Antimony and Arsenic in the Macleay River: Understanding the legacy of historic mining

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Southern Cross University Research

Australian Government
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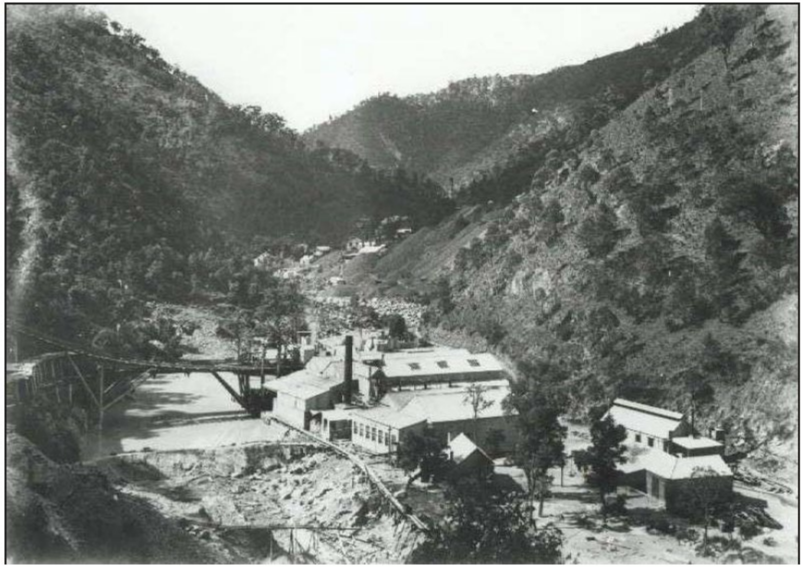
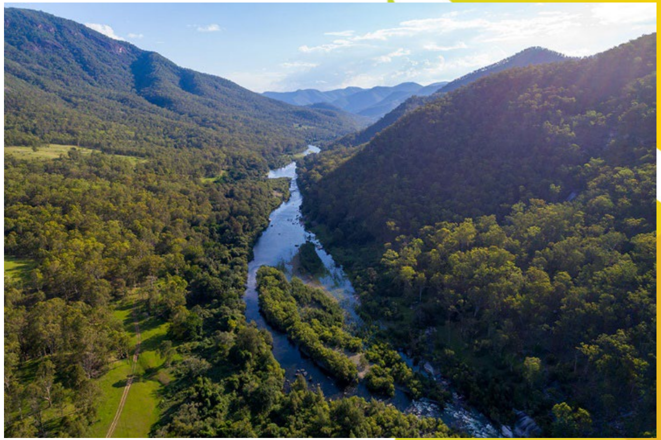
Overview

- Introduction and background to study
- Purpose and approach
- Antimony (Sb) and Arsenic (As) over time
  - guideline values
  - drivers and dynamics, flow
- Annual export loads
  - dissolved vs sediment transport
- Climate cycles
- Estimated duration of legacy impacts
- Conclusions and questions

Introduction

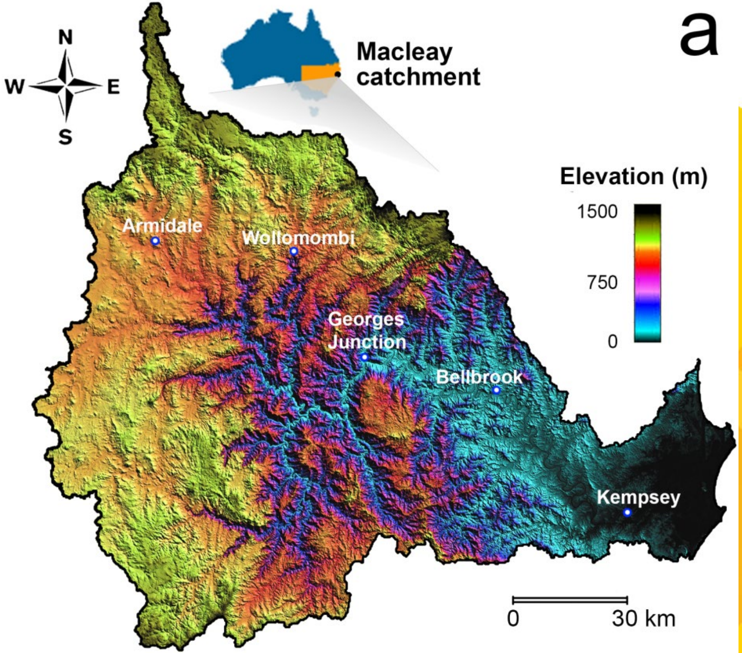
- Background to study
- Legacy impacts of historic mining
  - Bakers Creek: sulfide-bearing Au–Sb–As
- Excellent prior studies by UNE
  - Wilson
  - Ashley
  - Tighe
  - (GHD)
- Limited information on antimony and arsenic in Macleay main channel
- No long-term water quality study to date





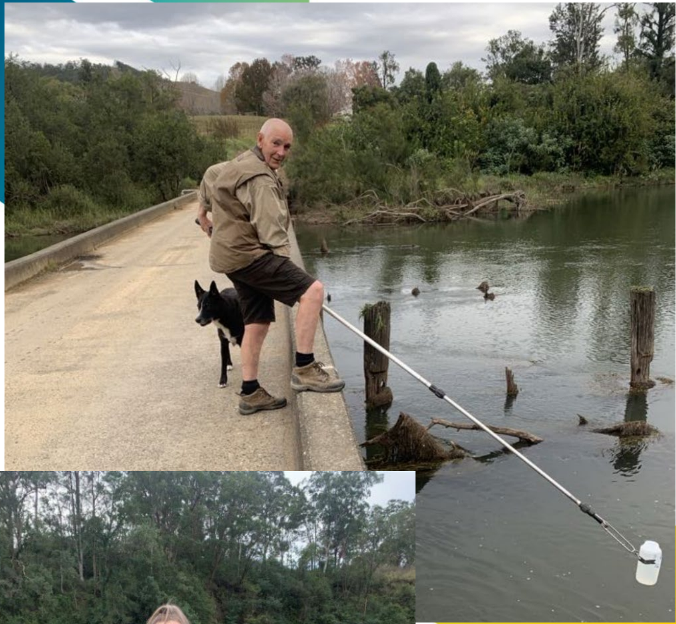
Purpose of research

- Provide information about antimony and arsenic in the Macleay main channel over time
  - Concentration range?
  - Relative to guideline values?
  - Seasonal variability?
  - Controls on their behaviour?
  - Amount transported downstream?
  - Dissolved or in sediments?
  - Climate relationships?
  - Long-term trends?



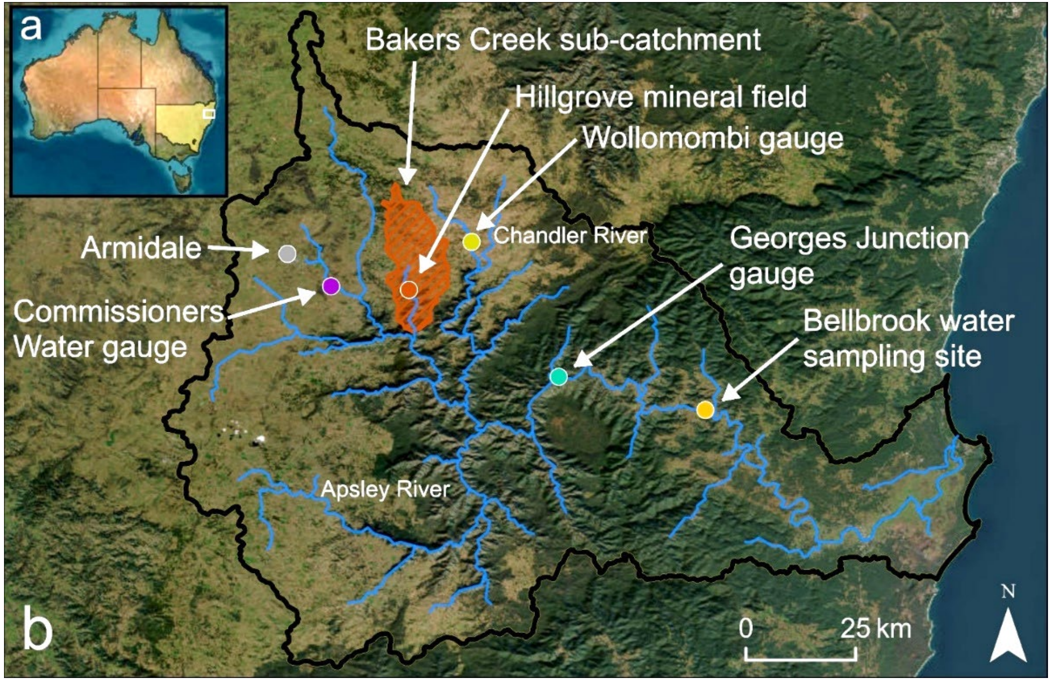
Approach

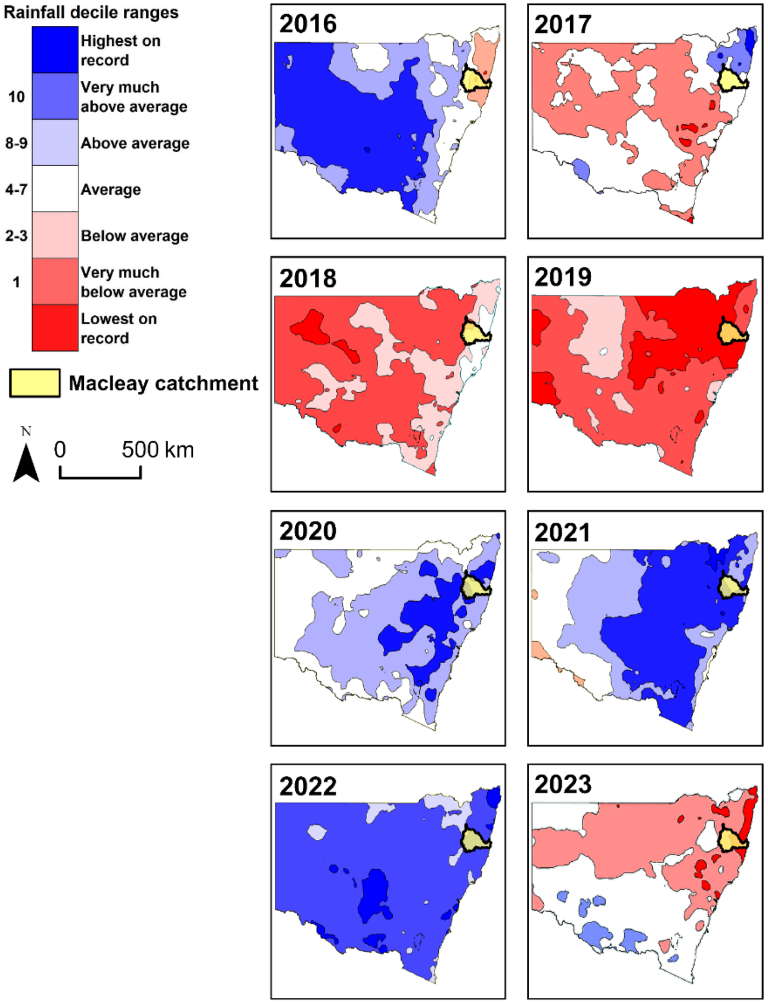
- Citizen Science-University collaboration, >500 samples over 7+ years, 2016-2023
- **SOMR** – trained volunteers collecting water samples in ultra-clean bottles
  - HUGE shout out to Arthur and Nise!!
  - At Bellbrook bridge, mid-channel,
  - Collected daily to ~7-10 days, flow dependent
  - Frozen > Analysis at Southern Cross University
  - Antimony, Arsenic, major ions, trace metals, sediment, nutrients (N/P), organic carbon



Where and when: Changes over time

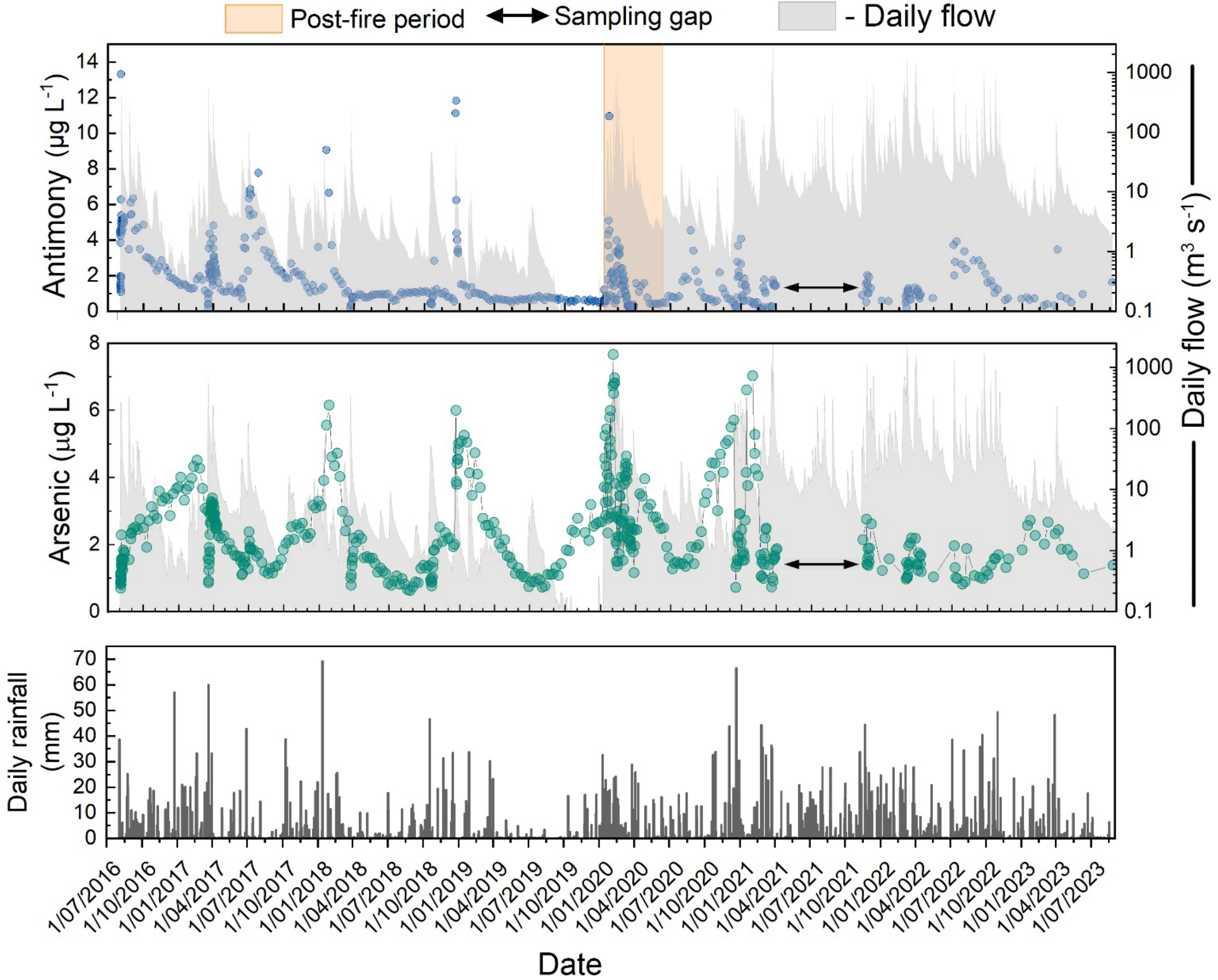
- The sampling period – 2016-2023
  - Spanned drought, fires and floods
  - Wide range of flow conditions (lucky!)



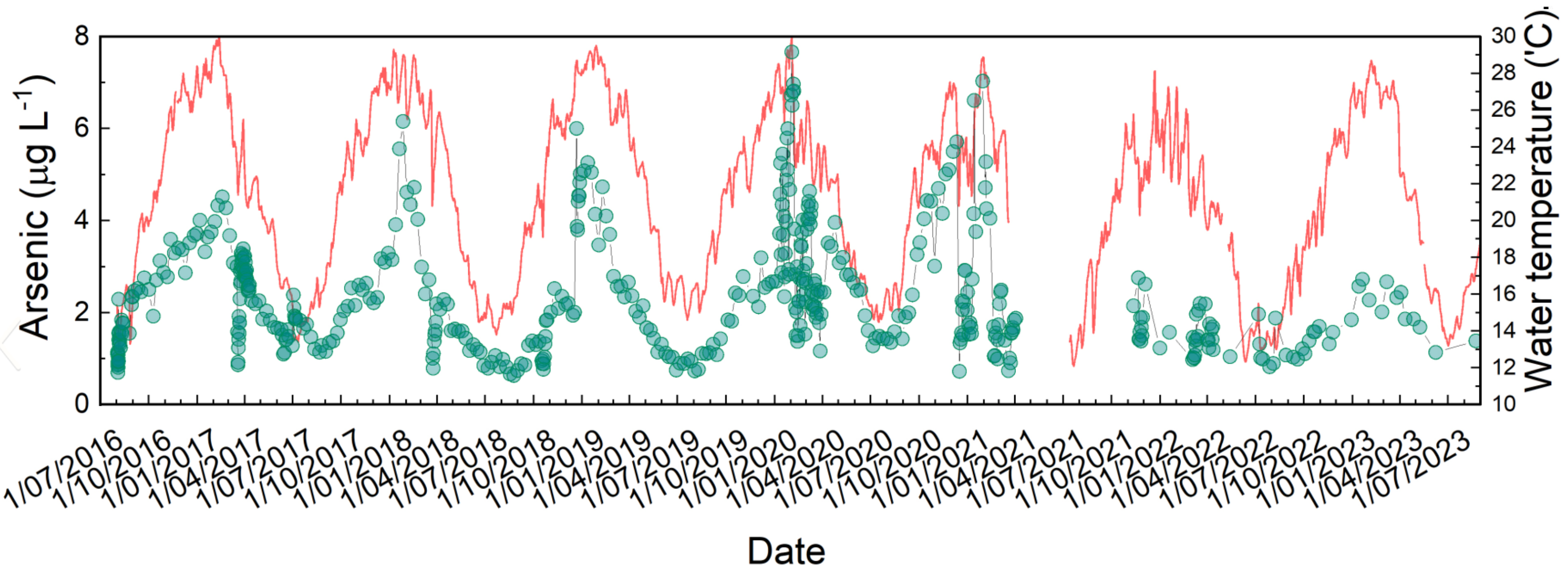


Changes over time

- Antimony and Arsenic
- Variable and complex behaviour
- There are **patterns**
  - Flow
  - Seasons



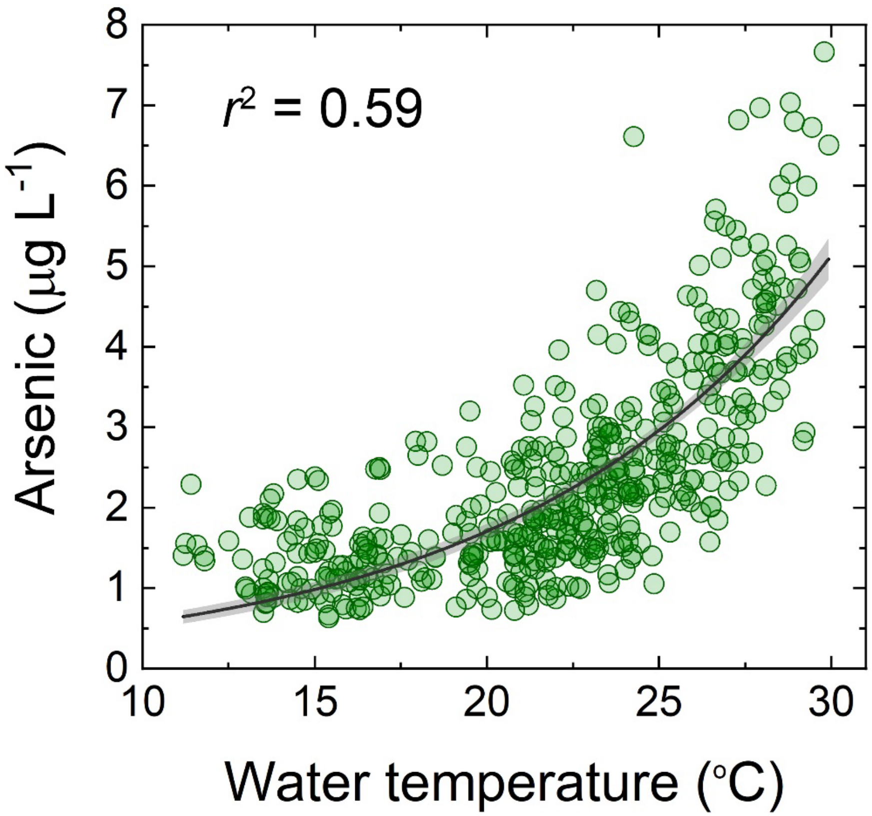
Arsenic



- Repeated peaks in concentration during **summer**
- Notable during periods of lower base flow

Arsenic

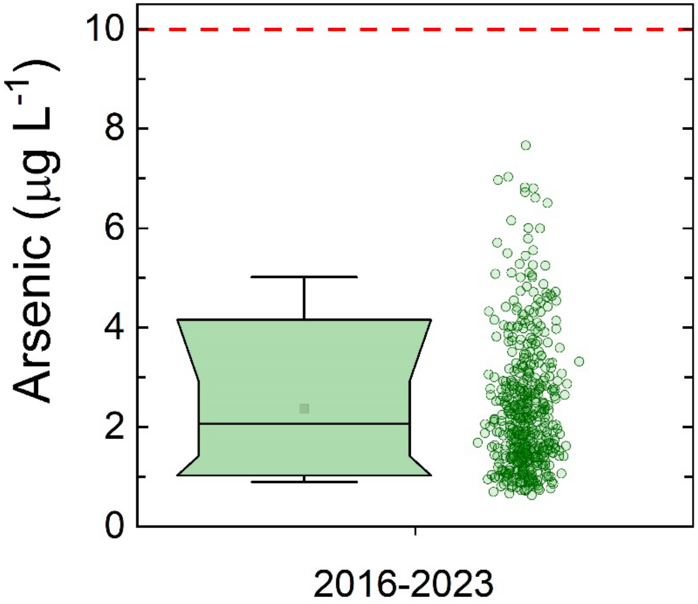
- Arsenic vs water temperature
- Higher concentrations when warmer - significant relationship
- Relates to geochemical processes in the riverbed sediments
- Effect is less noticeable when higher base flow > dilution
- Consistent with other studies
- Warming climate and warming waters…?



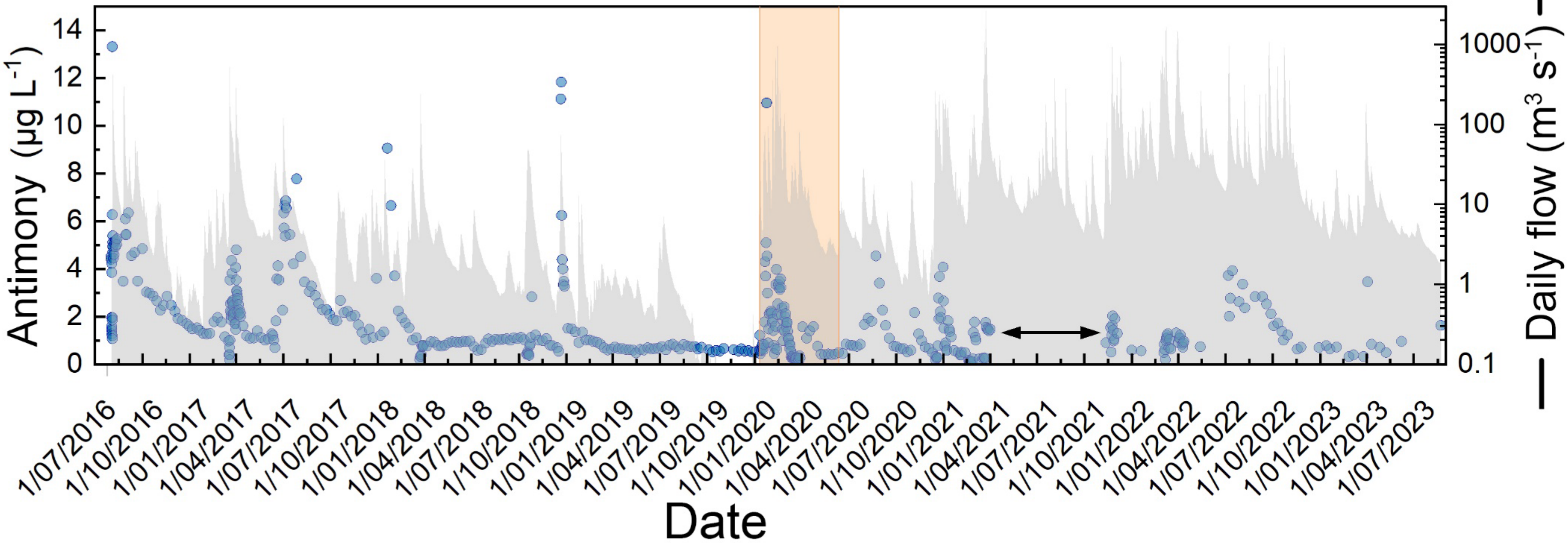
Arsenic

- Arsenic – did not exceed drinking water quality guideline values

Average	**2.37**
Maximum	**7.7**
Minimum	**0.6**
% above guideline value	**0**



Antimony

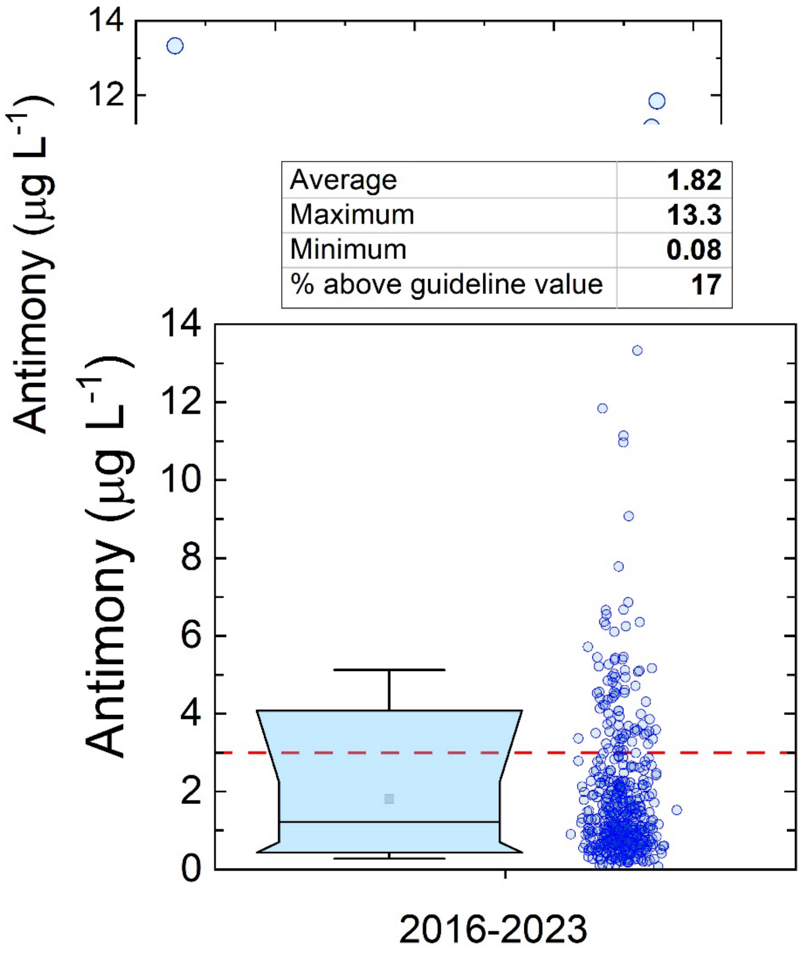


- Clear short-term peaks in concentrations
- Related to flow, but appears** inconsistent

Antimony

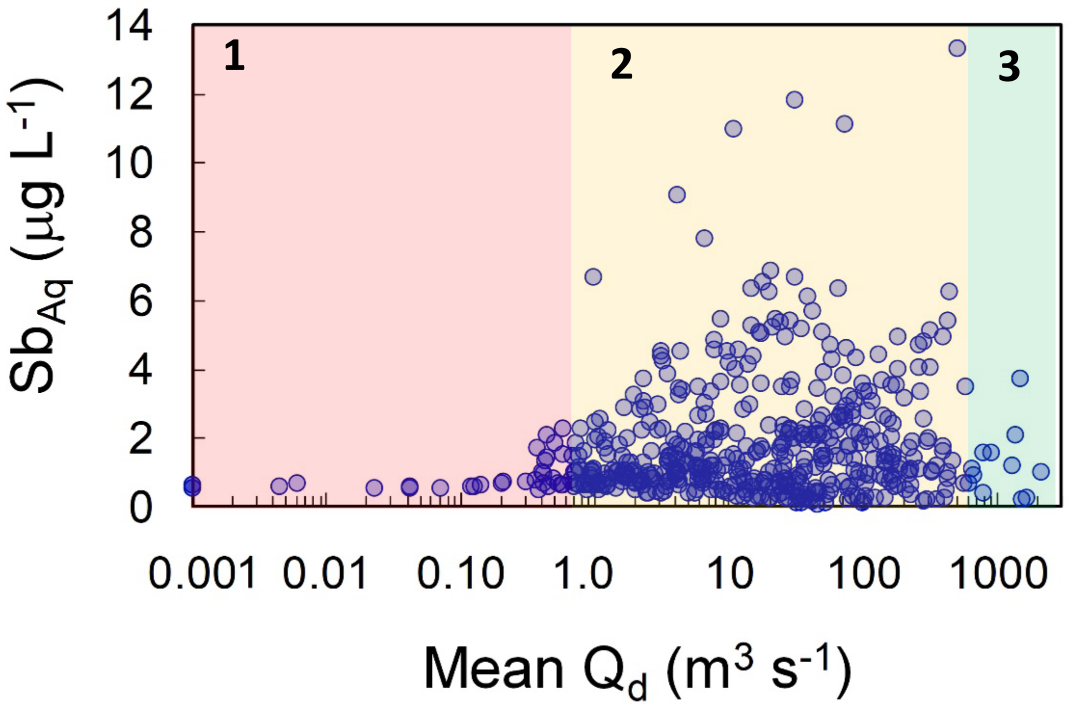
- Poorly related to temperature
- Can exceed drinking water guideline values (3 ppb)
- About 17% of samples over the drinking water guideline value
- Wider range of concentrations than Arsenic

Average	1.82
Maximum	13.3
Minimum	0.08
% above guideline value	17



Antimony

- Concentrations of Antimony at Bellbrook is related to flow…
- **1. Low flow** – lower Sb concentrations; *disconnected* from main Antimony source zone
- **2. Moderate flow** – variable Sb, sometimes high concentrations; *connected* to main Antimony source zone, but variable dilution
- **3. High flow** – lower Sb concentrations; *connected* to main Antimony source zone, persistent dilution



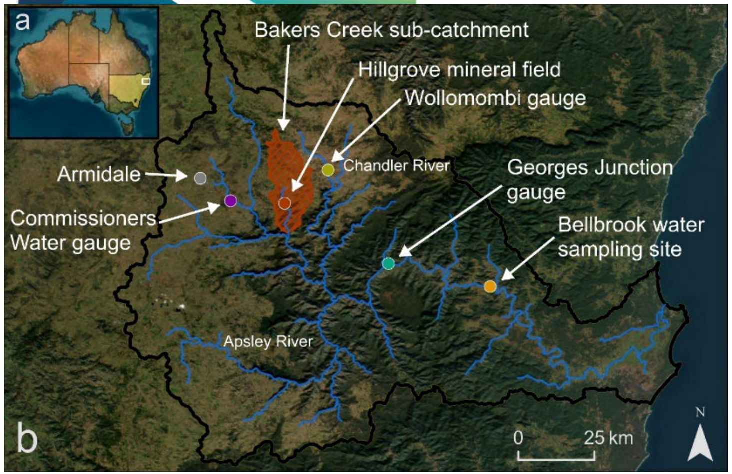
Antimony

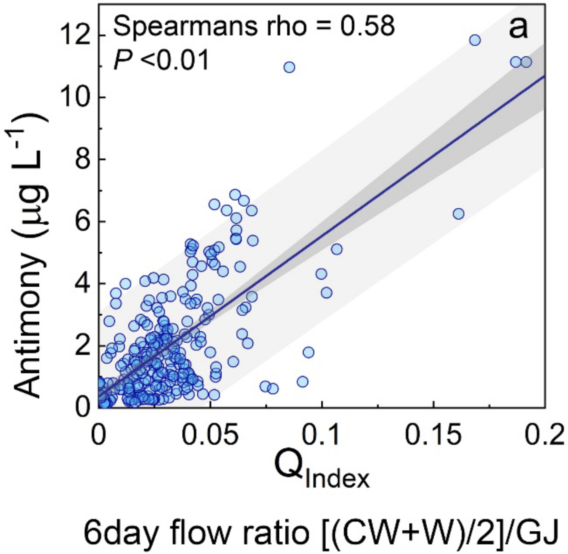
Dilution matters a lot…

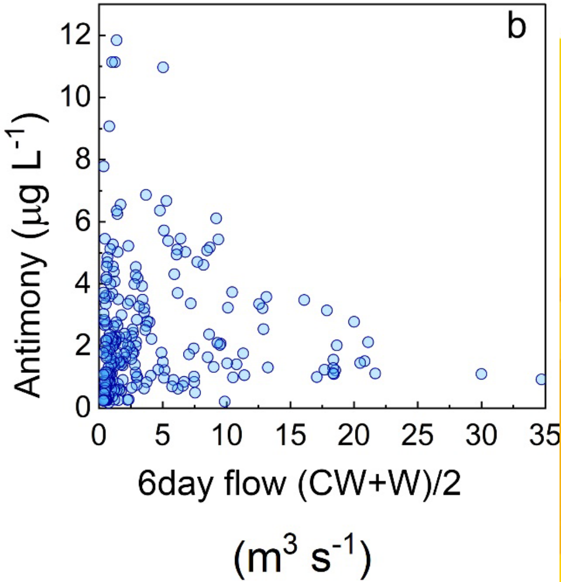
Flow ratio analysis

- **The proportion** of total river flow from Bakers Creek matters. Significant predictor of Antimony (a)
- Bakers Creek flow **alone** is not a significant predictor (b)

For Antimony - *where* the rain falls is important







Suspended Sediments at Bellbrook

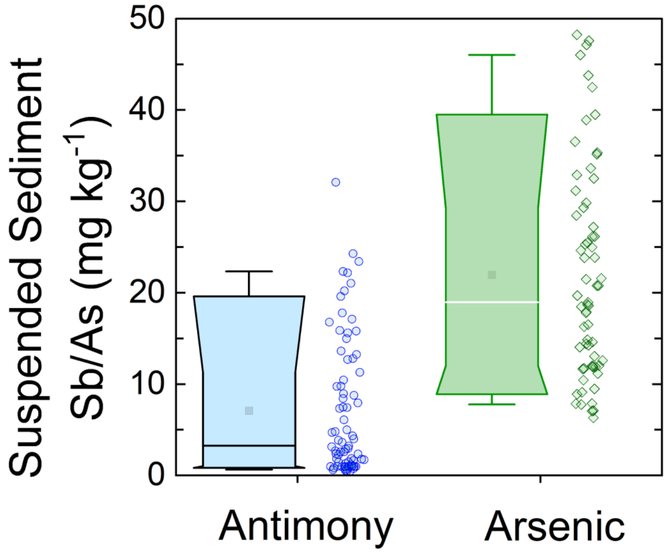
Antimony and Arsenic

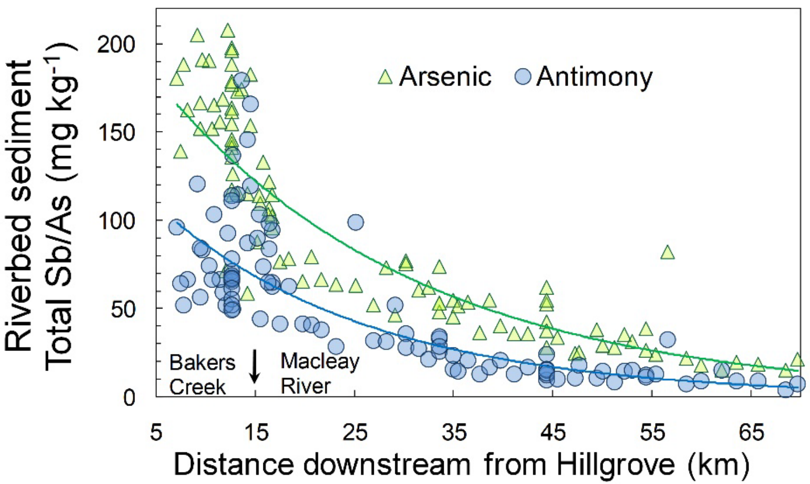
- Antimony is lower than Arsenic

Antimony in suspended sediment (mg kg^{-1})			
Average	Maximum	Minimum	Standard deviation
6.9	32.1	0.47	7.2

Arsenic in suspended sediment (mg kg^{-1})			
Average	Maximum	Minimum	Standard deviation
21.9	48.2	6.3	11.6

- Same as contamination patterns in upper catchment riverbed sediments



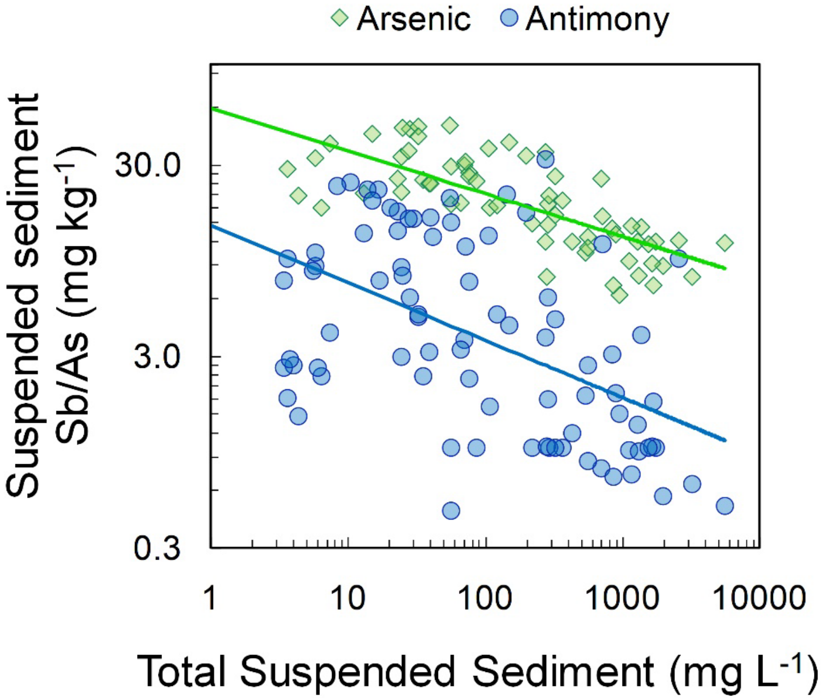


Suspended Sediments at Bellbrook

Southern Cross University

Antimony and Arsenic

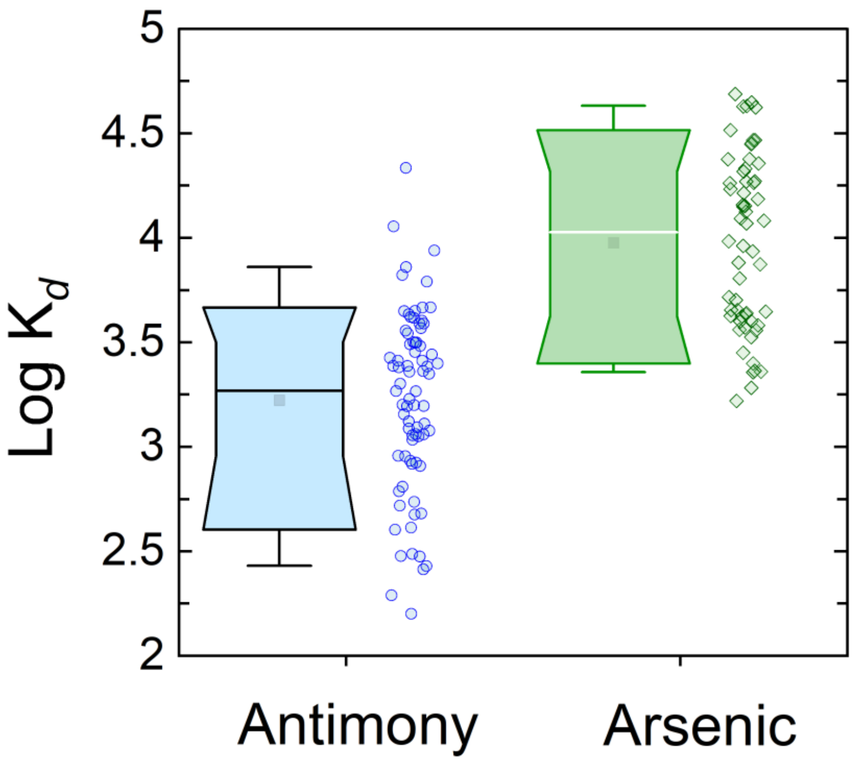
- As the sediment load increases, concentrations of Antimony and Arsenic *within* suspended sediment decrease



Suspended Sediments at Bellbrook

Antimony and Arsenic

- Contrasting solubility
- Antimony lower K_d = more "soluble" than Arsenic
- Antimony = for a given amount in the sediment, more is likely to be dissolved in the water



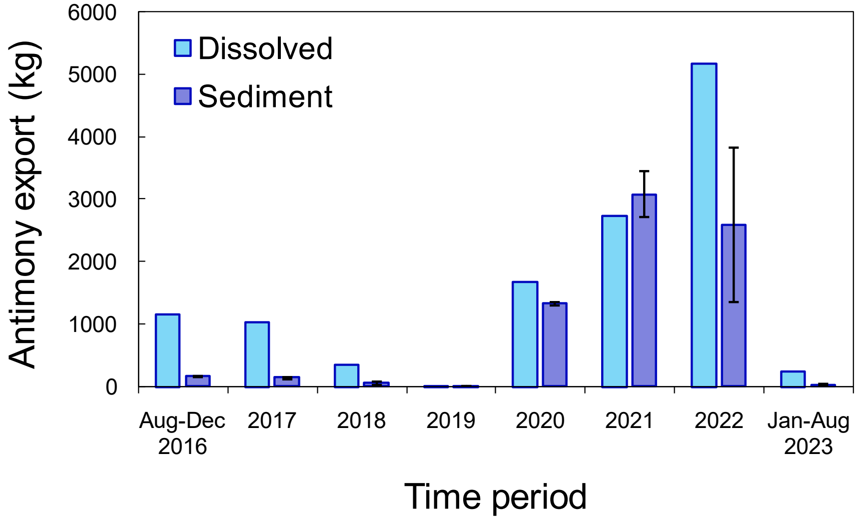
Annual export loads – comparing dissolved vs sediment

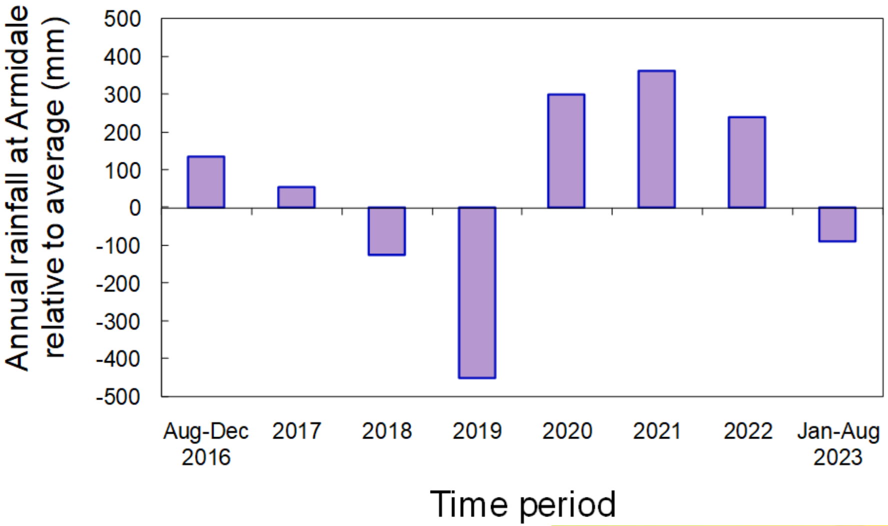
Antimony – 30 kg to >8,000 kg per year

- Varies, depending on rainfall and flow, dry vs wet years
- Antimony > more exported **dissolved** vs sediment

Total over 7 years

- **Dissolved** = ~12,000 kg
- Sediment = ~6000-8500 kg





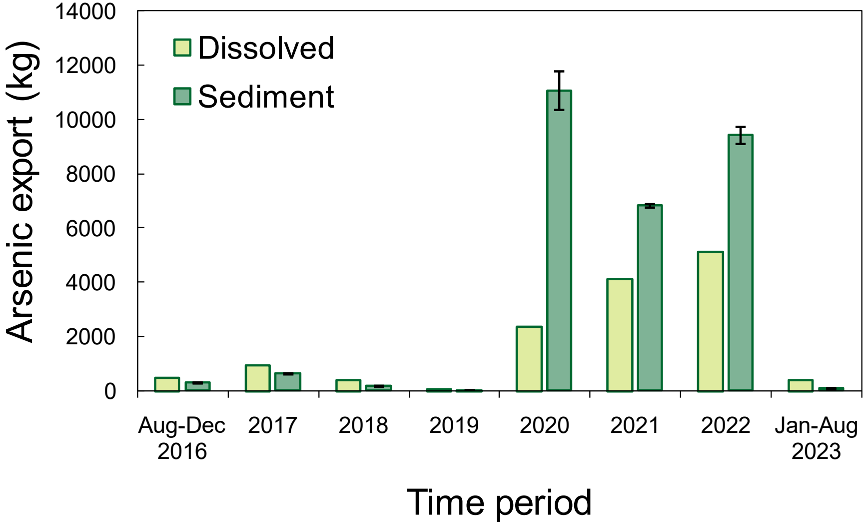
Annual export loads – comparing dissolved vs sediment

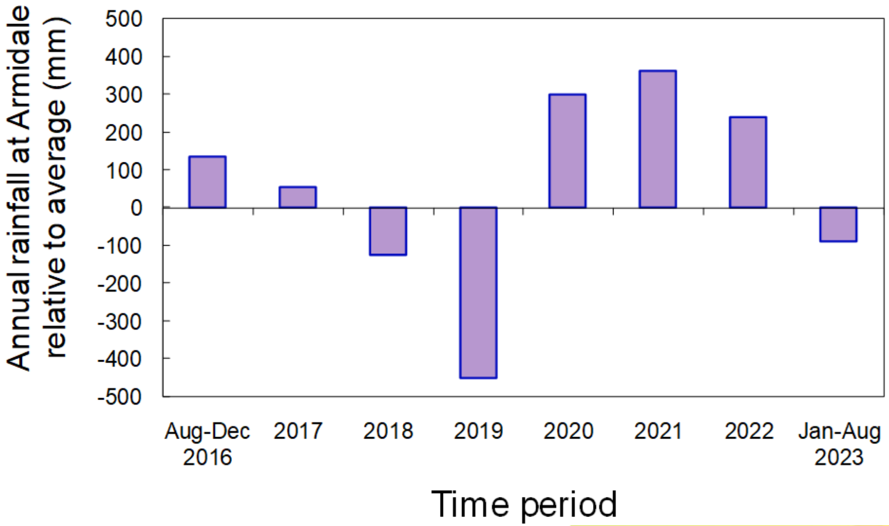
Arsenic - larger range, 70 – 14,000 kg per year

- Also rainfall / flow dependent
- Arsenic > more exported via **sediment** vs dissolved

Total over 7 years

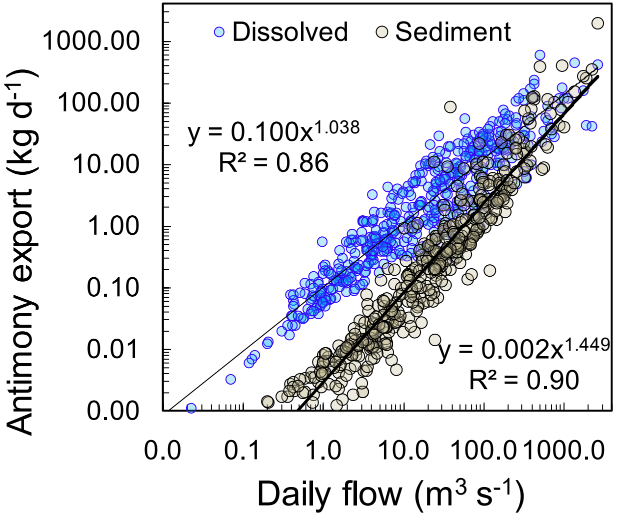
- Dissolved = ~14,000 kg
- **Sediment** = ~28,000-29,000 kg

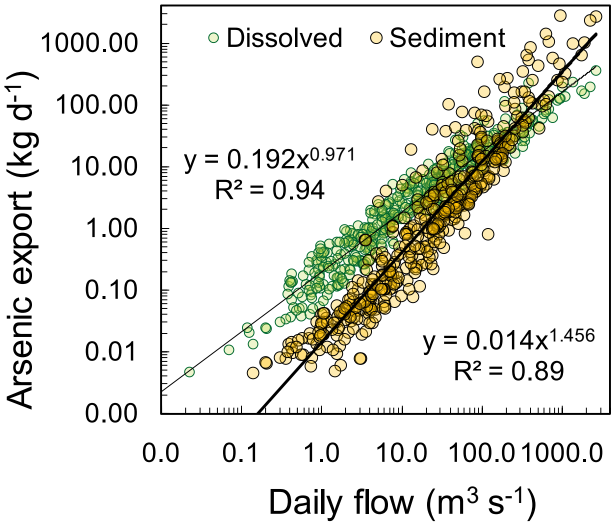




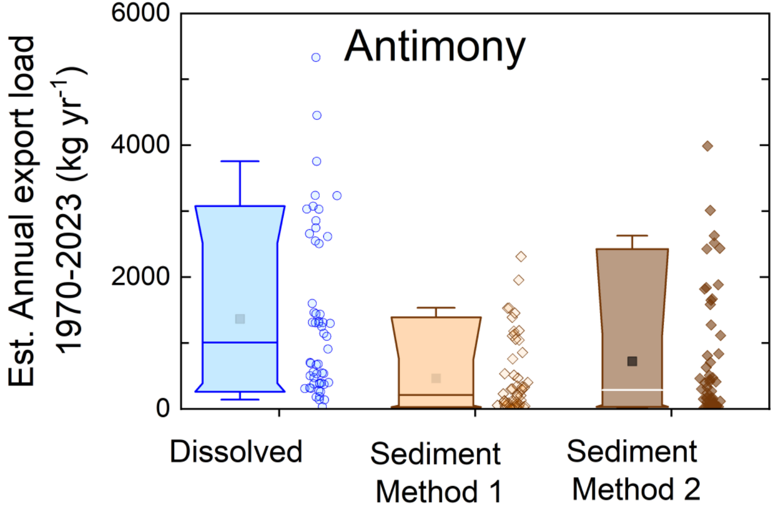
Estimating annual export loads back to 1970

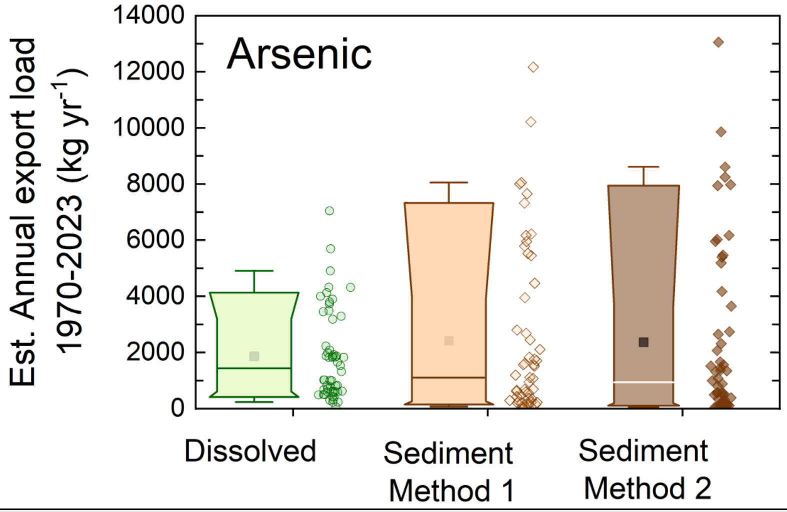
- ~500 data points, over 7 years of daily flow vs daily export
  - Relationships for Antimony and Arsenic can be used to estimate historical daily export based on flow data back to 1970





Annual export 1970-2023





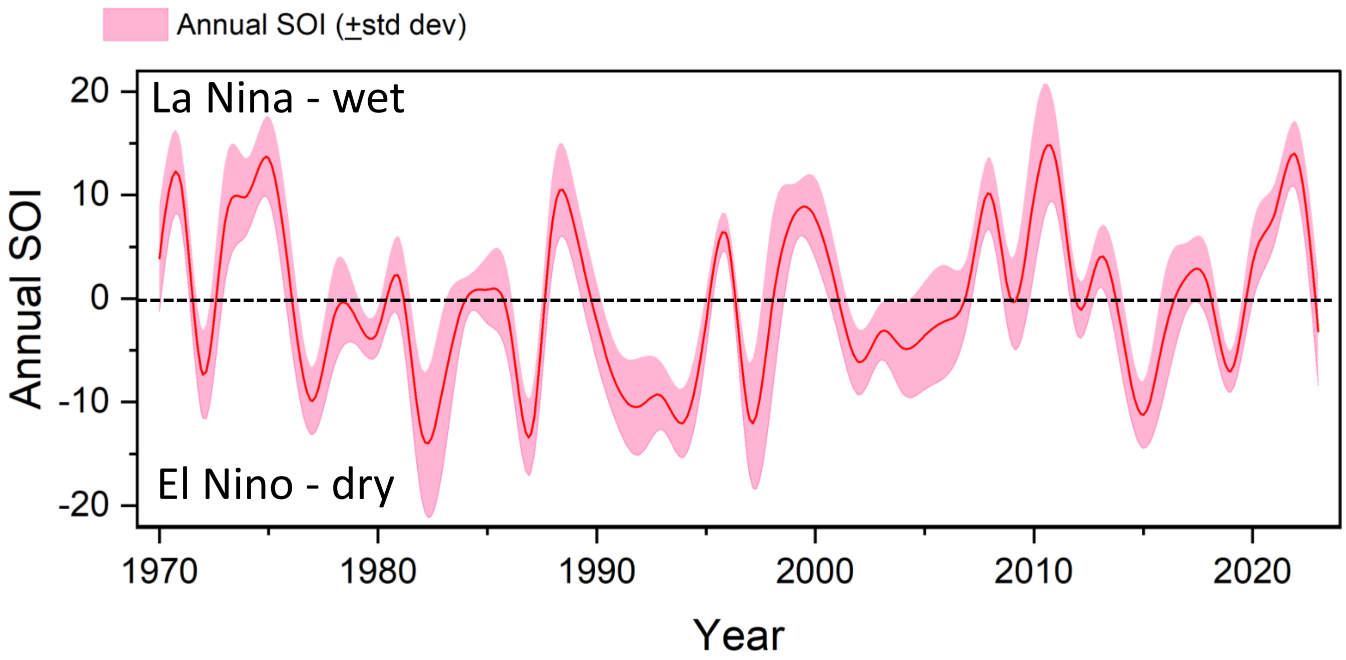
1970-2023: Antimony export loads (kg yr^{-1})		
Form	Average	Standard deviation
Dissolved	1367	1245
Sediment (Method 1)	463	569
Sediment (Method 2)	723	925

1970-2023: Arsenic export loads (kg yr^{-1})		
Form	Average	Standard deviation
Dissolved	1869	1605
Sediment (Method 1)	2422	2985
Sediment (Method 2)	2366	3092

- Large annual variability, depending on flow
- Arsenic export greater than Antimony
- A large proportion exported during flood years

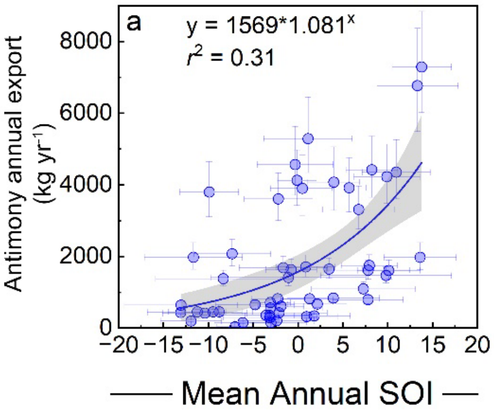
Big seasonal drivers: El Nino and La Nina

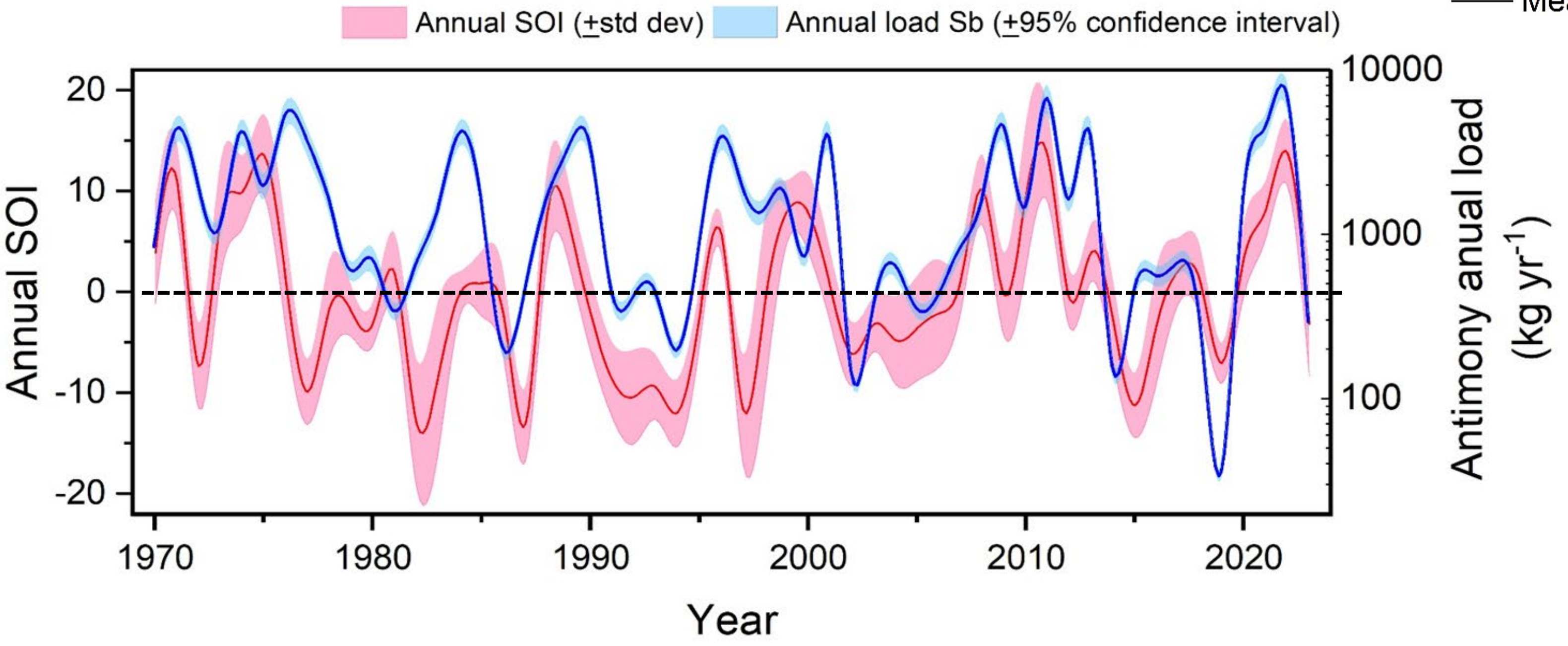
- El Nino Southern Oscillation Index
  - SOI values – 1970-2023



Big seasonal drivers: El Nino and La Nina

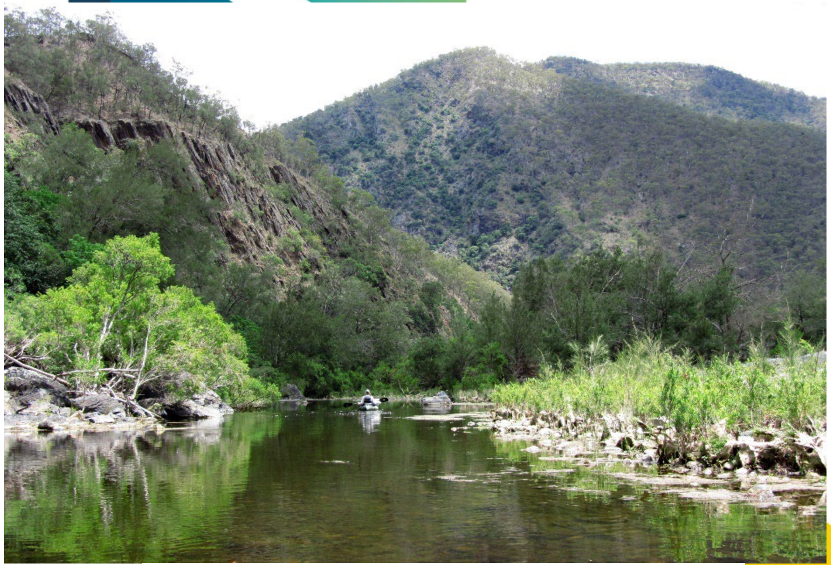
- El Nino Southern Oscillation Index
  - SOI values – 1970-2023
  - Annual loads related to SOI – more Antimony and Arsenic export during La-Nina phase

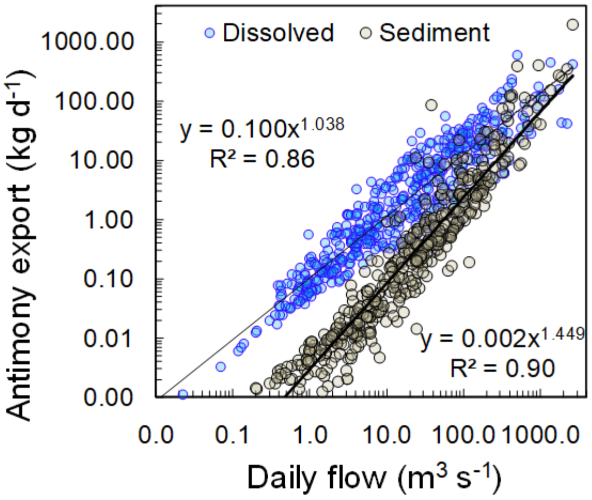




A legacy for how long…?

- Estimated ~1500 tons of Antimony in upper catchment river sediments (Ashley, 2007)
- Assume current rates of export remain ~constant,…
- About 600-1000 years before legacy Antimony is leached from the system





Conclusions

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	Antimony	Arsenic
Seasonal behaviour	Complex (contrasting)	Complex (contrasting)
Drinking water guideline values	Sometimes over, for short periods	Below
Key controls	Catchment hydrology, dilution	Temperature
Export	Dissolved > sediment – climate extremes	Sediment > dissolved – climate extremes
Legacy	600-1000 years	-

Topic | Journal publications

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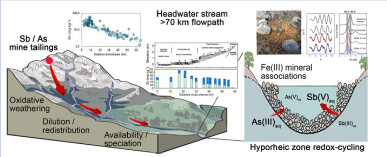
Sediment As / Sb geochemistry in the gorge country of the upper Macleay

Science of The Total Environment
Volume 710, 25 March 2020, 136354

Antimony and arsenic speciation, redox-cycling and contrasting mobility in a mining-impacted river system

Scott G. Johnston [a], William W. Bennett [b], Nicholas Doriean [b], Kerstin Hockmann [c], Niloofar Karimian [a], Edward D. Burton [a]

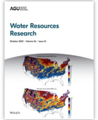


Effects of temperature on As and Sb mobility

Water Resources Research
Research Article | Free Access

Seasonal Temperature Oscillations Drive Contrasting Arsenic and Antimony Mobilization in a Mining-Impacted River System

Scott G. Johnston, Niloofar Karimian, Edward D. Burton



Bushfire impacts on water quality

Water Research
Volume 218, 30 June 2022, 118510

Drought, megafires and flood - climate extreme impacts on catchment-scale river water quality on Australia's east coast

Scott G. Johnston, Damien T. Maher

GIS mapping and controls on As and Sb distribution at Clybucca wetland

Journal of Hazardous Materials
Volume 476, 5 September 2024, 135013

Floodplain morphology influences arsenic and antimony spatial distribution in a seasonal acid sulfate soil wetland

Gretchen Wichman [a], Scott G. Johnston [a,b], Edward D. Burton [a,b], Damien T. Maher [a,b]