2006/2008 – 2017 Topographic Change Analysis of the Lower American River
Matt Weber, M.S., E.I.T., Chris Bowles, Ph.D., P.E., Chris Hammersmark, Ph.D., P.E.
9/6/2018
American River Watershed

Folsom Dam (1955) – 977,000 acre-ft

Lower American River

Reno

Lake Tahoe

Yuba City
Hydraulic Mining: American River Watershed

- ~257 million yd³ of sediment excavated/eroded (1849 – 1909)
- Baseflow WSEs rose by ~10 ft at the Lower American and Sacramento River confluence
- Followed by rapid incision

[Gilbert 1917]
Motivations

- **Protect Sacramento Metropolitan Area**
  - Levee and bank erosion risks
  - Sediment deficits

- **Enhance existing Salmonid habitat**
  - Augment with spawning gravels
  - Reconnect floodplain areas

- **Understand river sediment dynamics**
  - At different scales: segment, reach, landform
Topographic Change Presentation Outline

- Time period and data overview
- Uncertainty analysis
- Sediment budget results
- Next steps
DEM Data

2006/2008 DEM
- 2006 single-beam sonar bathymetry
- 2008 multi-beam sonar (lower ~3.5 miles of river)
- 2008 CVFED LiDAR topography

2017 DEM
- 2017 topo-bathymetric LiDAR (green + NIR sensor)
- 2017 single-beam sonar in deep pools
2007 – 2017 Water Year Flows

- **Top Five Flood Peaks:**
  - 82,000 2/10/2017
  - 60,000 1/11/2017
  - 33,000 12/16/2016
  - 31,000 12/16/2010
  - 26,000 3/17/2011
Problem:

- Each DEM has its own inherent uncertainty.
- How much change is necessary before we can consider it real?
  - What is our Level of Detection (LOD)?

Based on repeat surveys to create two raster-based DEMs.

Difference of DEM’s (DoD)
Uncertainty Estimates

- Factors:
  - Point densities / data gaps
  - Surface roughness and slope
  - Landcover type
  - Survey method
DEM Uncertainty Method Overview

• Basic Premise (Weber and Pasternack 2017):
  – For each raster cell, calculate confidence limits on the assigned elevation, “Zr”
  – The uncertainty is a function of:
    • The density of survey points, “N”
    • The variability of the topography (i.e., surface roughness and slope), “SD_Z”
    • The vertical and horizontal accuracy of the survey method with respect to land cover (incorporates instrument error), “LC”:
      – Bare earth LiDAR
      – vegetated LiDAR
      – bathymetric LiDAR
      – multibeam sonar
      – singlebeam sonar
Point Densities

2006/2008

2017
Slope (Degrees)

2006/2008

2017
Level of Detection (Uncertainty)

2006/2008

2017

Combined
Raw to Processed Topographic Change

Raw Difference

Adjusted Difference (Raw ± LOD)
Sediment Budget: Exclusions and Low Confidence Areas
## 2006 – 2017 LAR Sediment Budget Estimates

<table>
<thead>
<tr>
<th>Method</th>
<th>Total (yd³)</th>
<th>Annual (yd³/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Raw</td>
<td>-480,000</td>
<td>-44,000</td>
</tr>
<tr>
<td>2. Raw w/ LowConf zones excluded</td>
<td>-300,000</td>
<td>-27,000</td>
</tr>
<tr>
<td>3. Adjusted (Raw ± LOD)</td>
<td>-338,000</td>
<td>-31,000</td>
</tr>
<tr>
<td>4. Adjusted w/ LowConf zones excluded</td>
<td>-214,000</td>
<td>-19,000</td>
</tr>
</tbody>
</table>

1 & 4 represent the range (min and max) and 2 & 3 represent the best estimates of change.
Reach breakdowns

1. Sunrise reach steep and variable
2. Riverbend reach widest and multi-threaded
3. Watt reach tidal transition and narrowest
4. Discovery / Capital reach tidal and levees are setback
2006/2018 – 2017 LAR Reach Sediment Budget Estimates

<table>
<thead>
<tr>
<th>Reach</th>
<th>Raw Total (yd³/mile)</th>
<th>Adjusted Total (yd³/mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sunrise</td>
<td>-32,000</td>
<td>-23,000</td>
</tr>
<tr>
<td>2. Riverbend</td>
<td>6,000</td>
<td>1,000</td>
</tr>
<tr>
<td>3. Watt</td>
<td>-18,000</td>
<td>-12,000</td>
</tr>
<tr>
<td>4. Discovery/Capital</td>
<td>-16,000</td>
<td>-10,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-22,000</strong></td>
<td><strong>-15,000</strong></td>
</tr>
</tbody>
</table>

- Riverbend slightly aggraded while all other reaches were net exporters of sediment.
Longitudinal Profile
Longitudinal Profile of Topographic Change

4. Discovery/Capital
3. Watt
2. RB
1. Sunrise

Distance Upstream from Sacramento River Confluence (River Miles)
Summary

- LAR exported ~340,000 yd\(^3\) of sediment from 2006 – 2017 (~31,000 yd\(^3\)/yr), most is assumed to have occurred during the 2017 water year
- Current gravel augmentation projects range from 5,000 – 25,000 yd\(^3\)/yr
- Riverbend Reach behaves uniquely
- Visually: very little sediment interaction on the floodplain/terraces with localized bank collapses
Next Steps

- Create a baseline inventory of landforms and in-channel habitats
- Quantify the sources and sinks of sediment
- Assess channel/floodplain sediment connectivity and dynamics
- Repeat analysis for 1997 - 2006

(Weber and Pasternack 2017)
References:

Task 6: DEM Difference with Uncertainty Estimates

• Objectives:
  – Create a raw DEM difference map
  – Evaluate levels of uncertainty for each DEM
  – Adjust raw DEM difference map using the uncertainty method developed by Weber and Pasternack (2017)
  – Estimate the overall sediment budget
  – Break down the sediment budget longitudinally and at the reach scale
Survey Type and Land Cover Point Variability

- **Bare Earth LiDAR**
  - 0.127 ft

- **Vegetated LiDAR**
  - Use value within range reported in literature
  - 0.984 ft (0.3 meters)

- **Bathymetry**
  - Green LiDAR = 0.6 ft
  - MB sonar = 0.3 ft
  - SB sonar = 0.6 ft
Understanding Raster Elevation Uncertainty

Raster cells (oblique view)

Points (Profile view)

Point (Plan view)

Other information to consider: survey method, landcover type, info from adjacent cells
1. Classify Point Cloud

2. TIN to Raster DEM \( Z_r^{2017} \)

3. Create Survey/Land Cover Raster \( LC_{2017} \)
4. Ground Point Count Raster

\[ N_{2017} \]

5. Create a standard deviation raster

\[ SD_{2017} = \sqrt{(SD_{Z2017})^2 + (LC_{2017})^2} \]

6. Calculate Standard Error of the Mean

\[ SEM_{2017} = \frac{SD_{2017}}{\sqrt{N_{2017}}} \]

*Note, point count per raster cell [25 ft^2]. Darkest color ~5pts/ft^2

*Note, confidence of a highly variable surface is high due to high point count in bare earth landcover
7. Calculate Level of Detection (LOD)

\[
LOD = \sqrt{(SEM_{2008})^2 + (SEM_{2017})^2}
\]

8. Adjust the Raw Topographic Change by the LOD$_{95}$

\[
\Delta Z = (Zr_{2017} - Zr_{2008}) \pm LOD
\]
Summary of Uncertainty Method

• Uncertainty is treated as spatially variable
• Estimates are based on the observed characteristics of the data
• Factors include: point density, surface variability, survey method, and landcover type

• Benefits: objective, transparent, data-driven workflow
How do we know the uncertainty method works?

Compare estimated uncertainties to the RMSE calculated by Quantum Spatial’s control and check points:

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Ground Check</th>
<th>Ground Control</th>
<th>Wetted Edge</th>
<th>Submerged</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Obs.</td>
<td>24</td>
<td>328</td>
<td>34</td>
<td>176</td>
</tr>
<tr>
<td>LOD Mean</td>
<td>0.078</td>
<td>0.084</td>
<td>0.193</td>
<td>0.200</td>
</tr>
<tr>
<td>LOD Median</td>
<td>0.051</td>
<td>0.052</td>
<td>0.184</td>
<td>0.168</td>
</tr>
<tr>
<td>Q.S. RMSE</td>
<td>0.045</td>
<td>0.051</td>
<td>0.104</td>
<td>0.124</td>
</tr>
<tr>
<td>Mean Diff.</td>
<td>0.033</td>
<td>0.033</td>
<td>0.089</td>
<td>0.076</td>
</tr>
<tr>
<td>Median Diff.</td>
<td>0.006</td>
<td>0.001</td>
<td>0.080</td>
<td>0.044</td>
</tr>
</tbody>
</table>
Sediment Budget

• Objectives:
  – Understand how much material is being exported out of LAR
  – Separate fluvial vs. non-fluvial changes
  – Include uncertainty estimates in the sediment budget
  – Break down the sediment budget longitudinally or at the reach scale
Sediment Budget: Non-fluvial change