Appraising long-term mercury concentration and loading trends in the Carson River-Lahontan Reservoir system

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Outline of Presentation

• Background
  • Site overview
  • Legacy mercury from historical gold and silver mining
• Analysis of loads and long-term trends
  • Introduce the long-term dataset
  • LOADEST/WRTDS tools
  • Application of WRTDS to Ft. Churchill site
  • Application of WRTDS to below dam site
  • Mercury trapping in Lahontan Reservoir
• Presentation of sediment data
• Concluding thoughts
  • The importance of long-term monitoring
Carson River/Lahontan Reservoir System

Comstock Lode

Long-term monitoring
Lahontan Reservoir Monitoring

Below Lahontan Dam

Week’s Bridge

Lahontan Reservoir
Sites Downstream

<table>
<thead>
<tr>
<th>Fallon</th>
<th>Lahontan Reservoir</th>
</tr>
</thead>
</table>

Henny et al. (2017)

Table 3: Young snowy egrets with telemetry radios attached at Lahontan Reservoir (LR) and Humboldt River Reference Area (RRF), number known to have died in colony before dispersing and after dispersing but before migration.

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lahontan Reservoir (LR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attached</td>
<td>10</td>
<td>23</td>
<td>38</td>
<td>71</td>
</tr>
<tr>
<td>Died “in colony”</td>
<td>7 (70%)</td>
<td>1 (4.3%)</td>
<td>6 (15.8%)</td>
<td>14 (19.7%)</td>
</tr>
<tr>
<td>Dispersed</td>
<td>3</td>
<td>22</td>
<td>32</td>
<td>57 (7.9%)</td>
</tr>
<tr>
<td>Died after dispersal</td>
<td>0 (4.5%)</td>
<td>4 (12.5%)</td>
<td>5 (6.5%, 9.3%)</td>
<td></td>
</tr>
<tr>
<td>Reference Area (RRF)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attached</td>
<td>24</td>
<td>35</td>
<td>20</td>
<td>79</td>
</tr>
<tr>
<td>Died “in colony”</td>
<td>1 (4.2%)</td>
<td>1 (2.9%)</td>
<td>1 (5.0%)</td>
<td>3 (3.8%)</td>
</tr>
<tr>
<td>Dispersed</td>
<td>23 (22%)</td>
<td>54</td>
<td>19</td>
<td>76 (75%)</td>
</tr>
<tr>
<td>Died after dispersal</td>
<td>8 (14.8%)</td>
<td>7 (20.6%)</td>
<td>4 (21.1%)</td>
<td>19 (25.0%, 25.3%)</td>
</tr>
</tbody>
</table>

Wentz et al. (2014)
Mine locations within the watershed

Source: USGS MRDS database
Data from SWRCB, Reservoir TMDL draft staff report (2017), Table B-1 plus unpublished USGS data
Legacy of Comstock Mining

- Total milled ore: 1860-1880: 7 million tons
- Peak production in 1877: $14 million gold
  $21 million silver
- Total gross production estimated at $320 million (1859-1878) Net profit: $55 million
- $1 in 1880 → $23.12 in 2018
- $55 million → $1,271,600,000
- An estimated 7,500 tons of Hg lost to the environment (Smith and Tingley, 1943)

Photo Credit: Charles Lynch Collection, Carson City Historical Society
Dayton Times, 1885

“...the project being to clean out the bed of the stream and capture the tons of quicksilver and amalgam...no doubt there are large quantities of precious stuff in the numerous pot-holes and swirls in the riverbed...”
Hg loading, Weeks Bridge Site

Number of Samples (blue dots) = 284

Graph showing daily discharge and days on which Hg sample was collected.
Uf.THg Distributions

Sediment mobilization from Carroll and Warwick (2016)

Number of Unfiltered and Filtered Mercury Samples

74 + 76 + 134 = 284

Coarse bed-sediment mobilized

Bank material mobilized
LoadEst and WRTDS

- As rich as the Carson River Hg dataset is, it is not continuous. Through modeling, we attempt to estimate daily concentrations and loads using two programs (though others are available):

  - LoadEst:
    \[
    \ln(Q) = \alpha_0 + \alpha_1 \ln(Q) + \alpha_2 \ln(Q^2) + \alpha_3 \sin(2\pi t) + \alpha_4 \cos(2\pi t) + \alpha_5 t + \alpha_6 t^2
    \]
    Flow Season Time

  - WRTDS:
    \[
    \ln(Q) = \beta_0 + \beta_1 t + \beta_2 \ln(Q) + \beta_3 \sin(2\pi t) + \beta_4 \cos(2\pi t) + \epsilon
    \]
    Time Flow Season

- Neither approach worked for MeHg below the dam, as we will see. May need to turn to other models, like LoadFlex
Annual Hg Loading at Weeks Bridge

- Jan 2nd 2006 loads:
  - Peak Q: 9,500 cfs
  - uf.THg exceeded entire annual load 7 out of 16 years
  - 2.6% of entire PoA load contributed on Jan 2nd, 2006
  - On average, 70% of total annual uf.THg load contributed during highest 10% flow days

Runkel et al. (2004)
Another Look at Loading Data

- 30% of the time, daily load exceeds 1 kg/d
- Recall an estimated 7,500 tons of Hg released (6.8 million kg)
- An estimated 20,590 kg (0.3% total lost) moved past Weeks Bridge during PoA
What about trends?

- Use WRTDS tool
- Written in R
- Data requirements
  - Requires a complete daily discharge record
  - Streamflow can’t be too flashy (low intra-day variability)
  - Works best with >100 samples
  - Water quality samples should cover most of the discharge range
  - For trends: 10 or more years of data
  - For average flux: 5 or more years of data

Hirsch and DeCicco (2015)
Flow-normalized trends – uf.THg

- Modeled fit is very good
- Concentration trend:
  - -11 ng/L per yr
  - Not significant
- Load trend:
  - -26 kg/yr (1.8% per year)
  - Reduction from 1,400 to 1,000 kg/yr over PoA
  - Statistically significant
Flow-normalized trends – f.THg

- Mean annual concentration increased by 56% over PoA
- Apparent acceleration (increasing slope) in concentration from a 1.7% per year increase (1998-2005) to 4.9% per year increase (2006-2013)
- From 1998 to 2013, flow-normalized load increased from 7.5 kg/yr to 12.7 kg/yr (70% inc.)
Investigating the 2006 f.THg break in slope

CARSON RV NR SILVER SPGS, NV
Filtered Mercury
Water Year
95% Cl on FN Concentration, Replicates = 500 Block= 150

Concentration, in ng L⁻¹

2000 2005 2010

1.7% per year 4.9% per year

Weeks Bridge, Jan 3, 2006

Sixmile Canyon (Dayton), Jan 4, 2006

Dayton, Jan 4, 2006
Flow-normalized trends - uf.MeHg

- 6.1% decrease in flow-normalized concentration over PoA (0.2 ng/L drop)
- Over PoA, flow-normalized uf.MeHg load trended down at 2.5% per year
- Total load decrease of 0.4 kg/yr during PoA (37%)
- uf.MeHg conc. Increased by 25-75% during low flow (<17.5 cfs)
Flow-normalized trends - f.MeHg

- f.MeHg concentration exhibited a subtle downward rate of 0.34% per year.
- f.MeHg trend does not mirror that of f.THg.
- Mean annual f.MeHg concentration cycling between 1 ng/L and 1.7 ng/L on a 5-7 year period.
Flow-normalized suspended sediment concentration trends

- No meaningful trends in suspended sediment

A

![Graph A](image)

B

![Graph B](image)

C

![Graph C](image)

D

![Graph D](image)
Trends in partitioning coefficient

- Statistically significant downward trend in the partitioning coefficient for the Carson River ($K_d$) for both Hg and MeHg
- A downward trending partitioning coefficient suggests a shift from the particulate phase toward the filtered phase
- Potential explanations for increasing $f \cdot THg$ trend:
  - Increase in primary production matches observed increase in pH (more basic)
  - Consistent with an increase in primary production (phytoplankton)
  - Nutrient and DOC concentrations were not monitored through time

$$K_{dTHg} = \frac{p \cdot THg \cdot 1 \times 10^6}{f \cdot THg} \quad K_{dMeHg} = \frac{p \cdot MeHg \cdot 1 \times 10^6}{f \cdot MeHg}$$
Shifting gears to downstream of Lahontan Reservoir and within Lahontan Reservoir
Downstream of Lahontan Dam

Number of Samples = 145
Lahontan Reservoir
Lahontan Reservoir Storage

Year:
97  98  99  00  01  02  03  04  05  06  07  08  09  10  11  12  13  14  15  16  17  18

Lahontan Reservoir storage, in million acre-feet

- Reservoir Storage
- Sample Collection
- Samples with High Methylmercury Concentrations
Concluding Remarks

- With the unique dataset, we have learned some things about load calculation, still more to learn.
- Calculated daily loads of uf.THg during individual high-flow events exceed the total annual uf.THg load calculated during relatively dry years.
- Flow-normalized analysis “integrates out” the considerable year-to-year variability in flow and allowed for a more robust long-term trend analysis of concentrations and loads, but requires long-term data (> 15 years).
- A mix of improved, unchanging, and deteriorating conditions with respect to the four monitored species of mercury.
- Questions remain regarding the specific factors that are driving the trends in upstream Hg speciation reported herein. Must adopt a holistic approach moving forward.
Concluding Remarks

- Below the dam: Very difficult to model non-conservative MeHg. MeHg is complicated, our dataset is incomplete for modeling released MeHg. This is because MeHg is non-conservative, and our physically-based parameters do not rise to the task (e.g., 45-day wetted lakebed area, delivered fine grain sediment, days above some high stage).

- Trapping efficiency during PoA is ~92%.

- Sediment-water interface: Seeing higher MeHg concentrations in the water column than in the bed sediment, but need to account for timing of data collection. Need further monitoring to better understand the methylation pathway.
Parting Thought

- “The only way to figure out what is happening [in a California reservoir] is to measure it, and this means tracking changes decade after decade and poring over the records.” - Bob Hirsch, USGS
2018 Webinar Series on “Mercury in Reservoirs”

presented by
U.S. Geological Survey
California Water & Environmental Modeling Forum

Wednesday, May 2, 10:00 am PST

*   *   *

Synthesis of mercury case studies in reservoirs – matching study design to research and management questions

Simplified Conceptual Model

*Temporally variable

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*USGS, Sacramento, CA; #USGS, Menlo Park, CA; ^USGS, Corvallis, OR; *Reed Harris Environmental, Ltd., Oakville, ON, Canada; †USGS, Middleton, WI

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1) WebEx: https://doilearn2.webex.com/doilearn2/j.php?MTID=emd1a0b0b3b313fab459d056052f0f168d

References


Santiago Mill
Brunswick Mill
THE BIG BONANZA:

AN AUTHENTIC ACCOUNT OF THE DISCOVERY, HISTORY, AND WORKING OF THE WORLD RENOWNED COMSTOCK SILVER LODE OF NEVADA

INCLUDING THE

PRESENT CONDITION OF THE VARIOUS MINES SITUATED THEREON; SKETCHES OF THE MOST PROMINENT MEN INTERESTED IN THEM; INCIDENTS AND ADVENTURES CONNECTED WITH MINING, THE INDIANS, AND THE COUNTRY; AMUSING STORIES, EXPERIENCES, ANECDOTES, &C., &C.

AND A FULL

EXPOSITION OF THE PRODUCTION OF PURE SILVER

BY

DAN DE QUILLE.
(WILLIAM WRIGHT.)

PROFUSELY ILLUSTRATED.

INTRODUCTORY.

One easily gets a surface-knowledge of any remote country, through the writings of travellers. The inner life of such a country is not very often presented to the reader. The outside of a strange house is interesting, but the people, the life, and the furniture inside, are far more so.

Nevada is peculiarly a surface-known country, for no one has written of that land who had lived long there and made himself competent to furnish an inside view to the public. I think the present volume supplies this defect in an eminently satisfactory way. The writer of it has spent sixteen years in the heart of the silver-mining region, as one of the editors of the principal daily newspaper of Nevada; he is thoroughly acquainted with his subject, and wields a practised pen. He is a gentleman of character and reliability. Certain of us who have known him personally during half a generation are well able to testify in this regard.

HARTFORD, May, 1876.

MARK TWAIN.

PREFACE.

I have put all I had to say into the body of this book; but, being informed that a preface is a necessary evil, I have written this one.

THE AUTHOR.