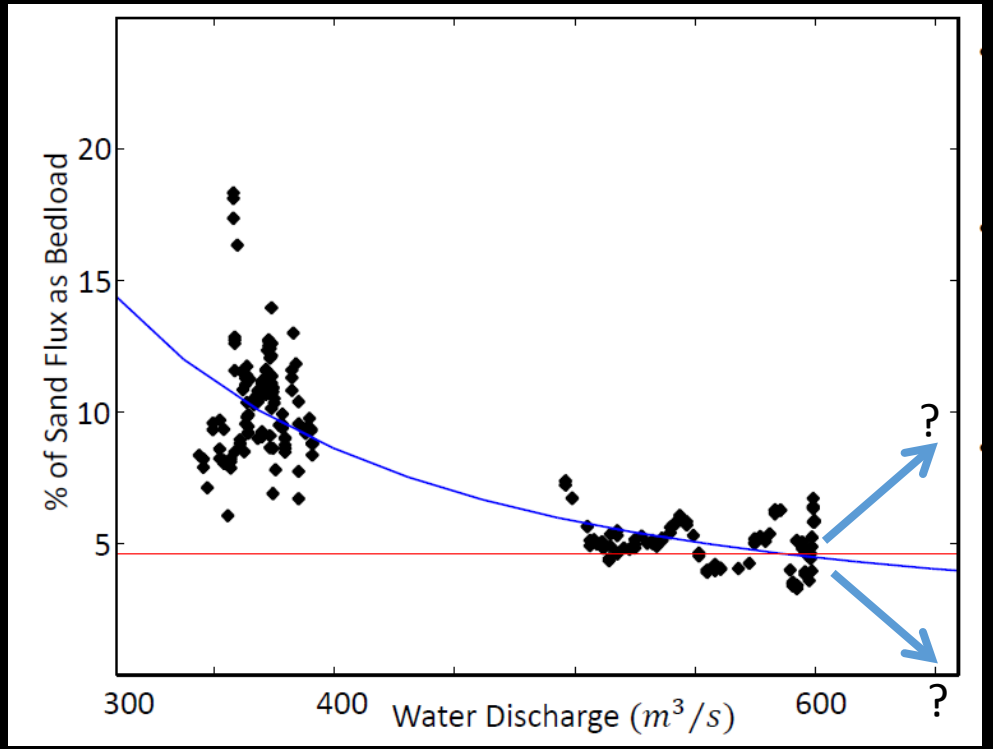
SUMMARY (SO FAR)

- Dune dimensions (height and wavelengths) scale with discharge
- Dune translation speed increased with higher discharge
- Preliminary results would suggest that bedload is 10-15% of suspended load at discharges of 11-13,000 cfs (higher than currently implemented in flux-based sediment budget)
- and bedload is around 5% of suspended load at discharges of 17 – 21,000 cfs (in line with previous measurements and current predictions)
- However, these are likely to be conservative estimates given a possible contribution of ‘deformation flux’ (ongoing work)
- Bedforms are very ‘3 dimensional’, especially at larger discharges
- Bedload would appear to have a weak – moderate correlation with discharge

ONGOING AND FUTURE WORK

- Conduct mapping work at Diamond creek during the next HFE



- Start mapping work at other gage sites (starting at 30-mile gage in May 2016)
- Account for flux contribution (if any) of dunes changing shape as they migrate (Tom Ashley's Masters thesis)
- As we acquire more data, develop and test relationships for bedload as a function of flow (velocity / discharge), grain size and suspended sediment
- Testing ways to autonomously and continuously monitor bedload

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Thank You