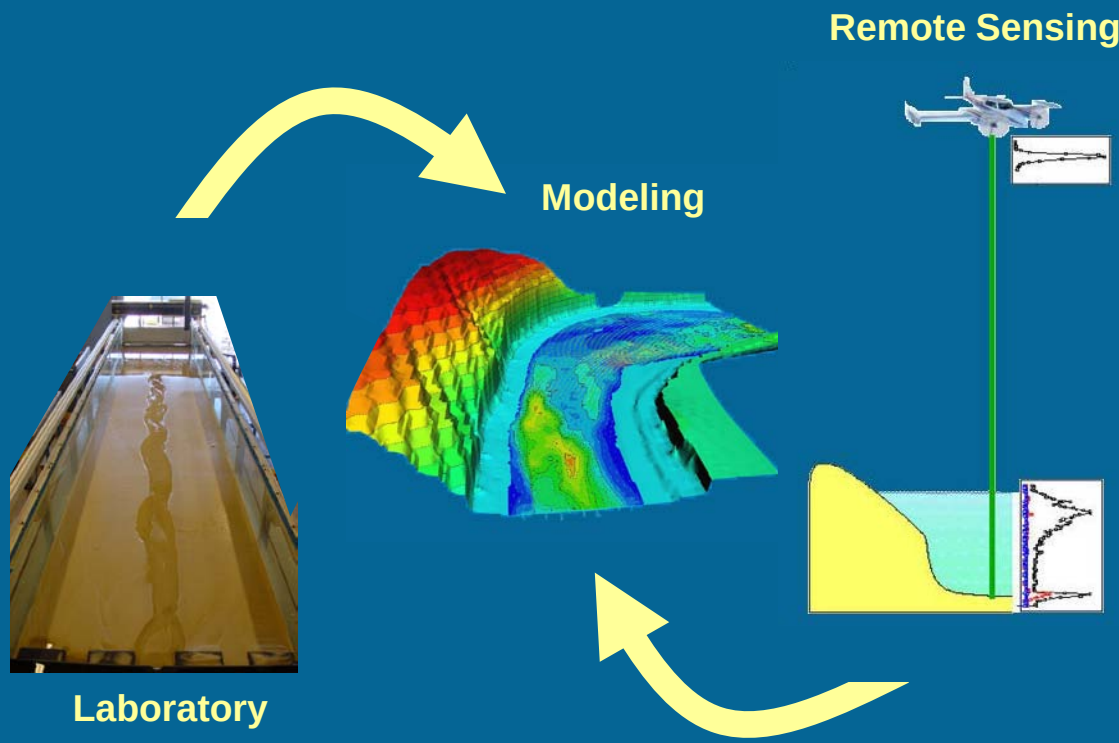
USGS
science for a changing world

Advanced Tools for River Science



U.S. Department of the Interior
U.S. Geological Survey

Paul J. Kinzel
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Golden, CO

Contributors

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- Mary Freeman – BRD (Athens, GA)
- Carl Legleiter – U. of Wyoming (Laramie, WY)
- Brandy Logan – NRP (Golden, CO)

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Overview

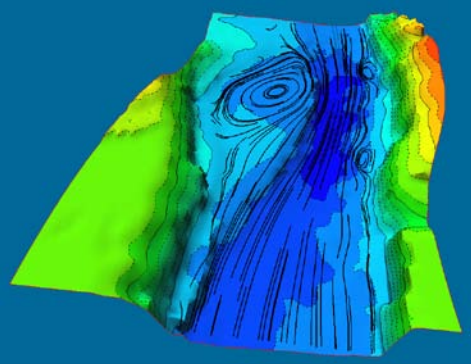
- USGS Surface Water Modeling System – (MD_SWMS) example Flint R., GA
- Remote sensing of rivers – improve field data collection for models, (EAARL) Platte R., NE, Trinity R., CA, and Blue R., CO
- Laboratory – validate and improve numerical modeling code, Kootenai R., ID, and Platte R., NE

USGS

USGS Multi-Dimensional Surface Water Modeling System (MD_SWMS)

- Windows™ interface for computational models of surface water hydraulics and sediment transport in rivers – (McDonald et al., 2001)
- Suite of models – FaSTMeCH, SToRM, H2KE
- Data intensive –requires ***detailed topographic*** map of river reach as well as verification data for calibration over a range of discharges
- Approach provides ***spatially explicit information*** to investigate linkages between channel form, flow, sediment transport, and ecological processes

http://wwwbrr.cr.usgs.gov/gstl/2D-Download.php

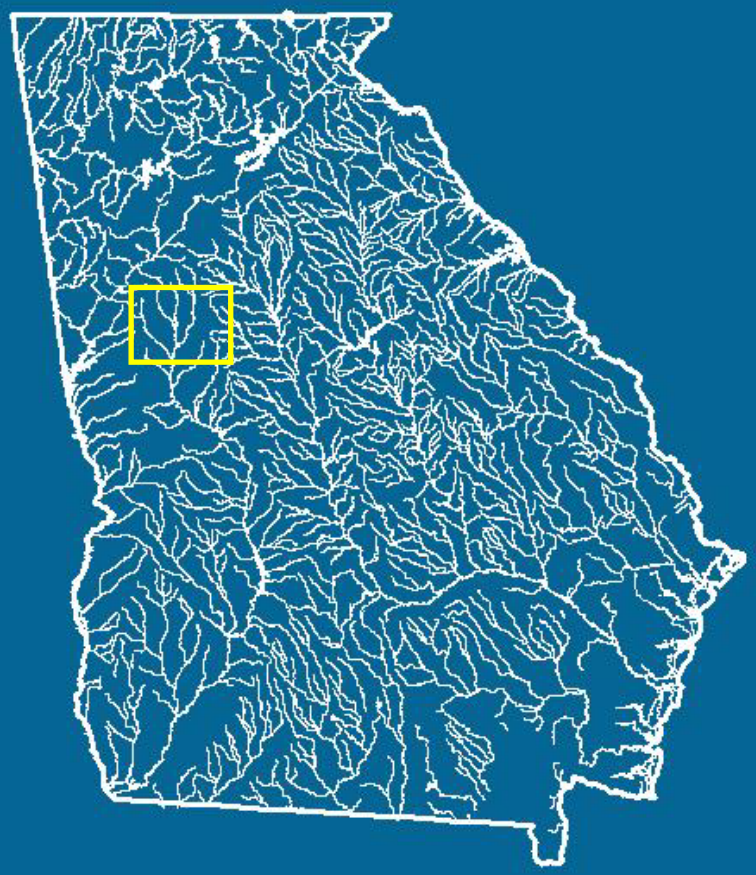


USGS

McDonald, R.R., J.P. Bennett, and J.M. Nelson, 2001. The USGS multi-dimensional surface water modeling system: *Proceedings of the Seventh Interagency Sedimentation Conference*, March 25 to 29, 2001, Reno, NV, v. 1, p. I161-167.

Example - Flint River, GA

GEORGIA



Issues:

- Water resources impacted by drought, population growth
- Concern for native fish, shoal habitat
- How much water for ecological needs*?

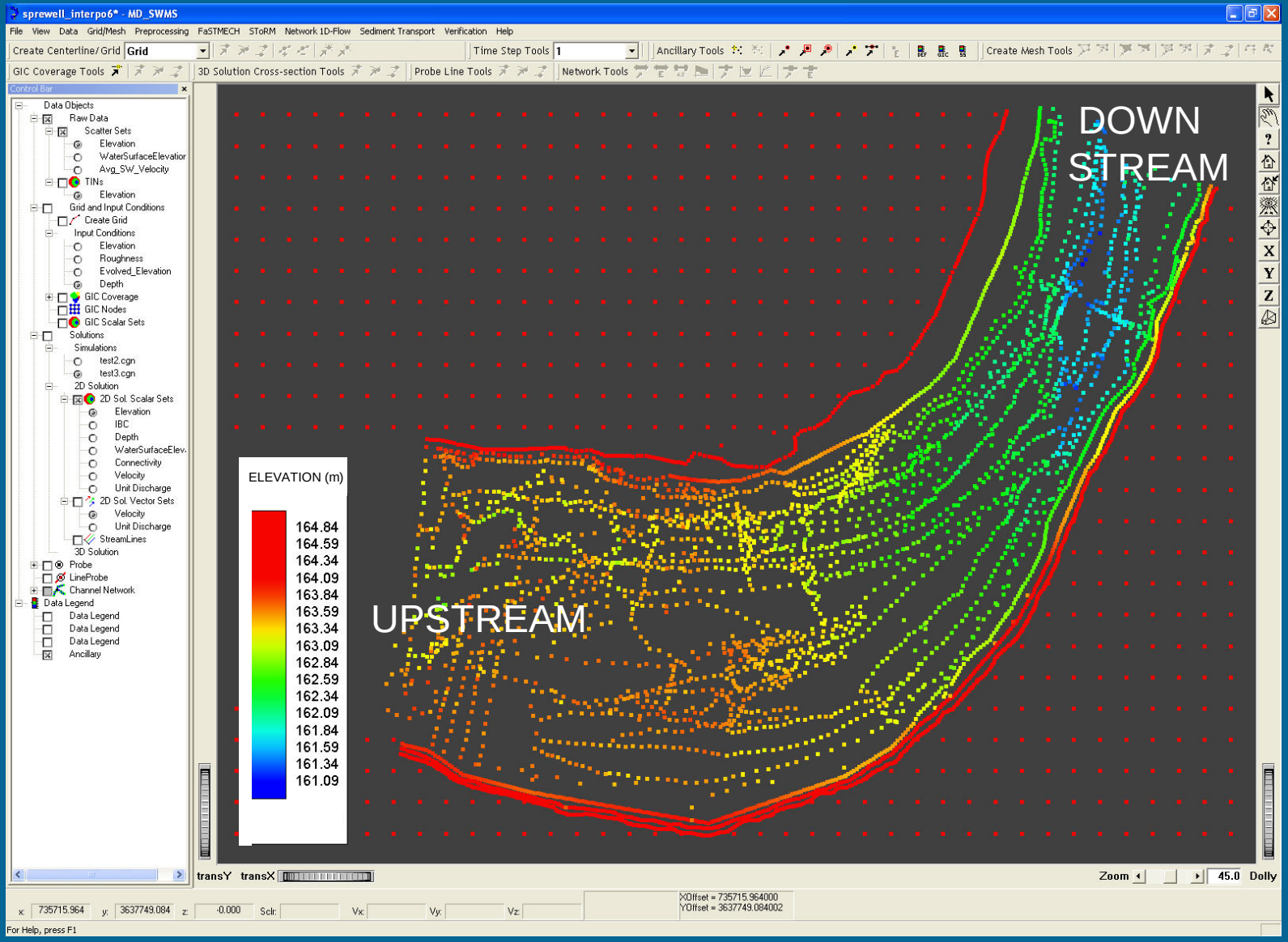
USGS

*http://ga.water.usgs.gov/flintriver/

Sprewell Bluff Pilot Study

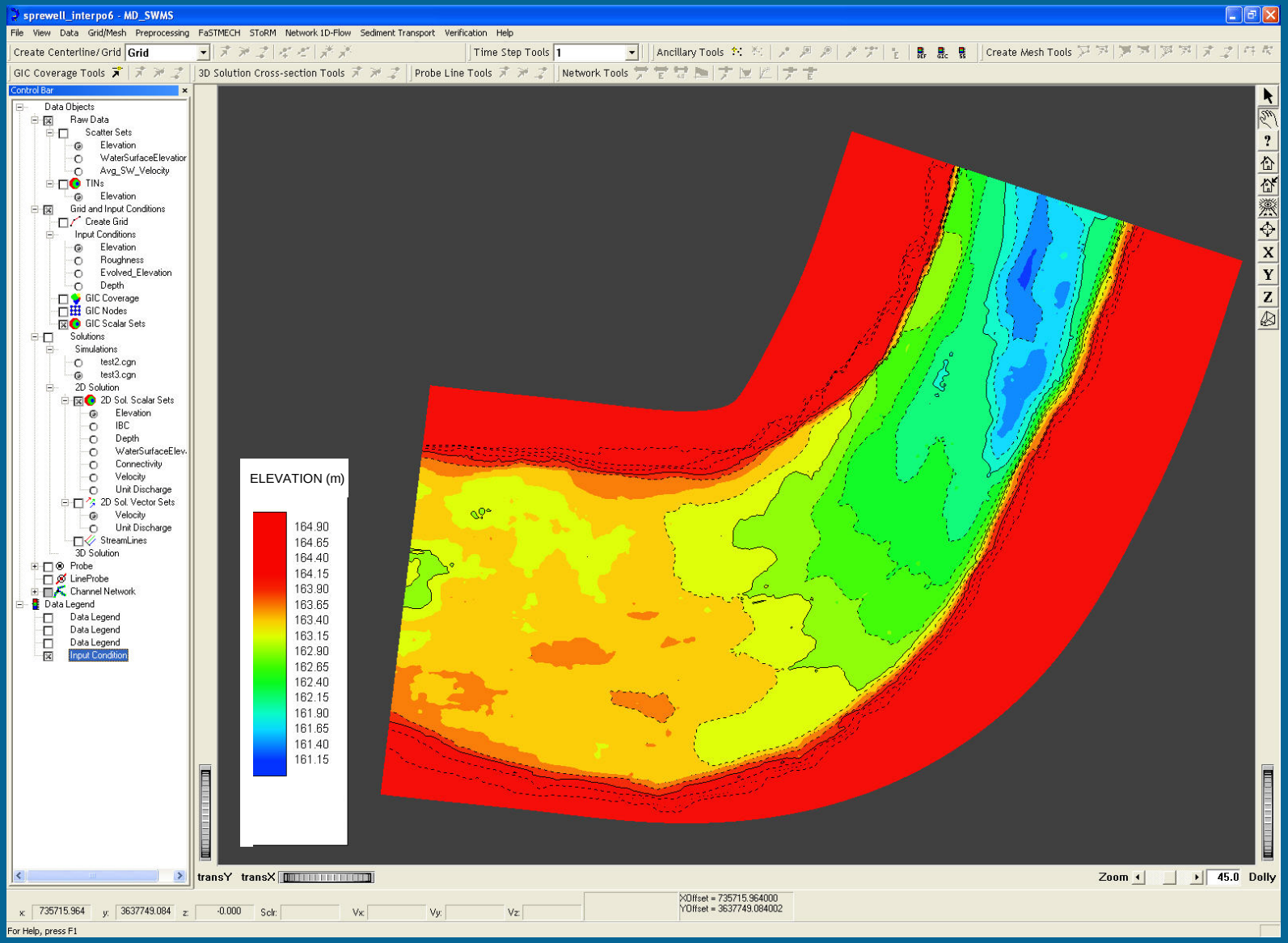
- Topographic survey above and below water surface with survey-grade GPS (1 base station receiver and 3 roving receivers) 2,770 points in 2 days.
- Discharge collected along 1 cross section using SonTek FlowTracker Acoustic Doppler Velocimeter
- Water-surface elevation measurements collected for calibration of channel roughness
- Spatial distribution of aquatic vegetation mapped (*Podostemum ceratophyllum*)

USGS



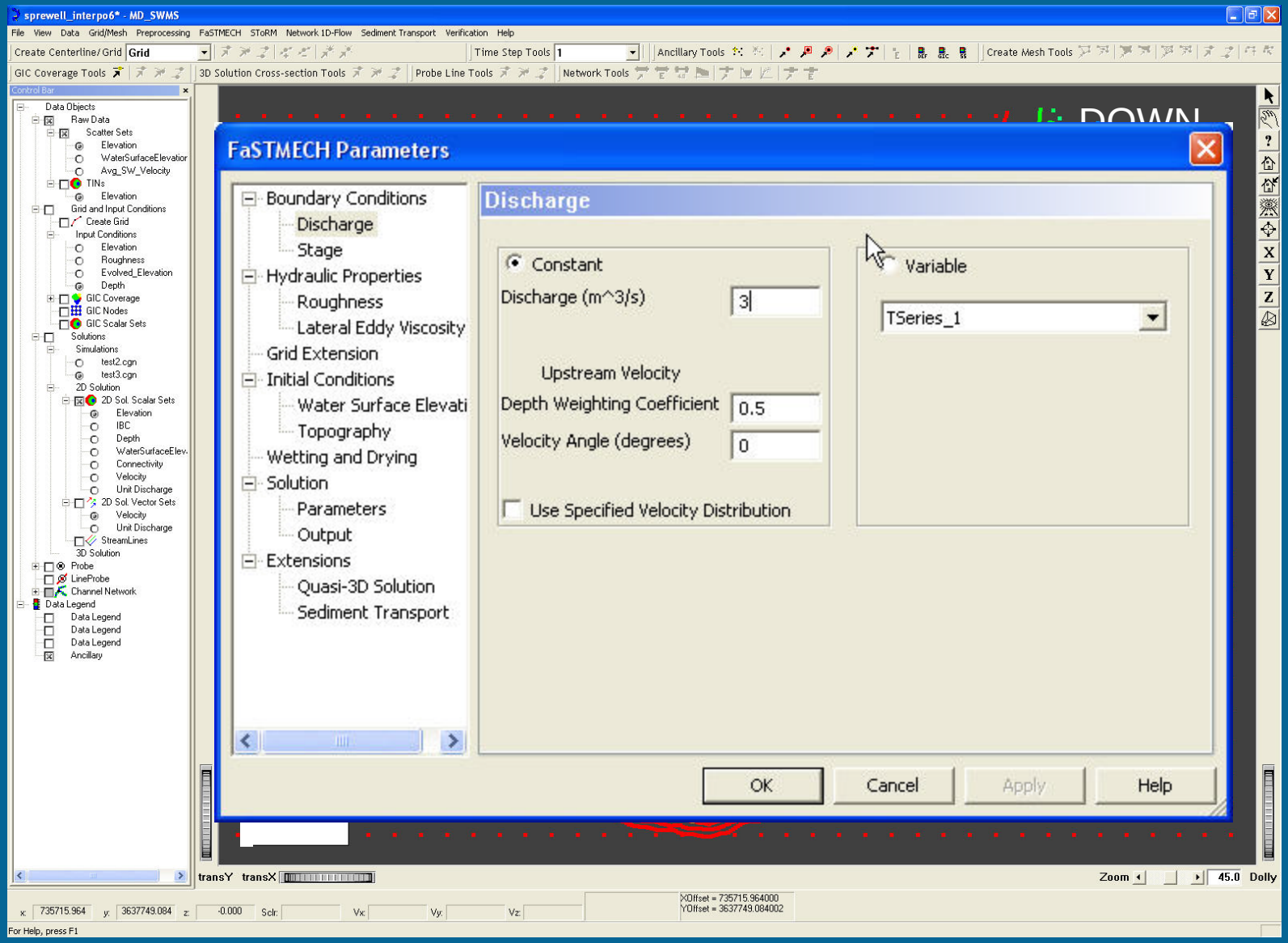
USGS

Topographic Data (Ground survey and DEM)



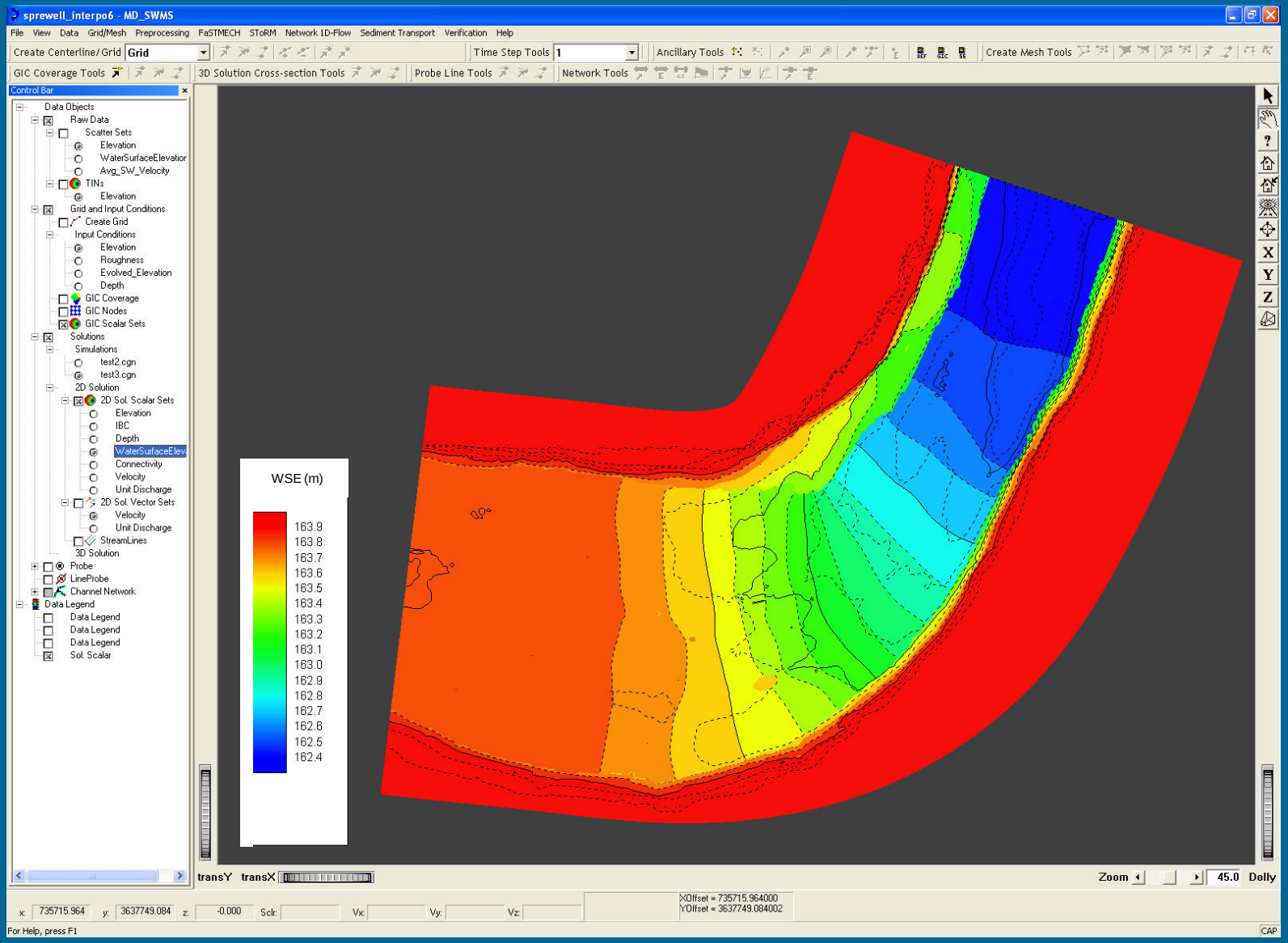
USGS

Interpolated Channel Topography



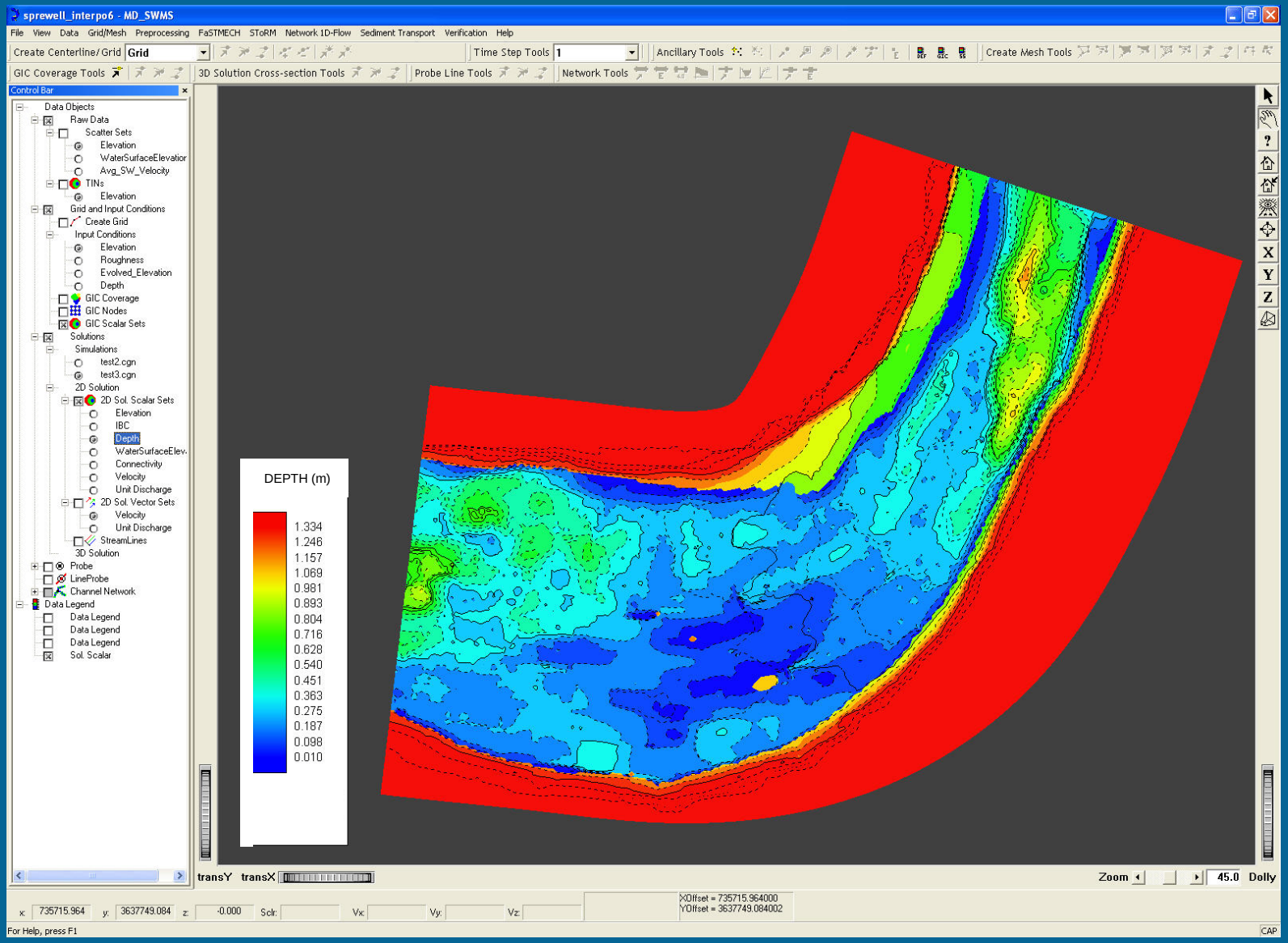
USGS

FaSTMECH Model Input Dialog



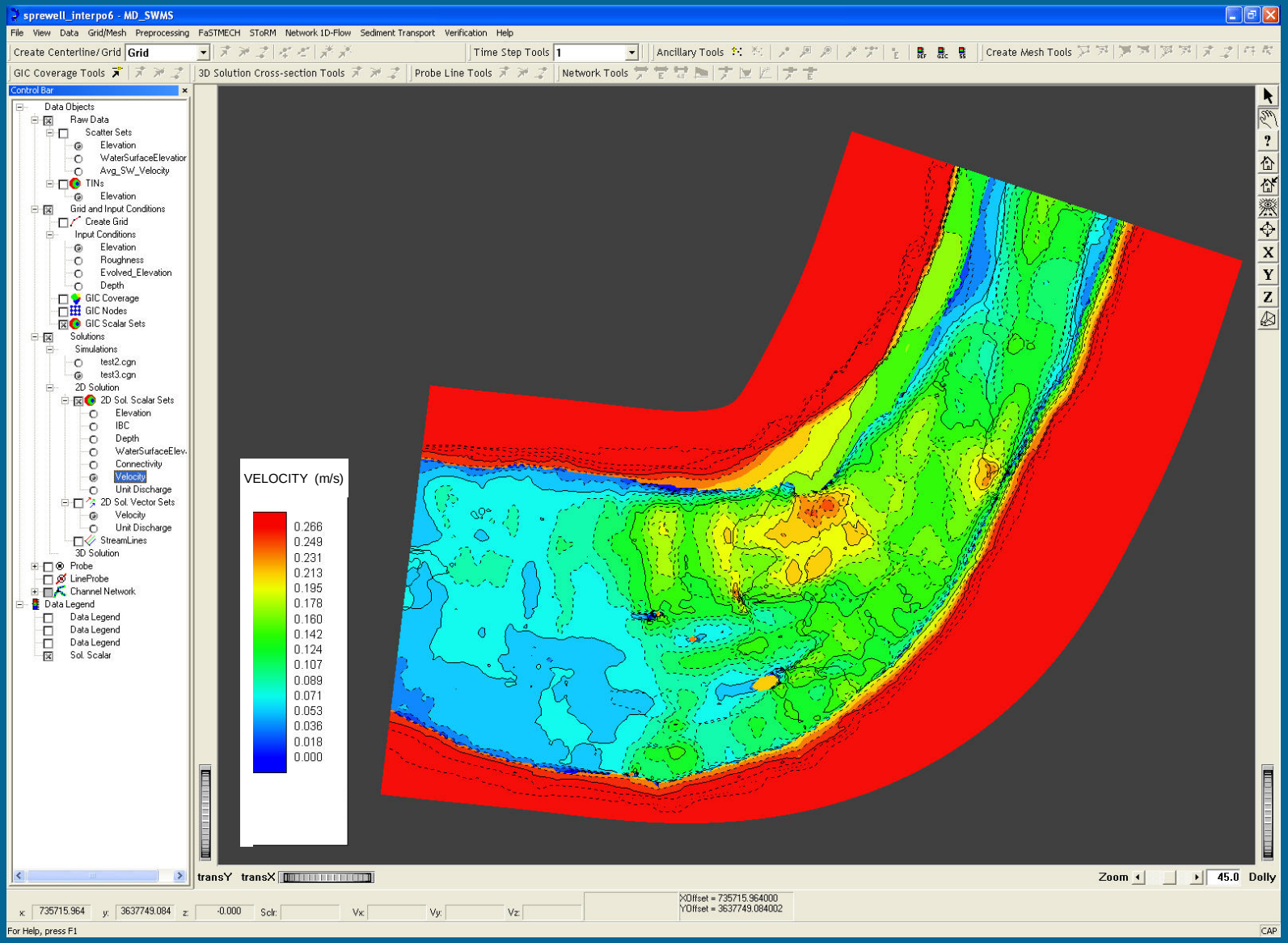
USGS

Predicted Water Surface Elevation (Q = 3 m^3/s)



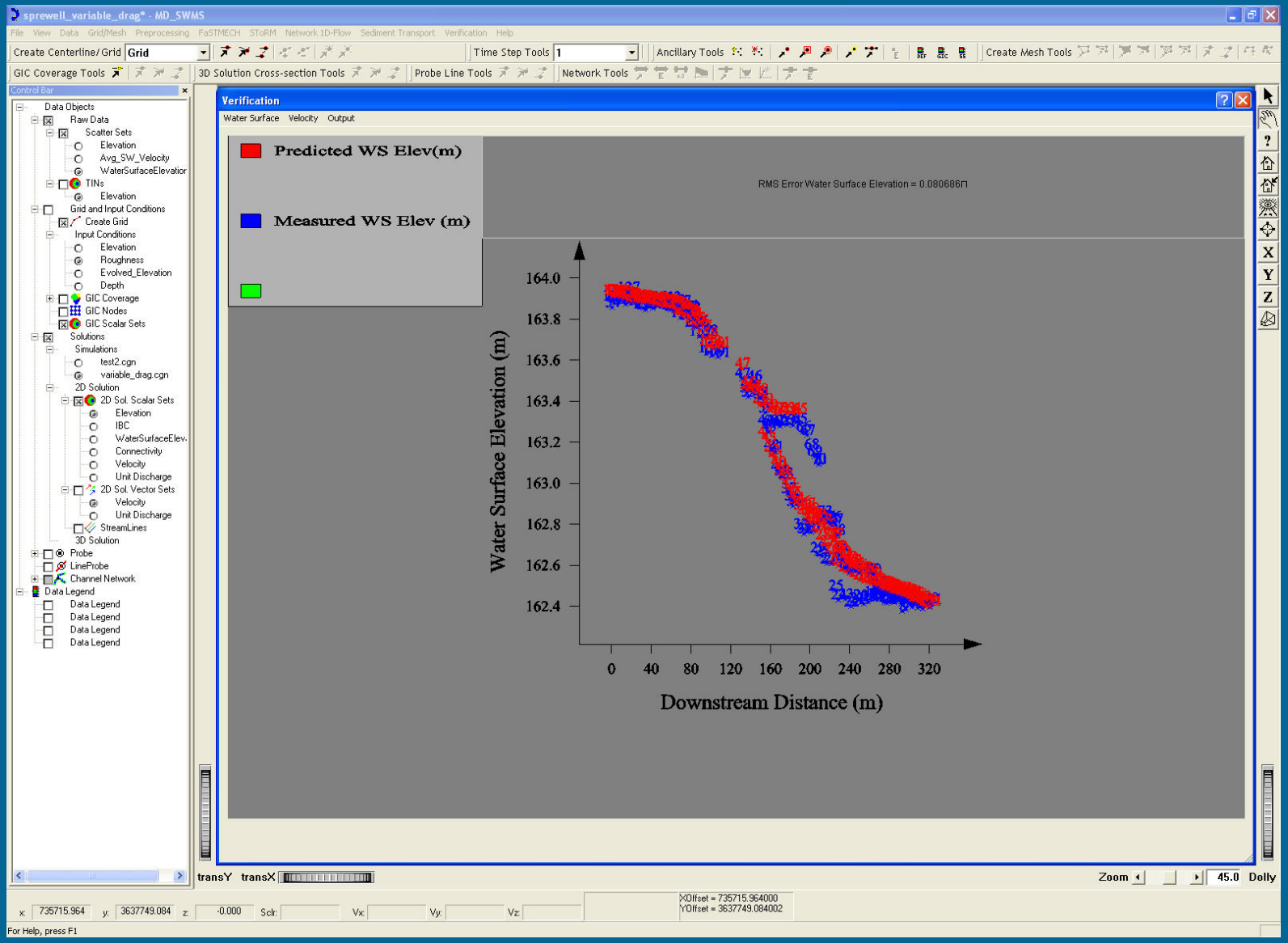
USGS

Predicted Depth Distribution (Q = 3 m^3/s)



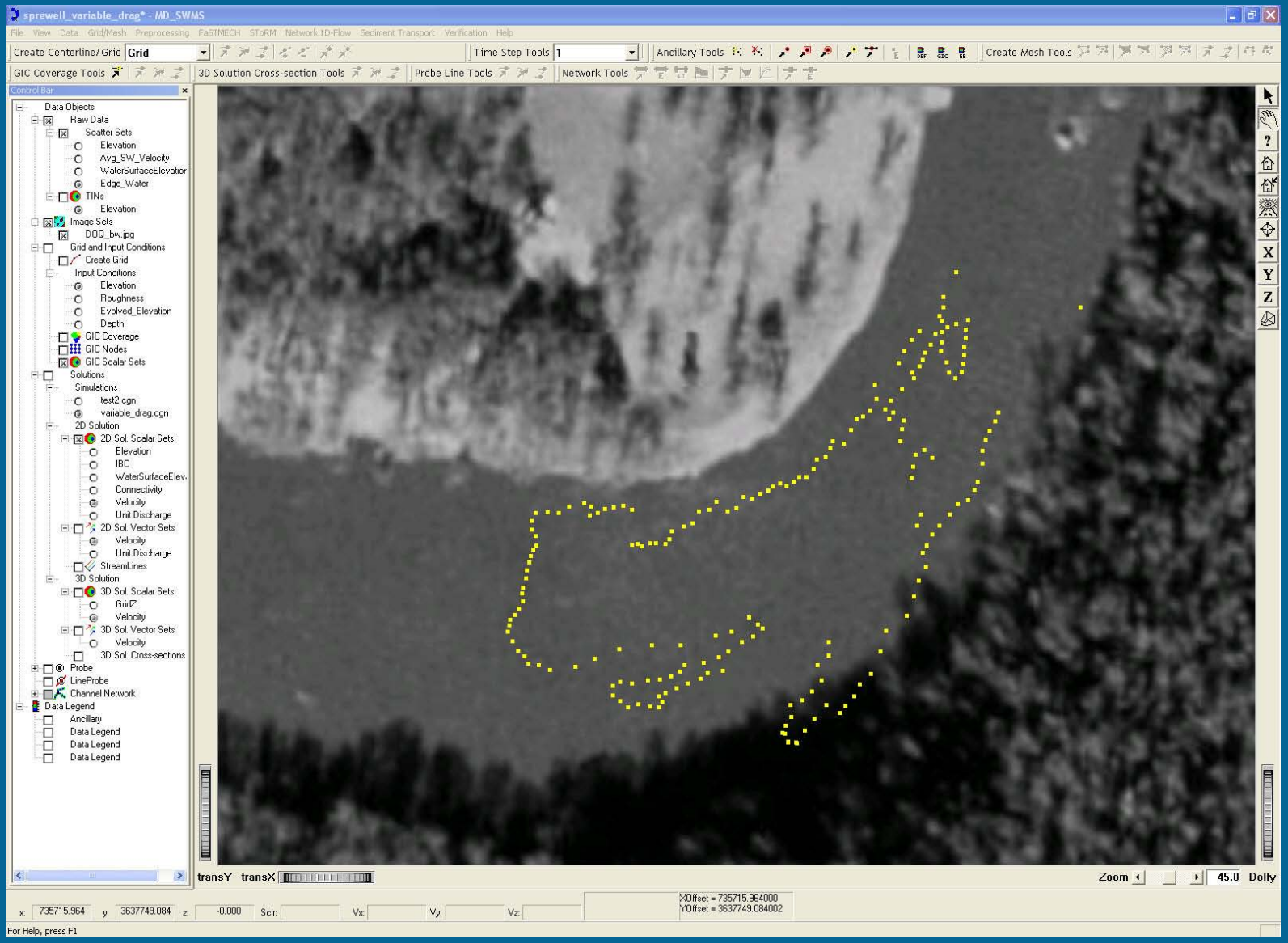
USGS

Predicted Velocity Distribution (Q = 3 m^3/s)



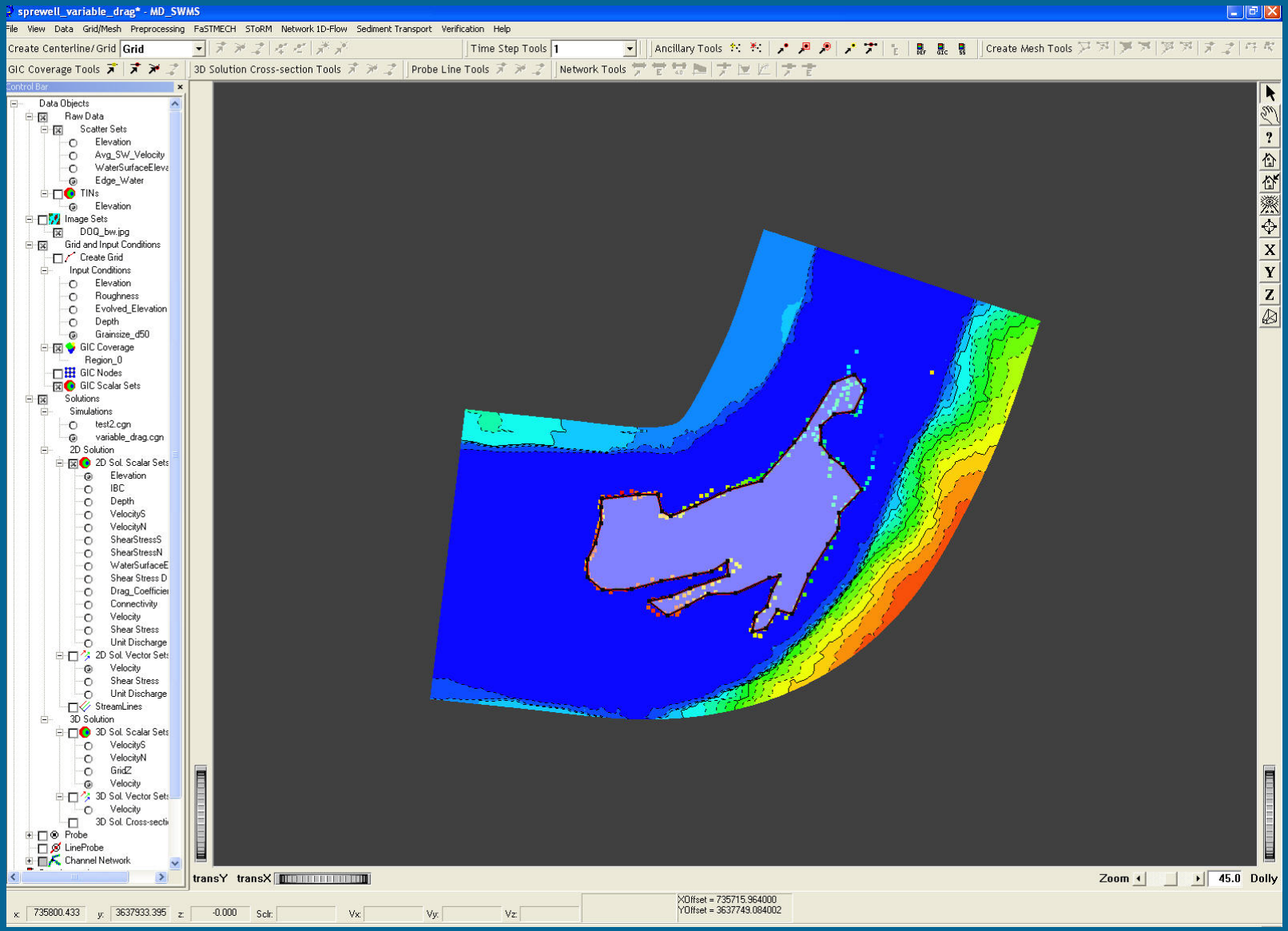
USGS

WSE Verification – Uniform drag coefficient

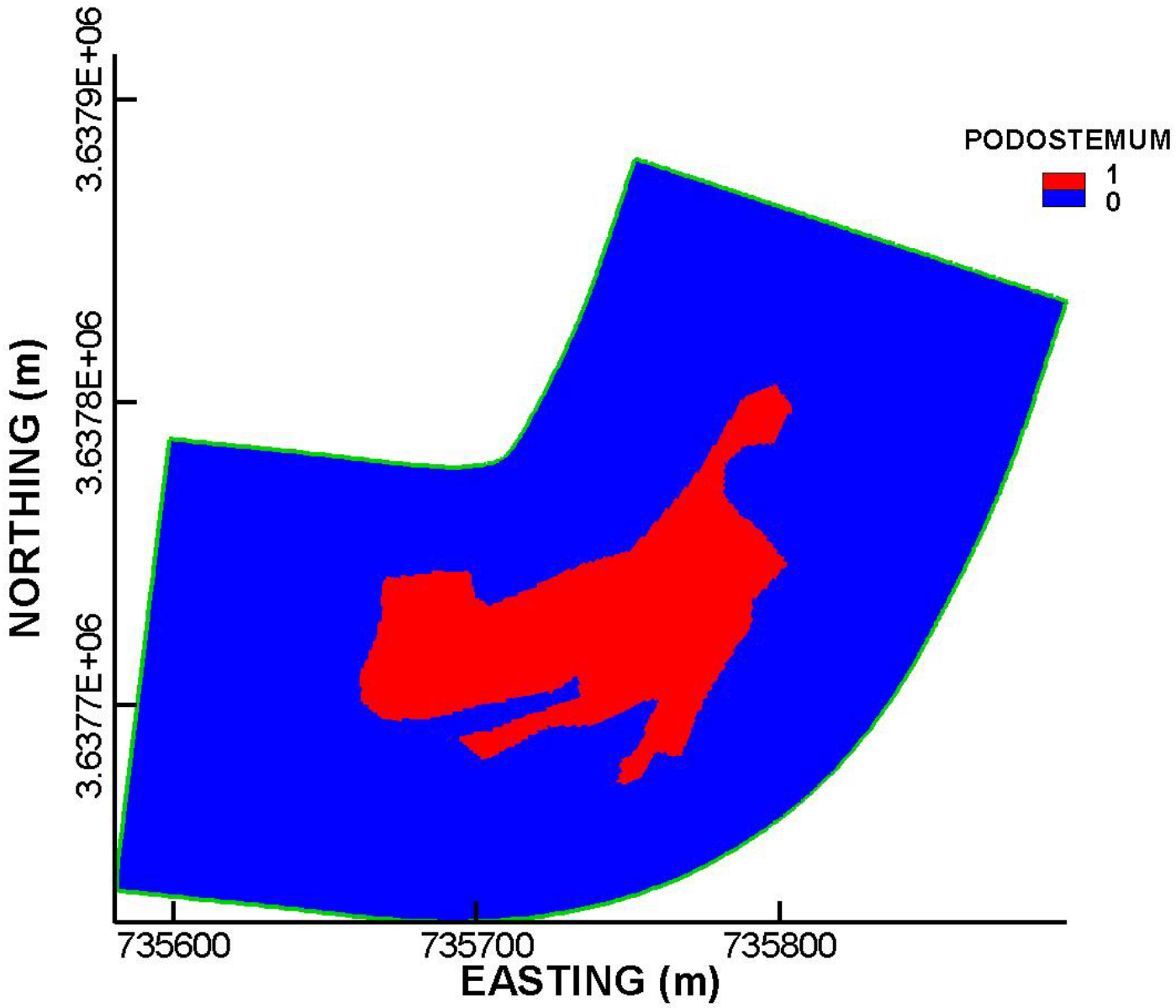


Locations of riverweed –(*Podostemum ceratophyllum*)

USGS

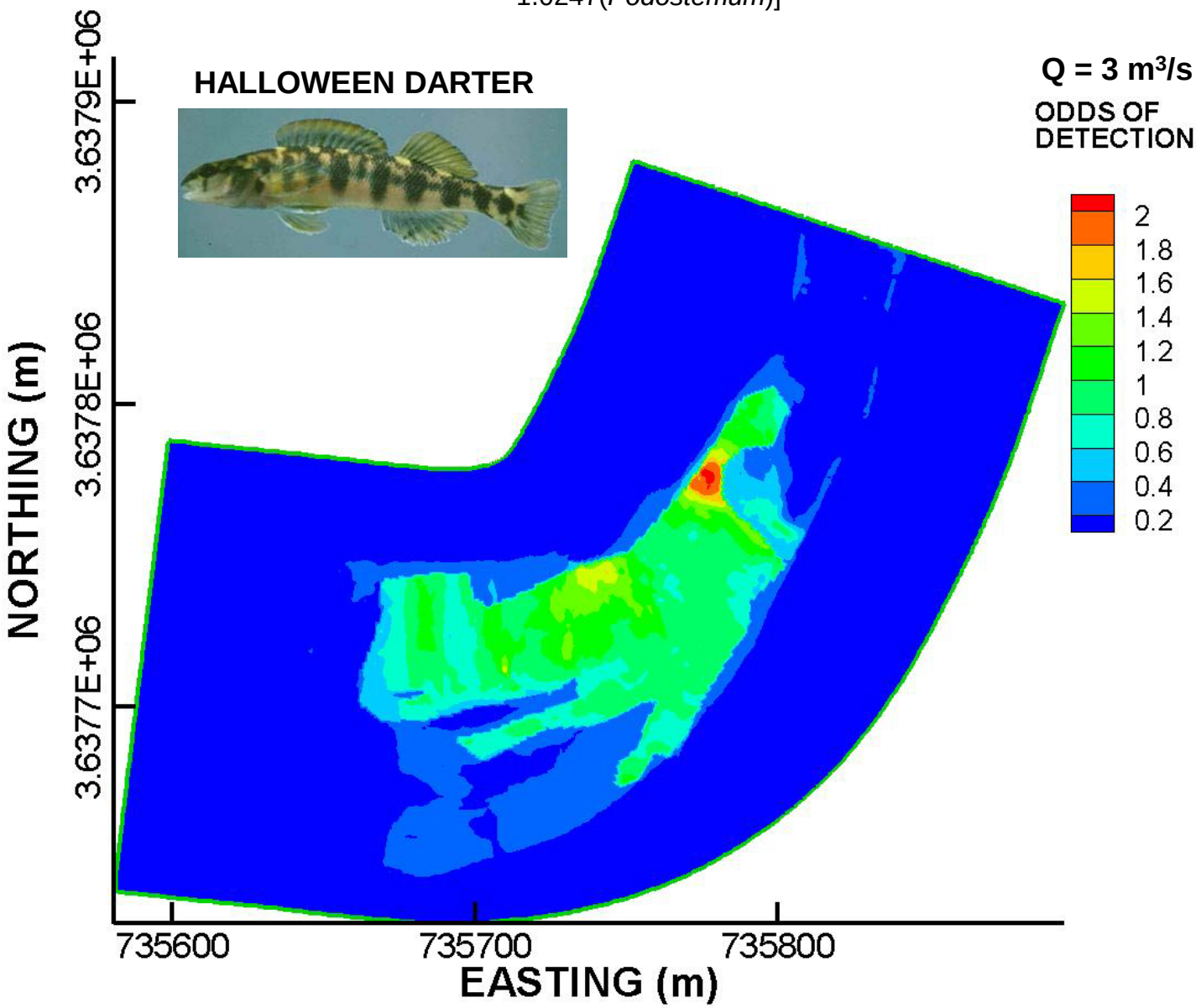

sprewell_variable_drag* - MD_SWMS
File View Data Grid/Mesh Preprocessing FaSTMECH SToRM Network 1D-Flow Sediment Transport Verification Help
Create Centerline/Grid
Grid
Time Step Tools
Ancillary Tools
Create Mesh Tools
GIC Coverage Tools
3D Solution Cross-section Tools
Probe Line Tools
Network Tools
Control Bar
Data Objects
Raw Data
Scatter Sets
Elevation
Avg_SW_Velocity
WaterSurfaceElev
Edge_Water
TINs
Elevation
Image Sets
DOQ_bw.jpg
Grid and Input Conditions
Create Grid
Input Conditions
Elevation
Roughness
Evolved_Elevation
Depth
Grainsize_d50
GIC Coverage
Region_0
GIC Nodes
GIC Scalar Sets
Solutions
Simulations
test2.cgn
variable_drag.cgn
2D Solution
2D Sol. Scalar Sets
Elevation
IBC
Depth
VelocityS
VelocityN
ShearStressS
ShearStressN
WaterSurfaceE
Shear Stress D
Drag_Coefficie
Connectivity
Velocity
Shear Stress
Unit Discharge
2D Sol. Vector Sets
Velocity
Shear Stress
Unit Discharge
StreamLines
3D Solution
3D Sol. Scalar Sets
VelocityS
VelocityN
GridZ
Velocity
3D Sol. Vector Sets
Velocity
3D Sol. Cross-secti
Probe
LineProbe
Channel Network
transY
transX
Zoom
45.0
Dolly
x: 735800.433
y: 3637933.395
z: -0.000
Scl:
Vx:
Vy:
Vz:
XOffset = 735715.964000
YOffset = 3637749.084002

USGS


PODOSTEMUM
1
0
NORTHING (m)
3.6379E+06
3.6378E+06
3.6377E+06
735600
735700
735800
EASTING (m)

USGS

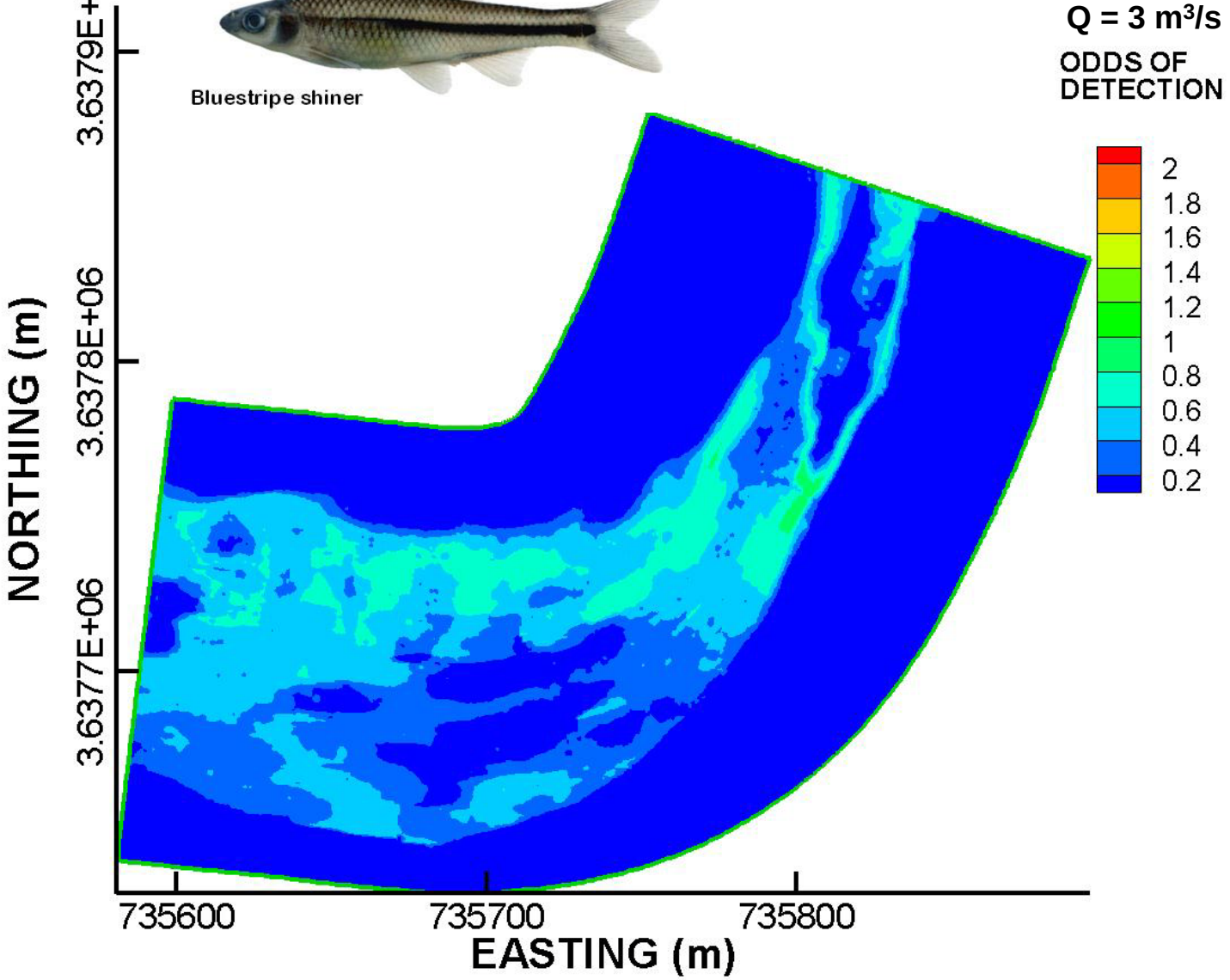
Odds of detection = exp[-2.5092 + 3.4287(Depth) – 8.4031(Depth)2 + 7.1102(Velocity) – 3.8879(Velocity)2 + 1.0247(*Podostemum*)]



USGS

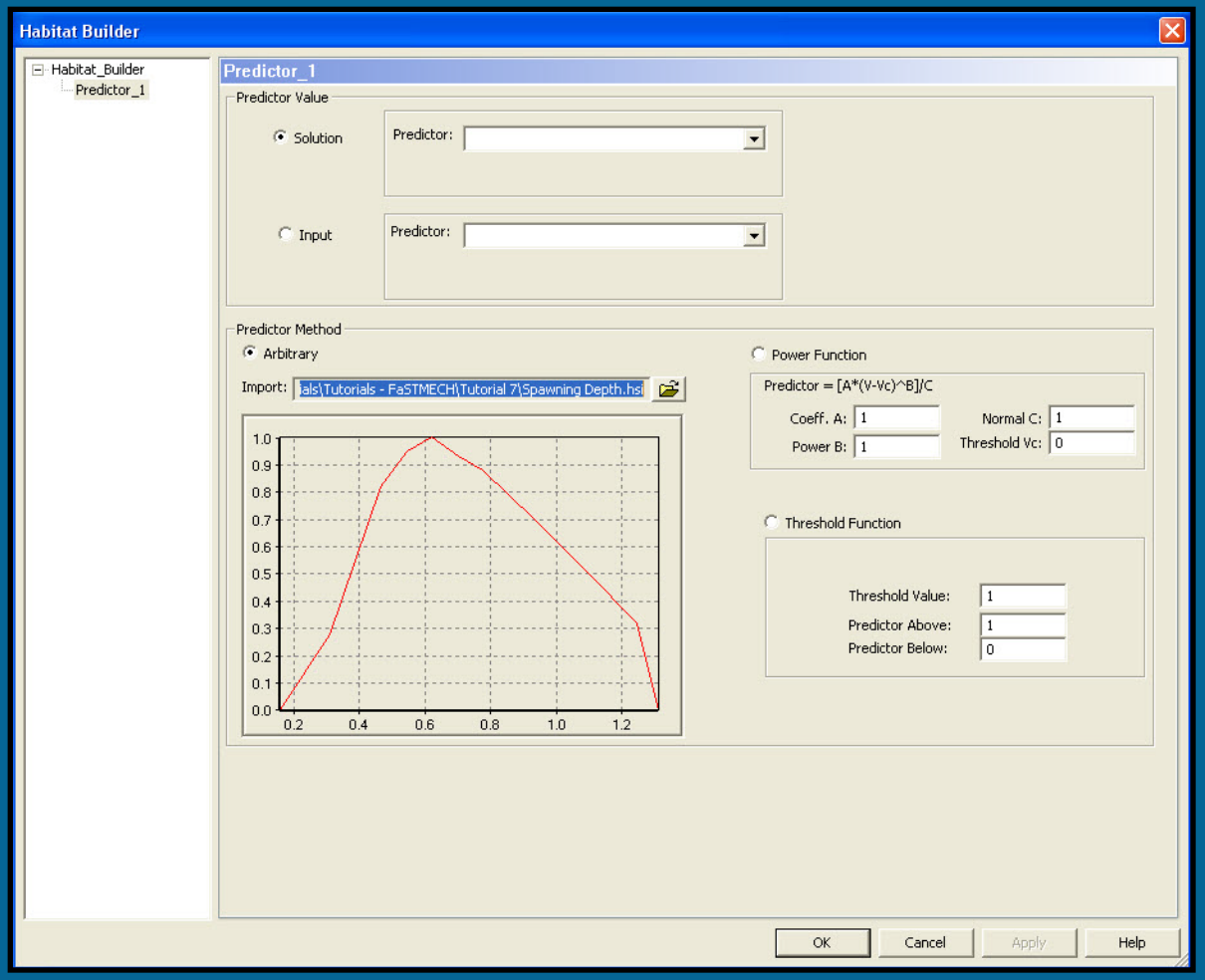
Odds of detection = exp[-3.5848 + 12.7566(Depth) – 14.2855(Depth)2 + 2.9797(Velocity) – 2.3758(Velocity)2]

Bluestripe shiner



USGS

MD_SWMS Habitat Builder



Other examples:

Green River, UT

- ❑ Juvenile Fish Rearing Habitat

Kootenai River, ID

- ❑ Sturgeon Spawning Habitat

Platte River, NE

- ❑ Crane Roosting Habitat

Trinity River, CA

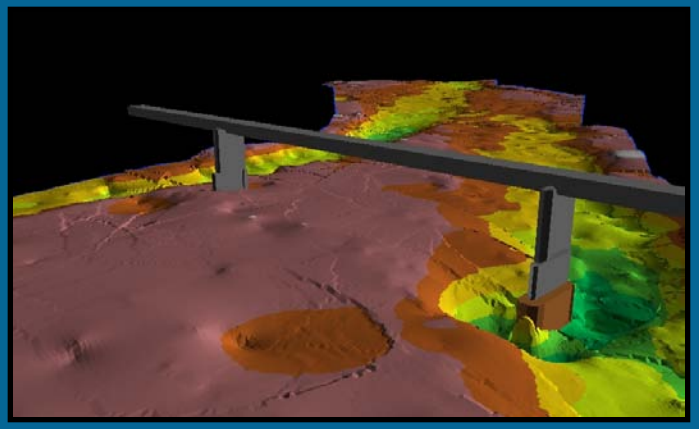
- ❑ Salmon Redd Habitat

USGS

Topographic and Bathymetric Data Collection for River Studies

PURPOSES

- Habitat Assessment
- Change Detection
- Flood Studies
- Modeling
- Bridge Scour



CONCERNS

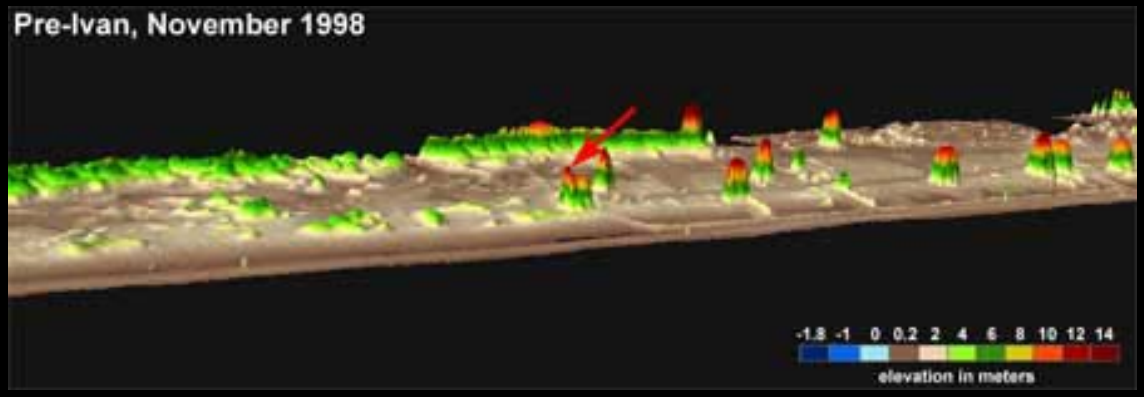
- Safety
- Cost
- Data Coverage
- Access
- Disturbance

USGS

Image of Tanana River courtesy of Jeff Conaway, USGS - Alaska

EAARL

- Experimental Advanced Airborne Research LiDAR
- Collaboration between NASA (Wallops Island, VA) and USGS Coastal and Marine Geology (St. Petersburg, FL)
- Blue-green laser to survey in clear, shallow water
- Applications – Coral Reefs (Brock), Vegetation (Nayegandhi), Coastal Erosion (Sallenger)

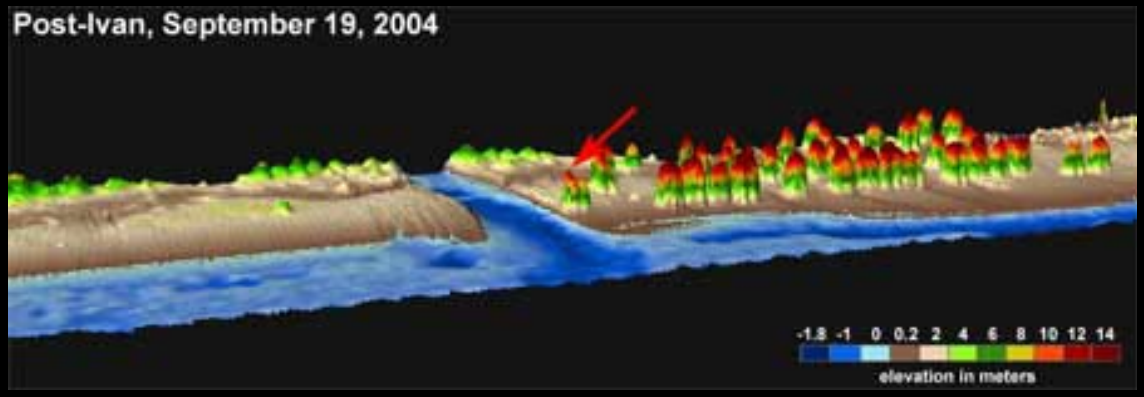


USGS

Images from USGS Hurricane Ivan Impact Studies web site (http://coastal.er.usgs.gov/hurricanes/ivan/lidar/breach.html)

EAARL

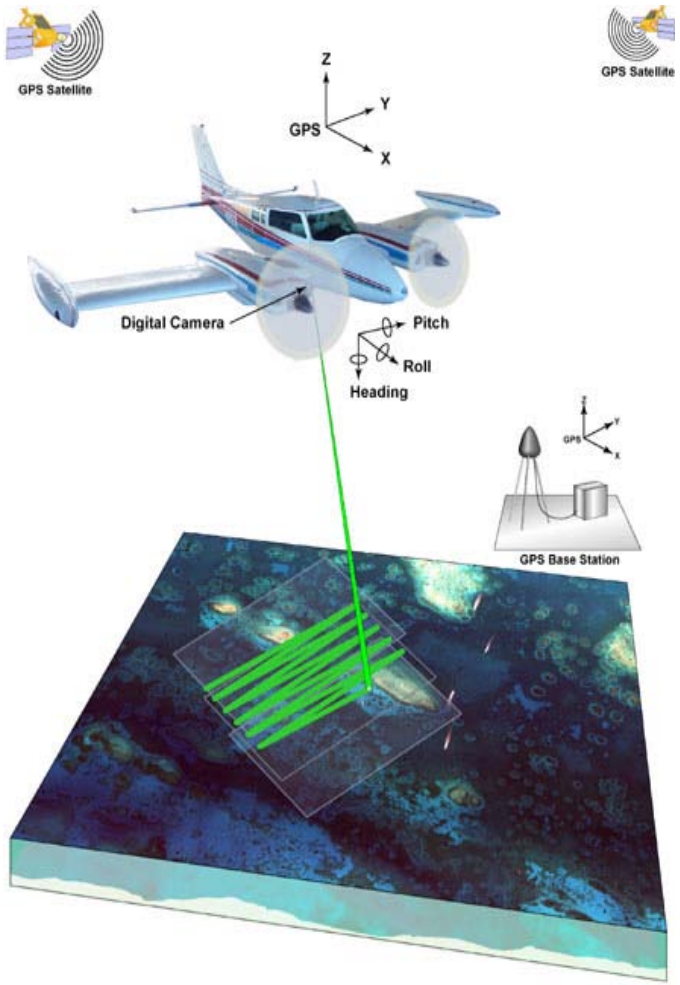
- Experimental Advanced Airborne Research LiDAR
- Result of collaboration between NASA (Wallops Island, VA) and USGS Coastal and Marine Geology (St. Petersburg, FL), now GD
- Blue-green laser to survey in clear, shallow water
- Applications – Coral Reefs (Brock), Vegetation (Nayegandhi), Coastal Erosion (Sallenger)



USGS

Images from USGS Hurricane Ivan Impact Studies web site (http://coastal.er.usgs.gov/hurricanes/ivan/lidar/breach.html)

EAARL Specifications

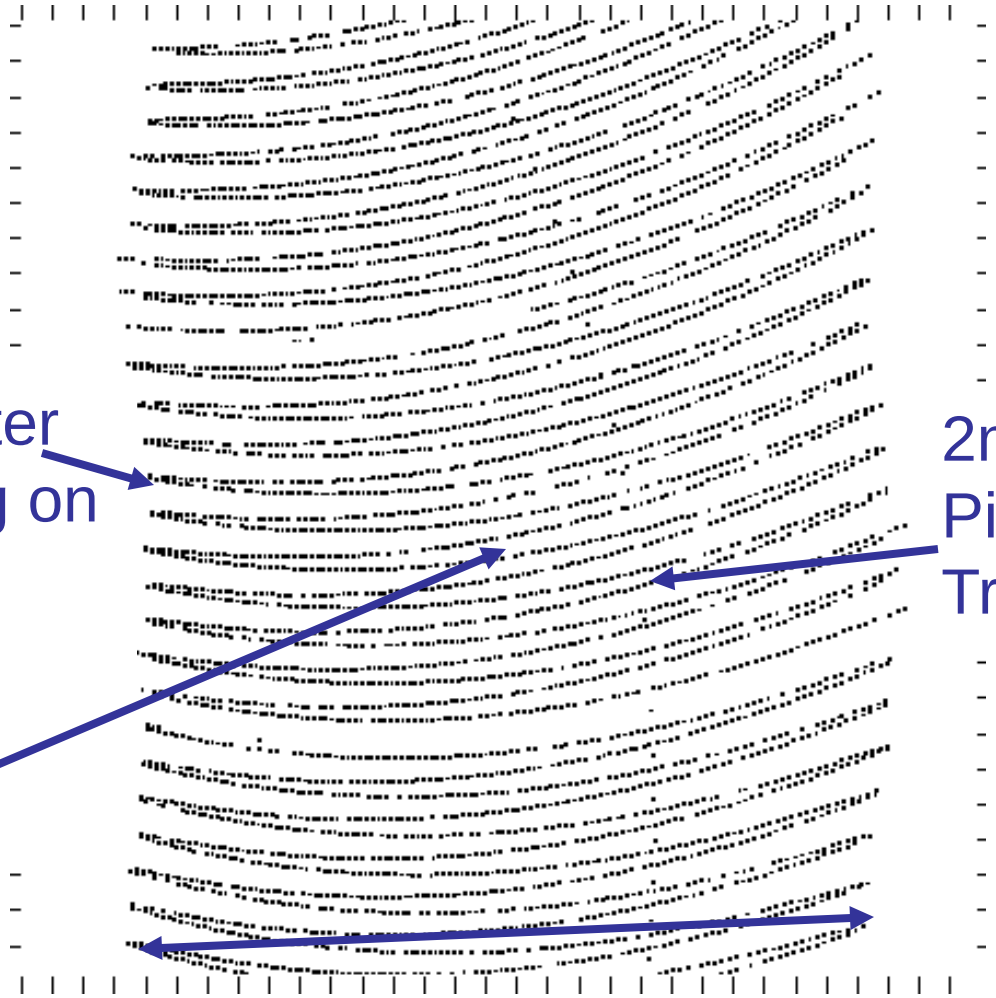


- Raster scanning 'full waveform', low power (70µJ) green (532nm) topo-bathy lidar
- Maximum Pulse Rate = 5000Hz
- Swath width 240m at altitude 300m
- TANS Attitude System w/ KGPS & IMU
- 15-20 cm diameter footprint
- Digitizer sample interval 1ns (15cm in air, 11cm in water)
- Digital RGB and CIR imagery

USGS

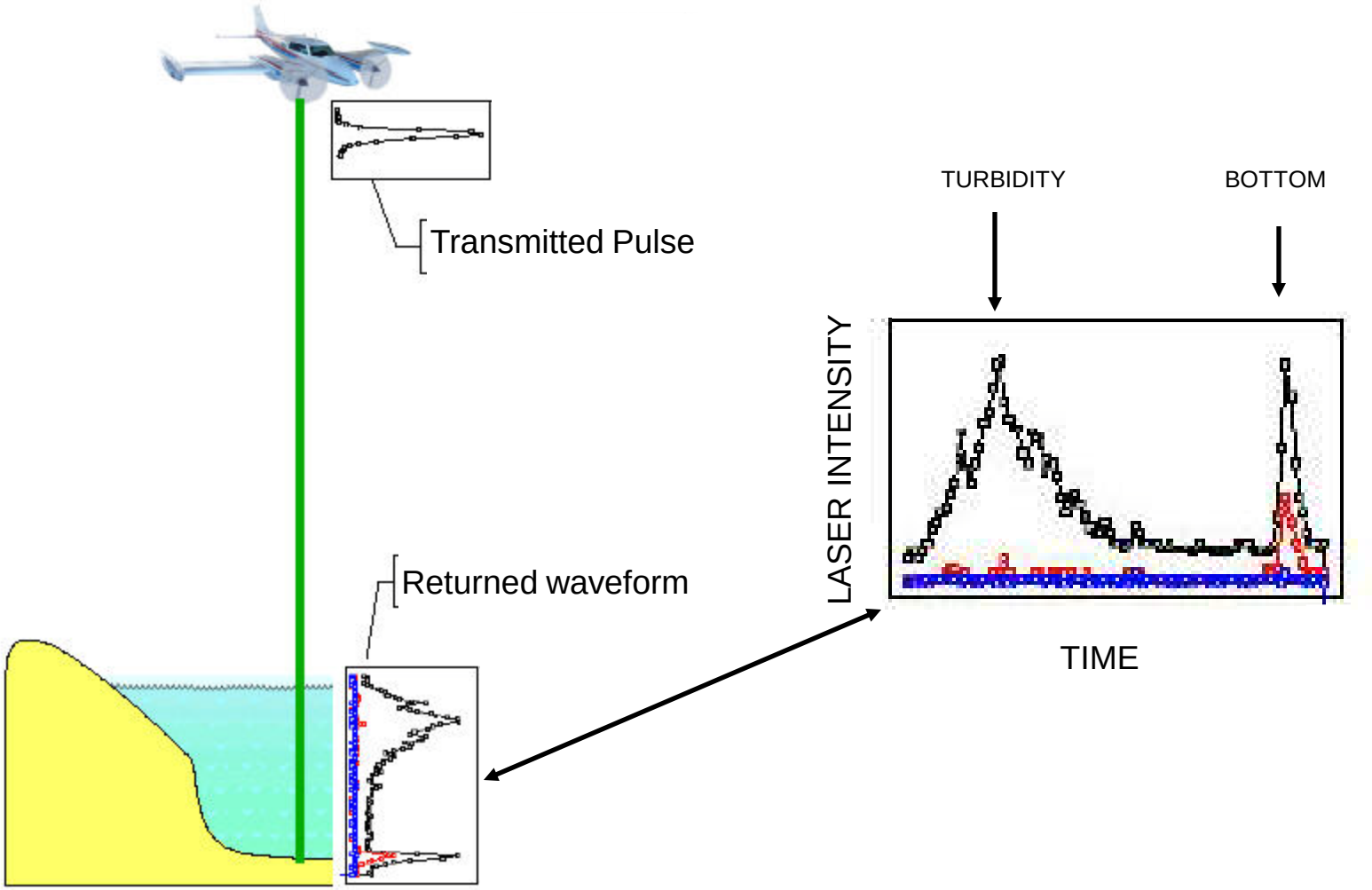
Slide courtesy of Amar Nayegandhi (USGS)

EAARL Raster Sampling



Slide courtesy of C. Wright

EAARL Coastal Waveforms



Three channels – 90%, 9% and 0.9% of the reflected photons

USGS

Figure modified from Wright and Brock, 2002

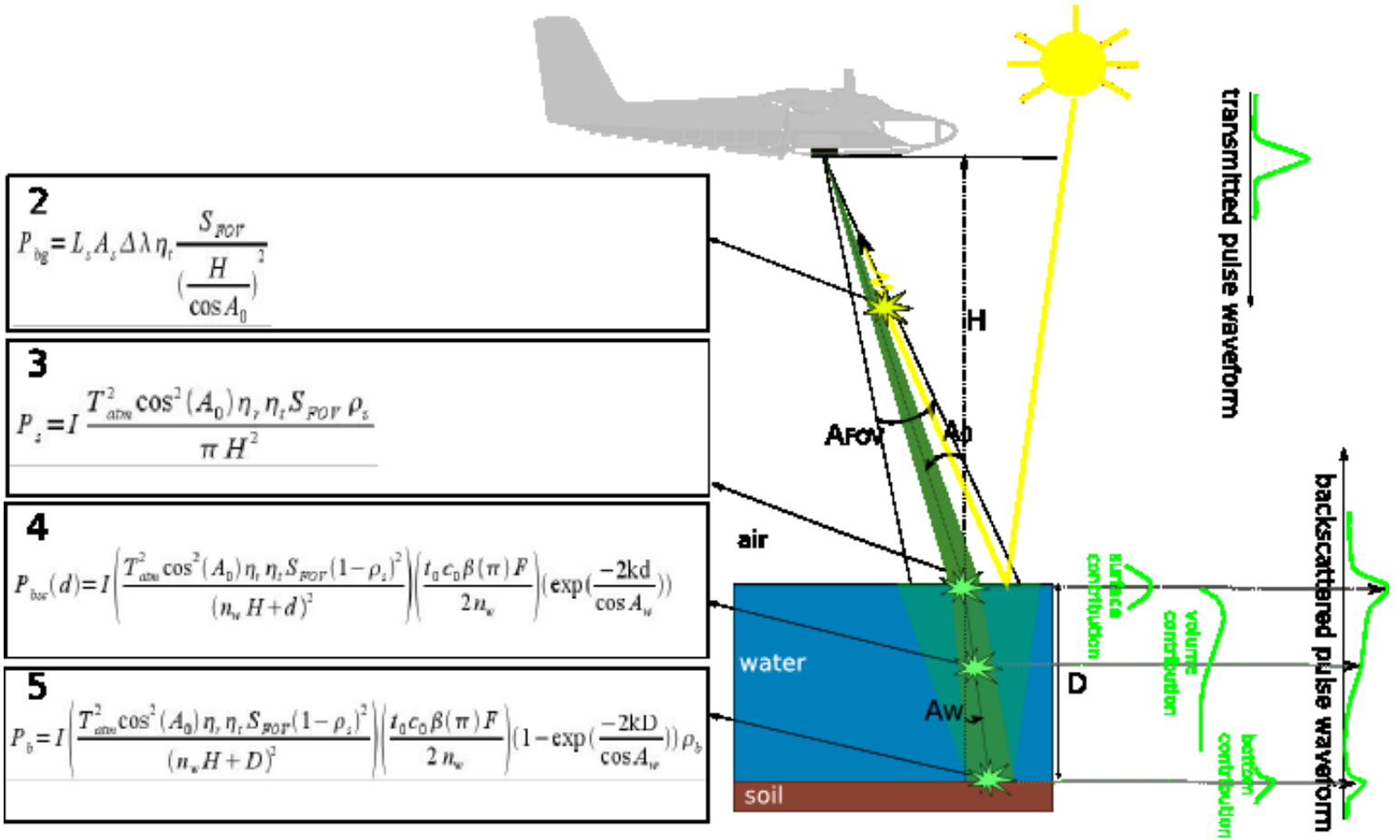


Figure from J.S. Bailly, P.J. Kinzel, T. Allouis, D. Feurer, Y. Le Coarer, in review, **Airborne Lidar Methods Applied to Riverine Environments** in Remote Sensing of Rivers: Management and Applications, P. Carbonneau and H. Piegay Eds.

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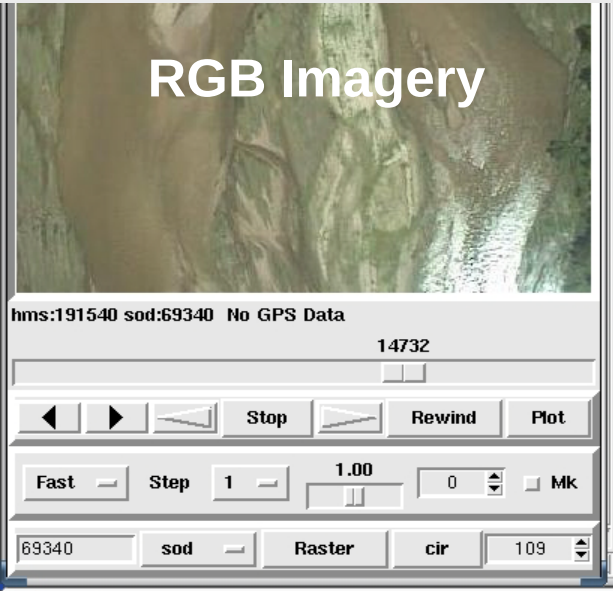
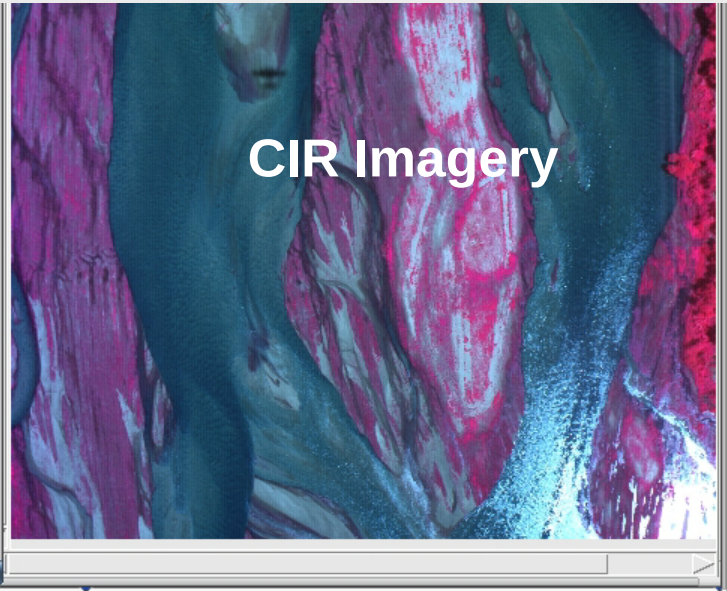
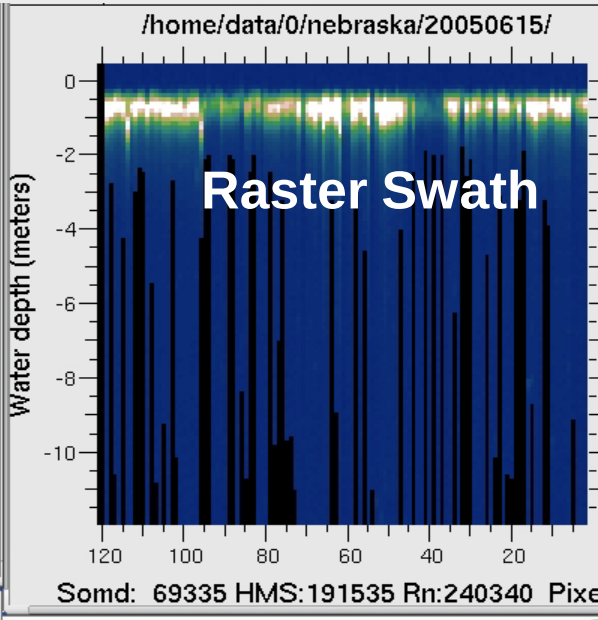
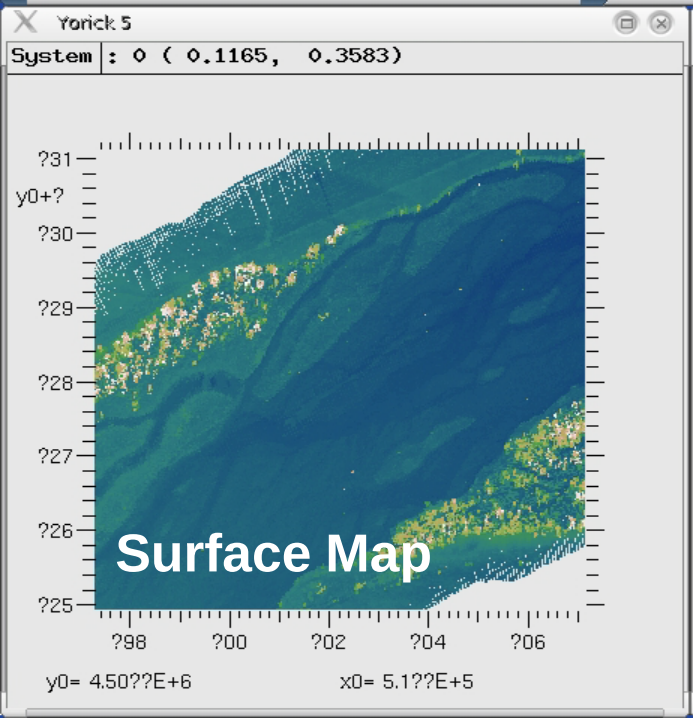
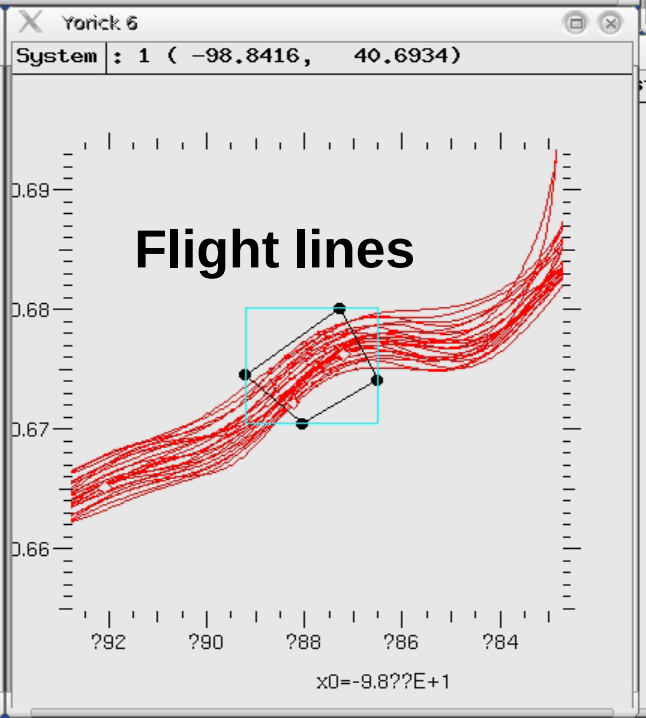
ALPS Interface

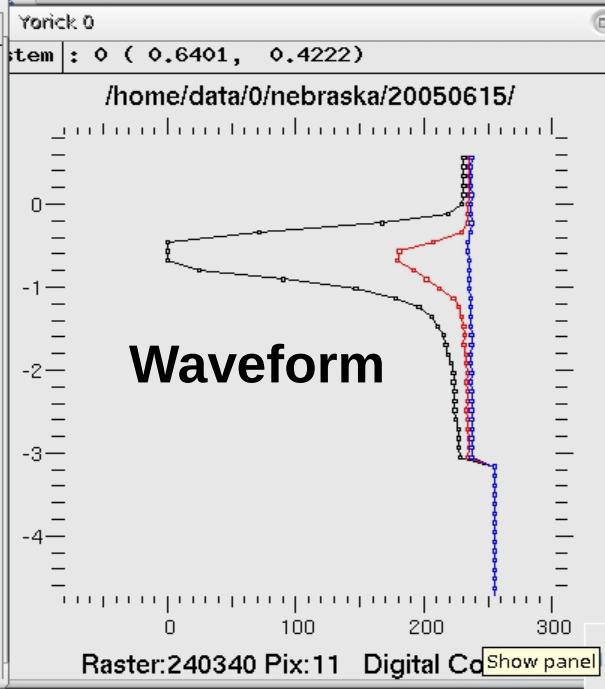












Mapping River Morphology with the EAARL

- Initial surveys along Platte River with USGS Venture Capital Funding in 2002 and 2005
- GSTL awarded grant from ONR (2009-2010)
- Investigate accuracy and precision of EAARL in various river channels
- Evaluate the effect of using EAARL and other RS technologies to collect bathymetry for hydraulic models
- Reaches of the Trinity, Klamath, and Colorado Rivers have been mapped
- Flights in 2010 - Shenandoah, Kootenai, Platte River

USGS

ONR

OFFICE OF NAVAL RESEARCH

Example – Trinity River, CA

Issues:

- Upstream regulation
- Reduced gravel supply
- Placer mining altered channels
- Restore floodplain connectivity and salmon and steelhead habitat

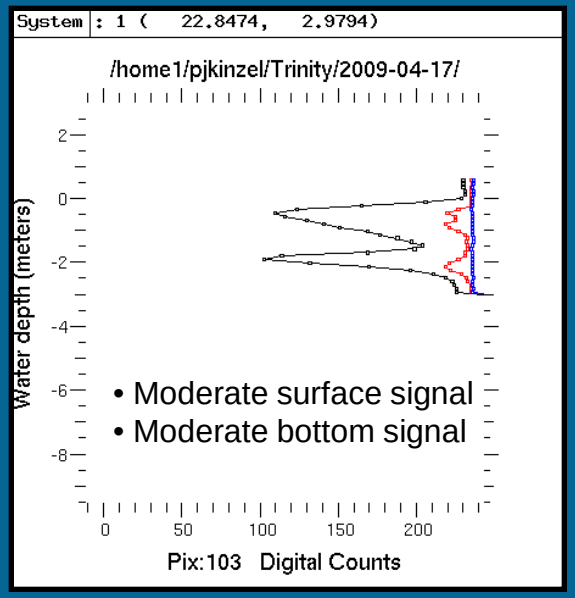
Narrow Meandering Morphology

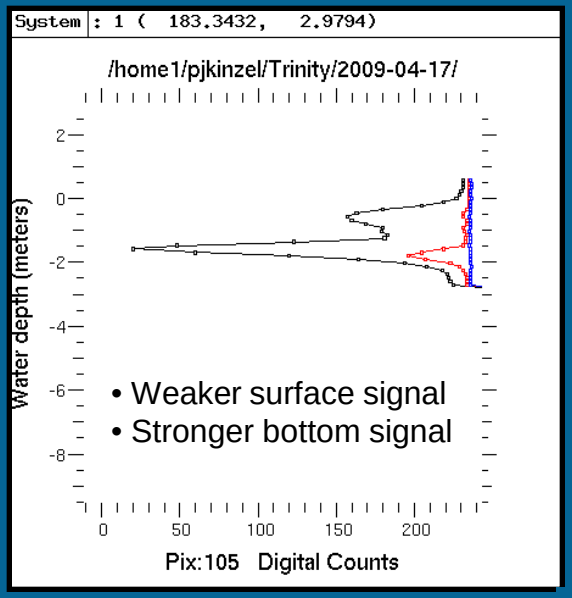
- **Gravel bed**
- **Bare gravel bars**
- **Forested floodplains**

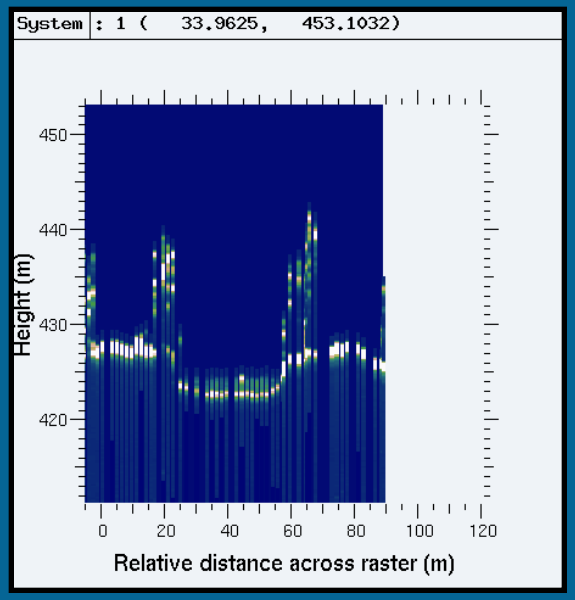
USGS

Trinity River Waveforms

Return Pulses of Laser Intensity vs. Time

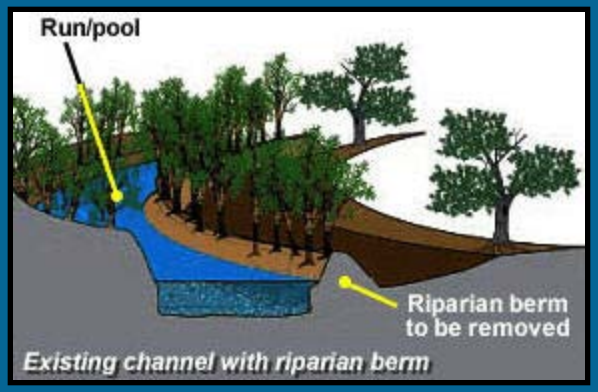


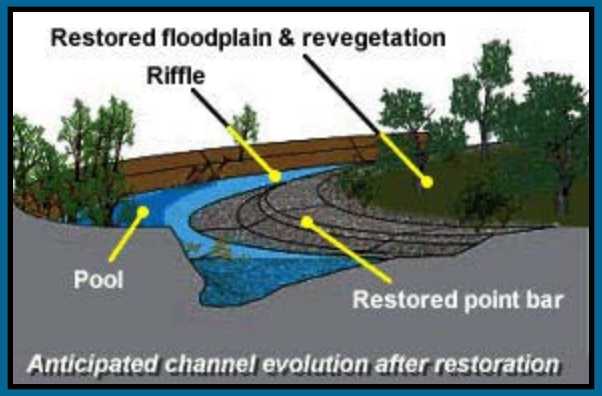




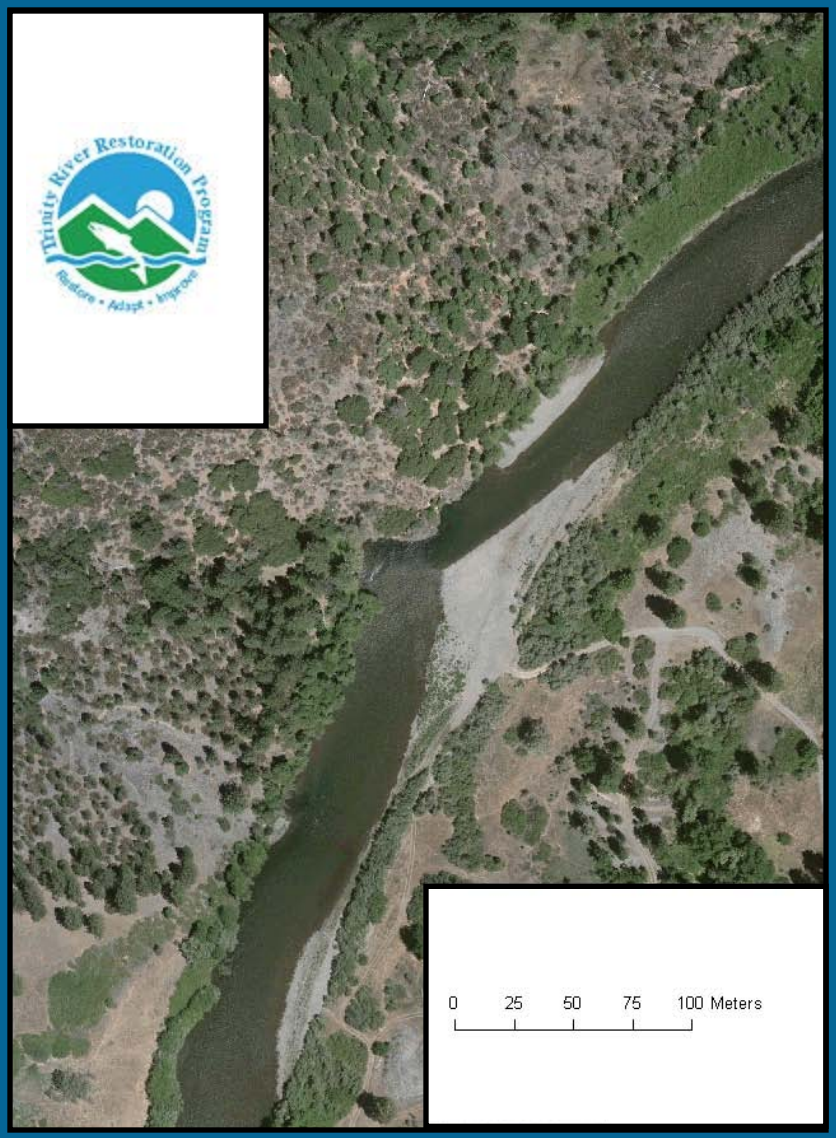
USGS

Trinity River, CA – Sheridan Bar Reach





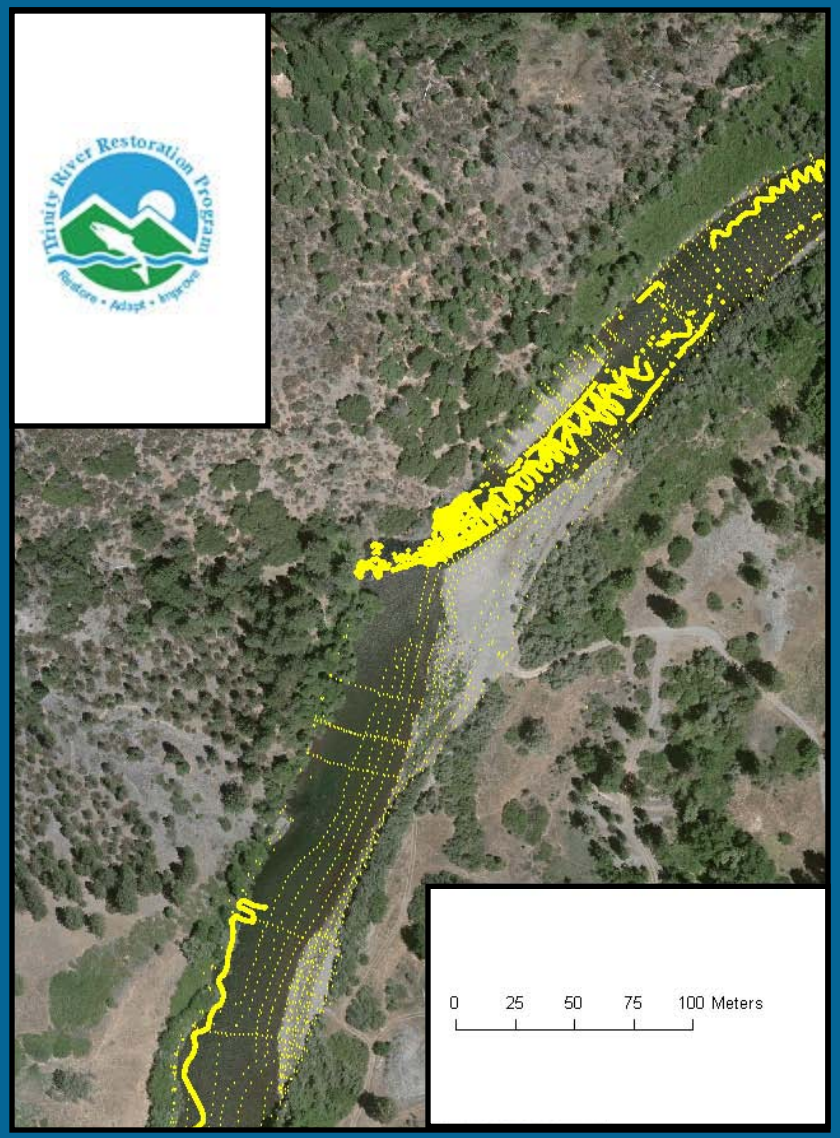
http://www.trrp.net/index.htm



Natural color orthophotograph 04/09

USGS

Trinity River, CA – Sheridan Bar Reach

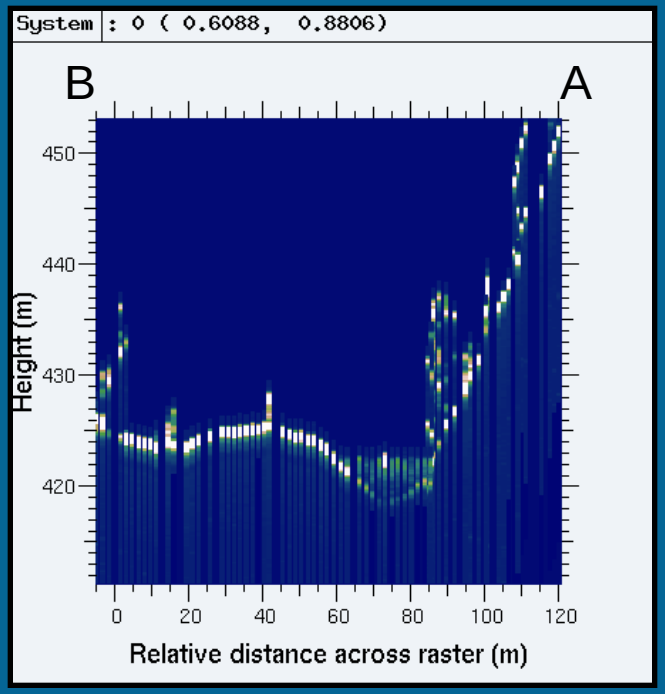


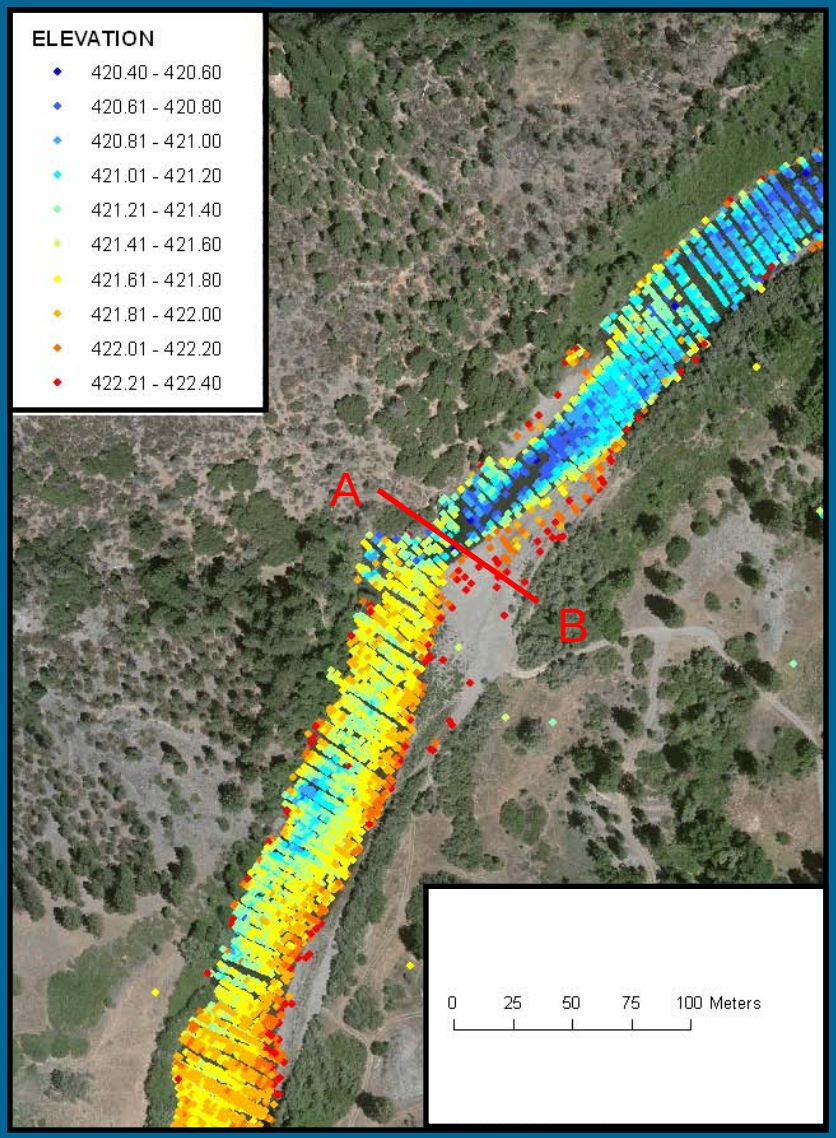
USGS

- RTK GPS, TS, and Sonar Points

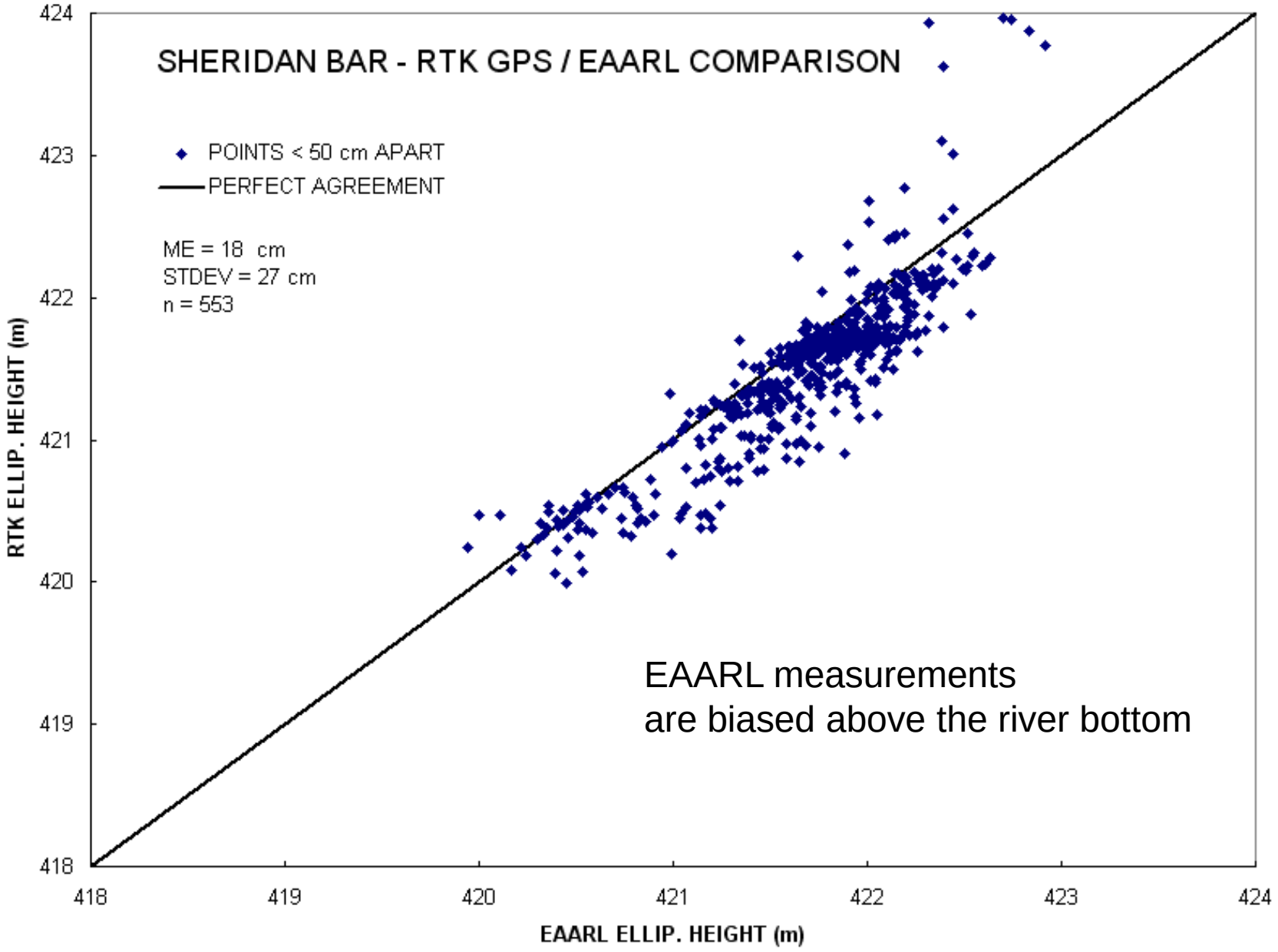
Trinity River, CA – Sheridan Bar Reach

- Points identified with EAARL bathymetry algorithm





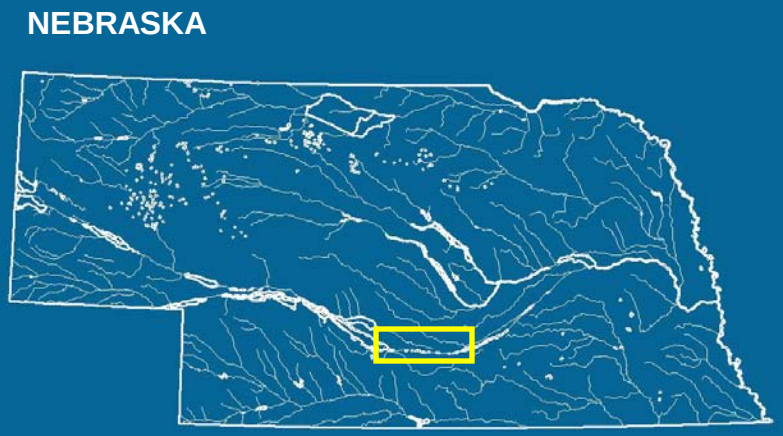
USGS



EAARL measurements
are biased above the river bottom

USGS

Example – Platte River, NE



Issues:

- Altered hydrology
- Reduced sand supply
- Vegetation encroachment
- Avian habitat

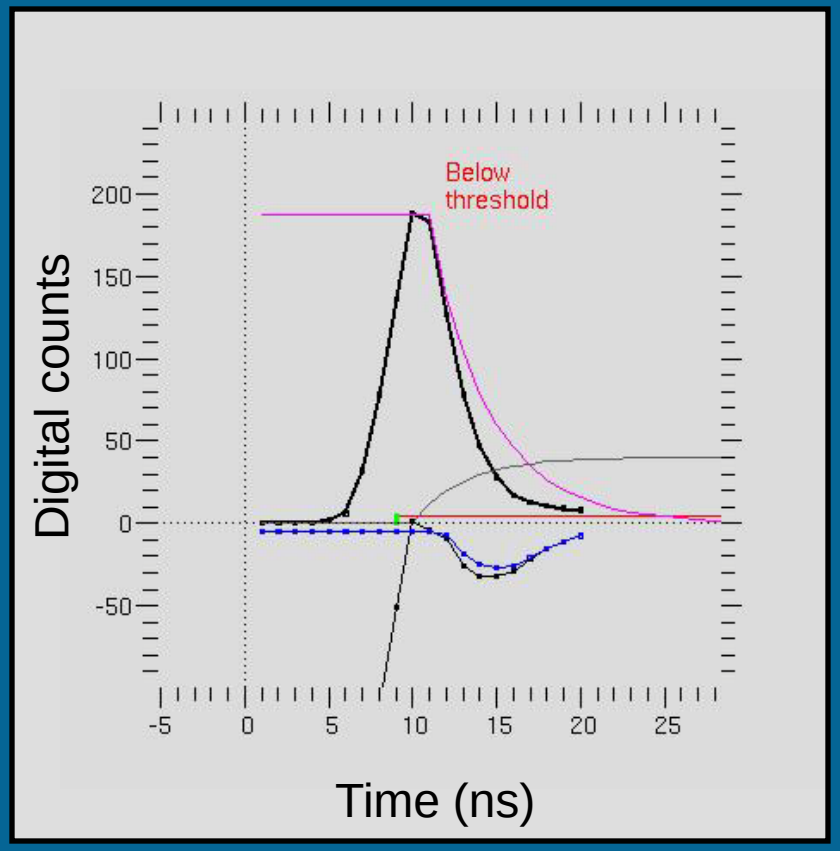
Braided morphology

- **Sandbed**
- **Bare and vegetated (sandbars / islands)**
- **Forested floodplains and riparian areas**

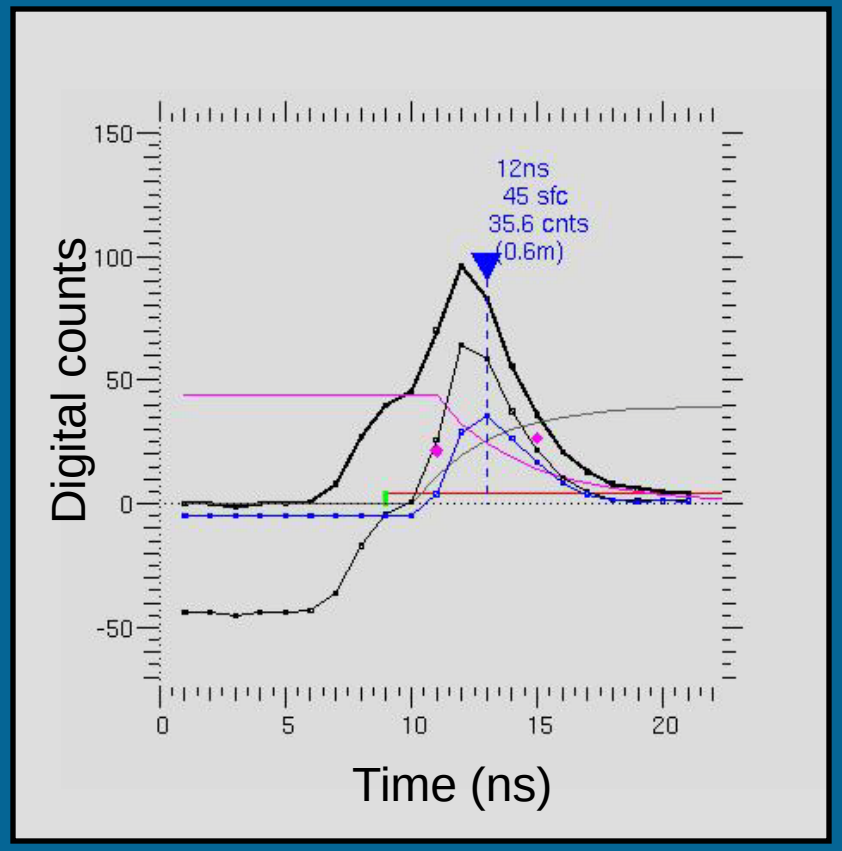
USGS

Platte River Waveforms

Return Pulses of Laser Intensity vs. Time



Single Peaked Waveform
First-Surface Algorithm

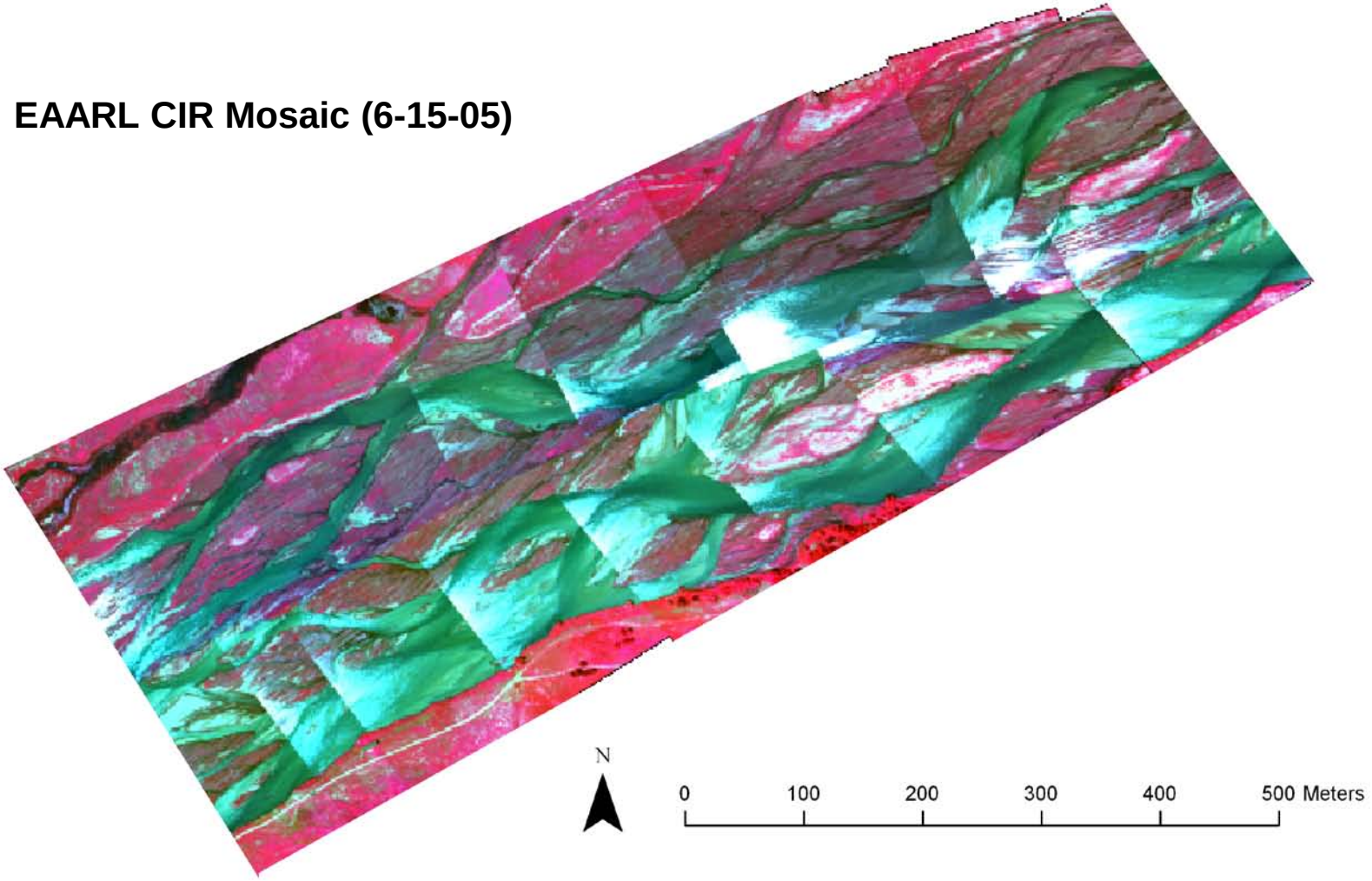


Convolved Waveform
Bathymetry Algorithm

USGS

Platte River, NE - Rowe Sanctuary Reach

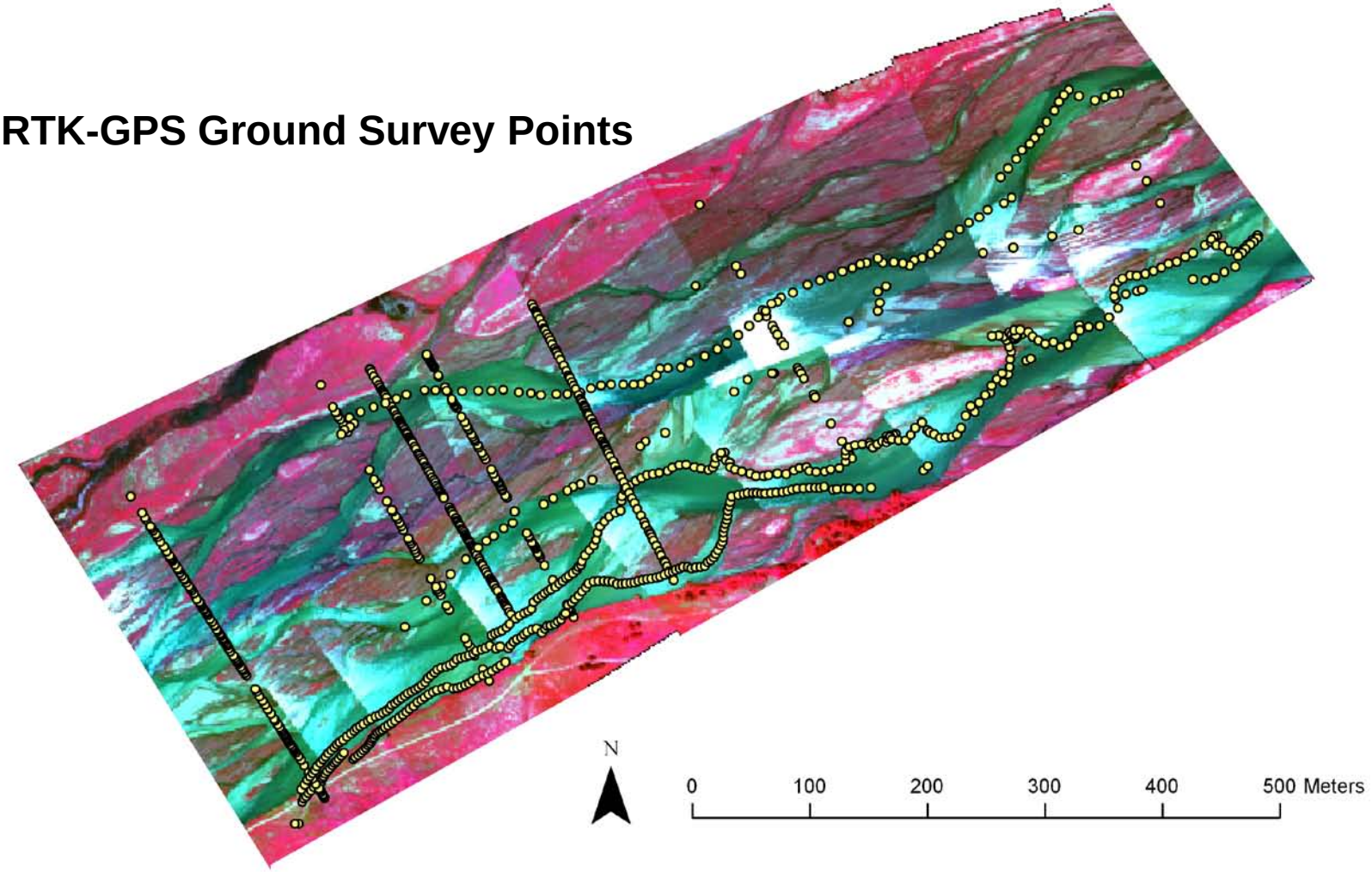
EAARL CIR Mosaic (6-15-05)



USGS

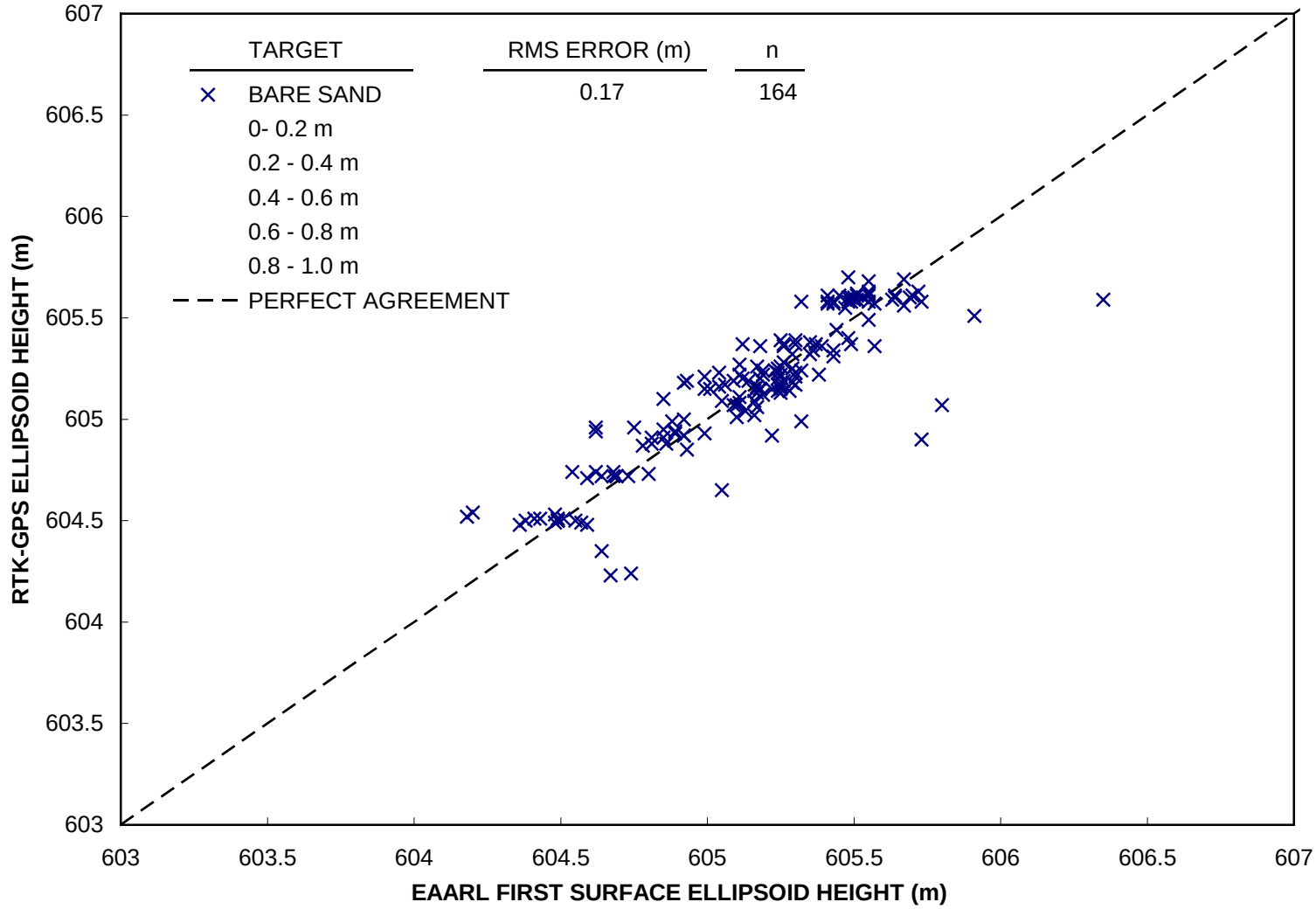
Platte River, NE - Rowe Sanctuary Reach

RTK-GPS Ground Survey Points



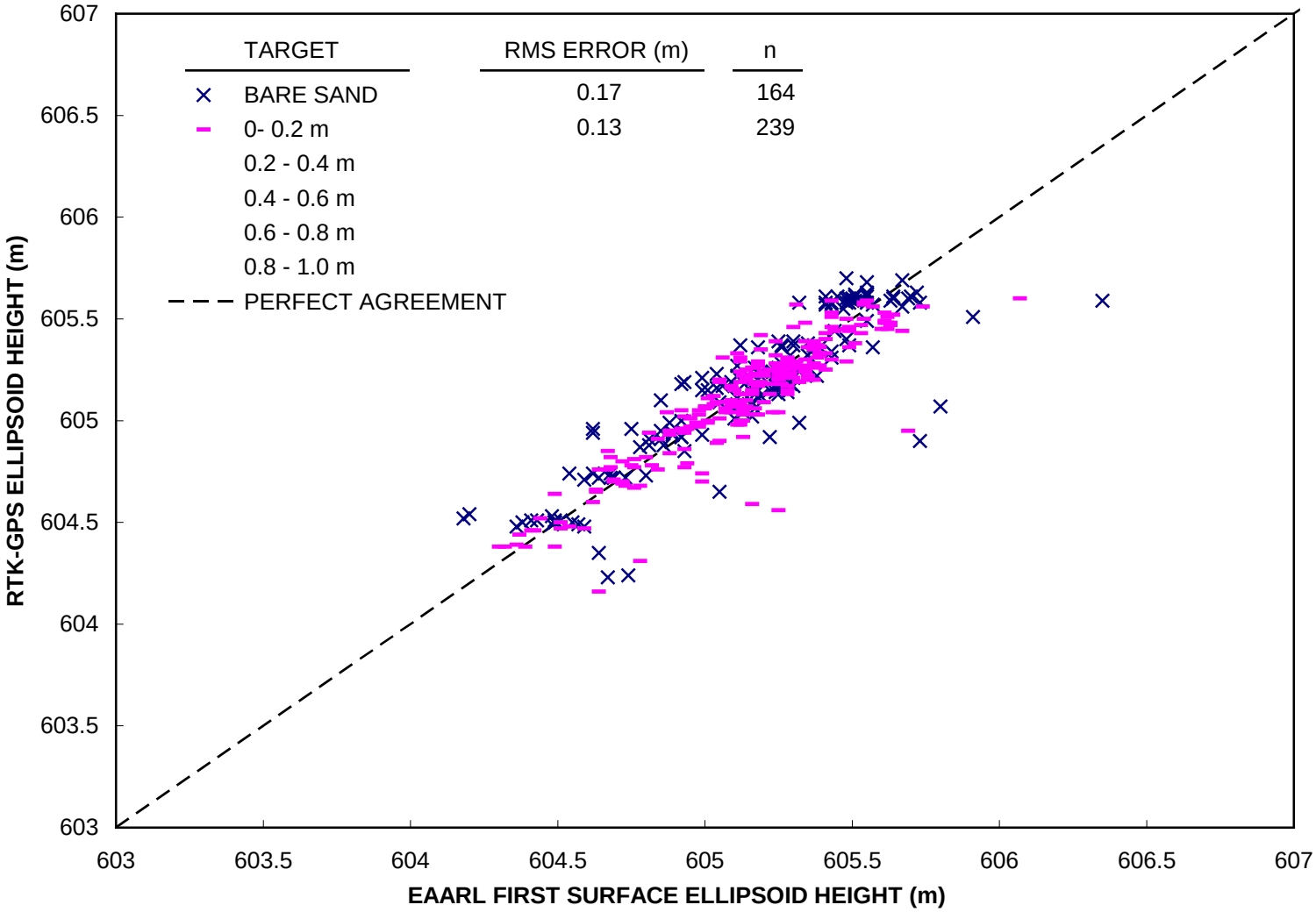
USGS

GROUND-TRUTH COMPARISON



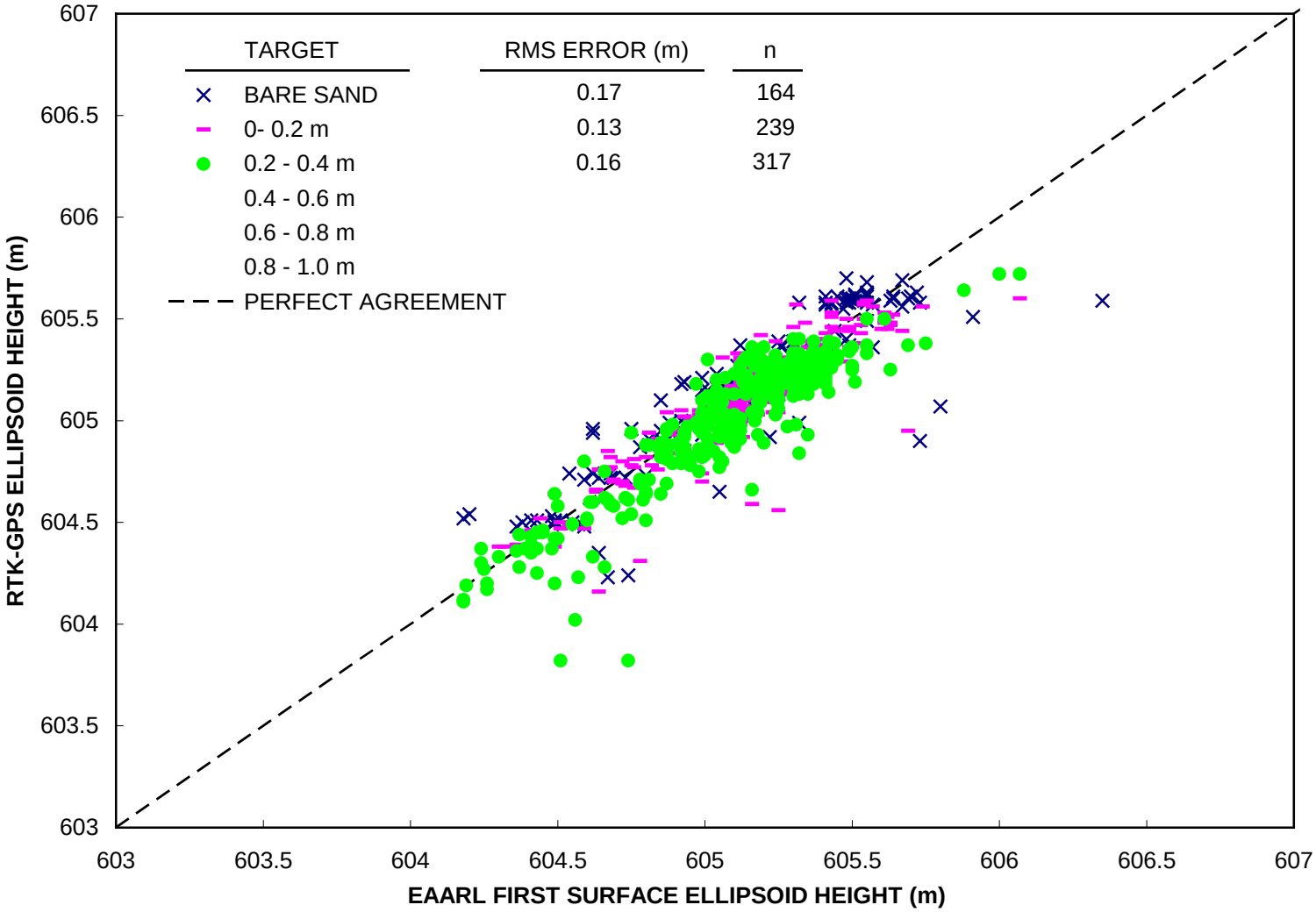
USGS

GROUND-TRUTH COMPARISON



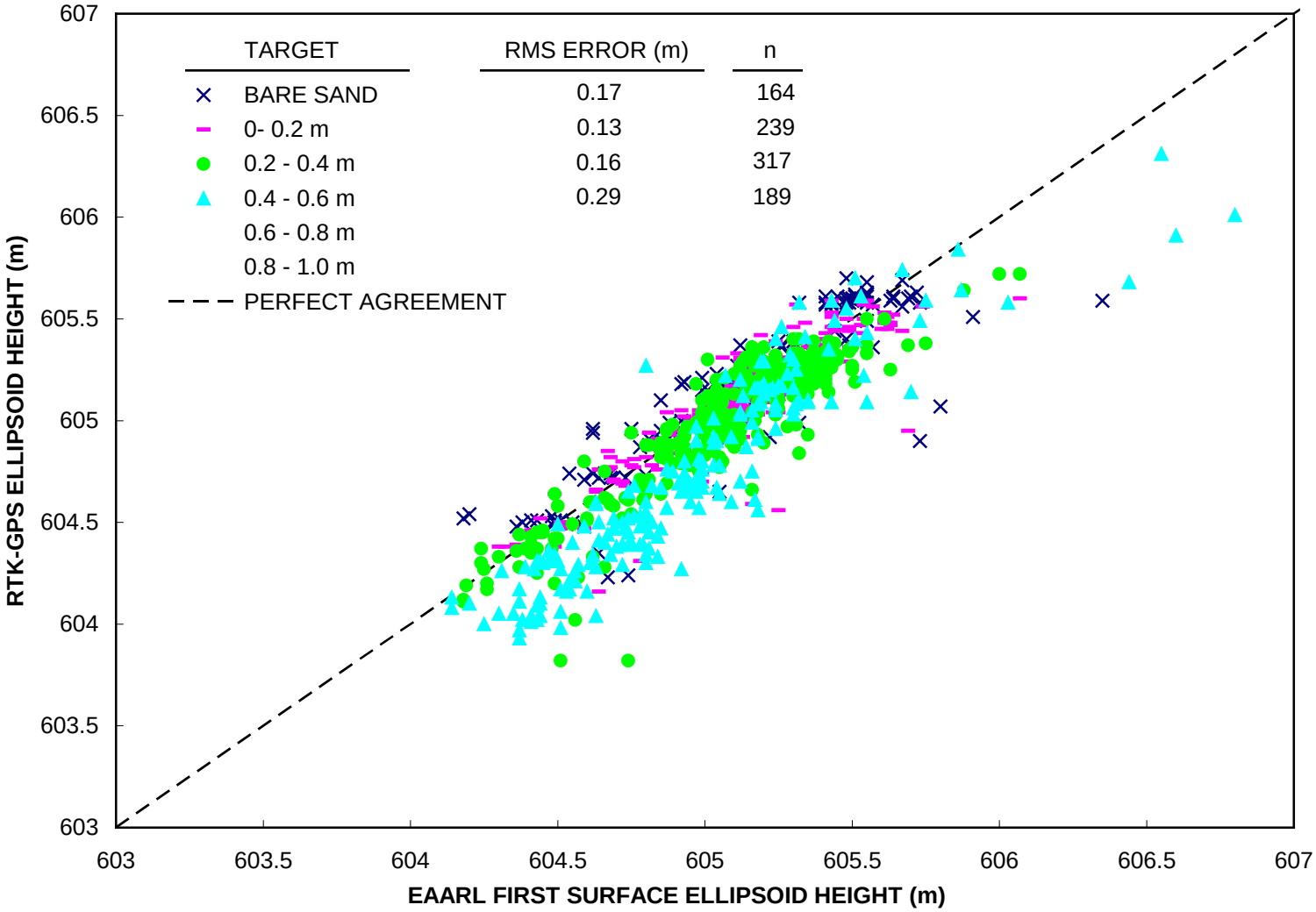
USGS

GROUND-TRUTH COMPARISON



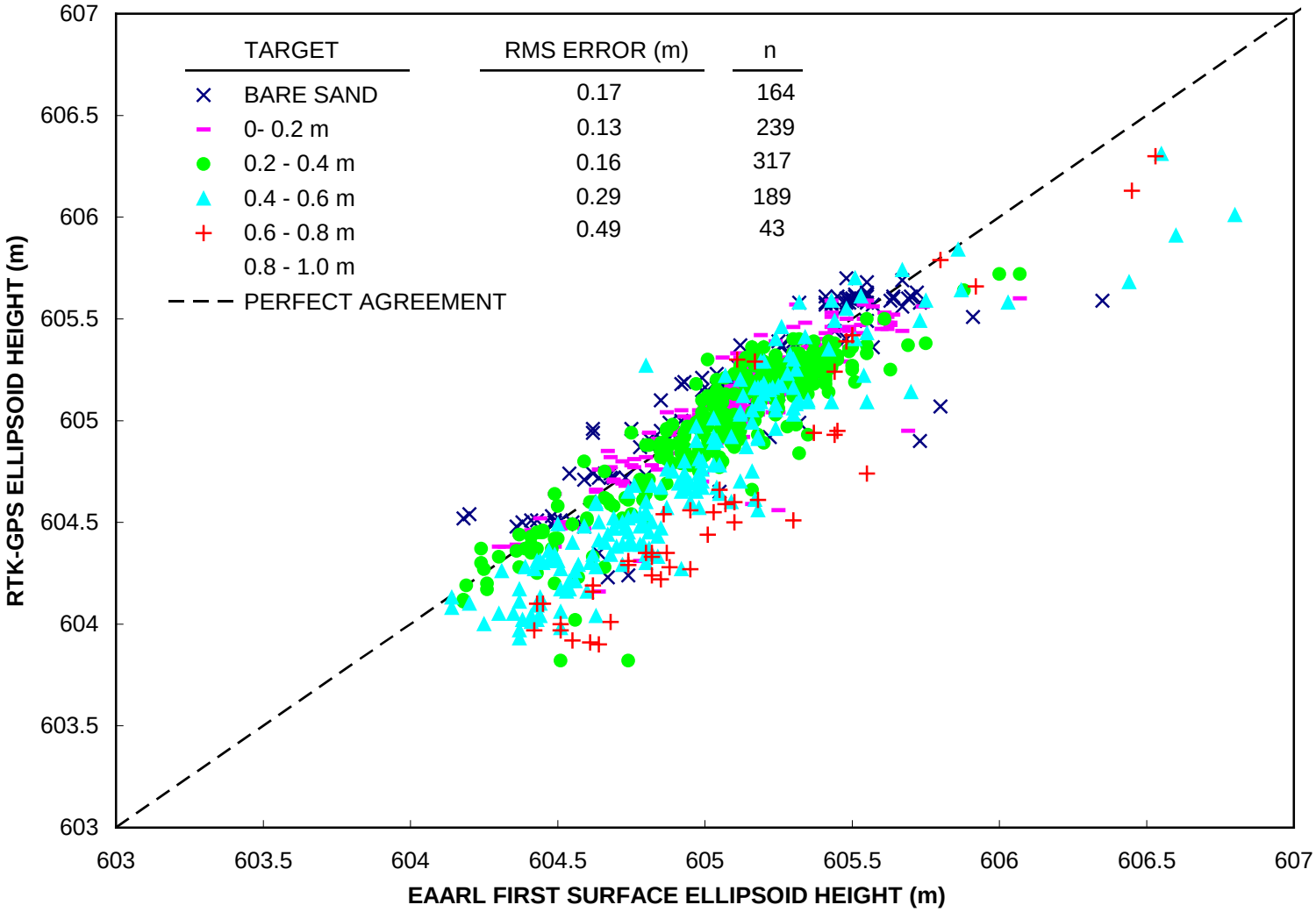
USGS

GROUND-TRUTH COMPARISON



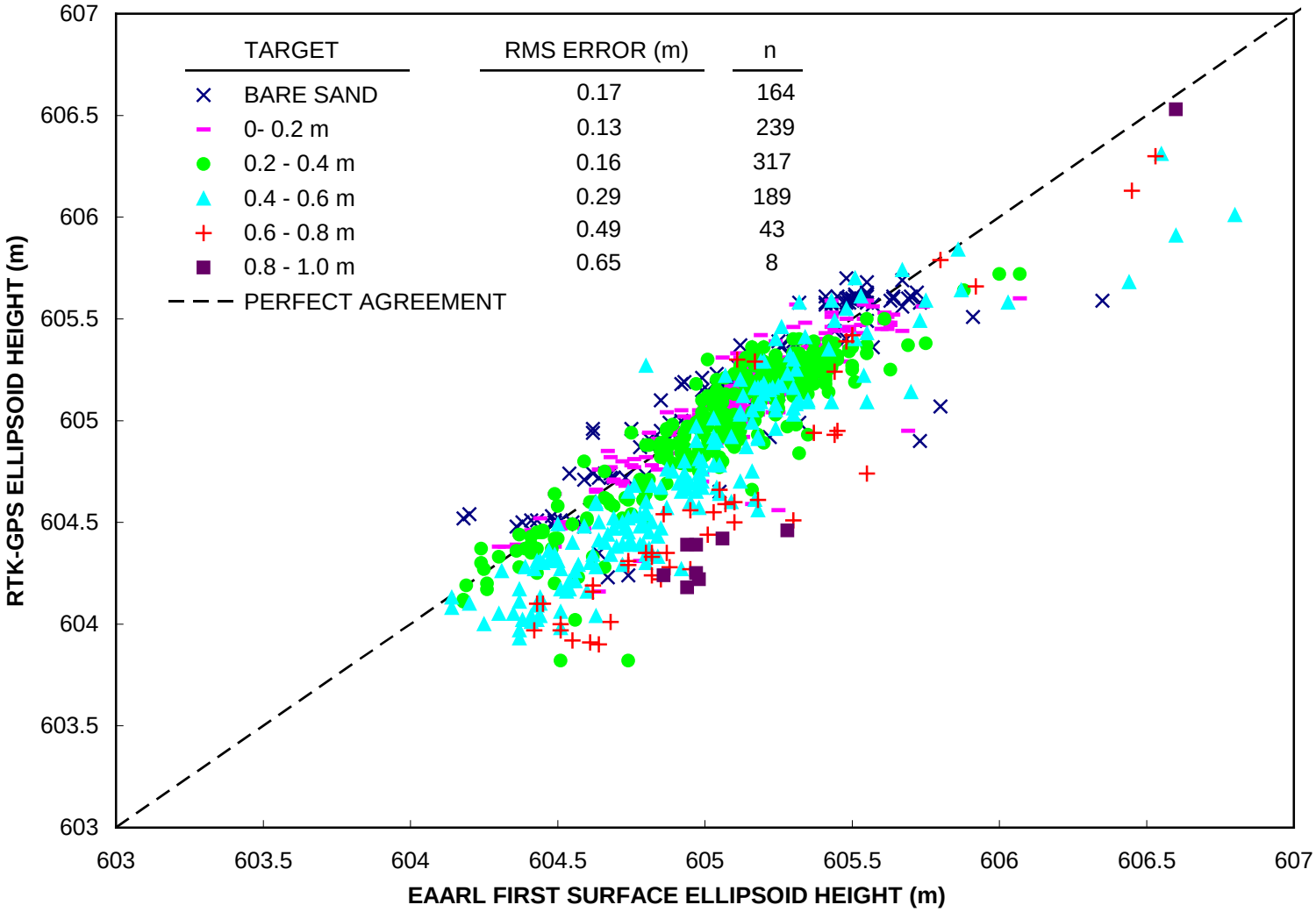
USGS

GROUND-TRUTH COMPARISON



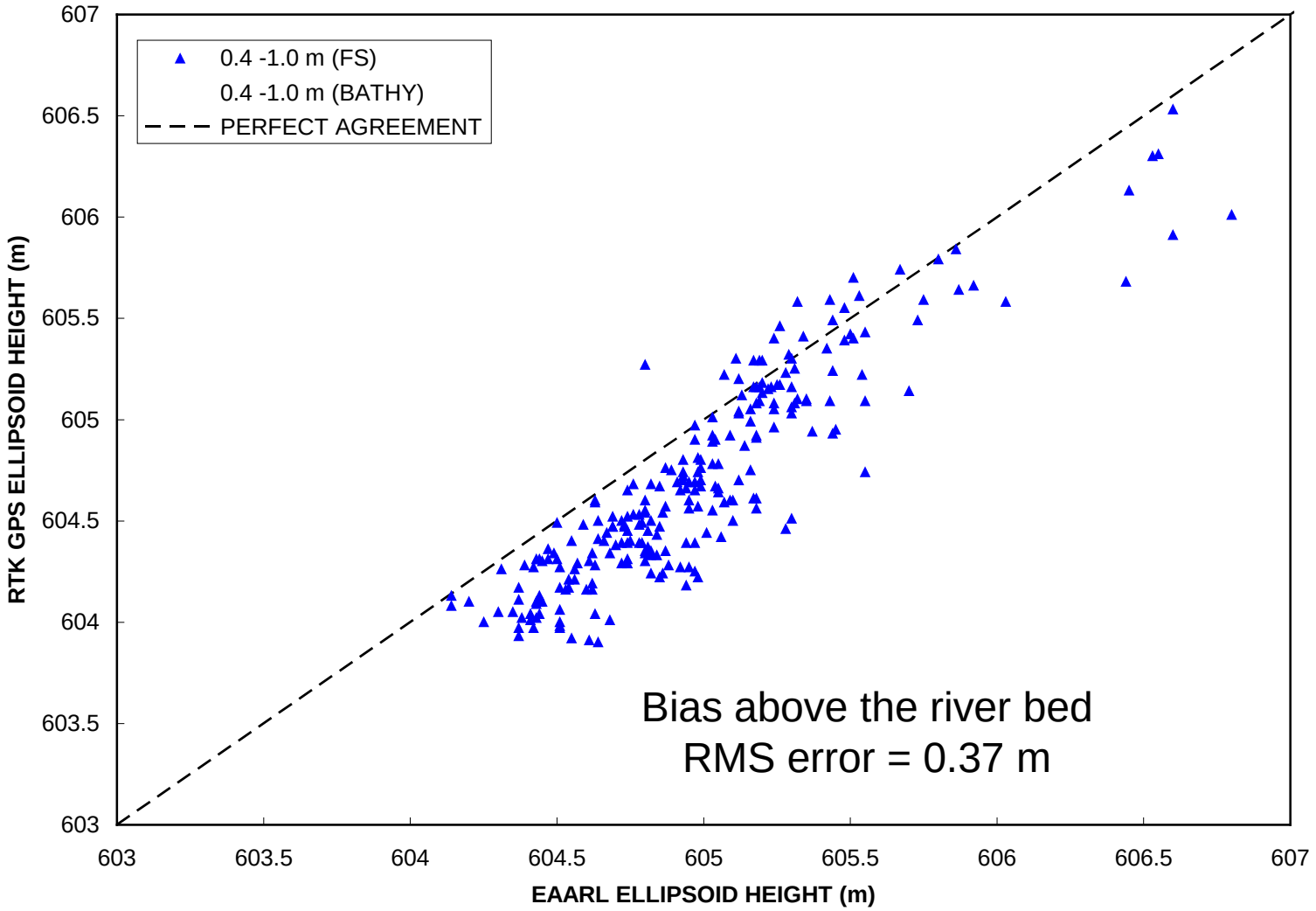
USGS

GROUND-TRUTH COMPARISON



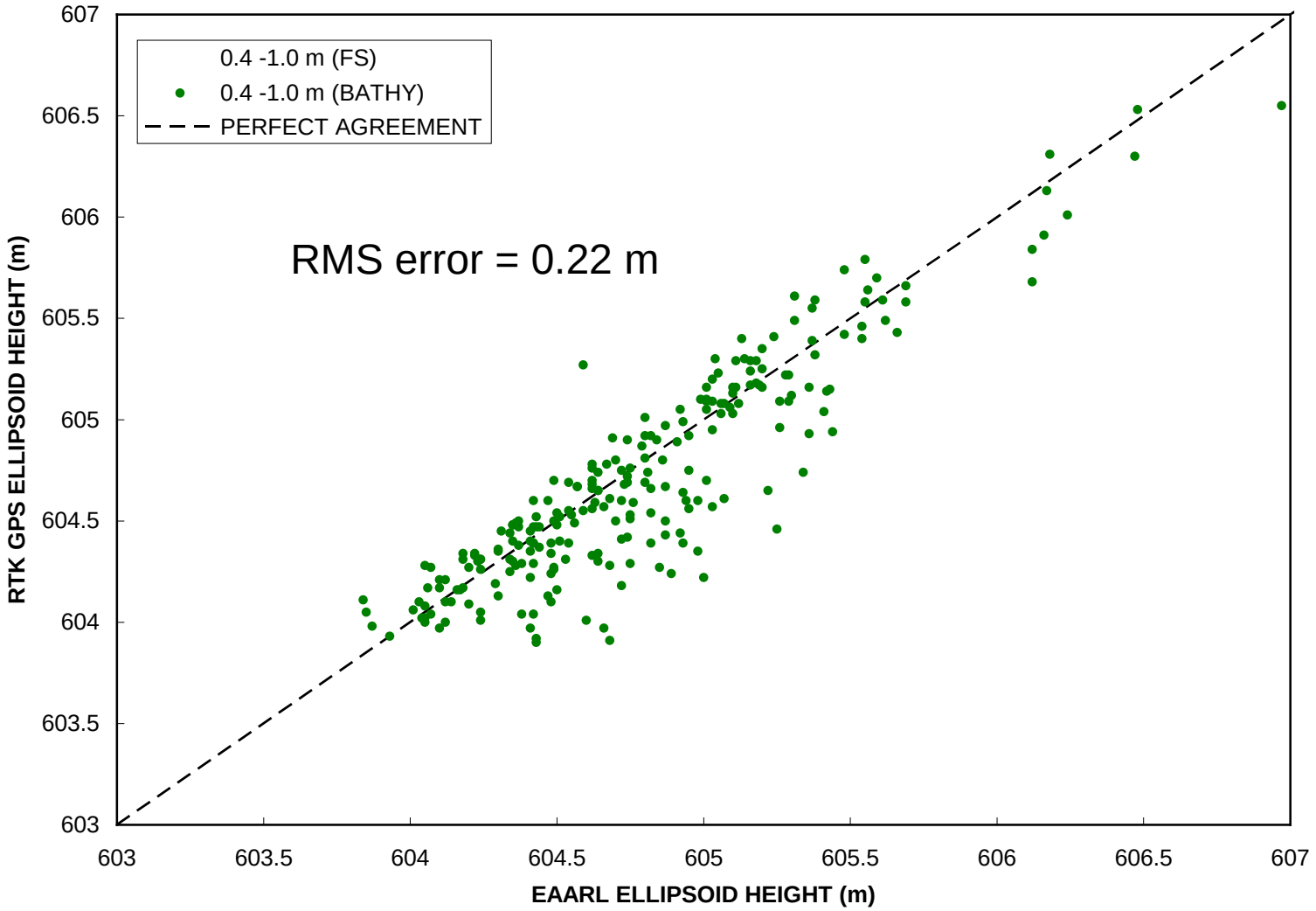
USGS

GROUND-TRUTH COMPARISON



USGS

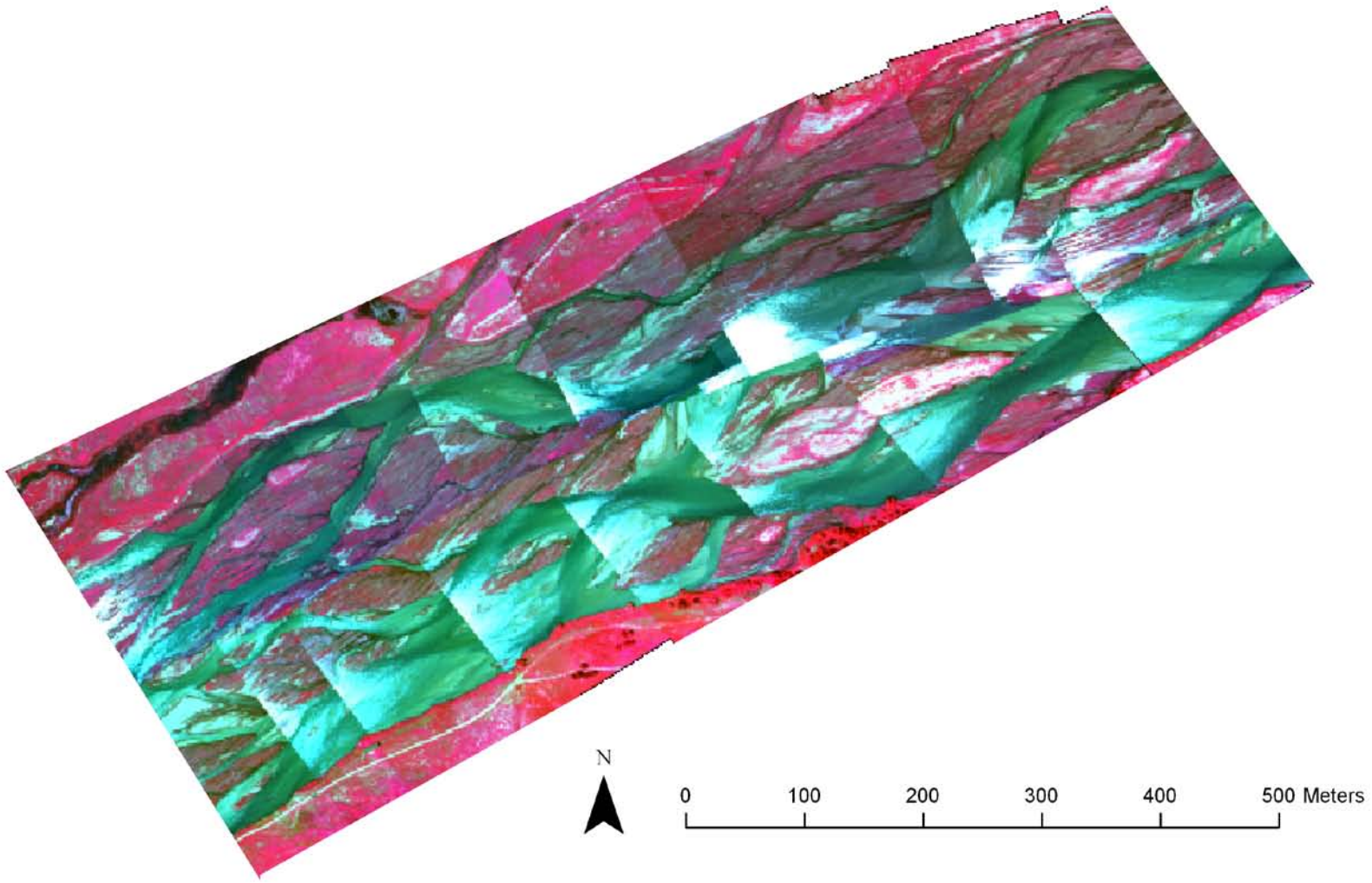
GROUND-TRUTH COMPARISON



USGS

Kinzel and others 2007, Journal of Hydraulic Engineering, 133(7), 838-842.

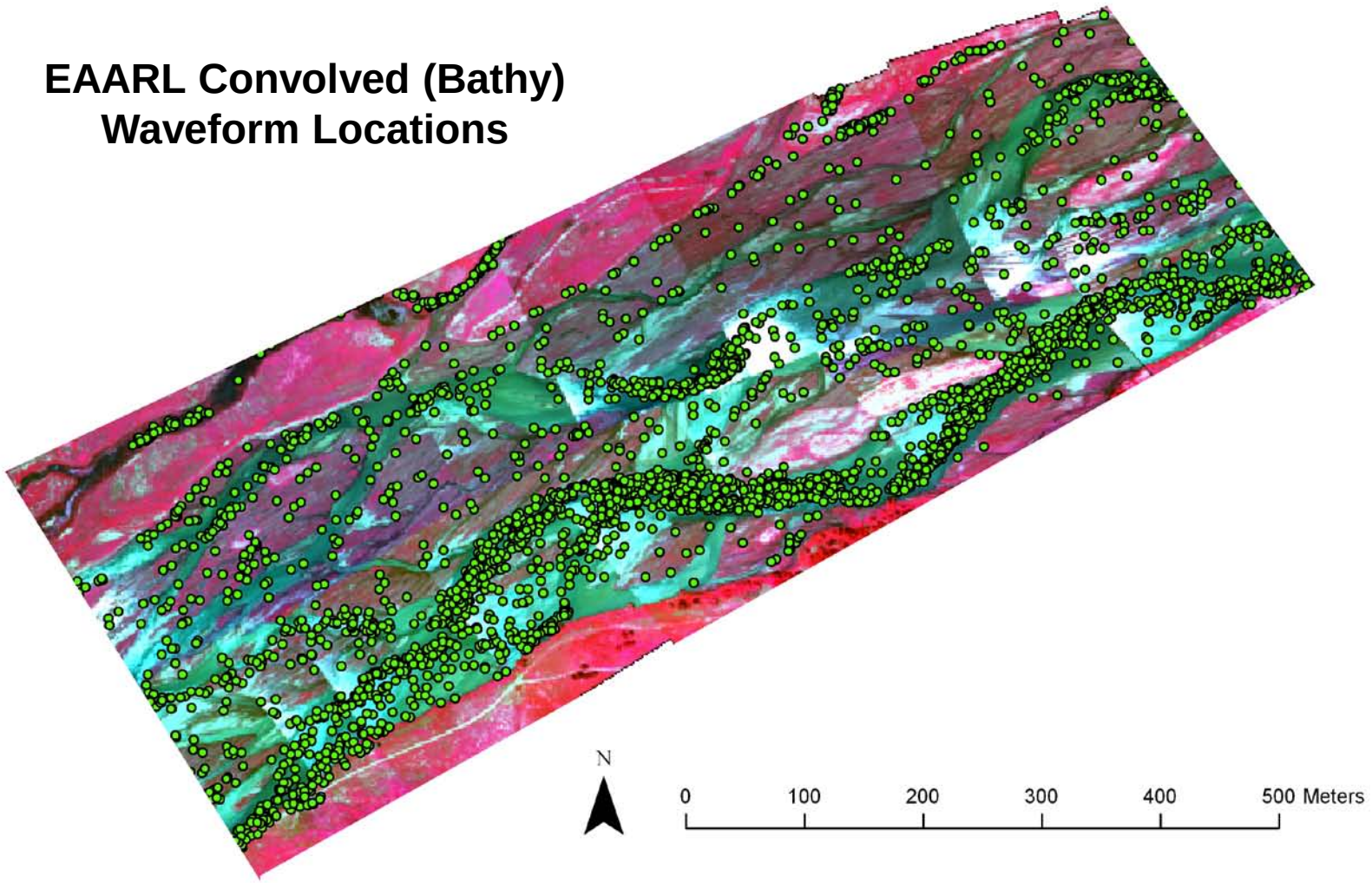
Platte River, NE - Rowe Sanctuary Reach



USGS

Platte River, NE - Rowe Sanctuary Reach

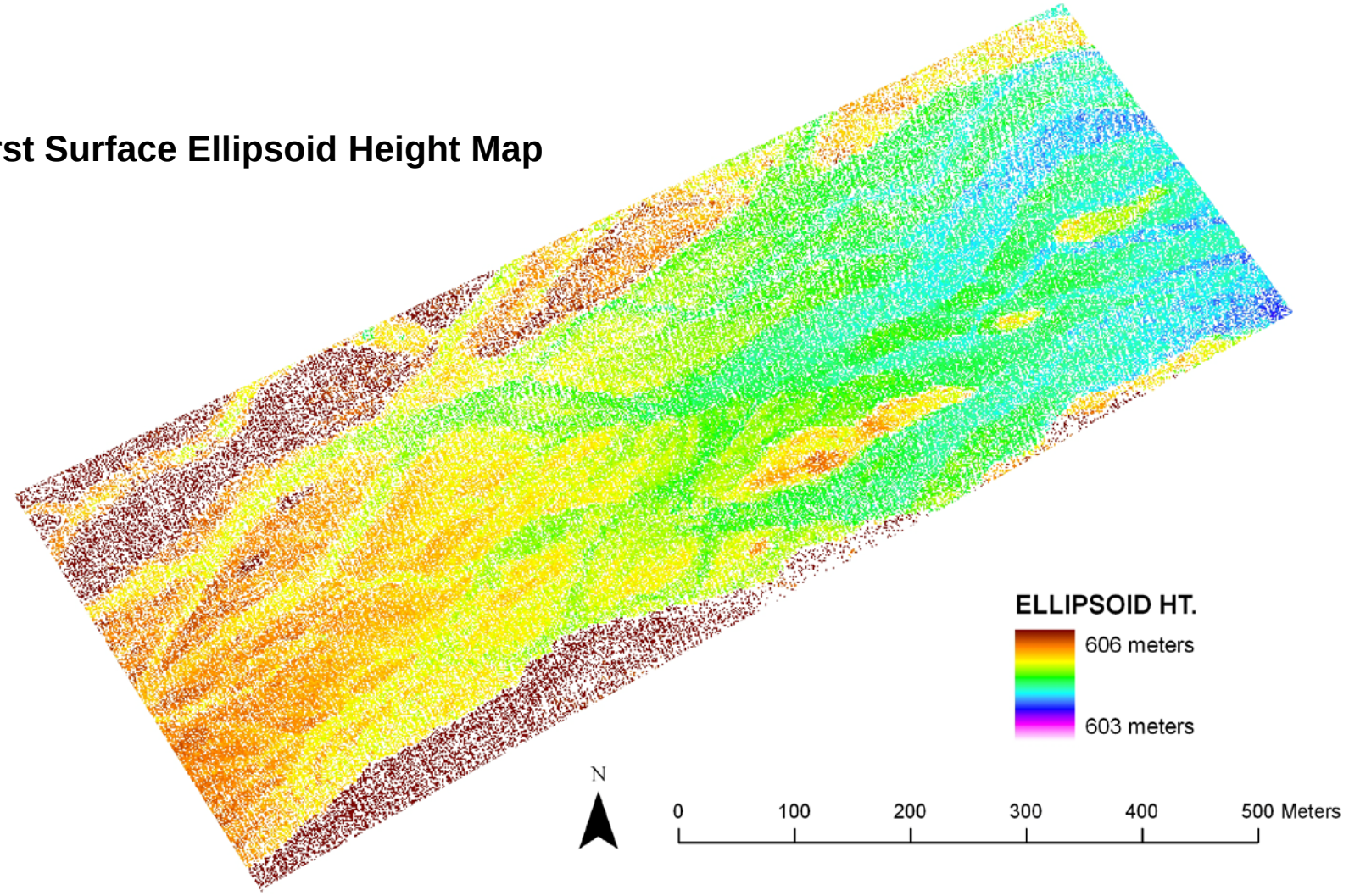
EAARL Convolved (Bathy) Waveform Locations



USGS

Platte River, NE - Rowe Sanctuary Reach

First Surface Ellipsoid Height Map

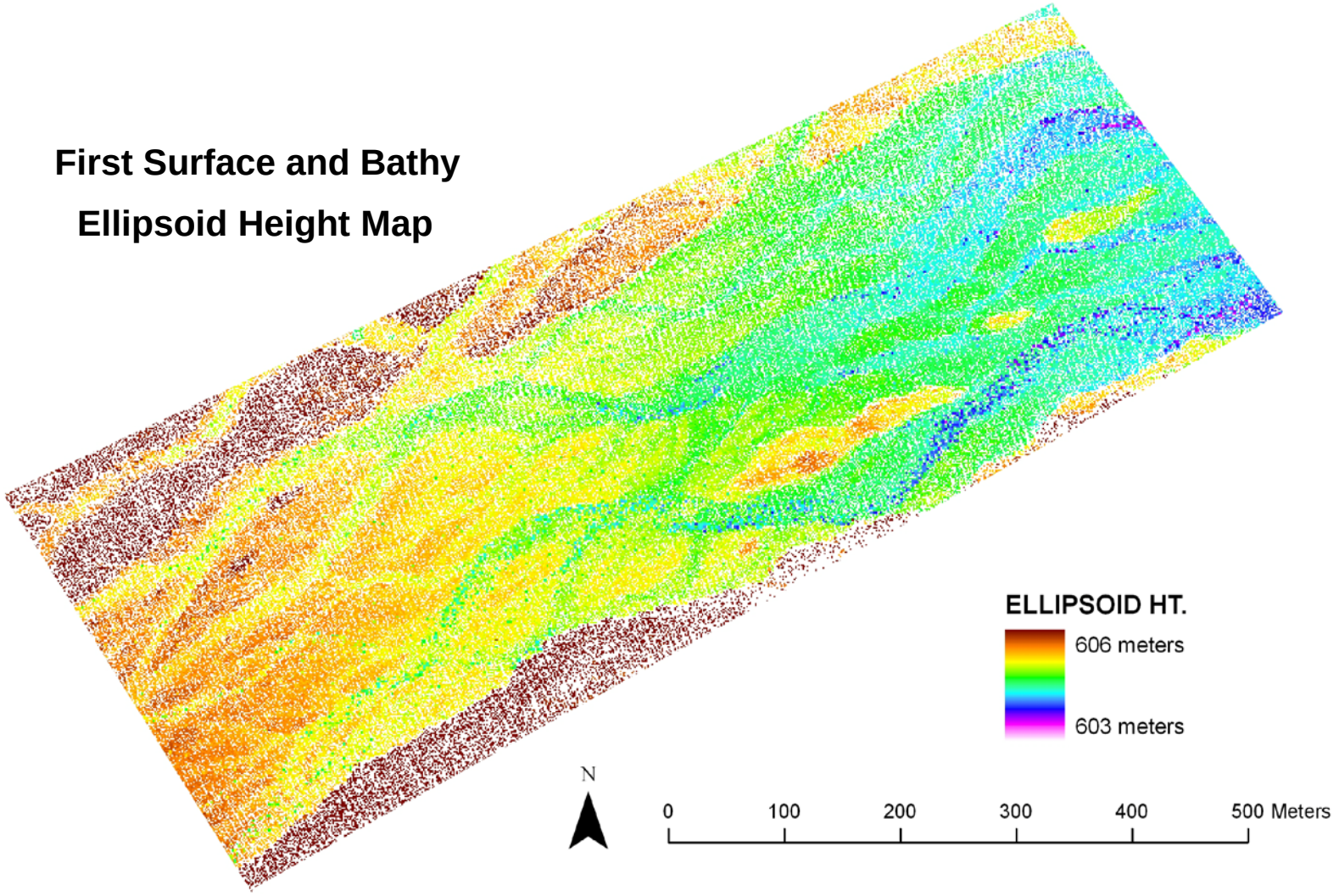


USGS

Platte River, NE - Rowe Sanctuary Reach

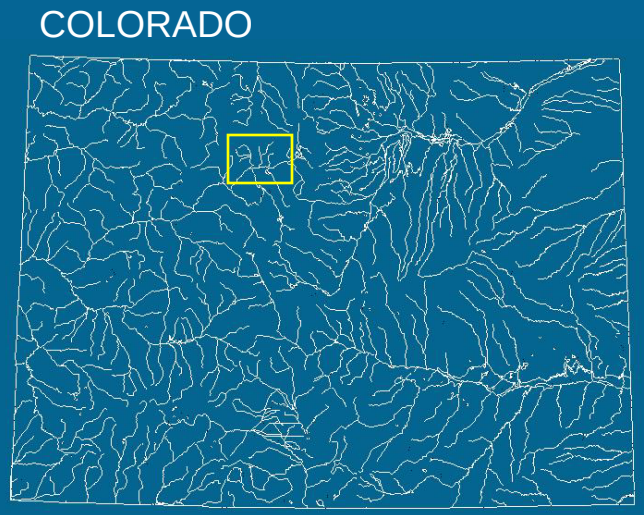
First Surface and Bathy

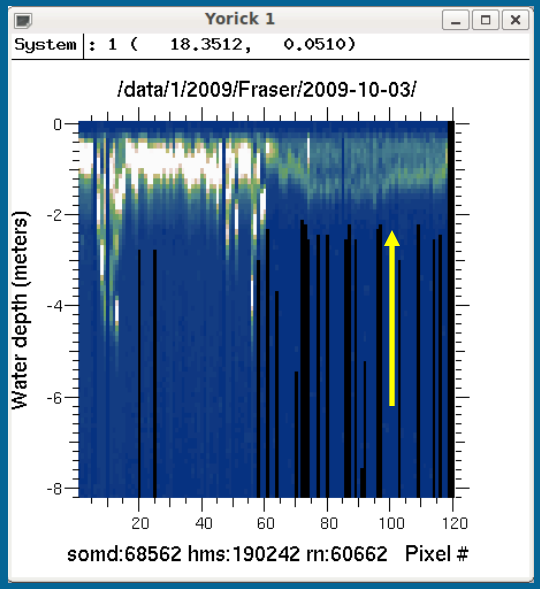
Ellipsoid Height Map

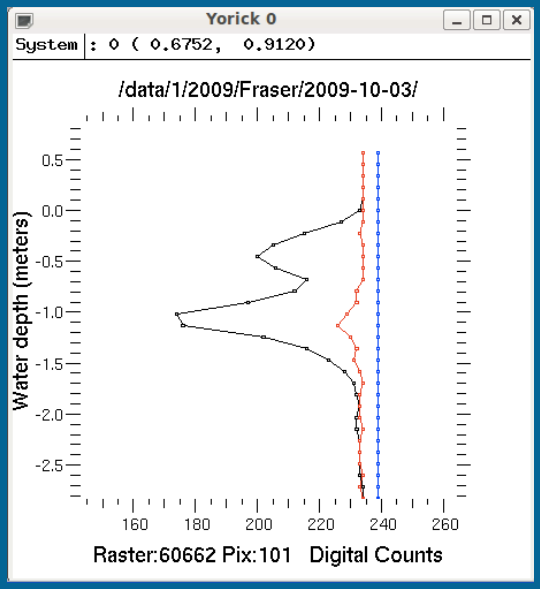


USGS

Example – Blue / Colorado R., CO

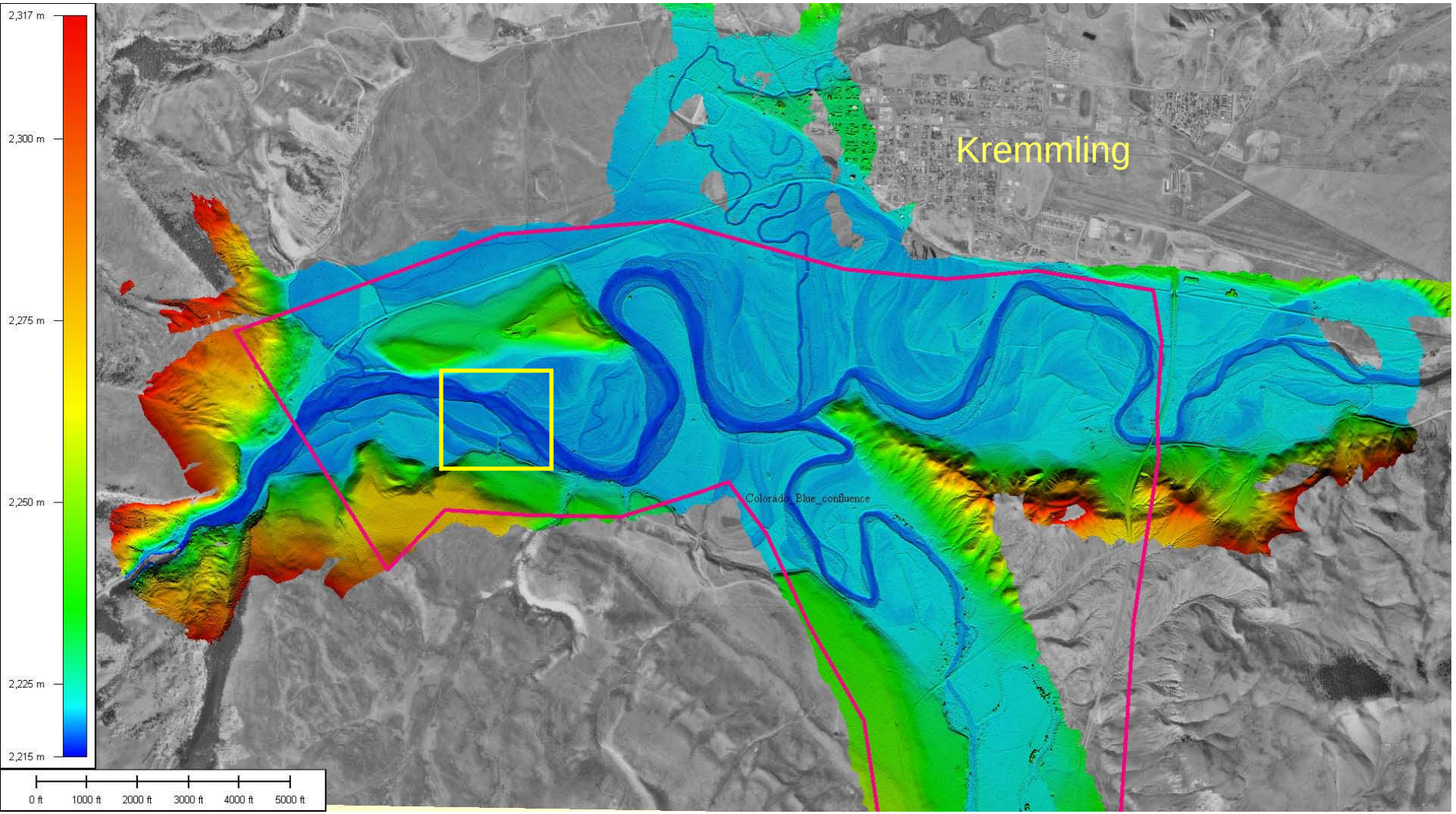




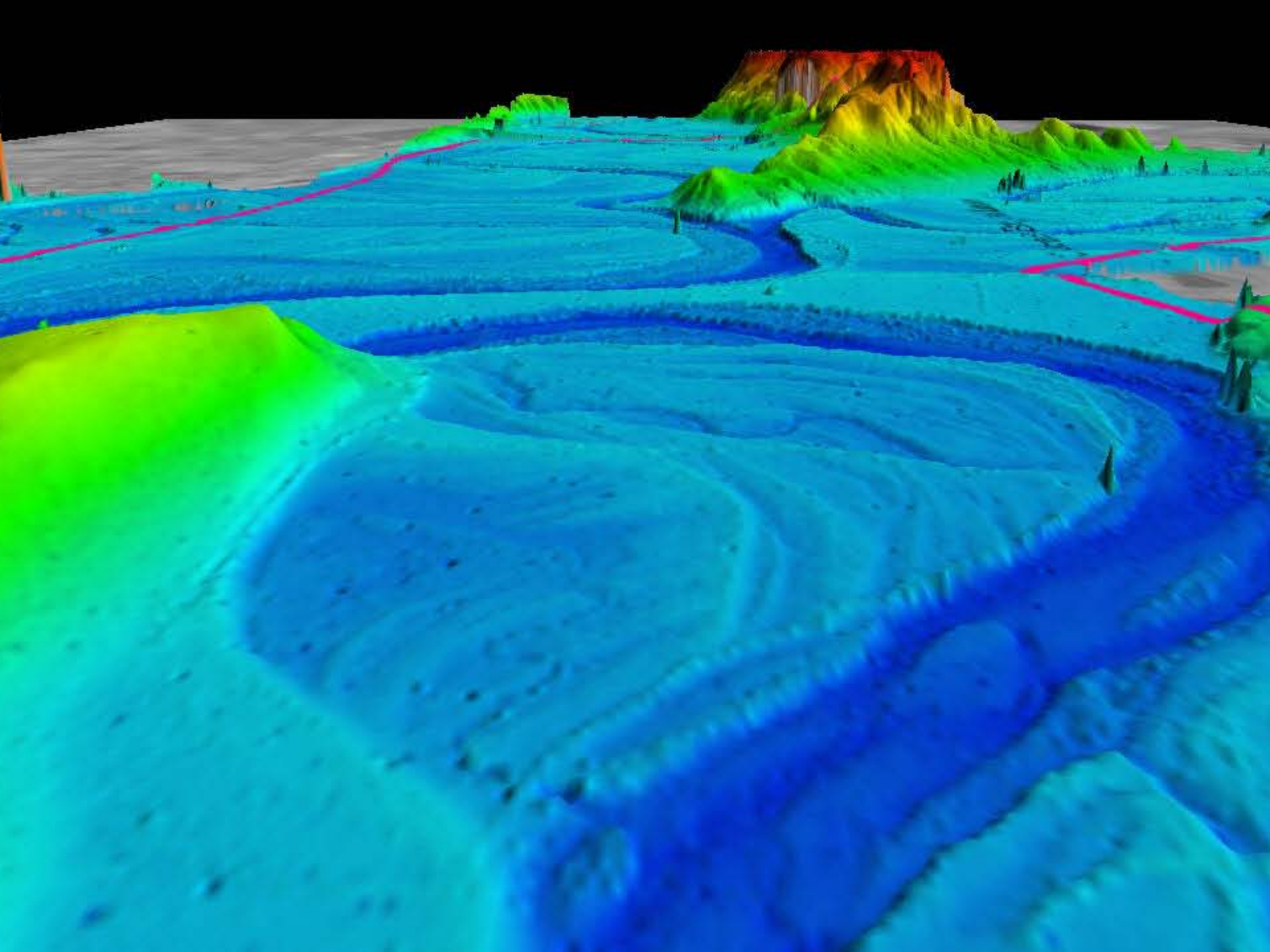


USGS

ALPS Bare Earth Processing -10/03/09

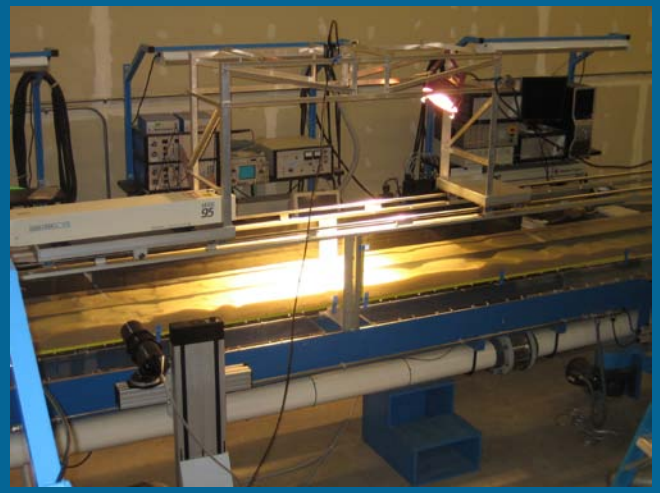


USGS



GSTL Facilities and Equipment

- Bedform mechanics flume
  7 m long x 0.3 m wide
- High speed videography (1000 fps)
- 3-D Laser Doppler Velocimeter (LDV) with Phase Doppler Particle Anemometer (PDPA)

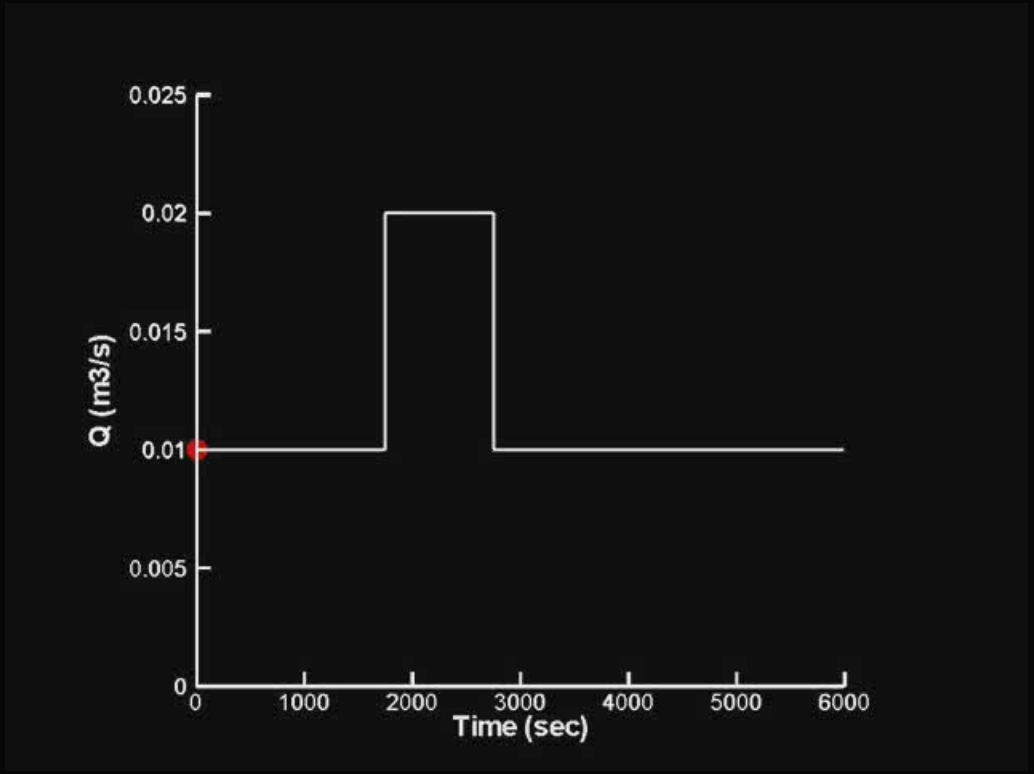


- Particle force transducer for measuring forces on sediment particles at 200 hz
- Purpose - conduct experiments to aid in model testing and development

USGS

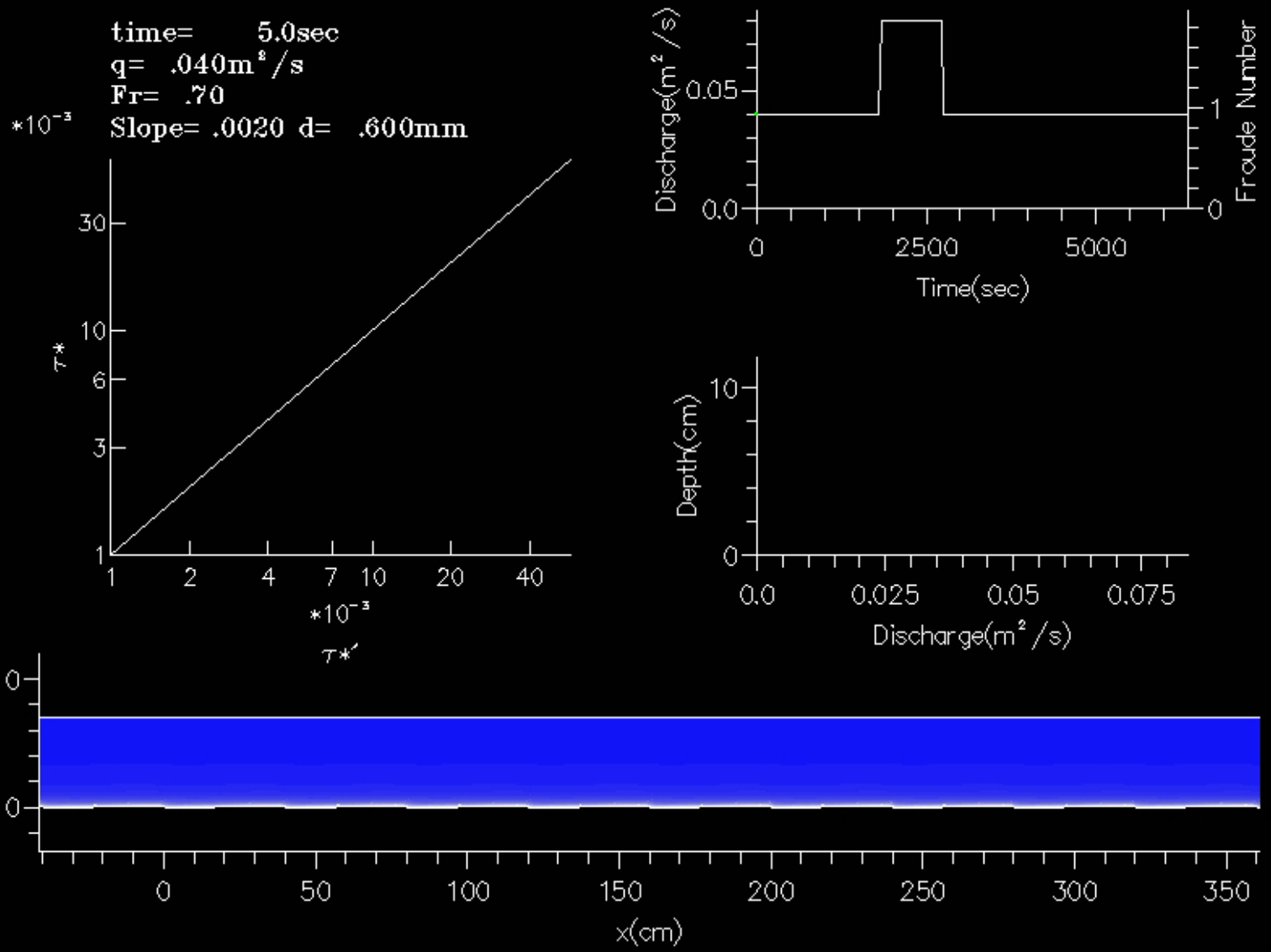
Observations of dune formation - unsteady flow

Slope = 0.002
d = 0.6 mm



USGS

Computational model* of dune formation under unsteady flow

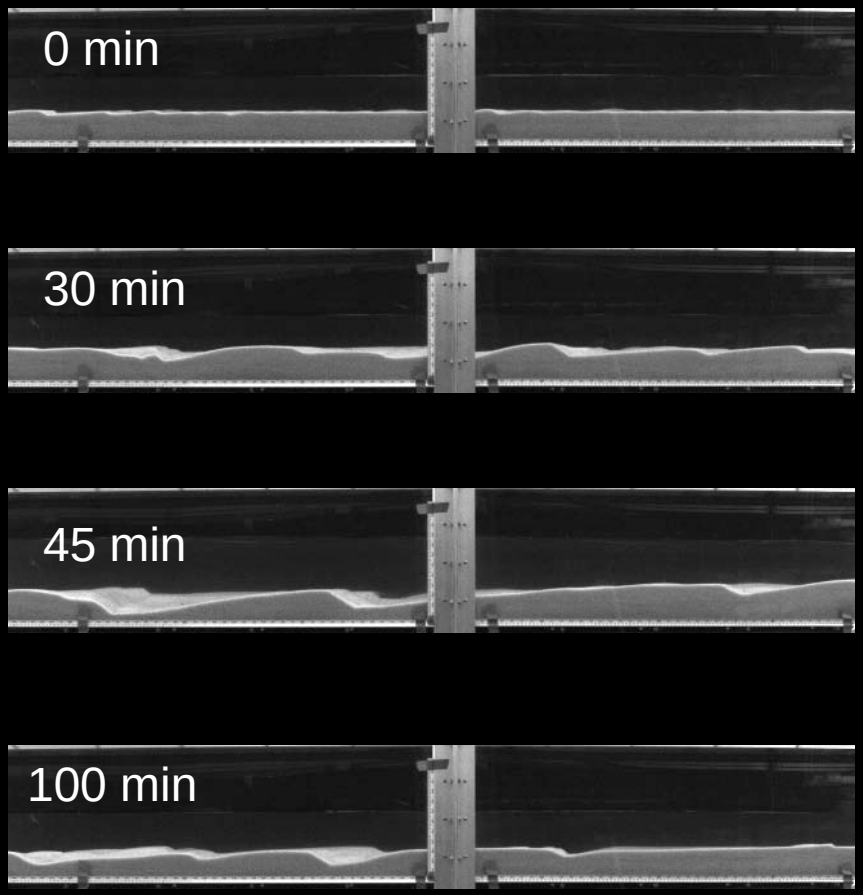


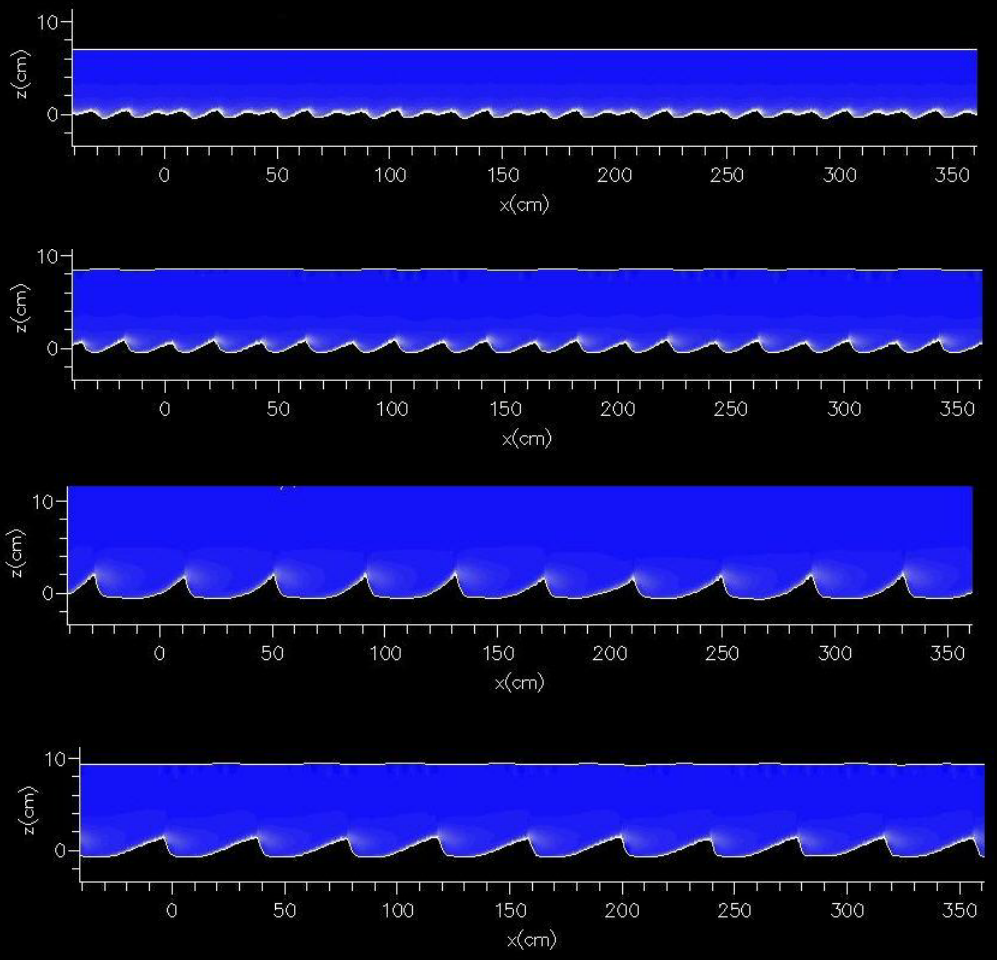
USGS

Shimizu, Y., Giri, S., Yamaguchi, S., and Nelson, J., 2009, Numerical simulation of dune-flat bed transition and stage-discharge relationship with hysteresis effect: Water Resources Research, v. 45,

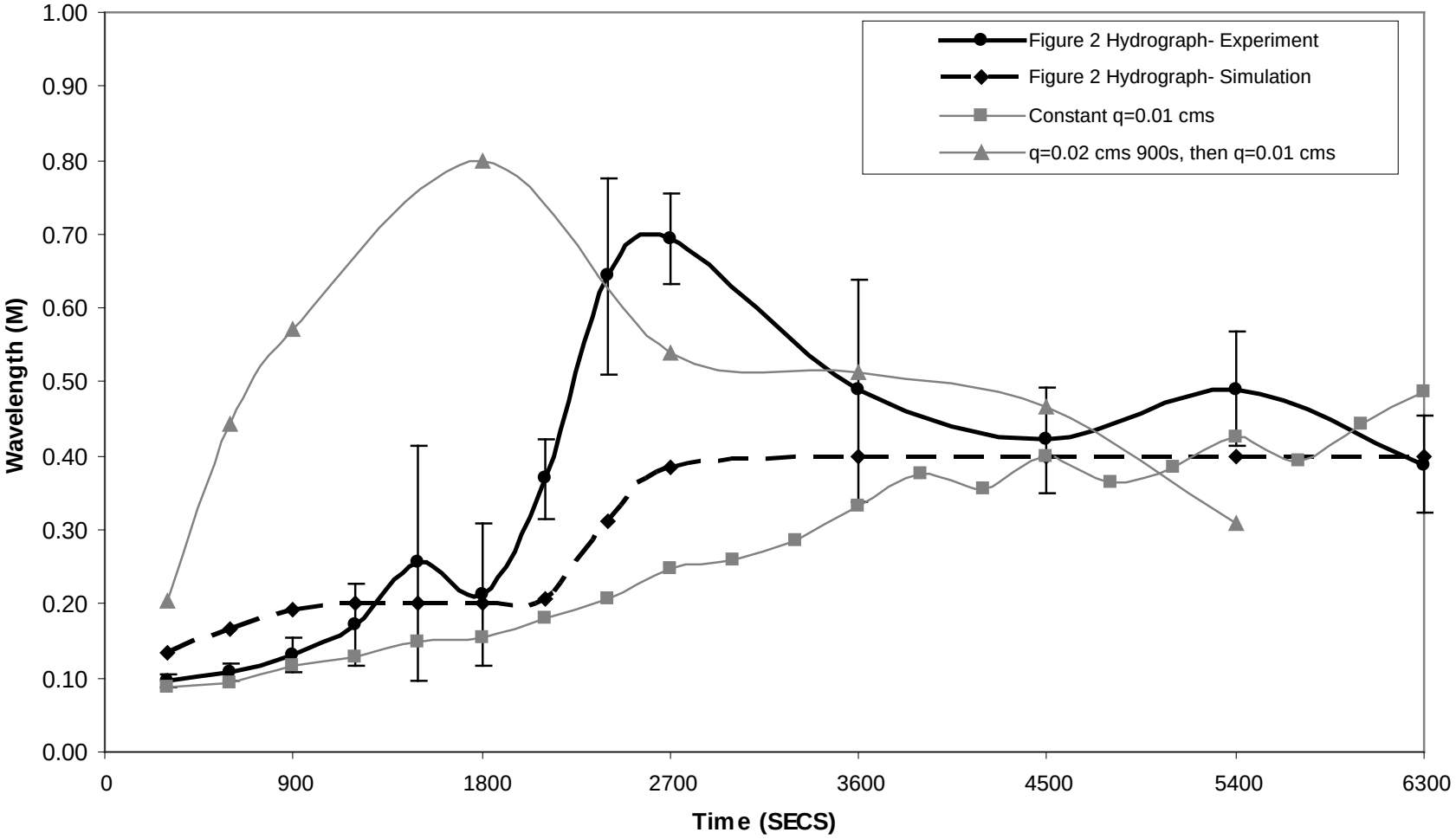
Observations

Predictions





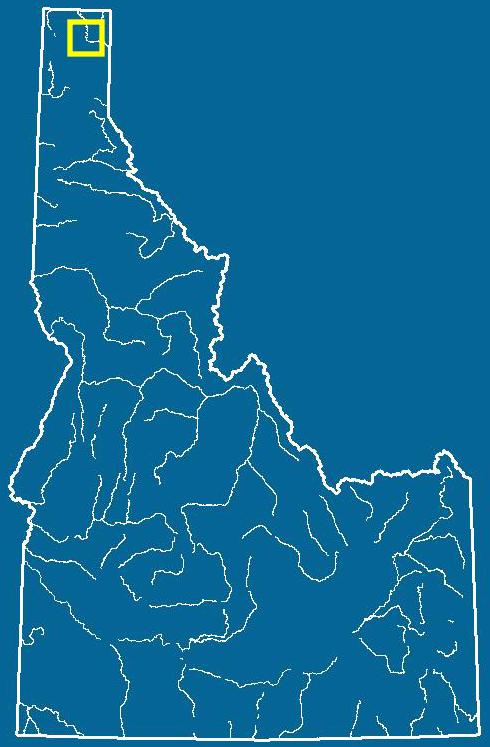
USGS



Nelson, J.M., Logan, B.L., Kinzel, P.J., Shimizu, Y., Giri, S., Shreve, R.L., and McLean, S.R., in press, Bedform Response to Flow Variability, Earth Surface Processes and Landforms.

USGS

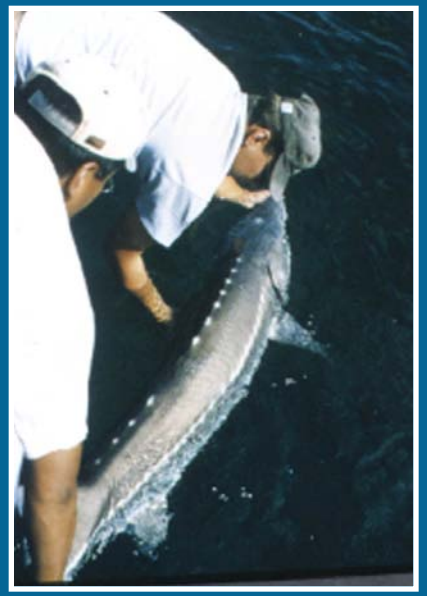
Ecological Motivation, Kootenai R., ID

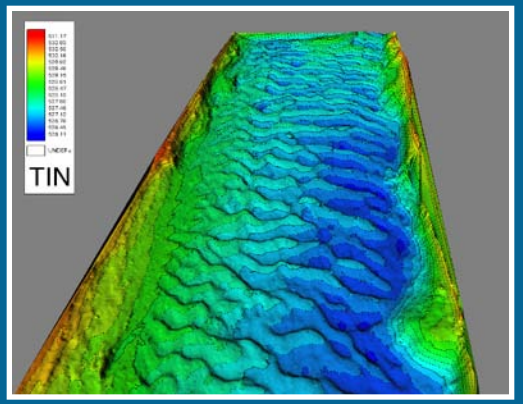


Idaho

Issues:

- Upstream regulation
- Reduced peak flows / transport
- Sturgeon spawning gravels covered with sand dunes
- Roughness changes as dunes evolve

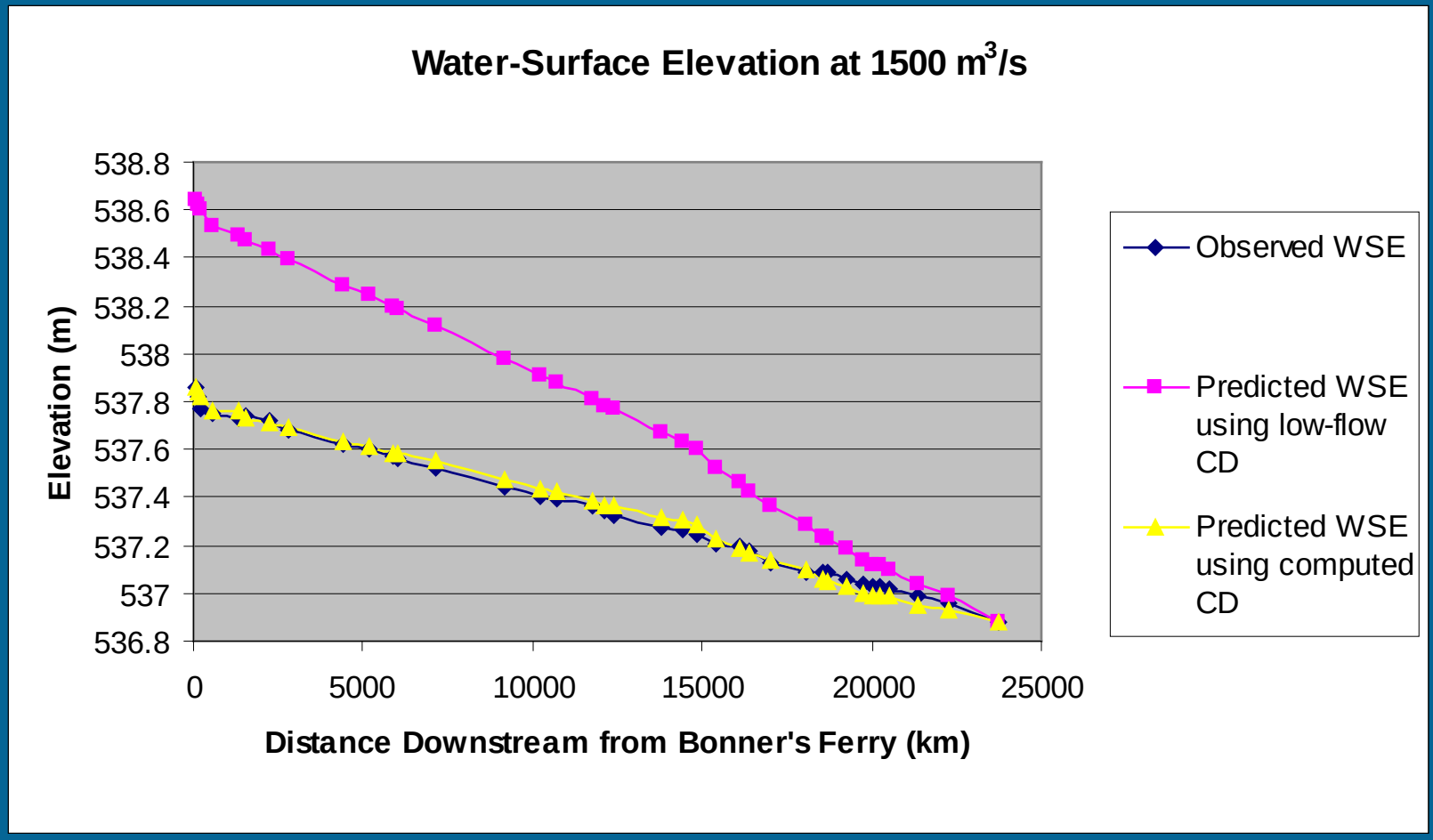




USGS

Images courtesy of Gary Barton, Rich McDonald

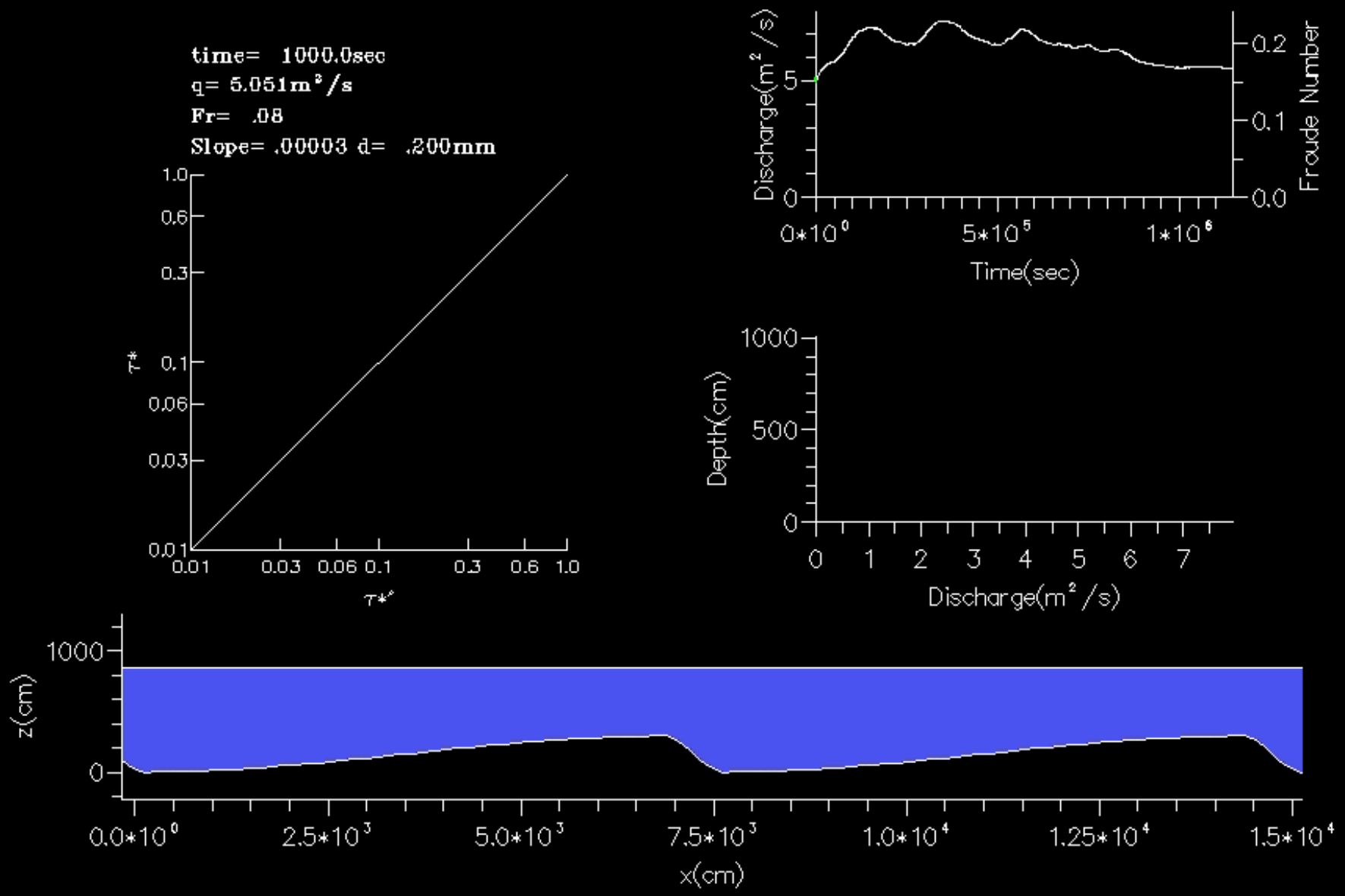
Effect of Dunes on Model Predictions



USGS

Can't assume dunes and drag coefficient from low flow can be applied to higher flow

Dune response to Kootenai R. high flow event (2006)



GSTL Facilities and Equipment

- Channel evolution flume
  6 m long x 1.2 m wide
  Given to USGS and CU by UCLA in 2006

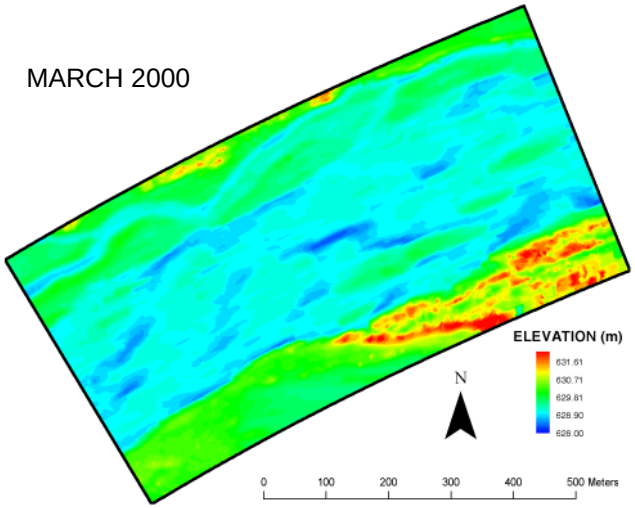
- 2 valves with flow sensors
- 3 axis variable-speed traverse
- Laser-based topographic measurement system and ultrasonic sensor
- Custom LabView ™ interface to control flow and sediment feed
- Purpose - conduct experiments to aid in numerical model testing and development

USGS

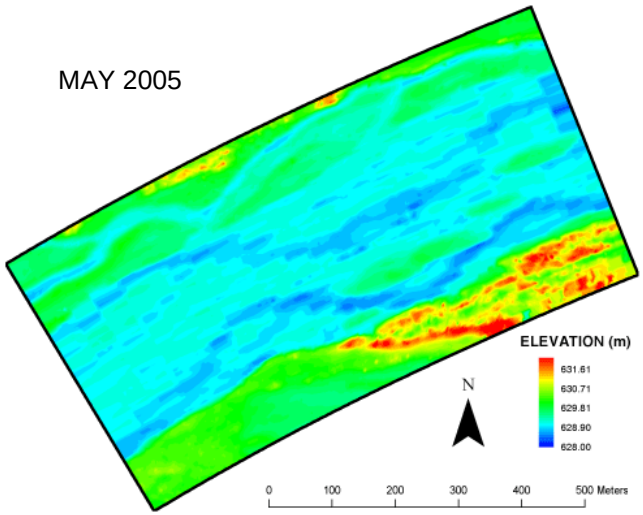
Ecological Motivation – Platte R., NE

- Cranes require wide channels with shallow depths for roosting
- Diminished flows promote vegetation, reduce the active width, connect bars and islands, and deepen channels*
- What flows are necessary to manage sandbars and habitat?

MARCH 2000



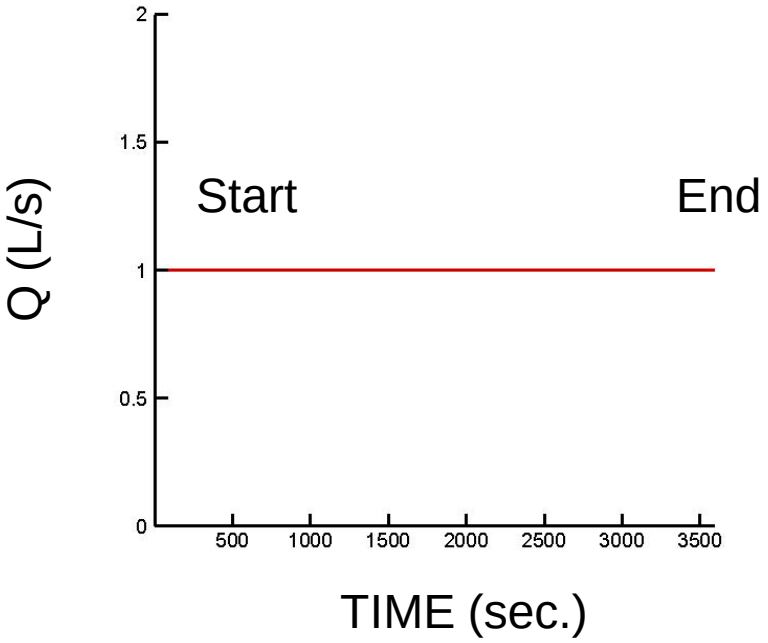
MAY 2005



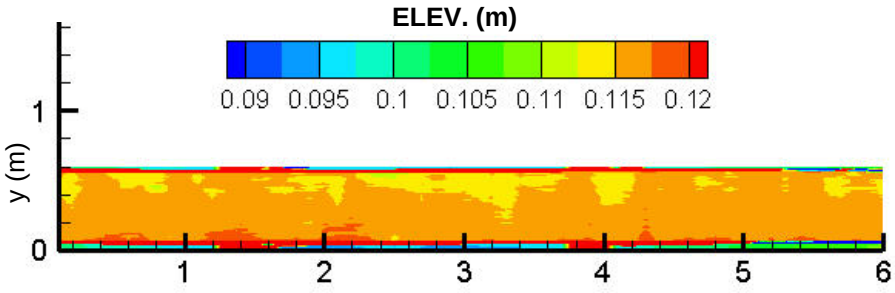
USGS

*** Kinzel and others, 2009, River Research and Applications, 25: 135-152.**

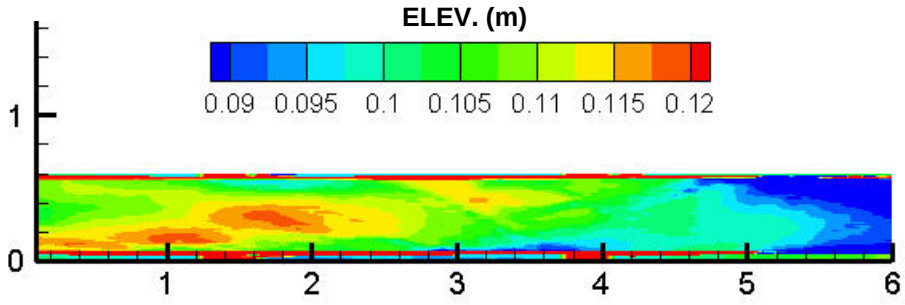
Observations of sandbar formation - steady flow



B = 0.5 m, d = 0.6 mm, S = 0.0125



Start – Plane bed



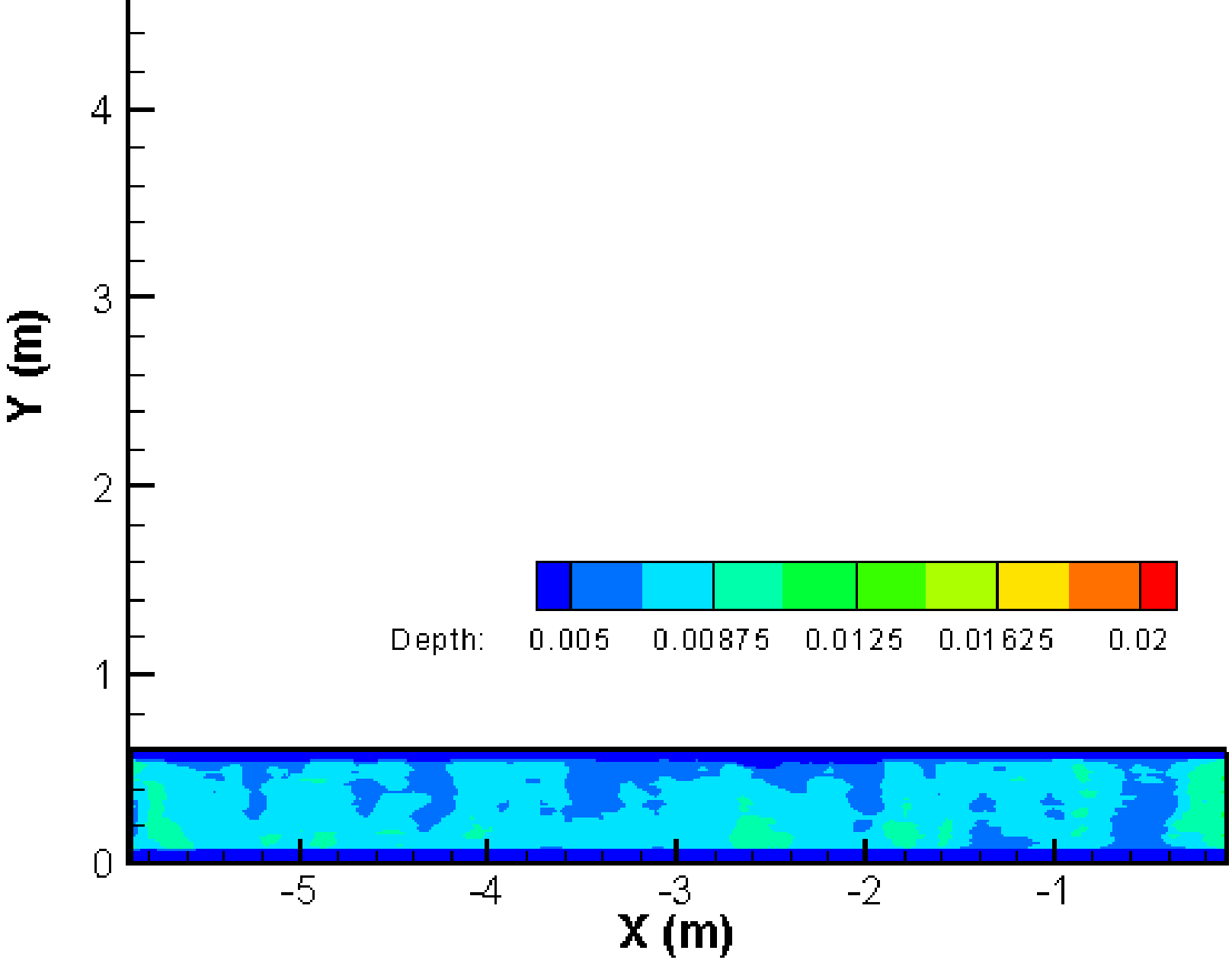
End – Bars 1-1.5 mode

USGS

Bed Evolution Modeling

- FaSTMECH model in MD_SWMS
- Specify constant or variable hydrograph
- Currently - choose bed load transport equation Yalin or Engelund Hansen and single grain size
- Calculate sediment flux and pattern of erosion and deposition

USGS

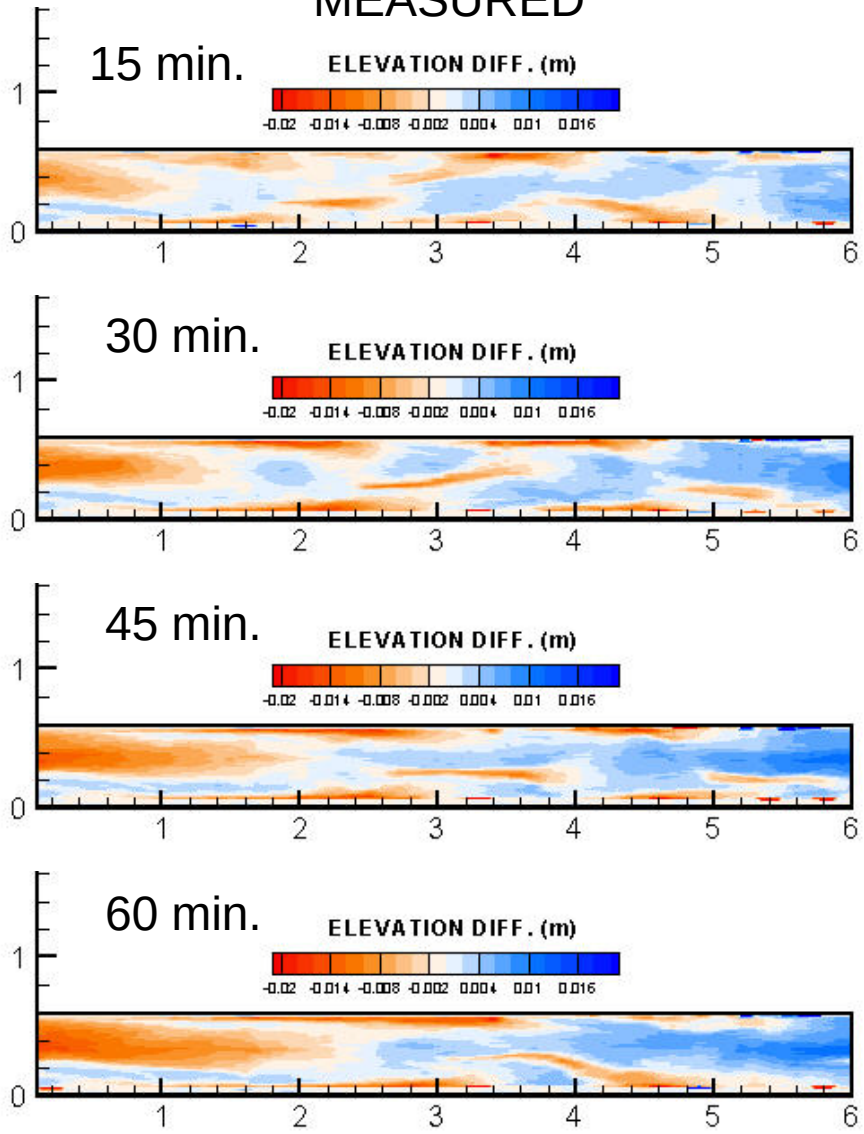


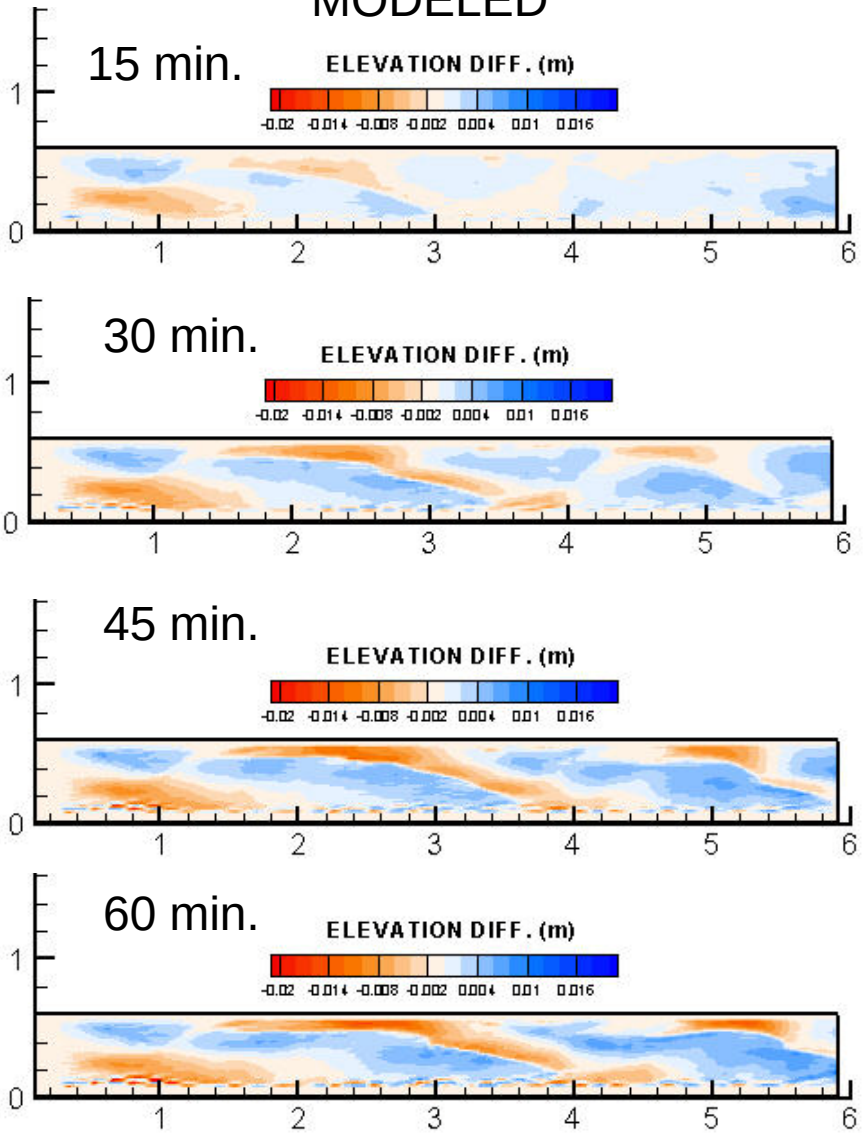
USGS

Q = 1L/s, B = 0.5 m, d = 0.6 mm, S = 0.0125, T = 1 hr

MEASURED

MODELED

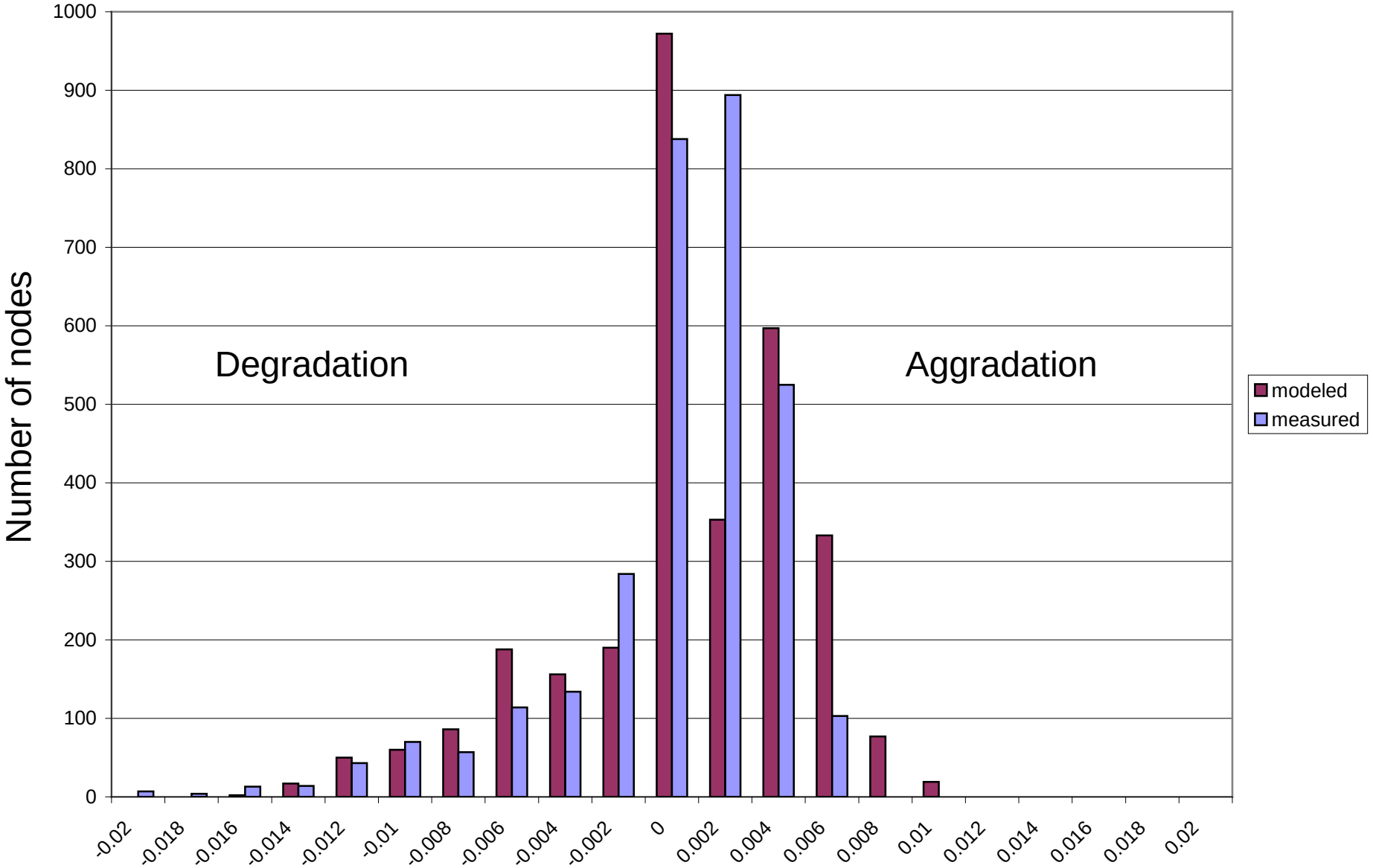




Mode 1.5

Mode 1

USGS



USGS

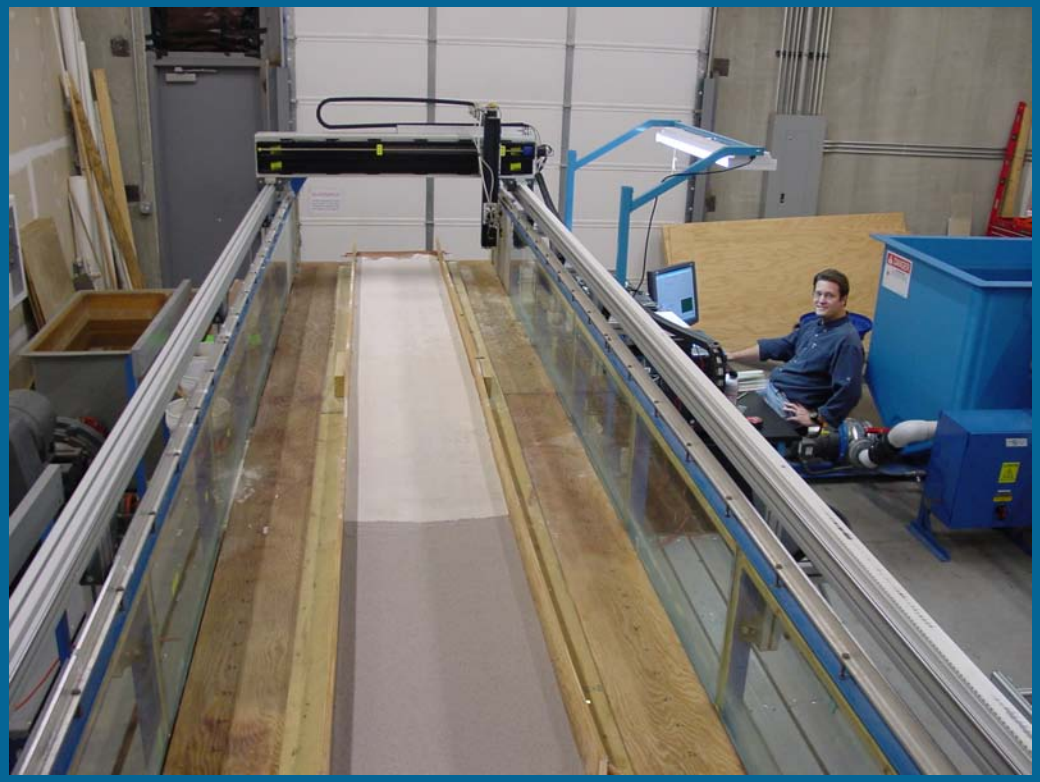
Histogram of measured vs modeled changes from plane bed

Conclusions

- MD_SWMS provide spatially explicit tools to address a variety issues related to river science
- EAARL sensor has shown promise for mapping meso-scale river features, more development is needed to improve vertical accuracy and precision for modeling applications
- Laboratory experiments at GSTL are being conducted to test sediment transport and bed evolution algorithms

USGS

Thank You



Paul Kinzel – pjkinzel@usgs.gov – 303-278-7941

http://wwwbrr.cr.usgs.gov/gstl/

USGS