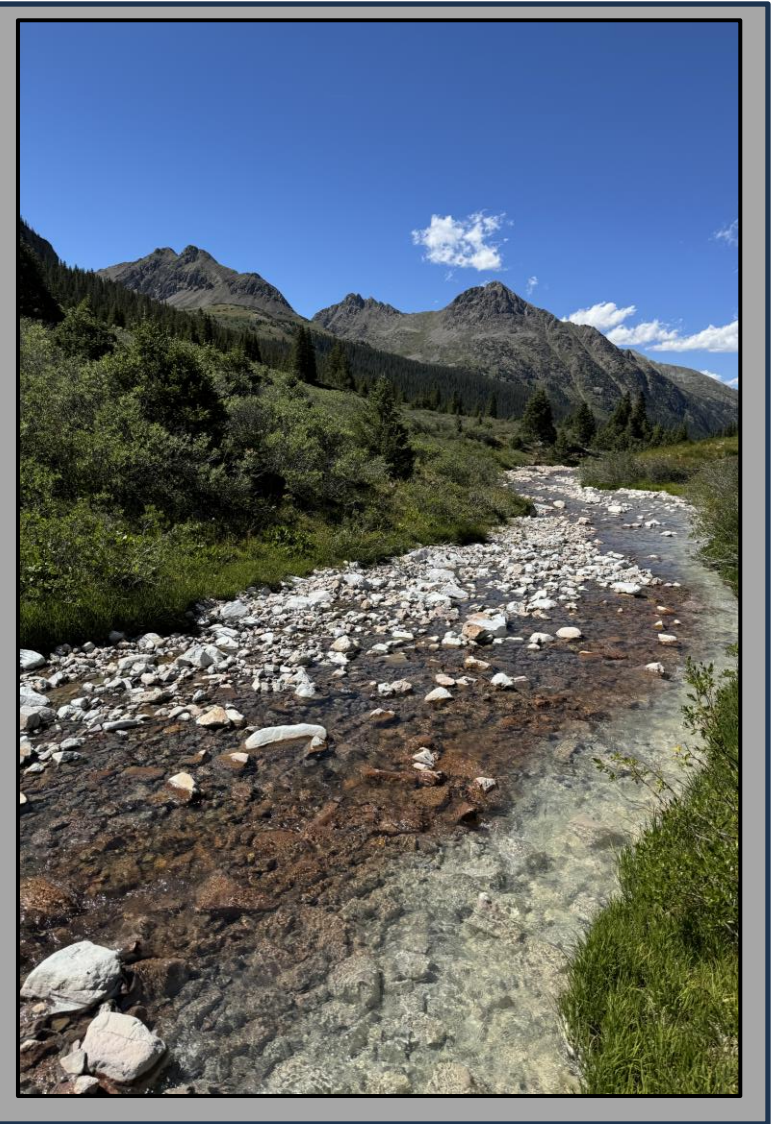


# Study of Metals and Rare- Earth Elements in Lincoln Creek



# Meet the CU-INSTAAR Team



Adam Odoriso  
Graduate Student



Athena Bolin  
Graduate Student



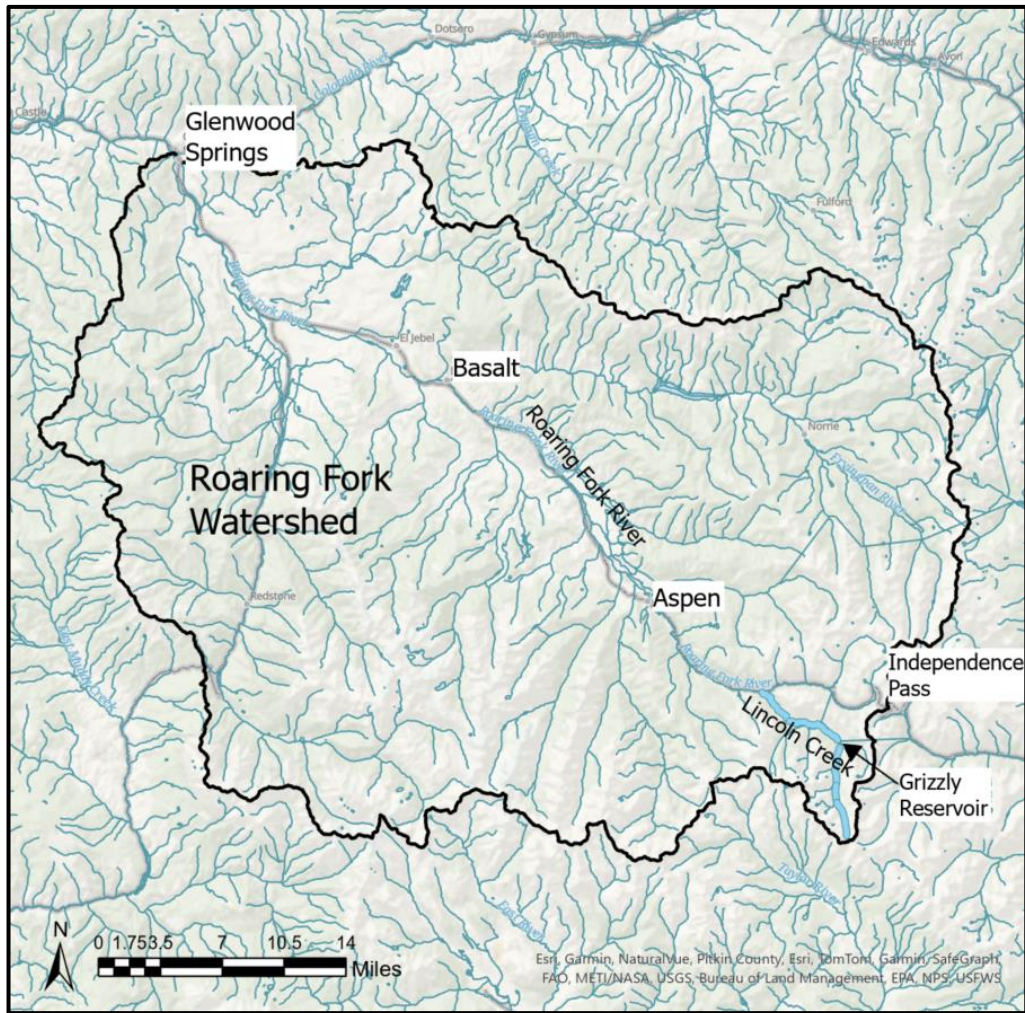
Diane M. McKnight, PhD  
Distinguished Professor



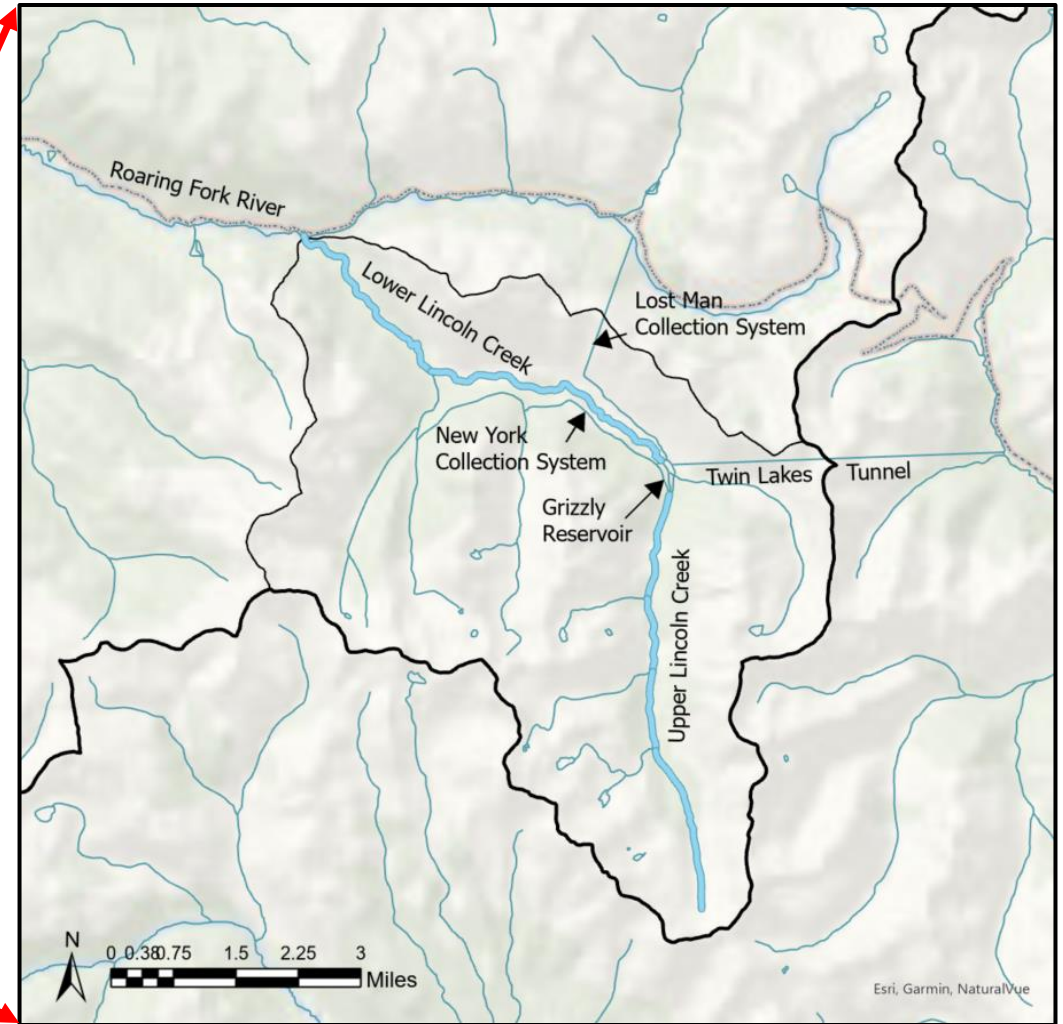
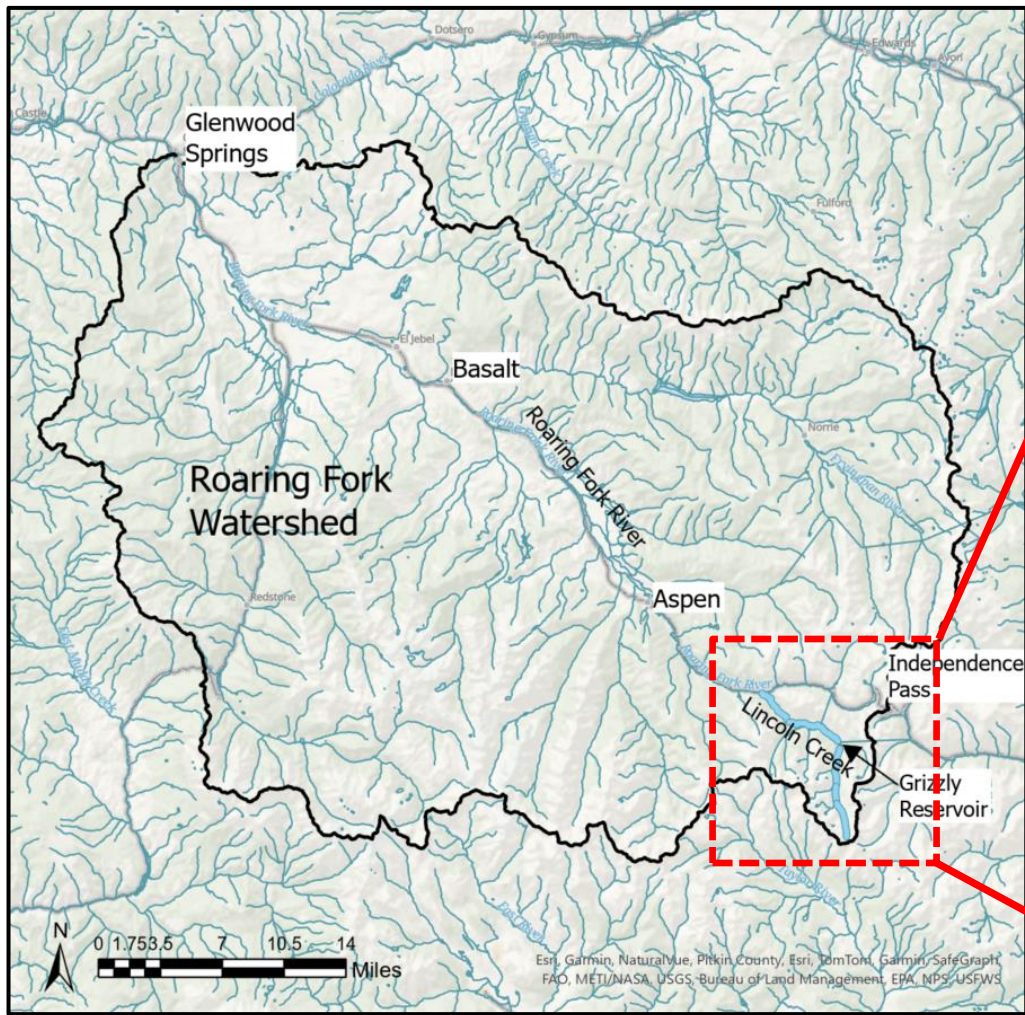
Tom Marchitto, PhD  
Professor



# Let's set the Stage. Where is Lincoln Creek?



# Let's set the Stage. Where is Lincoln Creek?



# Why is Lincoln Creek being Studied?

- Fish Kill Observed in Grizzly Reservoir August 2021
- Sampling revealed high amounts of **copper** originating near the Ruby Mine
- These findings prompted Colorado Parks and Wildlife to contact the EPA



# Why is Lincoln Creek being Studied?

- The **EPA** organized and funded two sampling efforts in July and September of 2022
- A Combined Assessment Report (CAR) was produced in November of 2023



# Primary Findings of the EPA's CAR

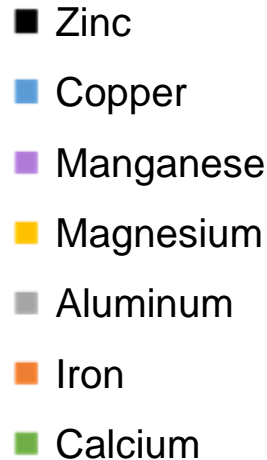
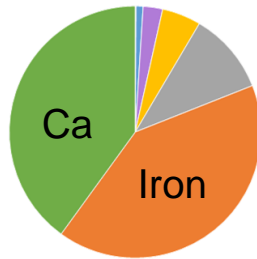
- Two primary sources of metal loading exist:
  - **Ruby Mine** Adits and Legacy Mining Activity (~ 2% of the copper)
  - The **Mineralized Tributary**, downstream of Ruby Mine (~98% of the copper)



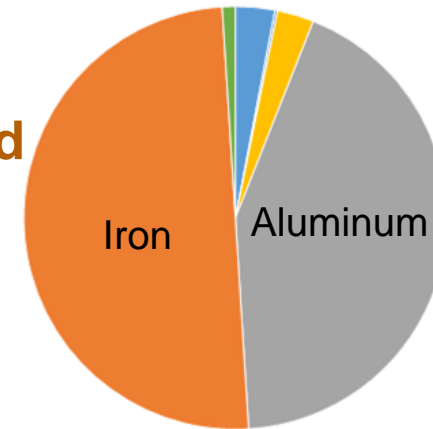
# Primary Findings of the EPA's CAR

- Two primary sources of metal loading exist:
  - **Ruby Mine** Adits and Legacy Mining Activity (~ 2% of the copper)
  - The **Mineralized Tributary**, downstream of Ruby Mine (~98% of the copper)
- Unique chemical signatures:

**Ruby Mine  
Source Area:**



**Mineralized  
Tributary:**

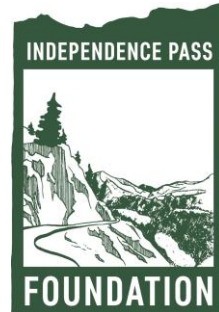


Because the majority of contamination is natural, EPA **does not have the authority to conduct clean-up actions**





# This issue is now in the hands of the Lincoln Creek Workgroup



**COLORADO**  
Water Quality Control Division  
Department of Public Health & Environment



**Twin Lakes  
Reservoir &  
Canal Company**



University of Colorado  
Boulder

# How did CU-INSTAAR get involved?

**March 2024** - Our group became aware of a need for additional research efforts

**May 2024** - Funding of our efforts was provided by **Pitkin County Healthy Rivers**

**June 2024** - First CU sampling trip alongside Pitkin County EH, RFC, and USFS



# What are we studying and why?

- Many entities in the Lincoln Creek Workgroup are studying the metals within Lincoln Creek. Each has their own distinct interests and responsibilities
- CU Team is focused on studying **Rare Earth Elements**, **Major Cations**, and **Trace Metals**



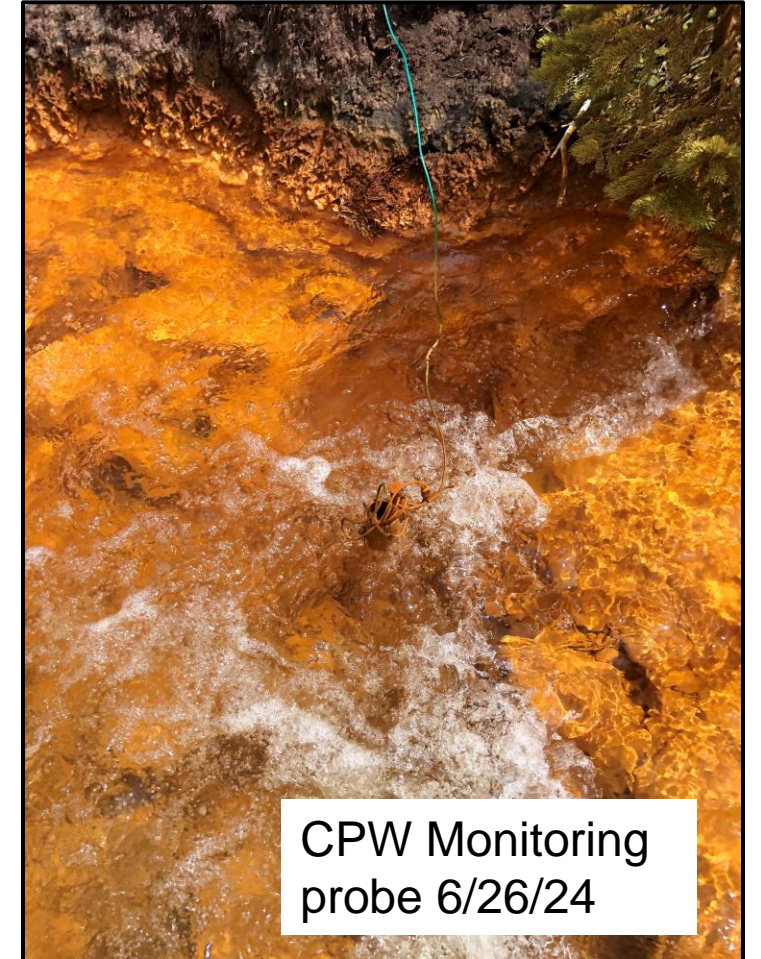
# Major Cations and Trace Metals

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
											Pnictogens		Chalcogens		Halogens			
1	<b>1</b> <b>H</b> Hydrogen 1.008	Atomic Symbol Name Weight																
2	<b>3</b> <b>Li</b> Lithium 6.94	<b>4</b> <b>Be</b> Beryllium 9.0122																
3	<b>11</b> <b>Na</b> Sodium 22.990	<b>12</b> <b>Mg</b> Magnesium 24.305																
4	<b>19</b> <b>K</b> Potassium 39.098	<b>20</b> <b>Ca</b> Calcium 40.078	<b>21</b> <b>Sc</b> Scandium 44.956	<b>22</b> <b>Ti</b> Titanium 47.867	<b>23</b> <b>V</b> Vanadium 50.942	<b>24</b> <b>Cr</b> Chromium 51.996	<b>25</b> <b>Mn</b> Manganese 54.938	<b>26</b> <b>Fe</b> Iron 55.845	<b>27</b> <b>Co</b> Cobalt 58.933	<b>28</b> <b>Ni</b> Nickel 58.693	<b>29</b> <b>Cu</b> Copper 63.546	<b>30</b> <b>Zn</b> Zinc 65.38	<b>31</b> <b>Ga</b> Gallium 69.723	<b>32</b> <b>Ge</b> Germanium 72.630	<b>33</b> <b>As</b> Arsenic 74.922	<b>34</b> <b>Se</b> Selenium 78.971	<b>35</b> <b>Br</b> Bromine 79.904	<b>36</b> <b>Kr</b> Krypton 83.798
5	<b>37</b> <b>Rb</b> Rubidium 85.468	<b>38</b> <b>Sr</b> Strontium 87.62	<b>39</b> <b>Y</b> Yttrium 88.906	<b>40</b> <b>Zr</b> Zirconium 91.224	<b>41</b> <b>Nb</b> Niobium 92.906	<b>42</b> <b>Mo</b> Molybdenum 95.95	<b>43</b> <b>Tc</b> Technetium (98)	<b>44</b> <b>Ru</b> Ruthenium 101.07	<b>45</b> <b>Rh</b> Rhodium 102.91	<b>46</b> <b>Pd</b> Palladium 106.42	<b>47</b> <b>Ag</b> Silver 107.87	<b>48</b> <b>Cd</b> Cadmium 112.41	<b>49</b> <b>In</b> Indium 114.82	<b>50</b> <b>Sn</b> Tin 118.71	<b>51</b> <b>Sb</b> Antimony 121.76	<b>52</b> <b>Te</b> Tellurium 127.60	<b>53</b> <b>I</b> Iodine 126.90	<b>54</b> <b>Xe</b> Xenon 131.29
6	<b>55</b> <b>Cs</b> Caesium 132.91	<b>56</b> <b>Ba</b> Barium 137.33	57-71 89-103	<b>72</b> <b>Hf</b> Hafnium 178.49	<b>73</b> <b>Ta</b> Tantalum 180.95	<b>74</b> <b>W</b> Tungsten 183.84	<b>75</b> <b>Re</b> Rhenium 186.21	<b>76</b> <b>Os</b> Osmium 190.23	<b>77</b> <b>Ir</b> Iridium 192.22	<b>78</b> <b>Pt</b> Platinum 195.08	<b>79</b> <b>Au</b> Gold 196.97	<b>80</b> <b>Hg</b> Mercury 200.59	<b>81</b> <b>Tl</b> Thallium 204.38	<b>82</b> <b>Pb</b> Lead 207.2	<b>83</b> <b>Bi</b> Bismuth 208.98	<b>84</b> <b>Po</b> Polonium (209)	<b>85</b> <b>At</b> Astatine (210)	<b>86</b> <b>Rn</b> Radon (222)
7	<b>87</b> <b>Fr</b> Francium (223)	<b>88</b> <b>Ra</b> Radium (226)		<b>104</b> <b>Rf</b> Rutherfordium (267)	<b>105</b> <b>Db</b> Dubnium (268)	<b>106</b> <b>Sg</b> Seaborgium (269)	<b>107</b> <b>Bh</b> Bohrium (270)	<b>108</b> <b>Hs</b> Hassium (277)	<b>109</b> <b>Mt</b> Meitnerium (278)	<b>110</b> <b>Ds</b> Darmstadtium (281)	<b>111</b> <b>Rg</b> Roentgenium (282)	<b>112</b> <b>Cn</b> Copernicium (285)	<b>113</b> <b>Nh</b> Nihonium (286)	<b>114</b> <b>Fl</b> Flerovium (289)	<b>115</b> <b>Mc</b> Moscovium (290)	<b>116</b> <b>Lv</b> Livermorium (293)	<b>117</b> <b>Ts</b> Tennessine (294)	<b>118</b> <b>Og</b> Oganesson (294)
	For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																	
	<b>57</b> <b>La</b> Lanthanum 138.91	<b>58</b> <b>Ce</b> Cerium 140.12	<b>59</b> <b>Pr</b> Praseodymium 140.91	<b>60</b> <b>Nd</b> Neodymium 144.24	<b>61</b> <b>Pm</b> Promethium (145)	<b>62</b> <b>Sm</b> Samarium 150.36	<b>63</b> <b>Eu</b> Europium 151.96	<b>64</b> <b>Gd</b> Gadolinium 157.25	<b>65</b> <b>Tb</b> Terbium 158.93	<b>66</b> <b>Dy</b> Dysprosium 162.50	<b>67</b> <b>Ho</b> Holmium 164.93	<b>68</b> <b>Er</b> Erbium 167.26	<b>69</b> <b>Tm</b> Thulium 168.93	<b>70</b> <b>Yb</b> Ytterbium 173.05	<b>71</b> <b>Lu</b> Lutetium 174.97			
	<b>89</b> <b>Ac</b> Actinium (227)	<b>90</b> <b>Th</b> Thorium 232.04	<b>91</b> <b>Pa</b> Protactinium 231.04	<b>92</b> <b>U</b> Uranium 238.03	<b>93</b> <b>Np</b> Neptunium (237)	<b>94</b> <b>Pu</b> Plutonium (244)	<b>95</b> <b>Am</b> Americium (243)	<b>96</b> <b>Cm</b> Curium (247)	<b>97</b> <b>Bk</b> Berkelium (247)	<b>98</b> <b>Cf</b> Californium (251)	<b>99</b> <b>Es</b> Einsteinium (252)	<b>100</b> <b>Fm</b> Fermium (257)	<b>101</b> <b>Md</b> Mendelevium (258)	<b>102</b> <b>No</b> Nobelium (259)	<b>103</b> <b>Lr</b> Lawrencium (266)			



# Major Cations and Trace Metals

- Pyrite weathering inherently adds sulfuric acid to natural waters
- Acid leaches trace metals from rocks
- Negative effects on aquatic biota
  - Irritating fish gills could lead to suffocation
  - Precipitating metal oxides can smother aquatic plants and algae



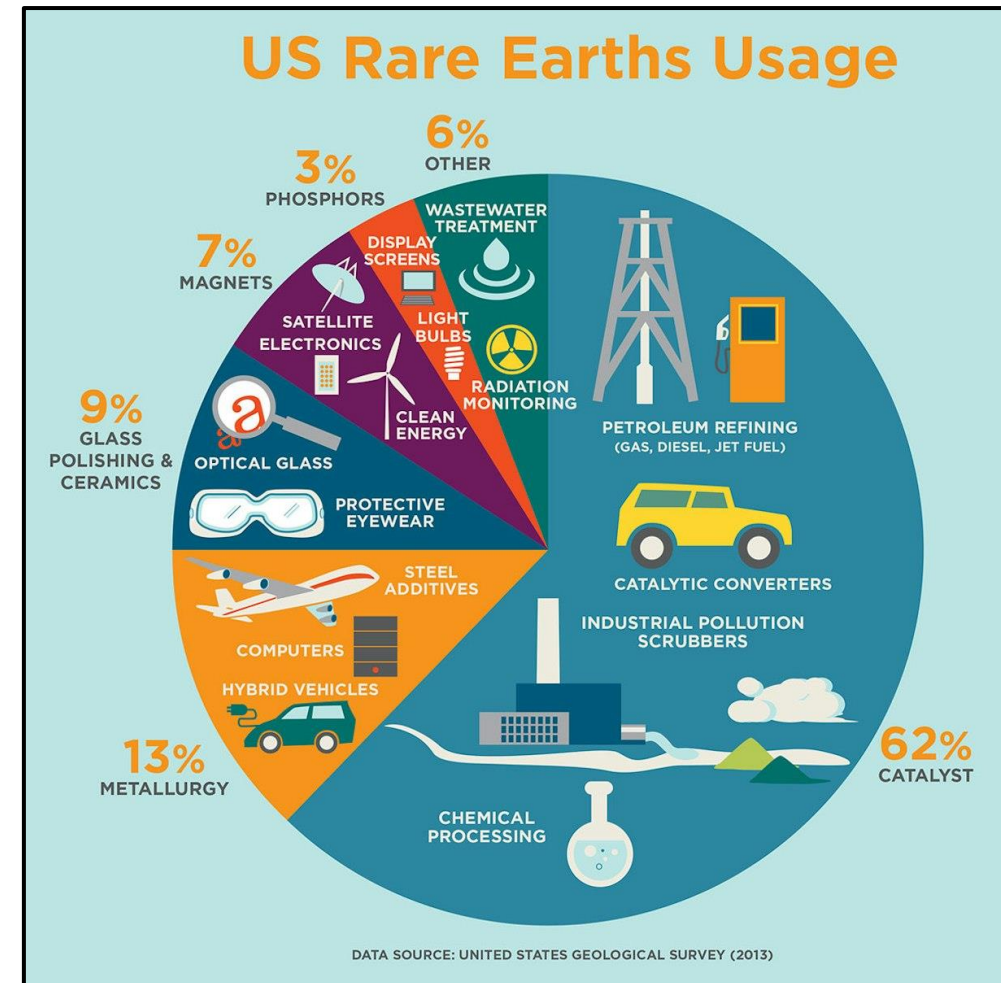
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metals	Lanthanoids						Transition metals	Post-transition metals			Reactive nonmetals	Noble gases	Actinoids						2	<b>He</b> Helium 4.0026	2	<b>Li</b> Lithium 6.94	<b>Be</b> Beryllium 9.0122																				10	<b>Ne</b> Neon 20.180	3	<b>Na</b> Sodium 22.990	<b>Mg</b> Magnesium 24.305																				18	<b>Ar</b> Argon 39.948	4	<b>K</b> Potassium 39.098	<b>Ca</b> Calcium 40.078	<b>Sc</b> Scandium 44.956	<b>Ti</b> Titanium 47.867	<b>V</b> Vanadium 50.942	<b>Cr</b> Chromium 51.996	<b>Mn</b> Manganese 54.938	<b>Fe</b> Iron 55.845	<b>Co</b> Cobalt 58.933	<b>Ni</b> Nickel 58.693	<b>Cu</b> Copper 63.546	<b>Zn</b> Zinc 65.38	<b>Ga</b> Gallium 69.723	<b>Ge</b> Germanium 72.630	<b>As</b> Arsenic 74.922	<b>Se</b> Selenium 78.971	<b>Br</b> Bromine 79.904	<b>Kr</b> Krypton 83.798	5	<b>Rb</b> Rubidium 85.468	<b>Sr</b> Strontium 87.62	<b>Y</b> Yttrium 88.906	<b>Zr</b> Zirconium 91.224	<b>Nb</b> Niobium 92.906	<b>Mo</b> Molybdenum 95.95	<b>Tc</b> Technetium (98)	<b>Ru</b> Ruthenium 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<div style="display: flex; justify-content: space-between;"> <div style="width: 20%;"> <p><b>C</b> Solid</p> <p><b>Hg</b> Liquid</p> <p><b>H</b> Gas</p> <p><b>Rf</b> Unknown</p> </div> <div style="width: 60%;"> <table border="1"> <tr> <th colspan="10">Metals</th> <th colspan="2">Metalloids</th> <th colspan="2">Nonmetals</th> </tr> <tr> <td rowspan="2">Alkali metals</td> <td rowspan="2">Alkaline earth metals</td> <td colspan="6">Lanthanoids</td> <td rowspan="2">Transition metals</td> <td rowspan="2">Post-transition metals</td> <td rowspan="2"></td> <td rowspan="2"></td> <td rowspan="2">Reactive nonmetals</td> <td rowspan="2">Noble gases</td> </tr> <tr> <td colspan="6">Actinoids</td> </tr> </table> </div> <div style="width: 15%;"> <p>Atomic Symbol</p> <p>Name</p> <p>Weight</p> </div> </div>																			Metals										Metalloids		Nonmetals		Alkali metals	Alkaline earth metals	Lanthanoids						Transition metals	Post-transition metals			Reactive nonmetals	Noble gases	Actinoids						2			<b>He</b> Helium 4.0026																																																																																																																																																																																																												
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# Rare Earth Elements

- Valuable to humans due to their unique electrical properties
- Used heavily in computer manufacturing

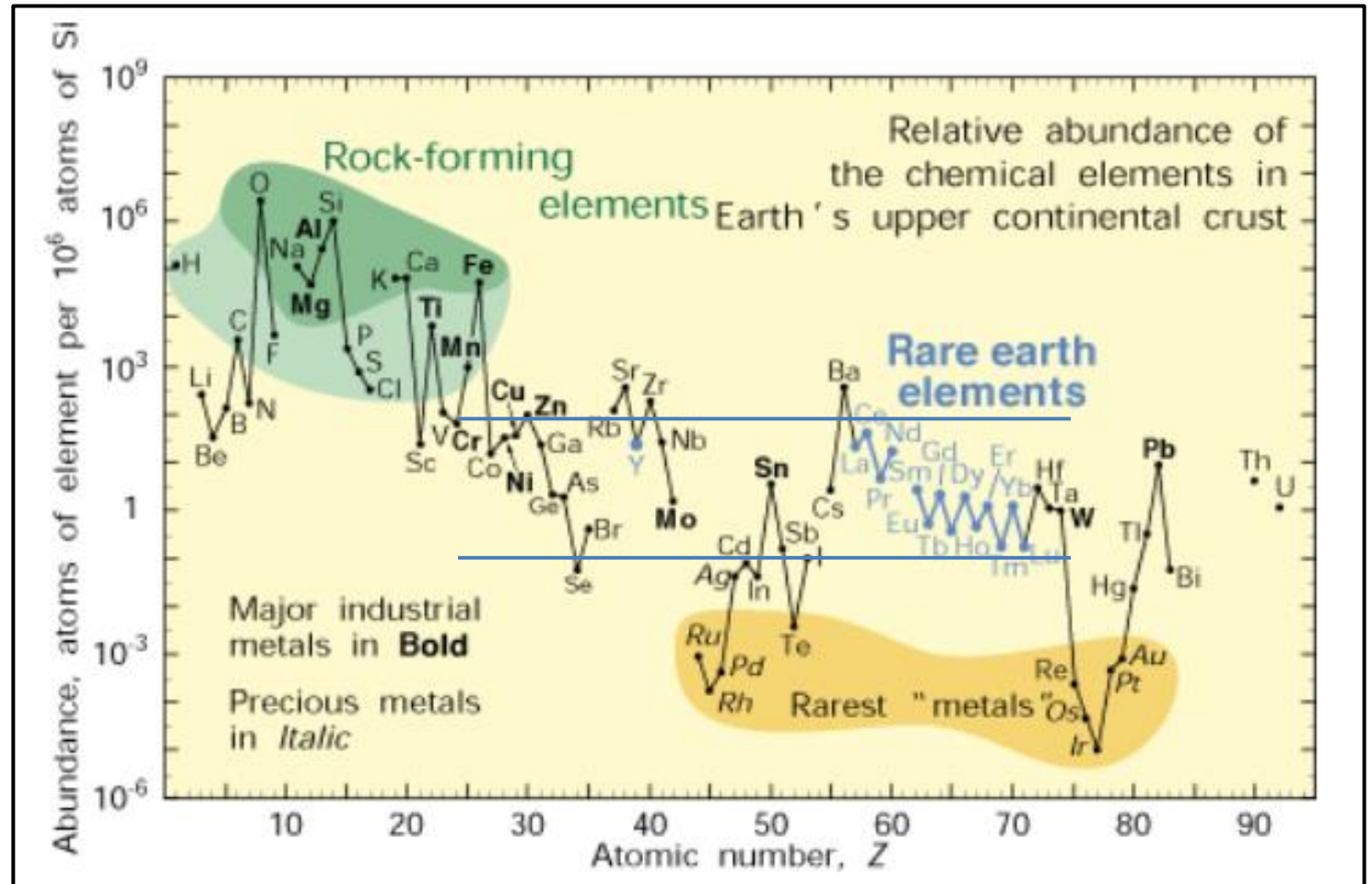


<https://massivesci.com/articles/rare-earth-elements-metals-not-really-that-rare/>



# Rare Earth Elements

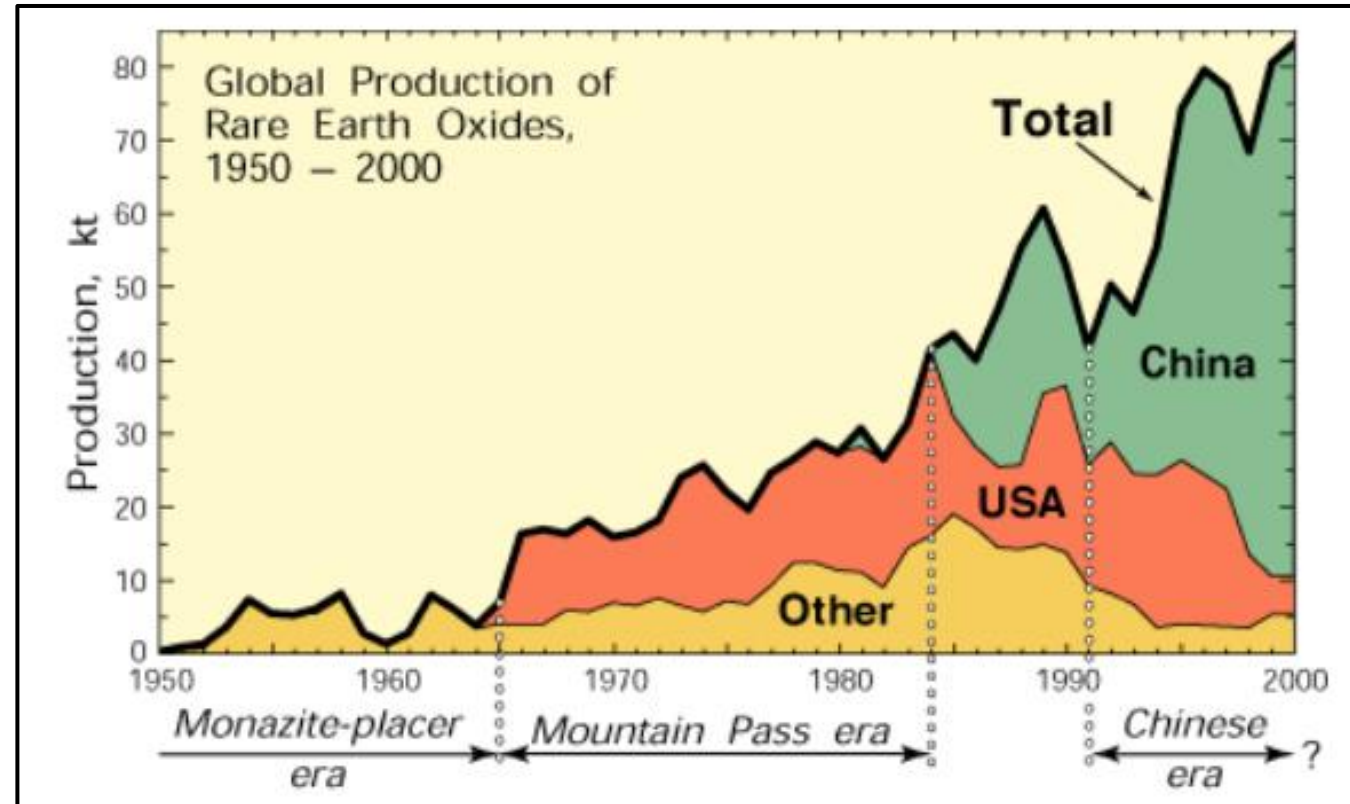
- “Rare” Earth Elements is a bit of a misnomer
- Relatively high crustal abundance
- Difficult to mine and many waste products created





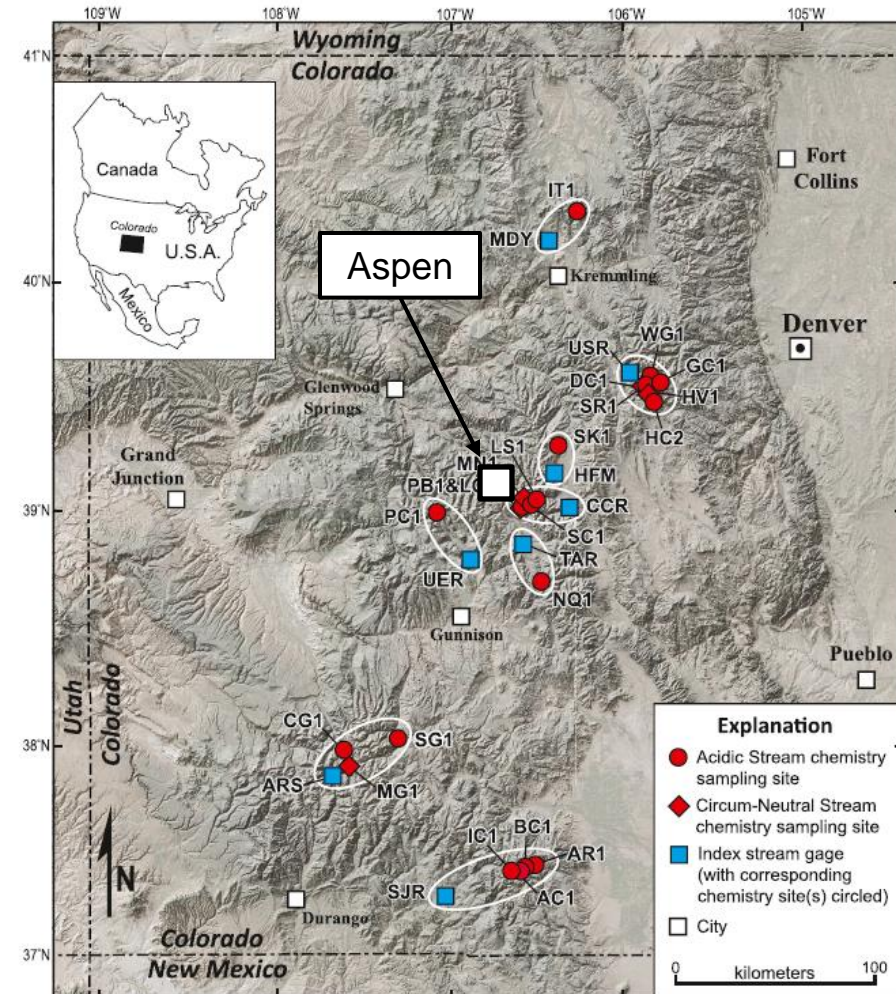
# Rare Earth Elements

- The U.S. is becoming increasingly dependent on REEs
- China is currently the largest supplier of REEs
- With shifting geopolitical landscapes, there is an interest in finding novel domestic sources of Rare Earth Elements



# Rare Earth Elements

- Acid Mine Drainage tributaries in the Colorado Mineral Belt are known to input REEs into aquatic systems
  - **A novel source?**
- Scientists across the U.S. are researching extraction methods to collect REEs from water
- **To extract aquatic REEs we must also identify where they can be found**
- No water quality standards for REEs for public health or aquatic life



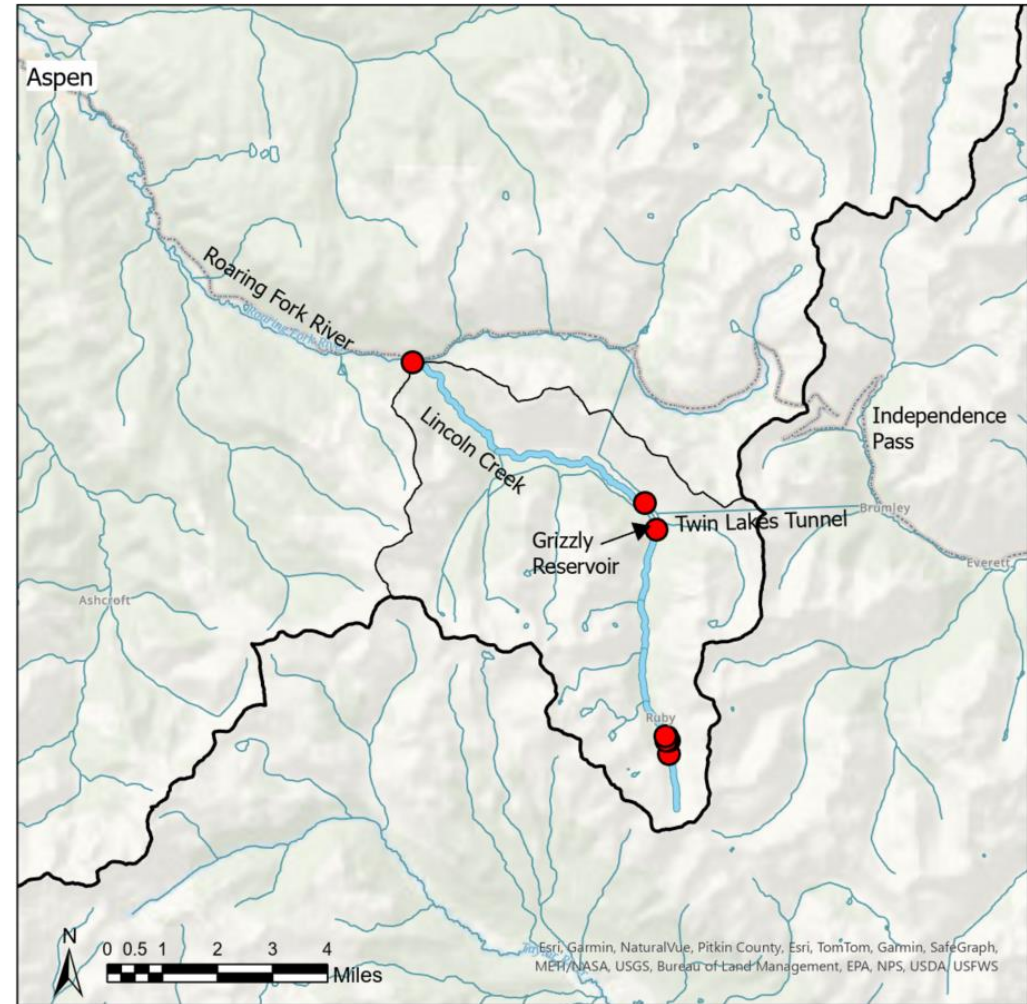
# CU's research goals

1. How **abundant** are REEs in Lincoln Creek?
  - Fluctuate seasonally?
2. What is the **fate** of REE's in Lincoln Creek?
  - Assimilated by the aquatic biota?
  - Adsorbing to sediment?
  - Precipitating out of the aquatic system as a solid?
3. How do REEs **interact** with Major Cations and Trace Metals?



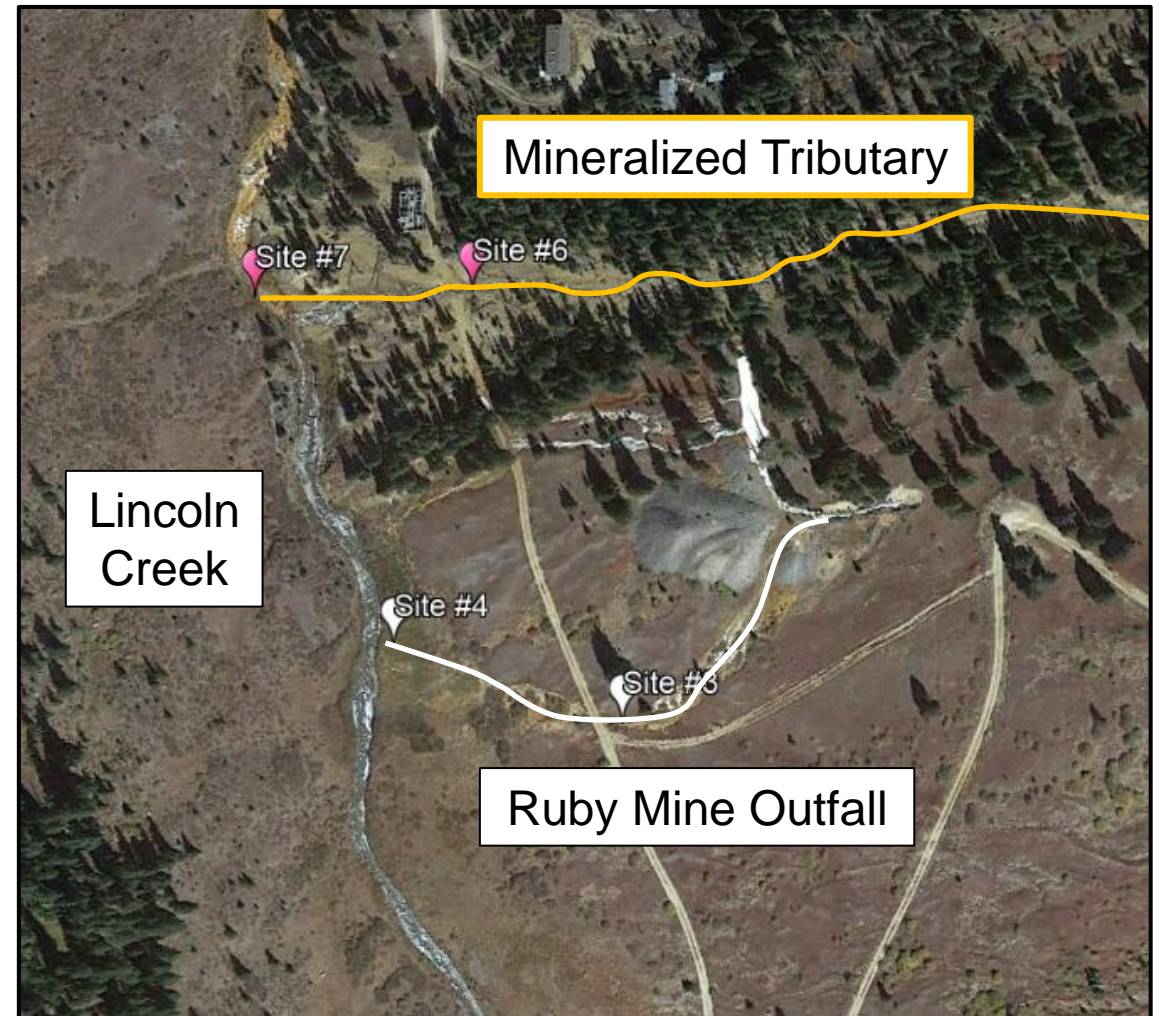
# How will we answer these questions?

- Collect samples for one season
  - Water
  - Precipitated flocculent scrapings
  - Benthic Macroinvertebrate (BMI) Collection
  - Sediment core samples
- Analyze samples
  - Ion Coupled Plasma Mass Spectrometry - concentration
  - Microwave Digest BMIs - biota assimilation
  - sediment core - adsorption

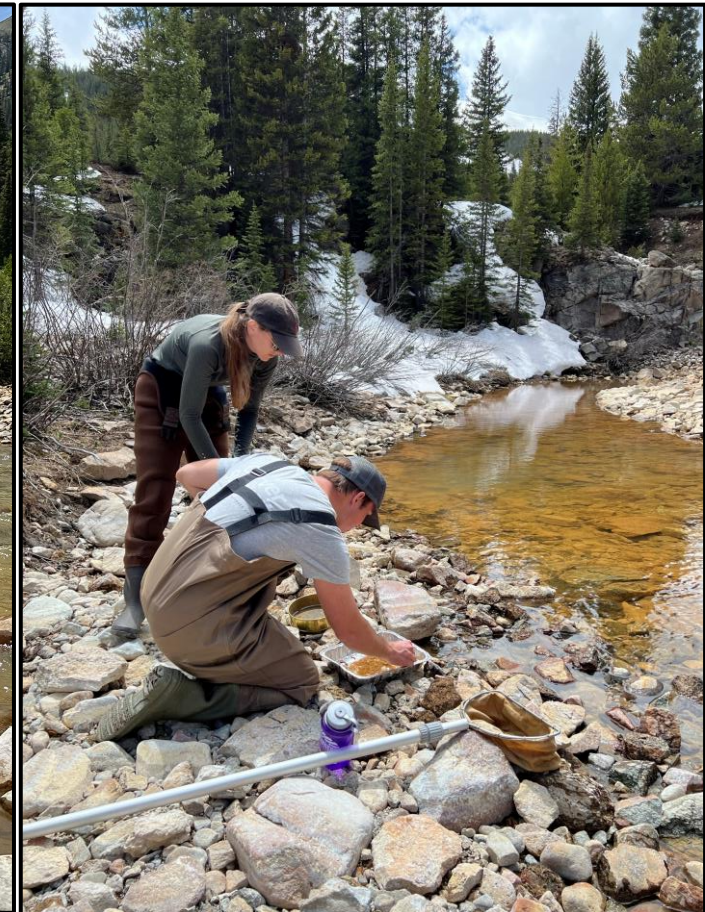


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  - Ion Coupled Plasma Mass Spectrometry - concentration
  - Microwave Digest BMIs - biota assimilation
  - sediment core - adsorption



# Sample collection was completed June – October 2024

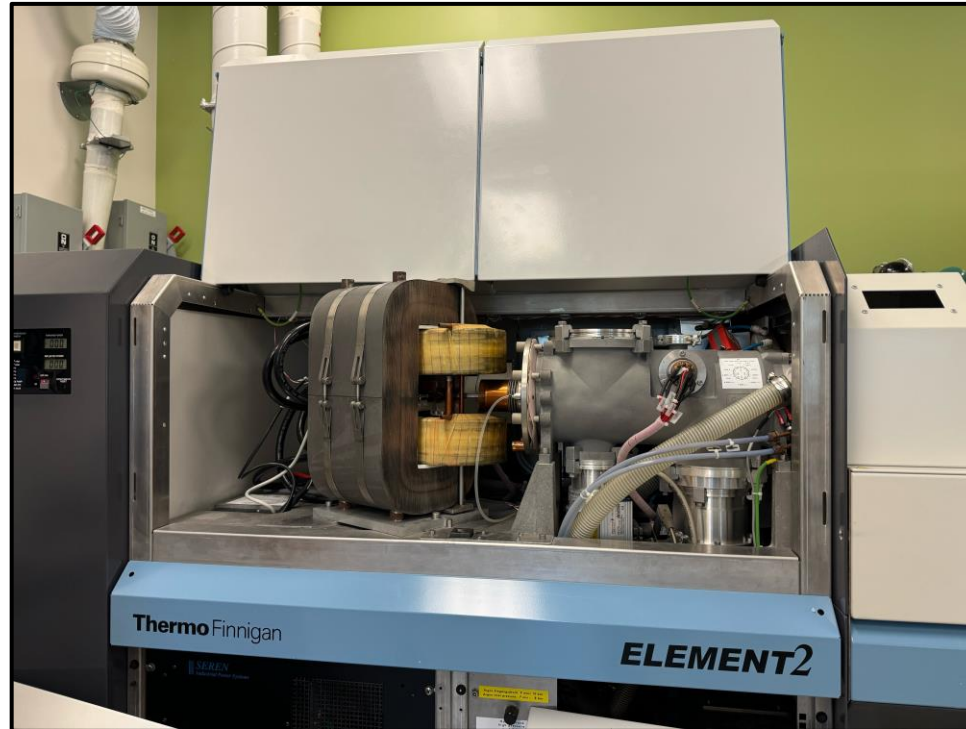




University of Colorado  
Boulder

# We are now in the analysis phase

- Most water samples have been run through ICP-MS
- Now analyzing flocculent scrapings
- Sediment cores up next



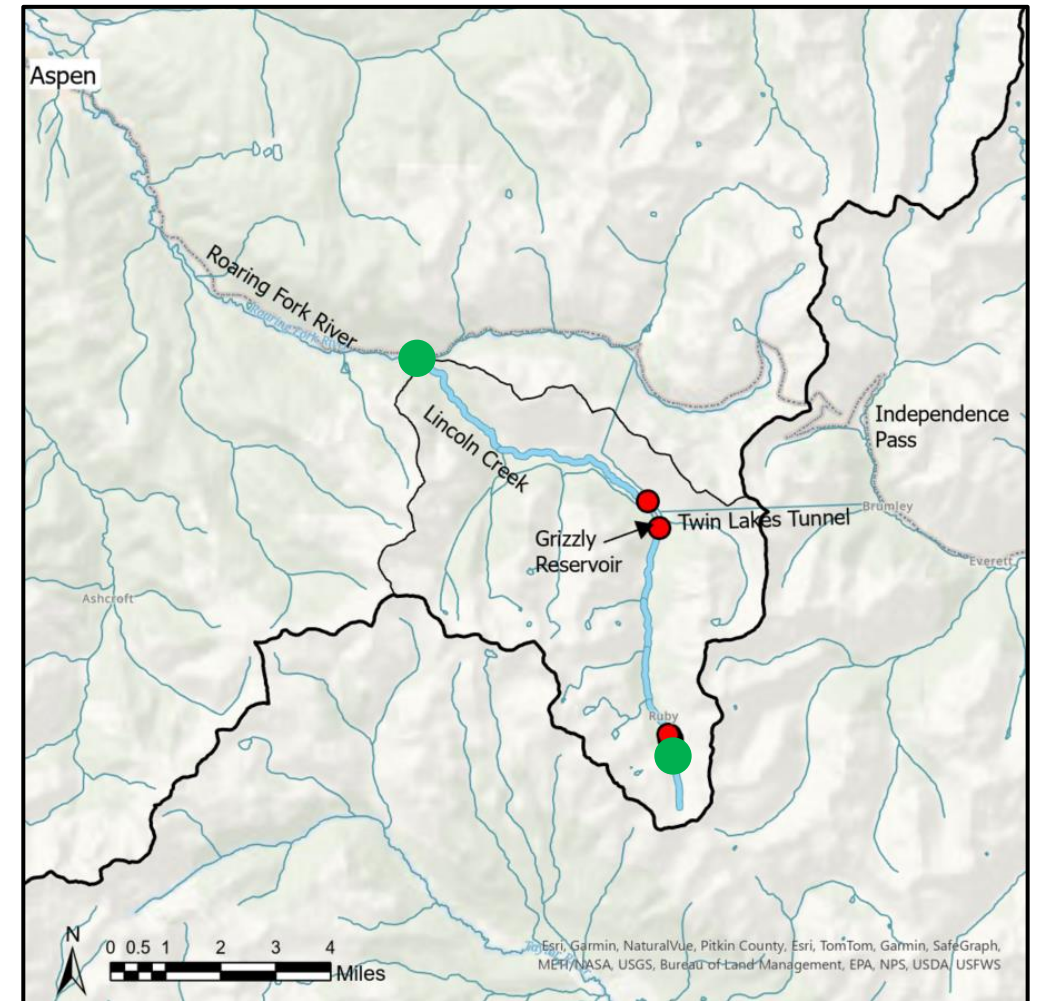


# Preliminary findings – Benthic Macroinvertebrates

- Unfortunately, none found in upper Lincoln Creek between tributaries and inlet to Grizzly Reservoir
  - **Why?**
- Observation of families present indicate healthy spread of BMIs above mine sources and at confluence with the Roaring Fork River



Perlodidae (stripe tail stonefly)

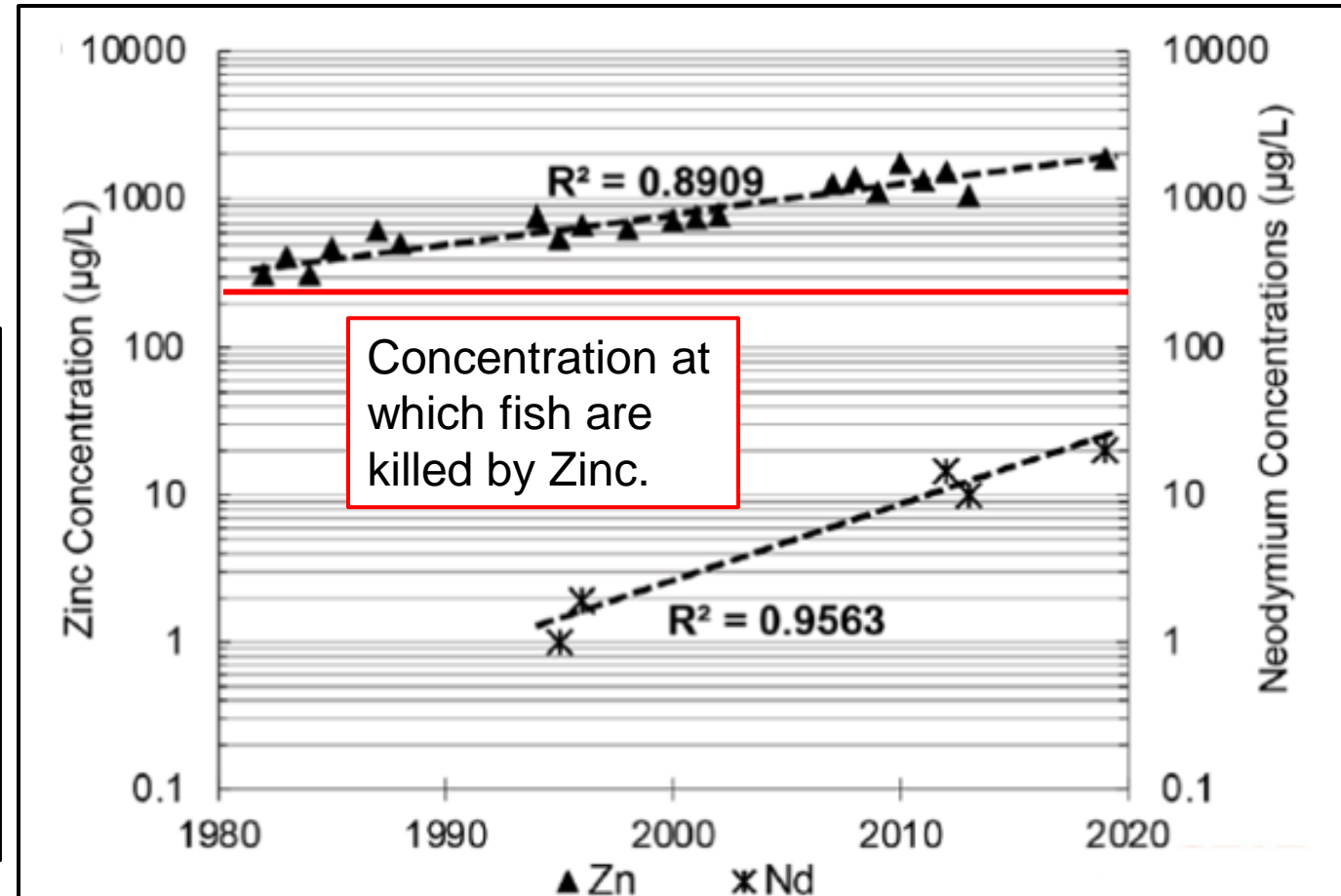


# Preliminary findings – Benthic Macroinvertebrates

- Snake River (near Dillion, CO)
  - High REE Concentrations
  - Lower trace metal concentrations
  - **Plenty of BMIs**
  - No fish



*Zapada Haysi* stonefly nymph

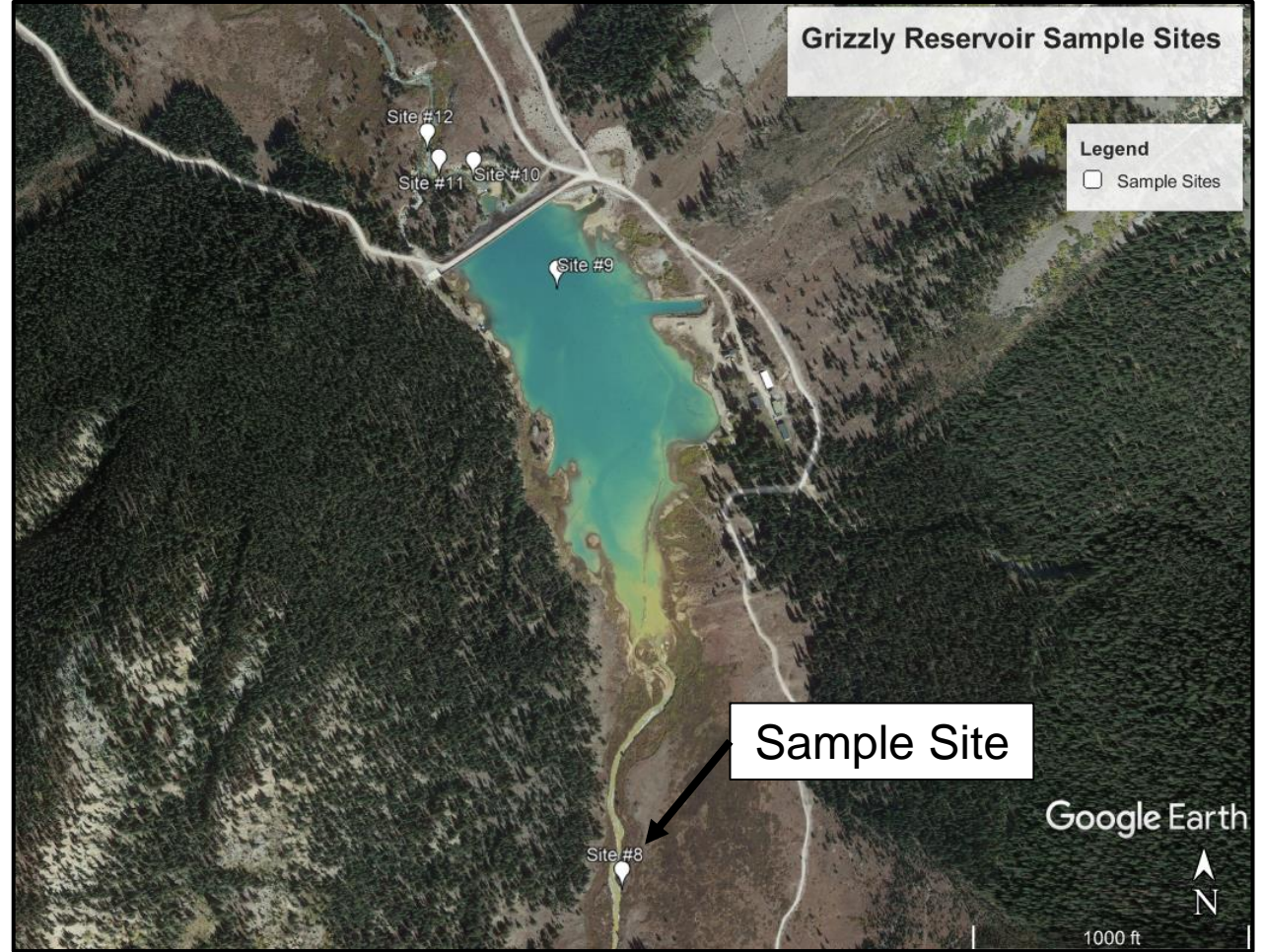


# Preliminary findings – Benthic Macroinvertebrates

- Something else must be harming the aquatic biota in Lincoln Creek
- We will analyze BMI collections from above the mine and below the reservoir for REE assimilation

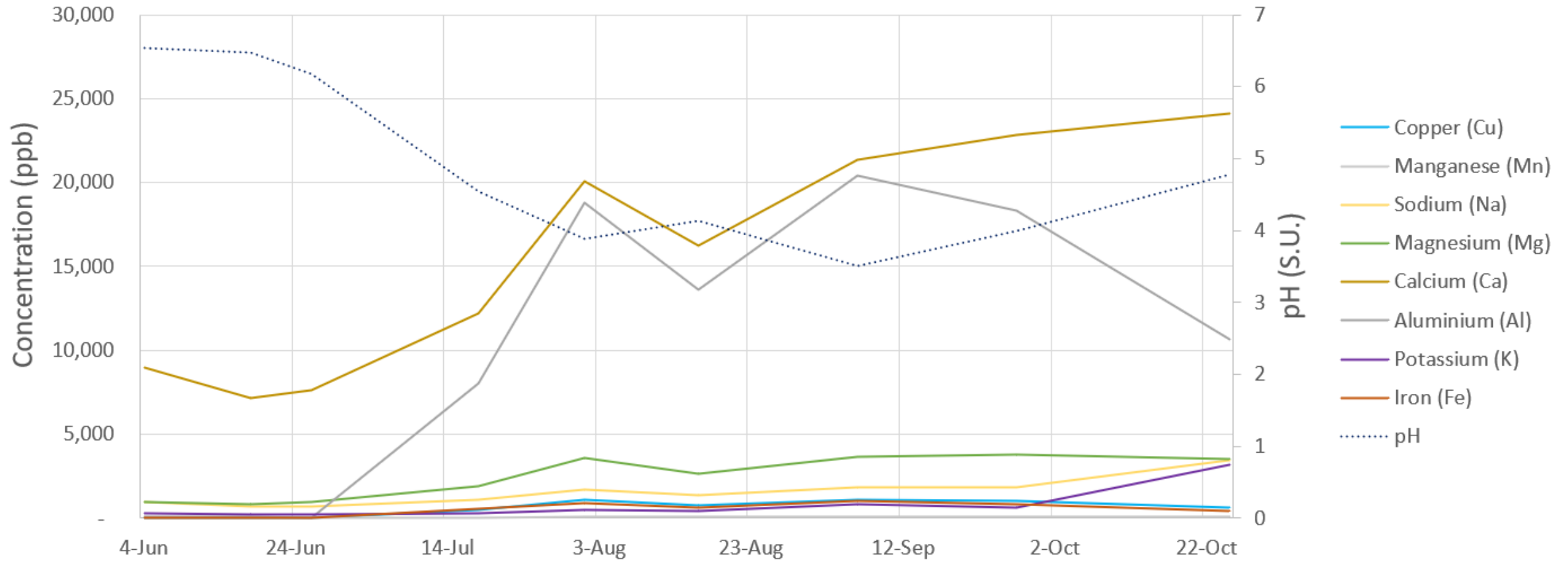


# Preliminary Findings – Grizzly Reservoir Inlet



# Preliminary Findings – Grizzly Reservoir Inlet

Major Cations, Trace Metals, and pH at Grizzly Reservoir Inlet



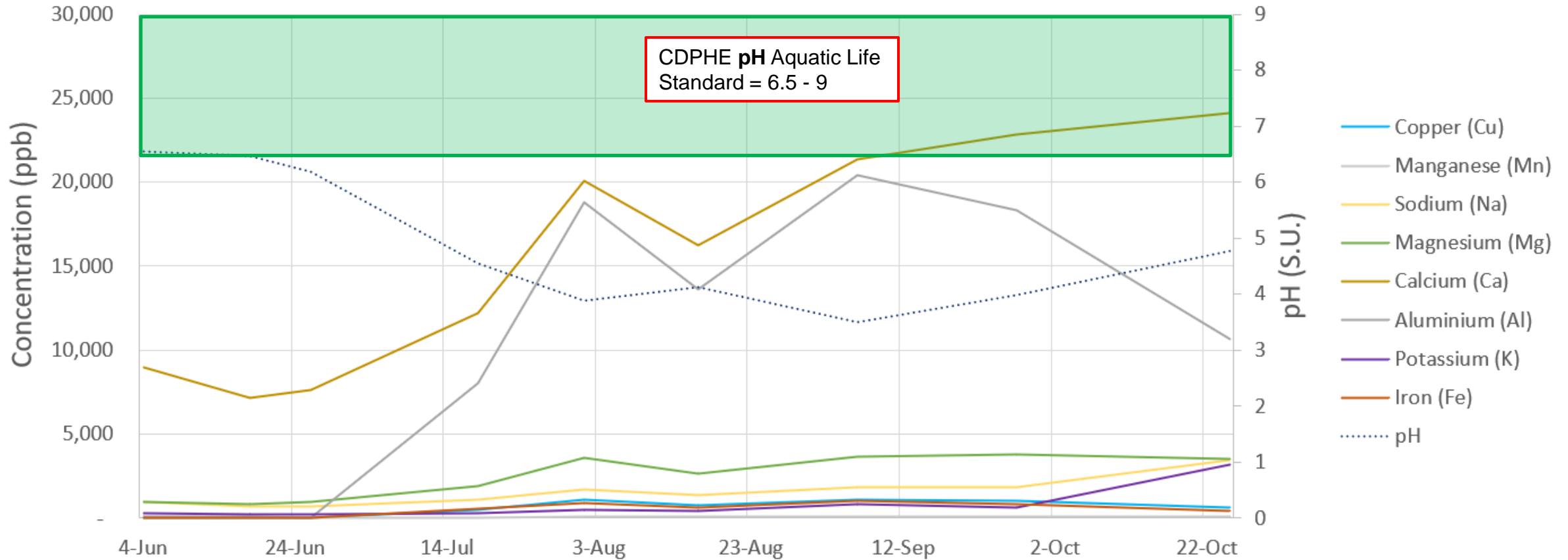
# What does “ppb” mean?

- Parts Per Billion
  - 1 ppb = 1 part element per 1 billion parts of water
- Think of this as one ounce of gold dissolved in one Olympic sized swimming pool
  - 1 pool = 2.5 million liters
  - 1 ounce of gold is approximately the mass of one large wedding ring



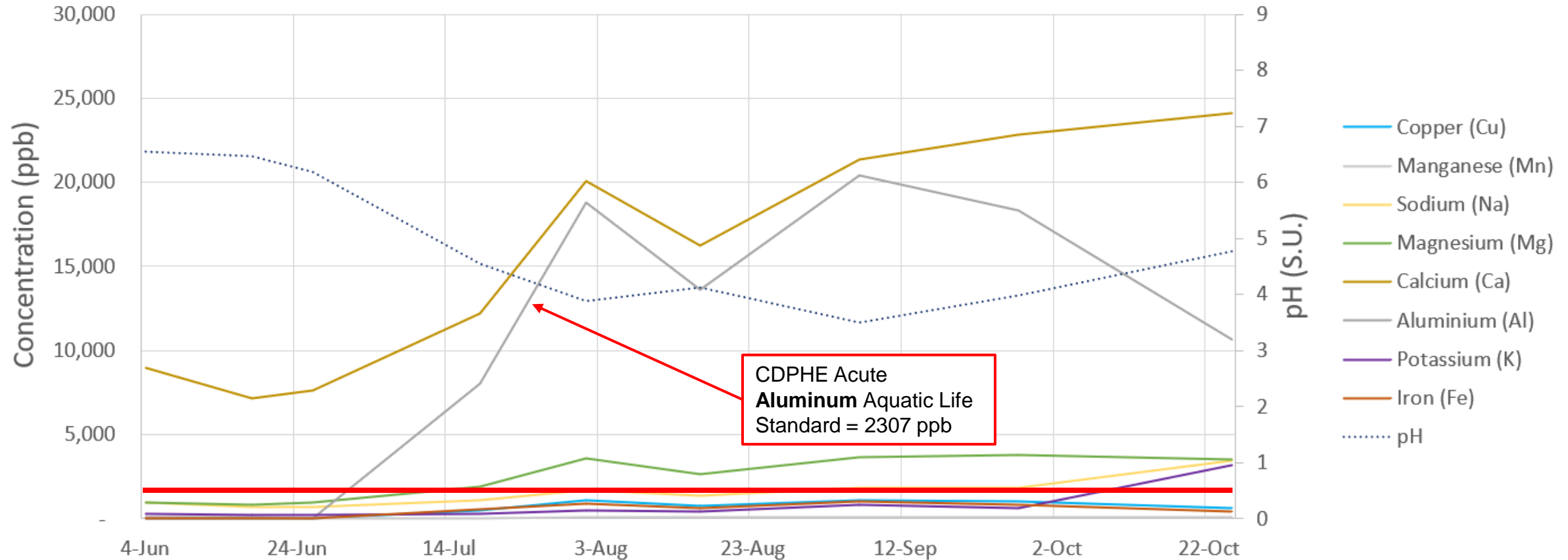
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Major Cations, Trace Metals, and pH at Grizzly Reservoir Inlet



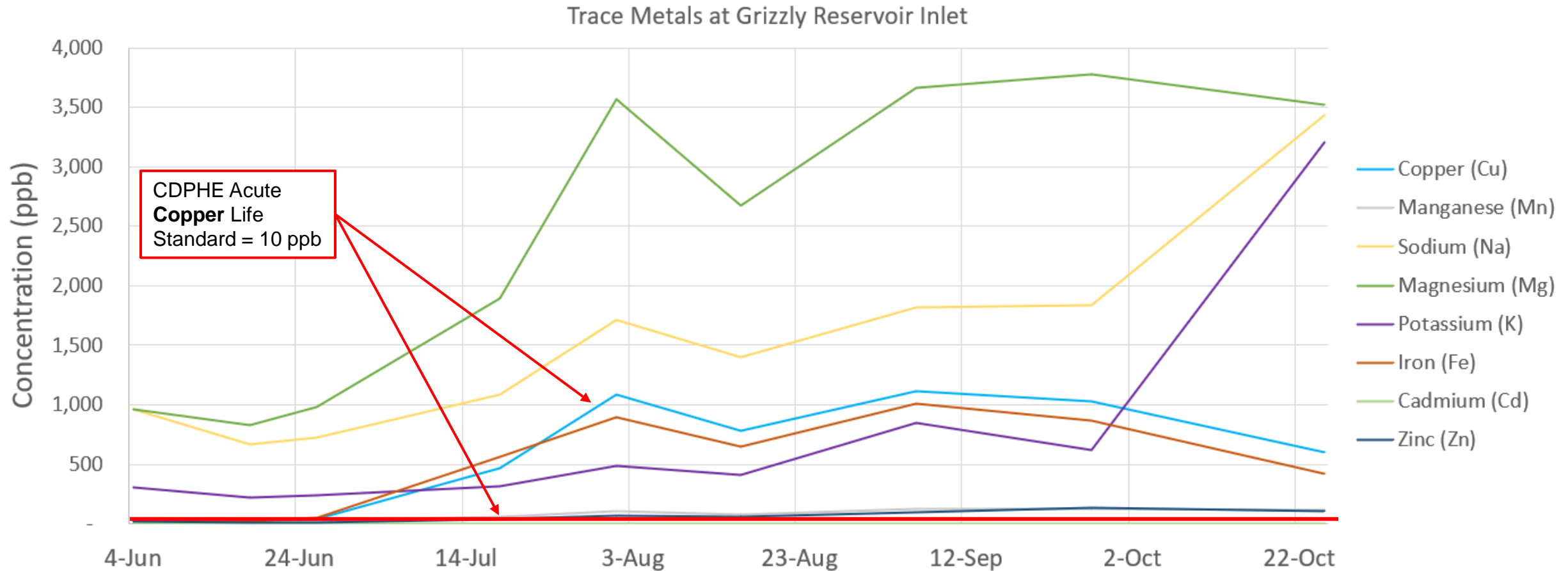
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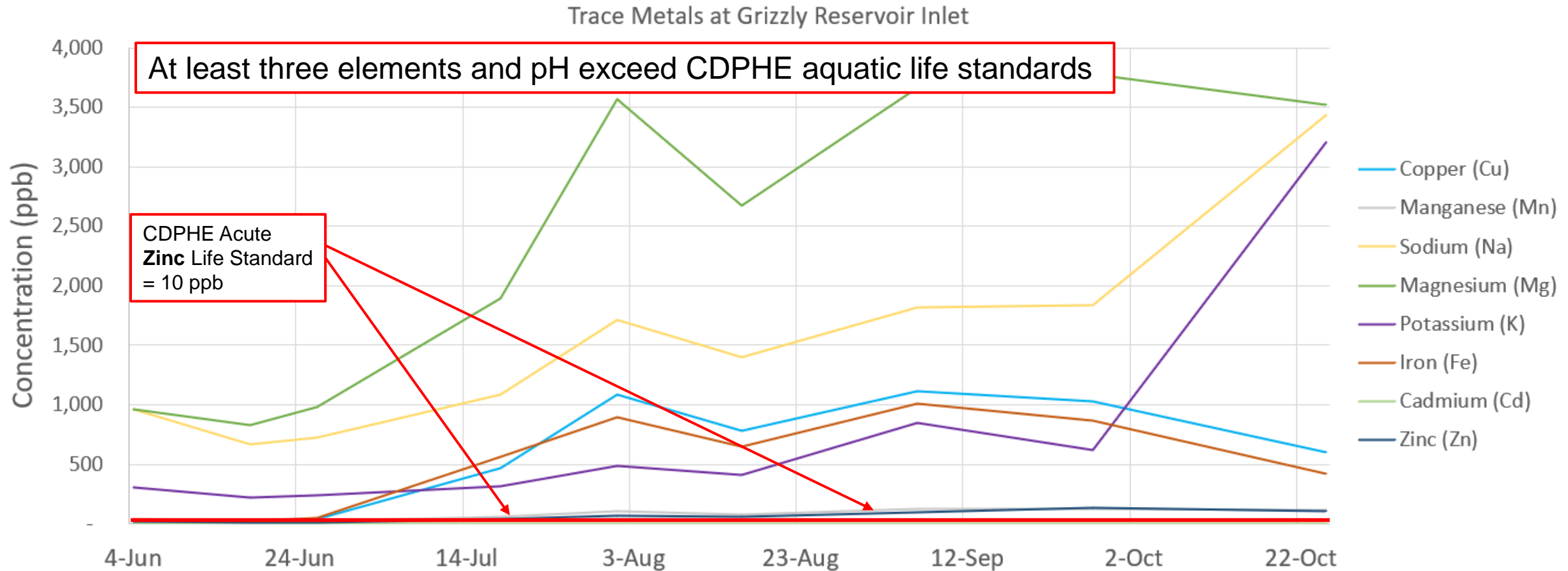




# Preliminary Findings – Grizzly Reservoir Inlet

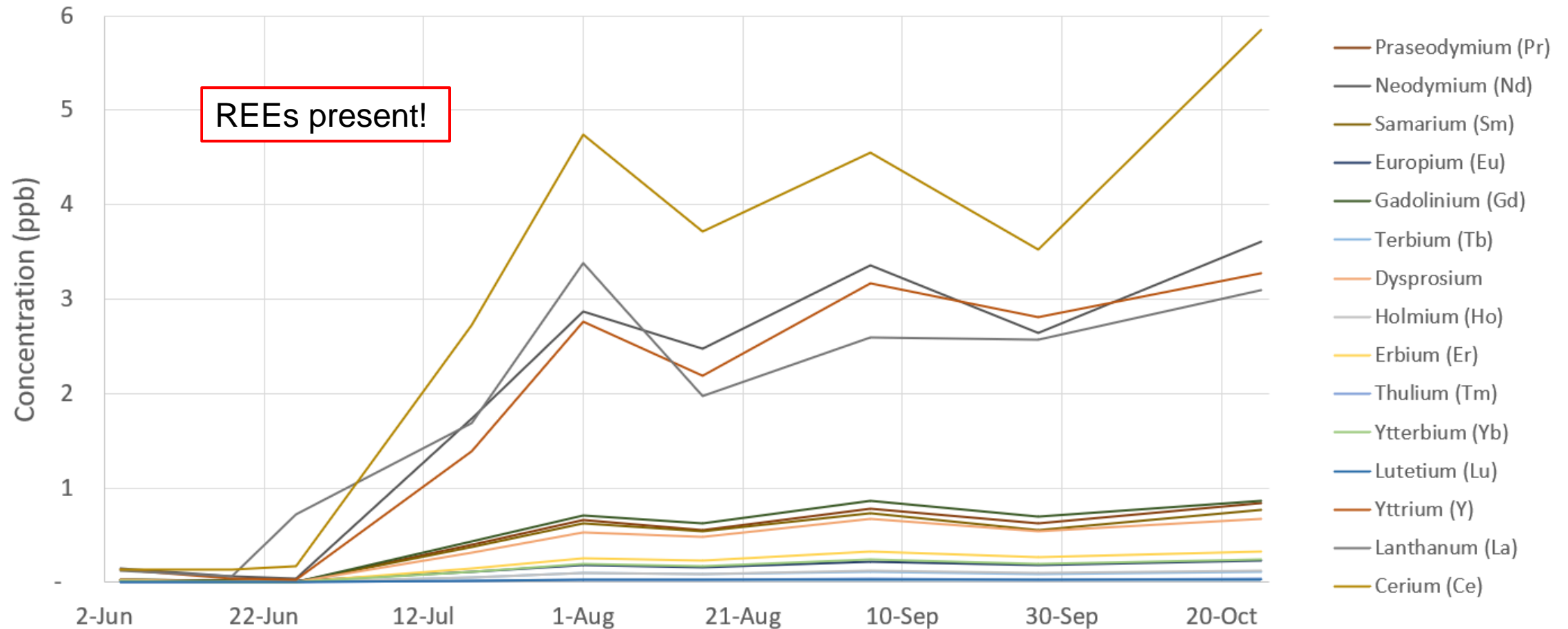


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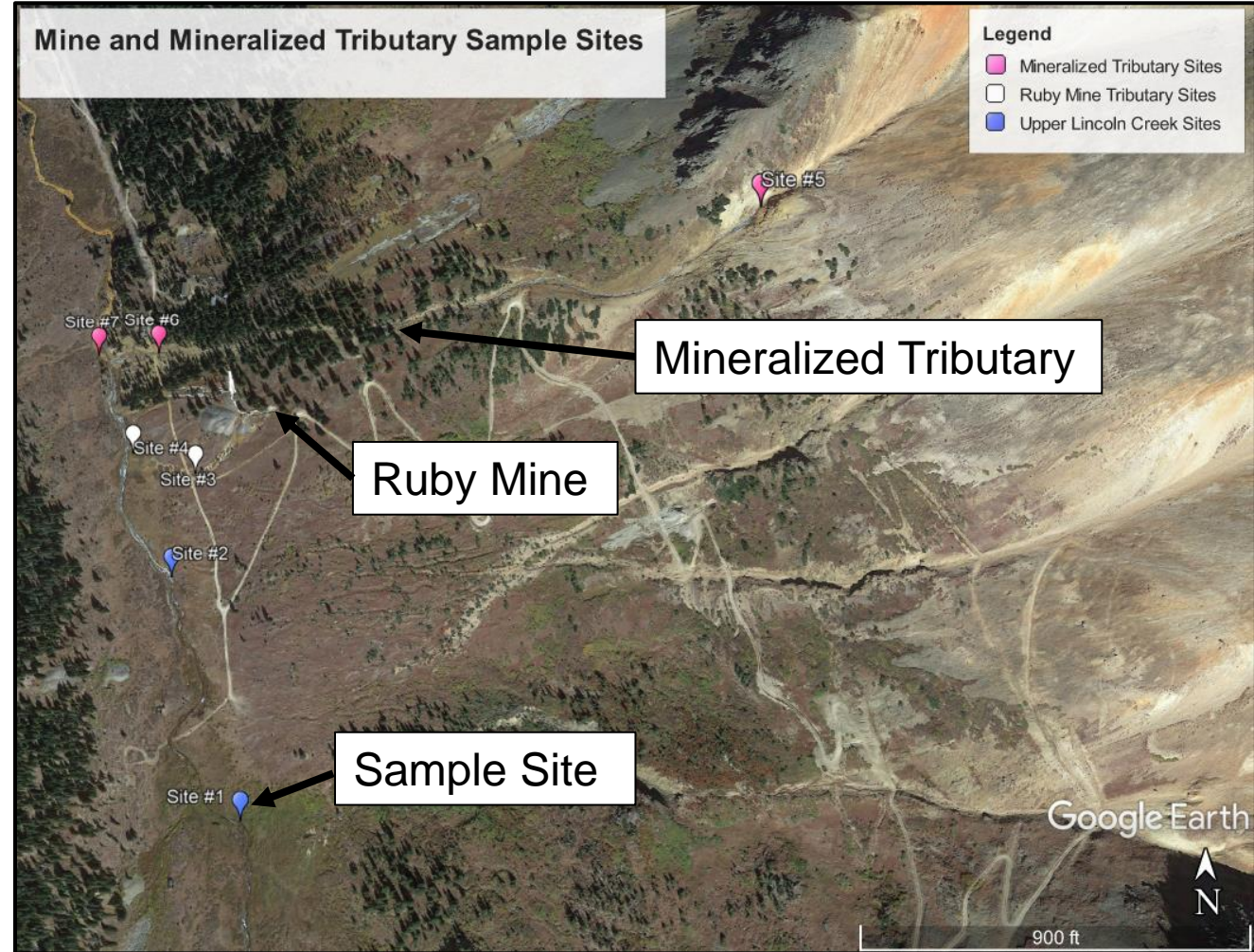


# Preliminary Findings – Grizzly Reservoir Inlet

Rare Earth Elements at Grizzly Reservoir Inlet



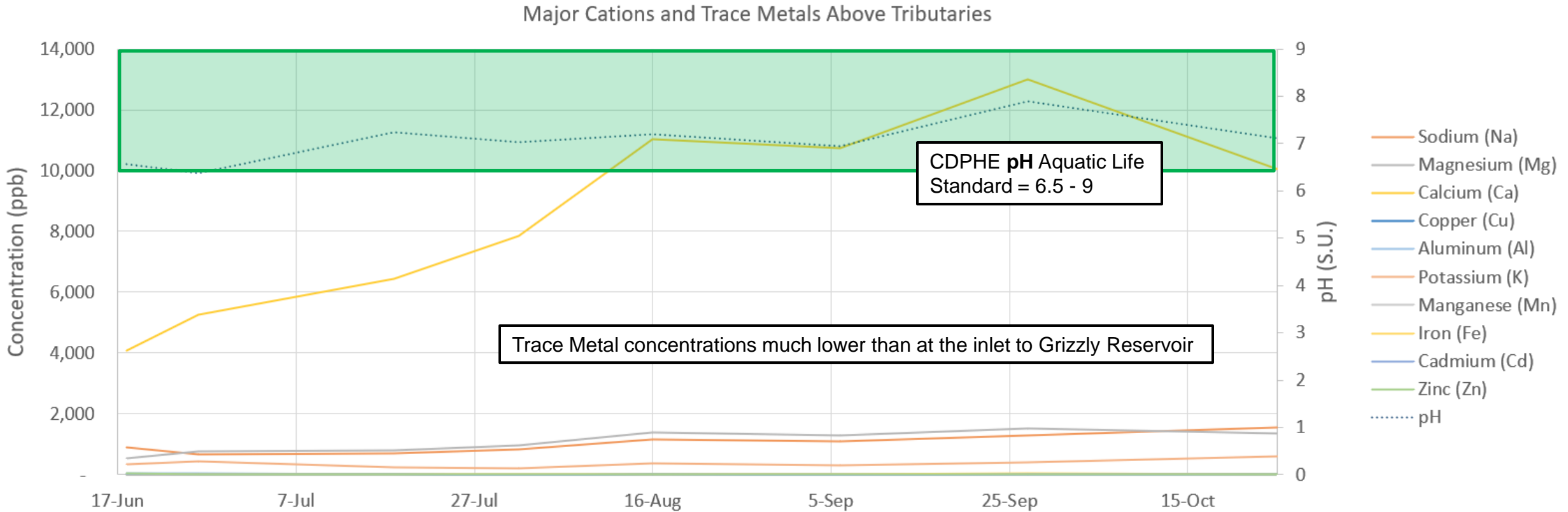
# Preliminary Findings – Above Tributaries



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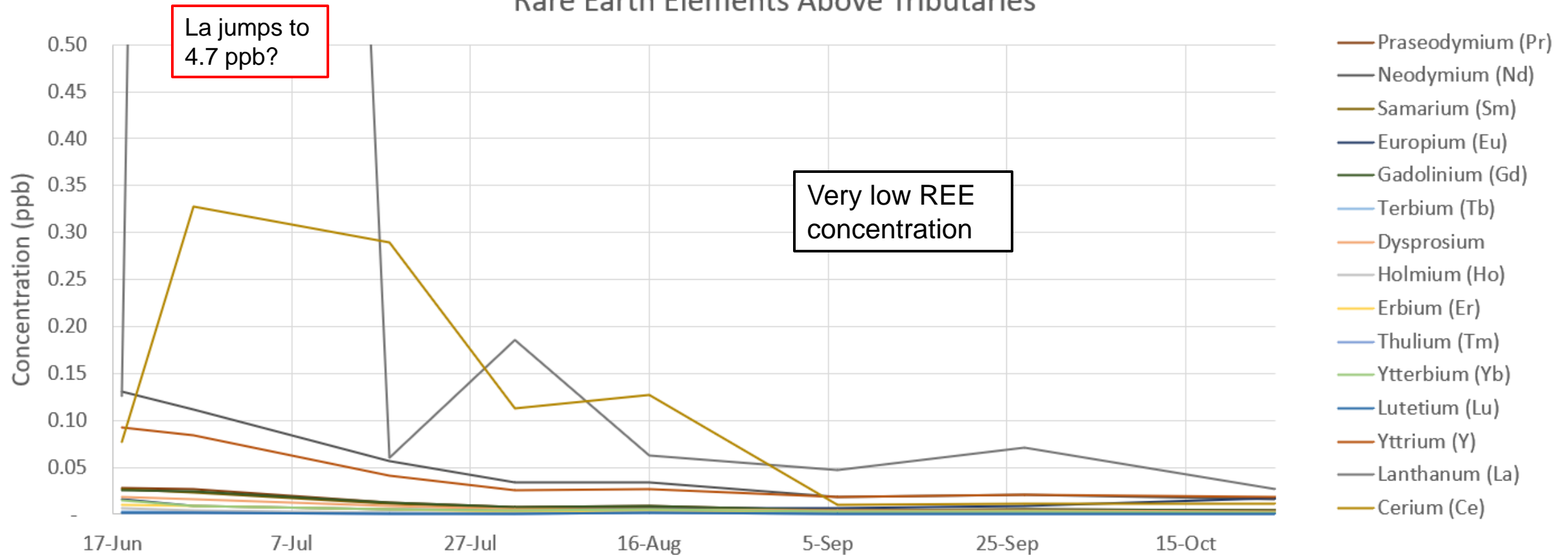


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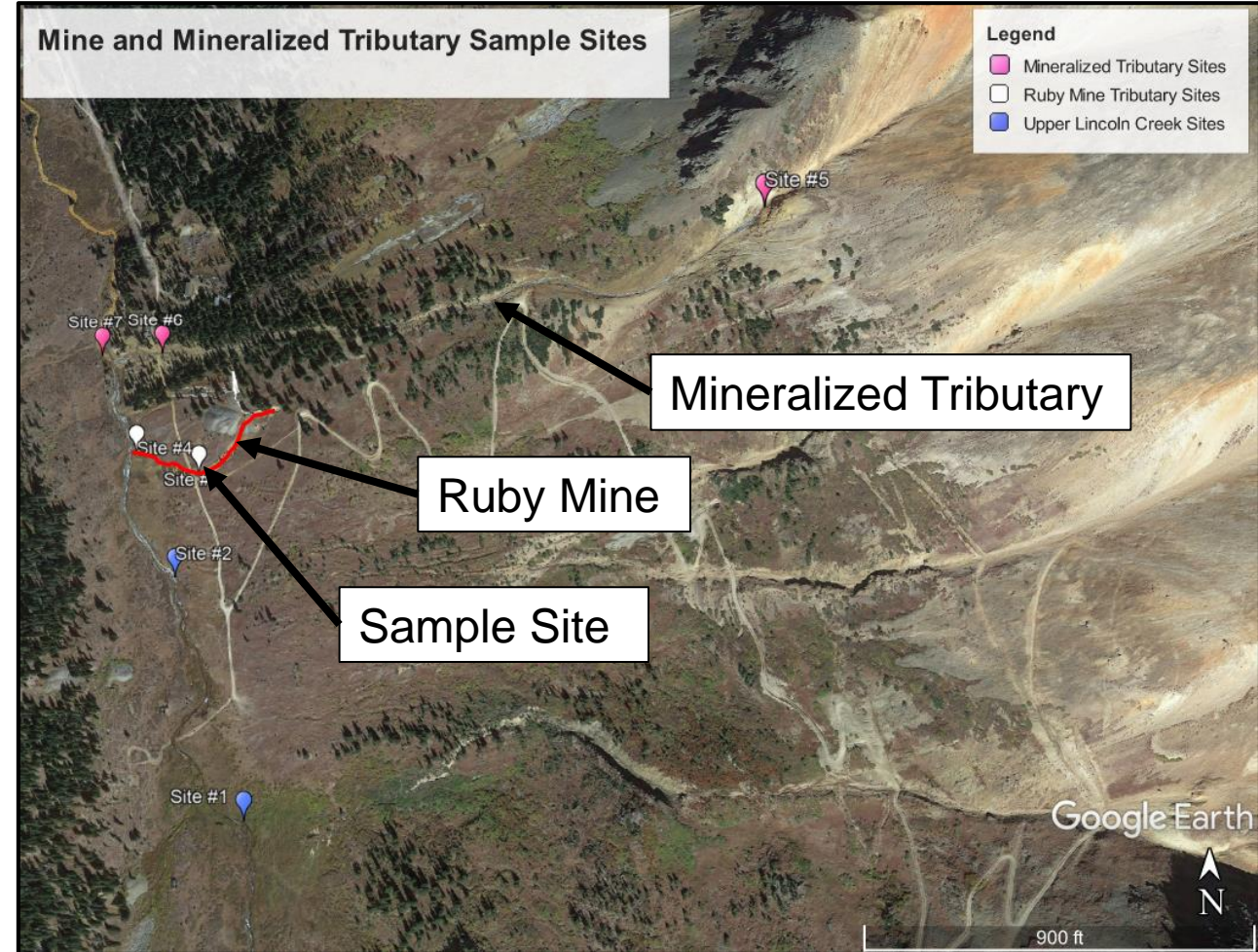


# Preliminary Findings – Above Tributaries

Rare Earth Elements Above Tributaries



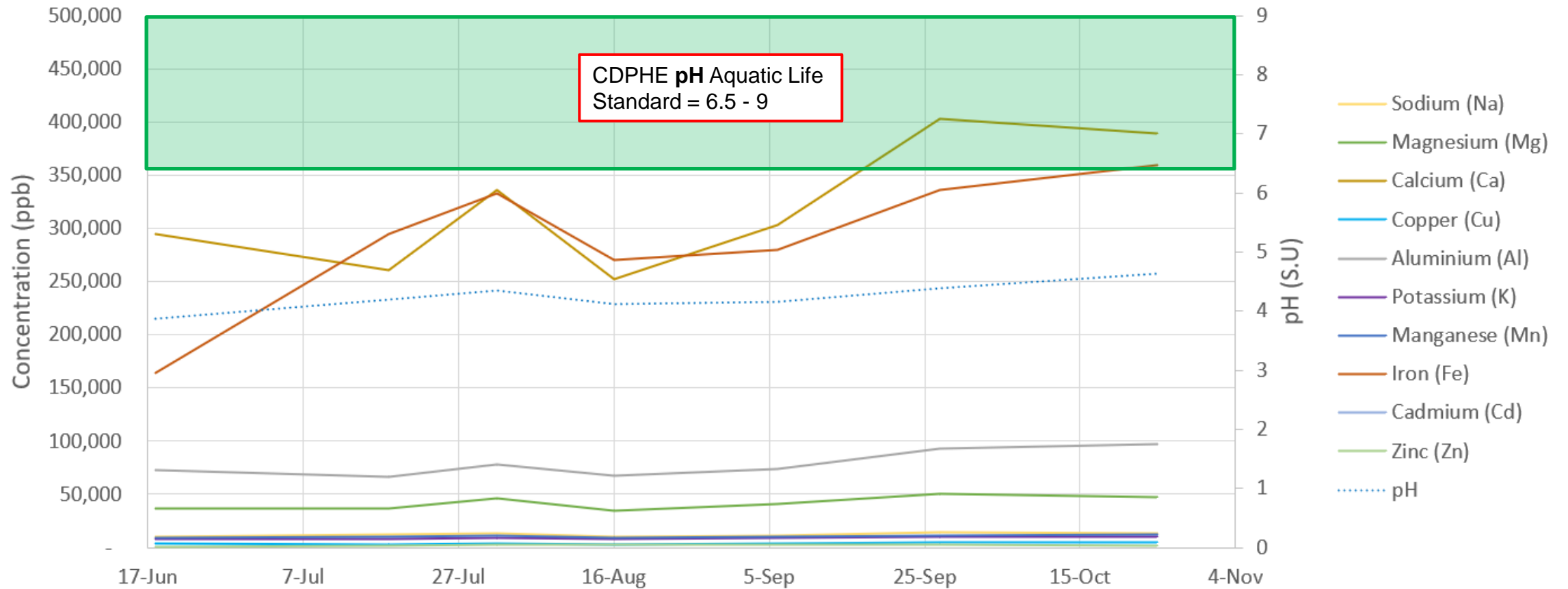
# Preliminary Findings – Ruby Mine Outfall





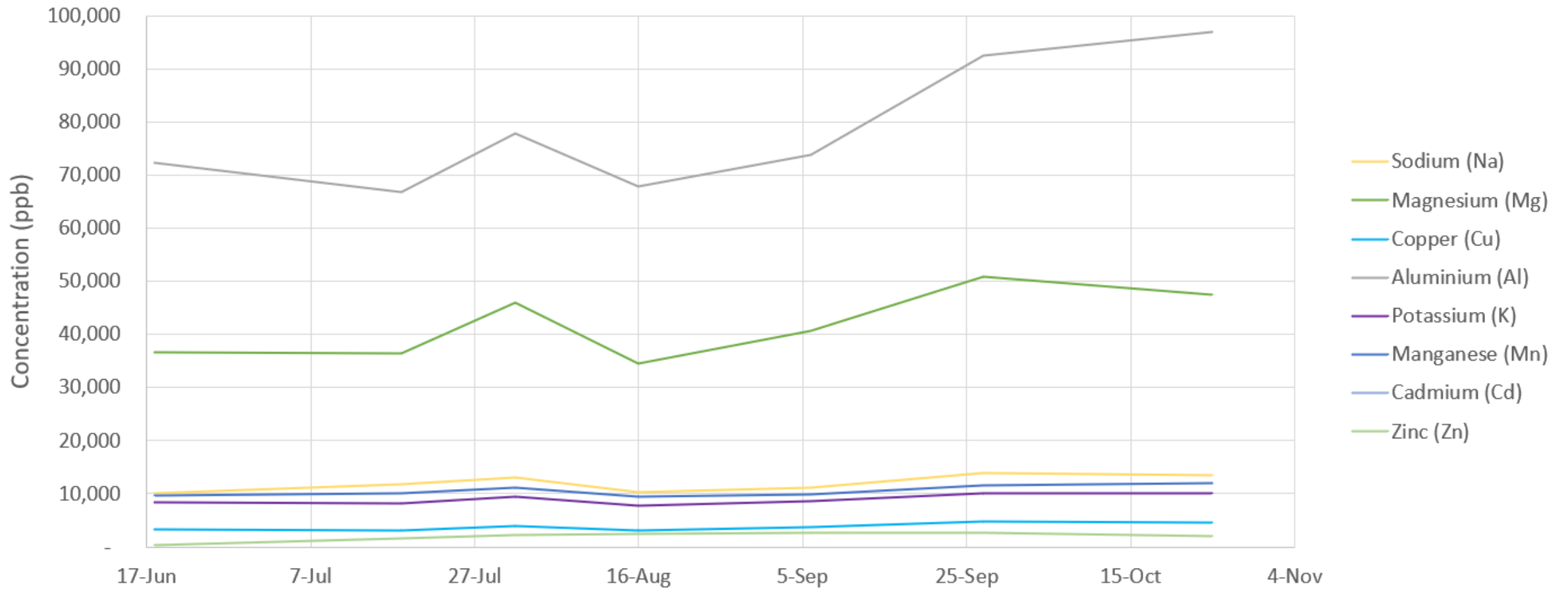
# Preliminary Findings – Ruby Mine Outfall

Major Cations and Trace Metals in Ruby Mine Outfall

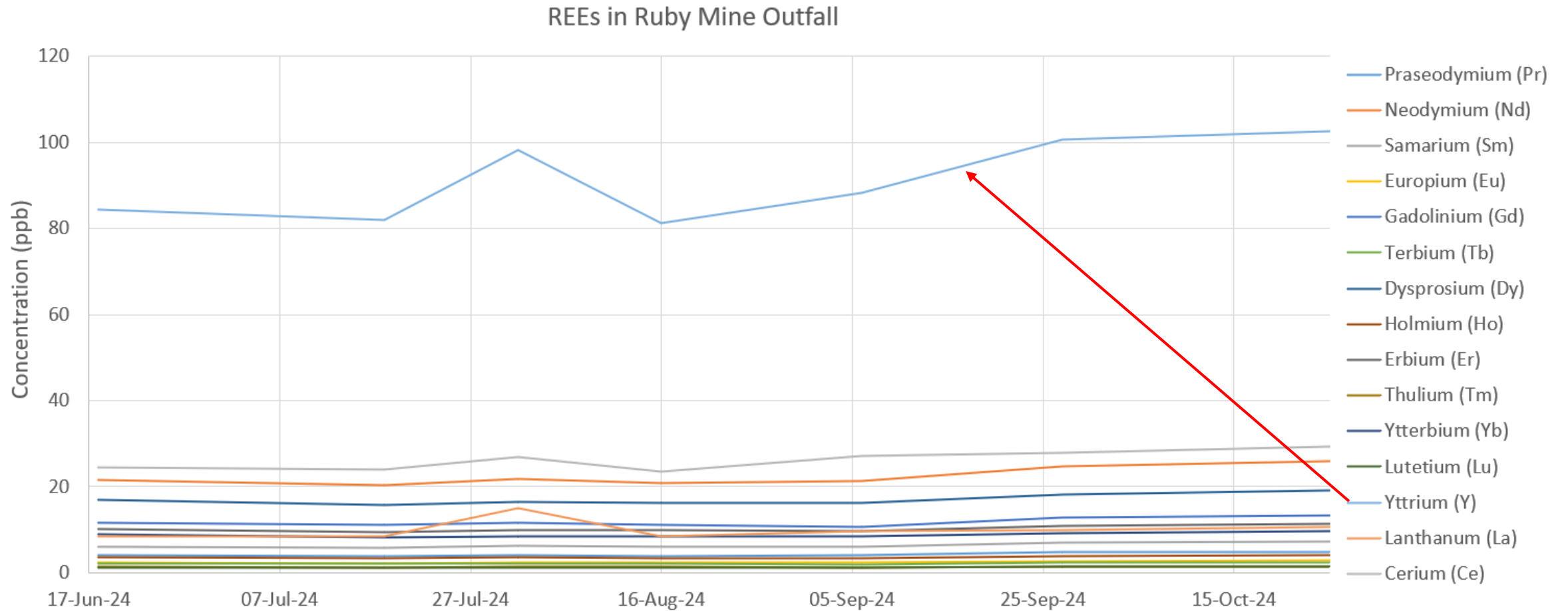


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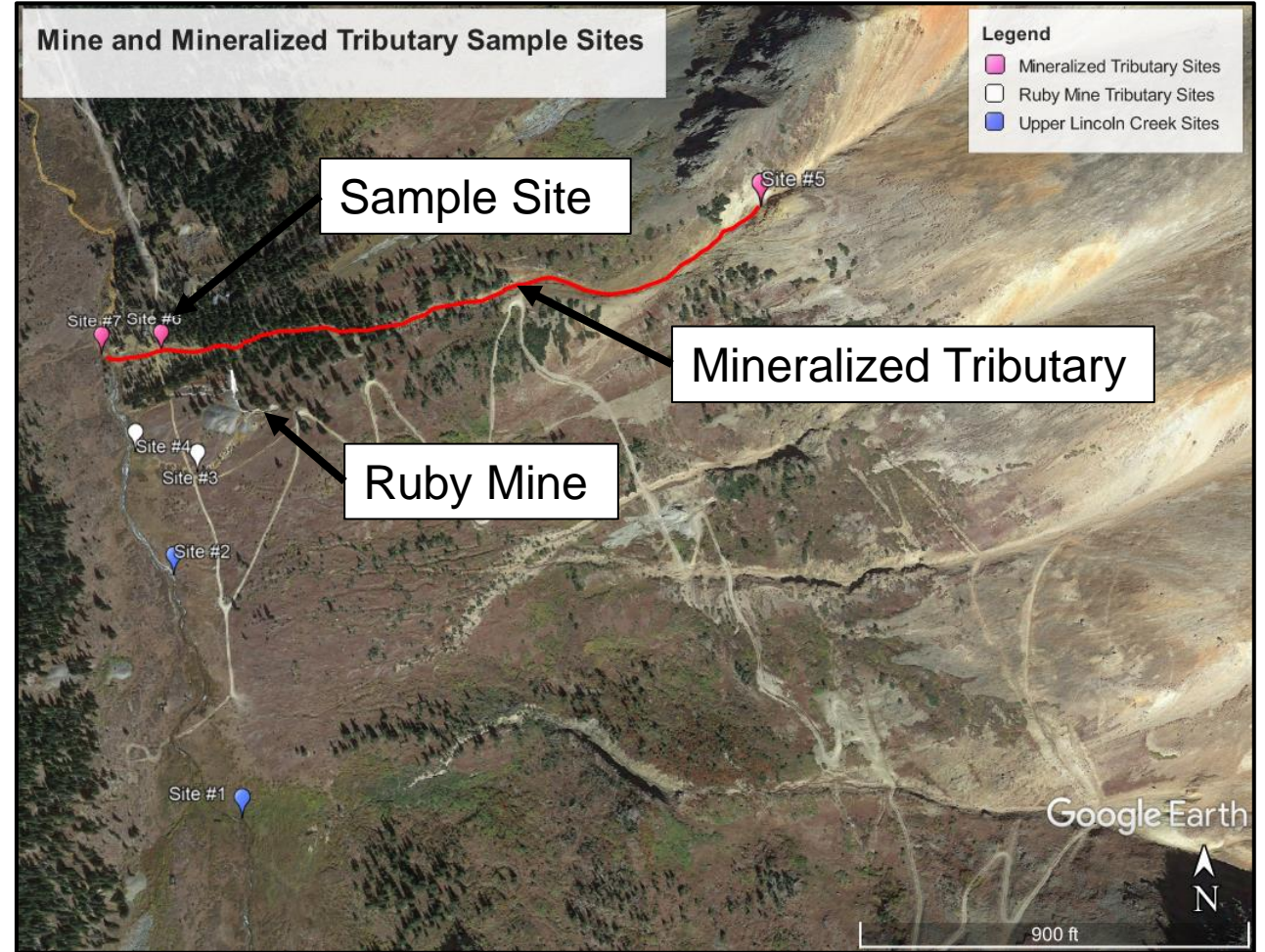
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# Preliminary Findings – Ruby Mine Outfall

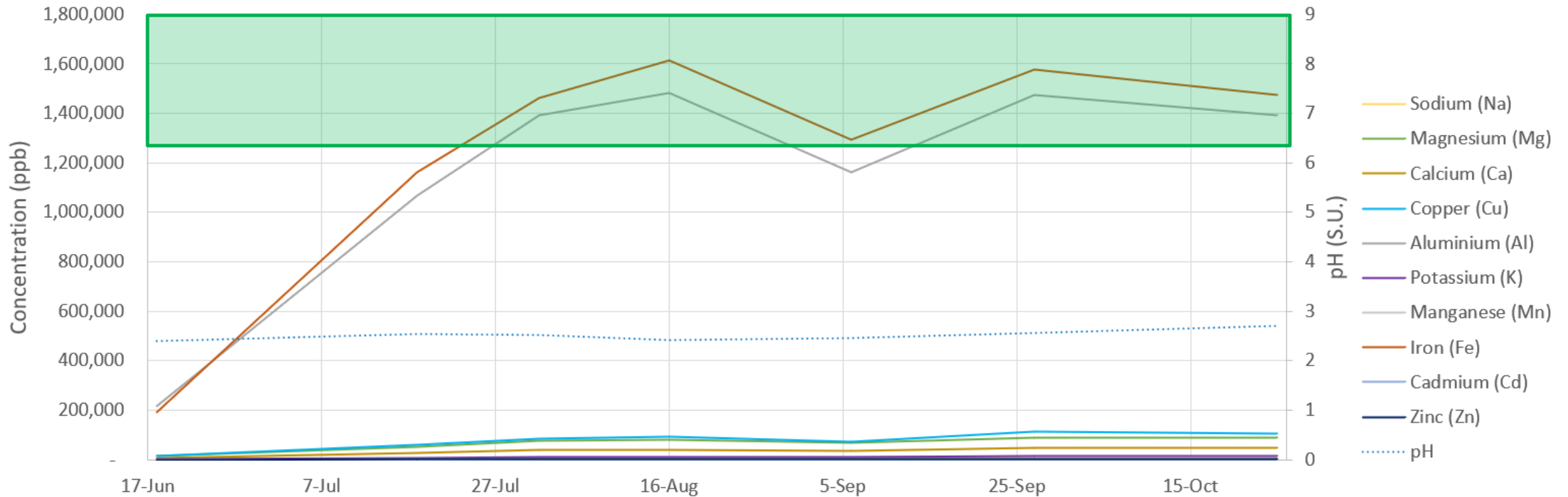


# Preliminary Findings – Mineralized Tributary



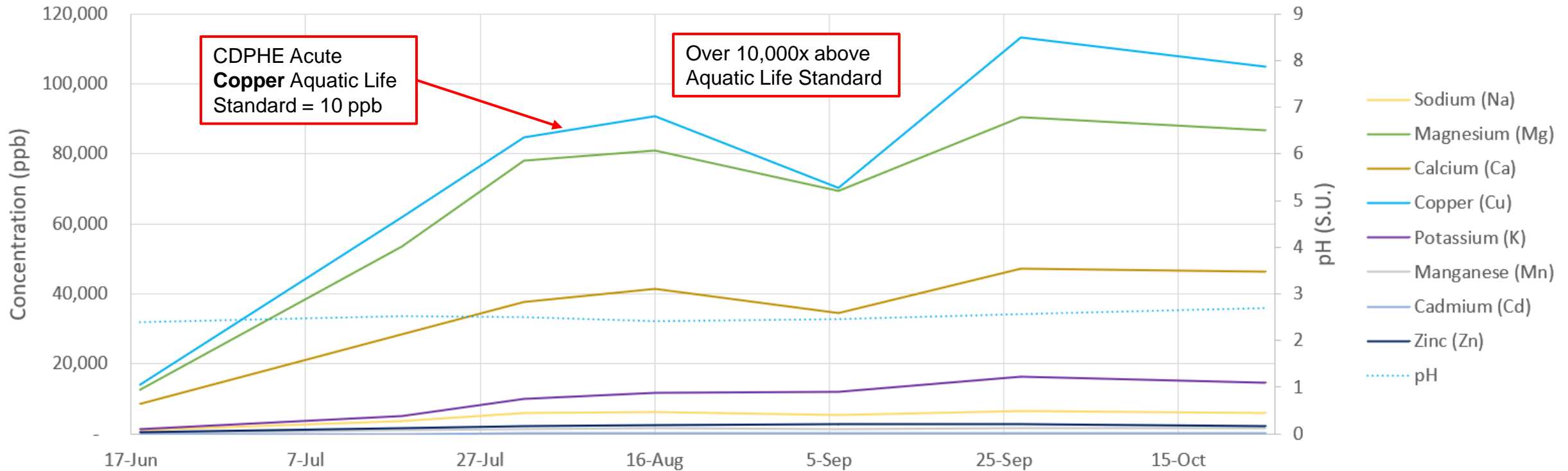
# Preliminary Findings – Mineralized Tributary

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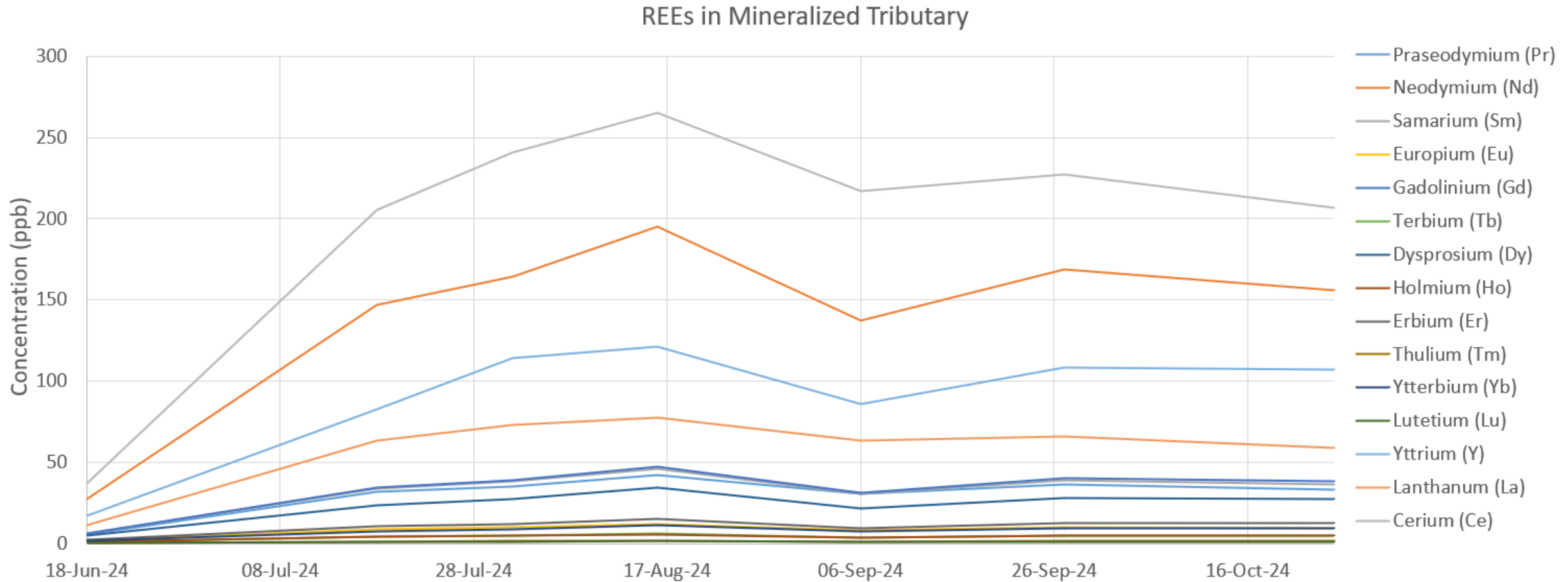


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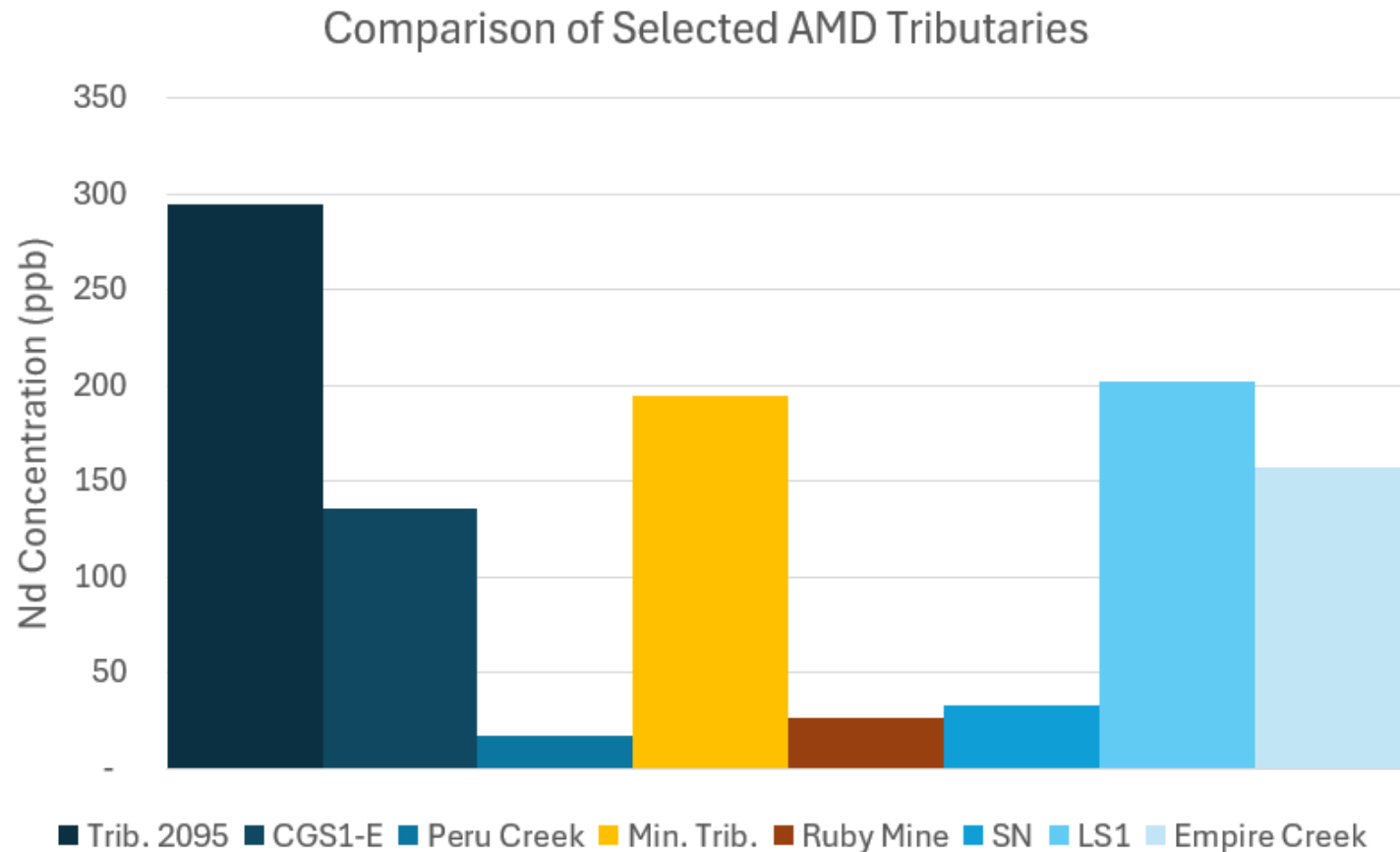
Major Cations and Trace Metals in Mineralized Tributary



# Preliminary Findings – Mineralized Tributary



# Let's put this in perspective. How much Neodymium is in the Mineralized Tributary?





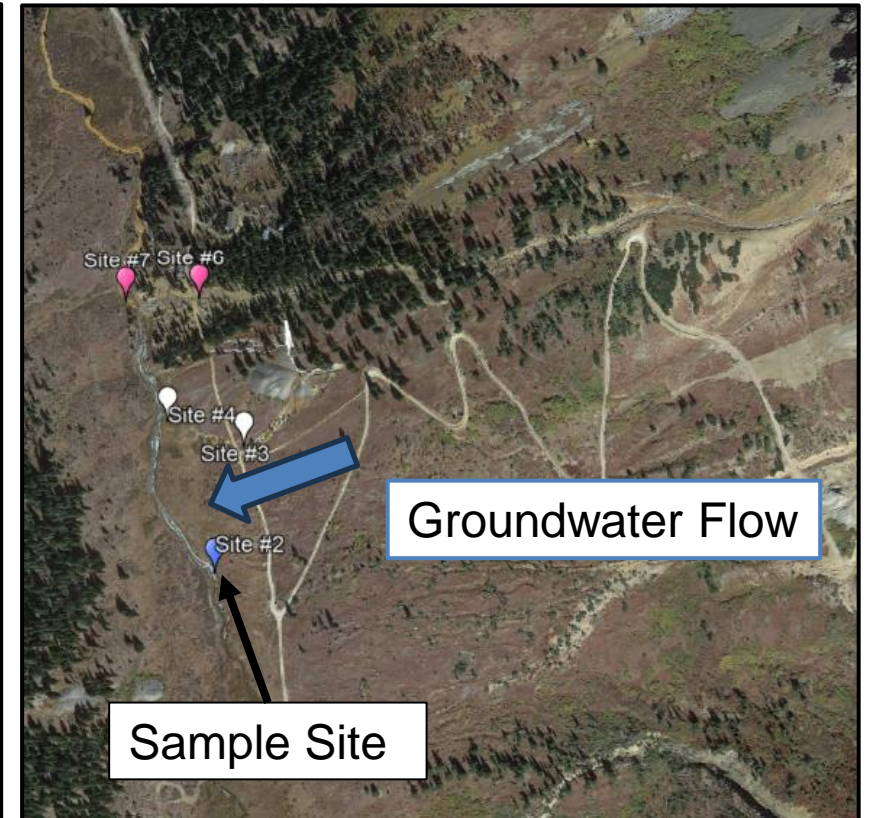
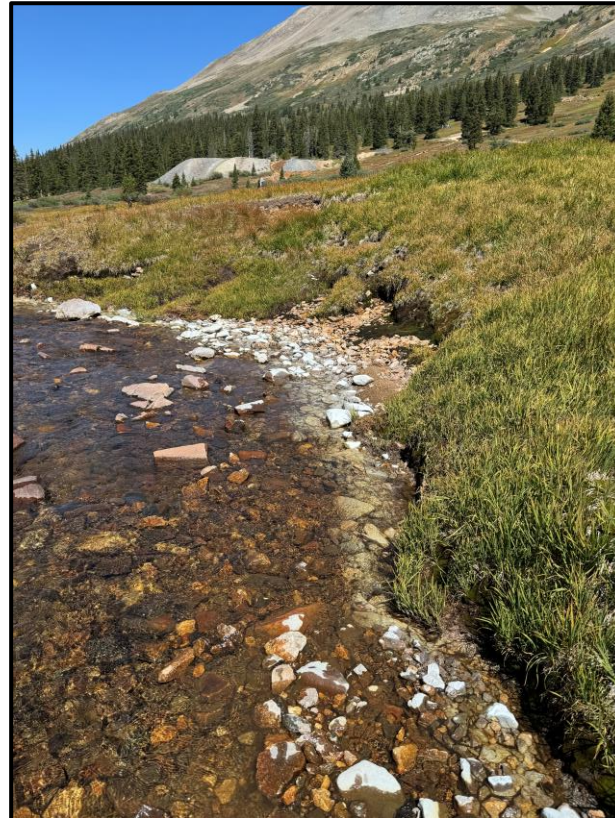
# Let's put this in perspective. How much Neodymium is in the Mineralized Tributary?

- 195 ppb Nd in the Mineralized Tributary at high concentration
- Flow is ~ 2.5 L/s
- Average amount of Nd in a phone is 160 mg
- 1 phone's worth of Nd every 5.5 minutes
- **Enough Nd to supply 96,000 phones per year**
  - This is for a single tributary!



# A third source of metals?

- Water quality team noticed white floc appearing just above the tributaries
- Could indicate a third source of metals to Lincoln Creek entering through groundwater



# Summary of Preliminary Findings

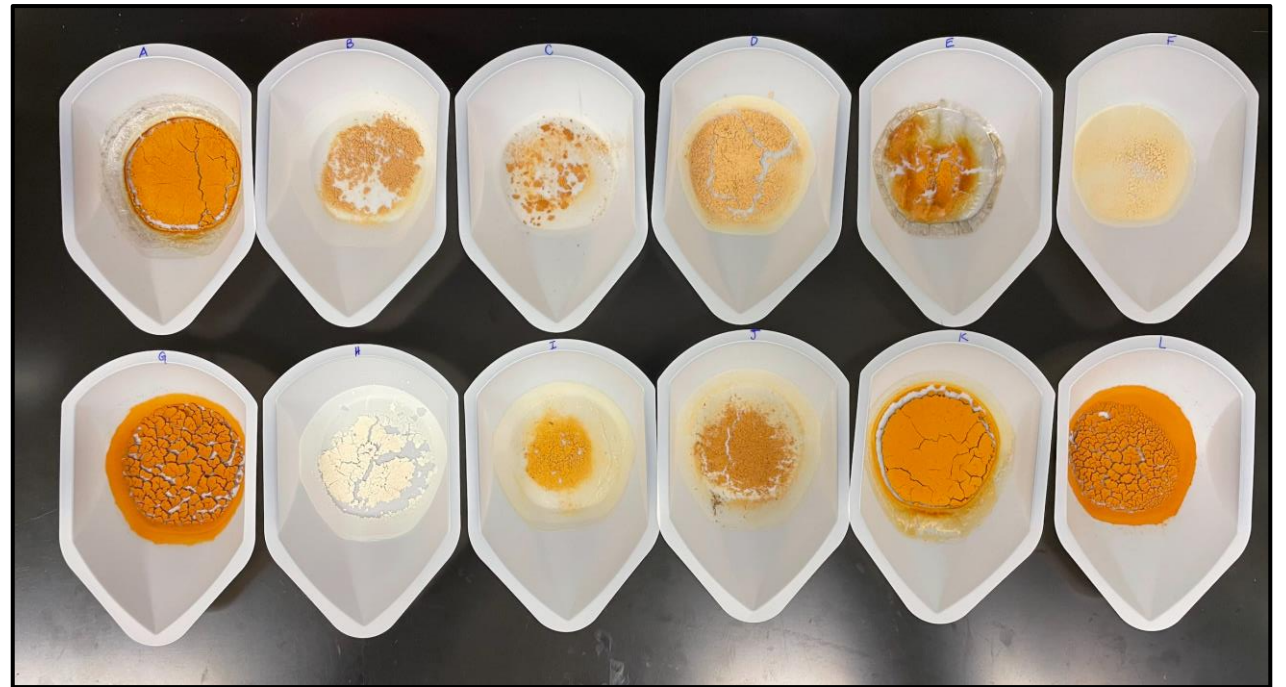
- Trace metal findings align with those from the EPA
  - Entering Grizzly Reservoir, copper, aluminum, and zinc concentrations are high enough to harm aquatic life according to CDPHE aquatic life standards
- REEs added to Lincoln Creek via the Mineralized Tributary and Ruby Mine Tributary
- The concentration of REEs in the Mineralized Tributary is comparable to other low pH AMD/ARD tributaries
- A groundwater source could also be adding metals to Lincoln Creek



# Next Steps – Flocculent Scrapings

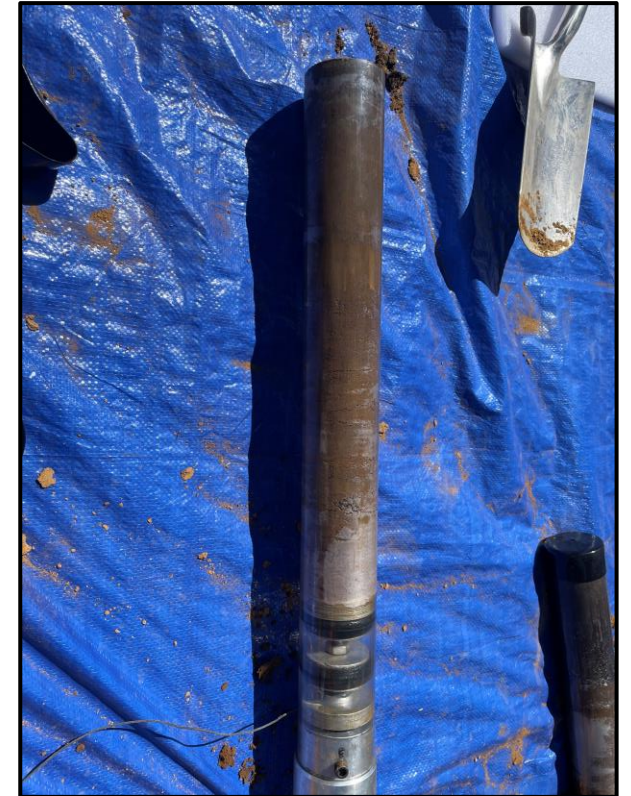


- Major Cation, Trace Metal, and REE mass in floc.
- Are REEs precipitating alongside other metals?



# Next Steps – Sediment Cores

- Carbon-14 dating
- Has the metal contamination of Lincoln Creek always been this severe?
- Major Cation, Trace Metal, and REE mass in sediment
- Are REEs adsorbing to sediment?



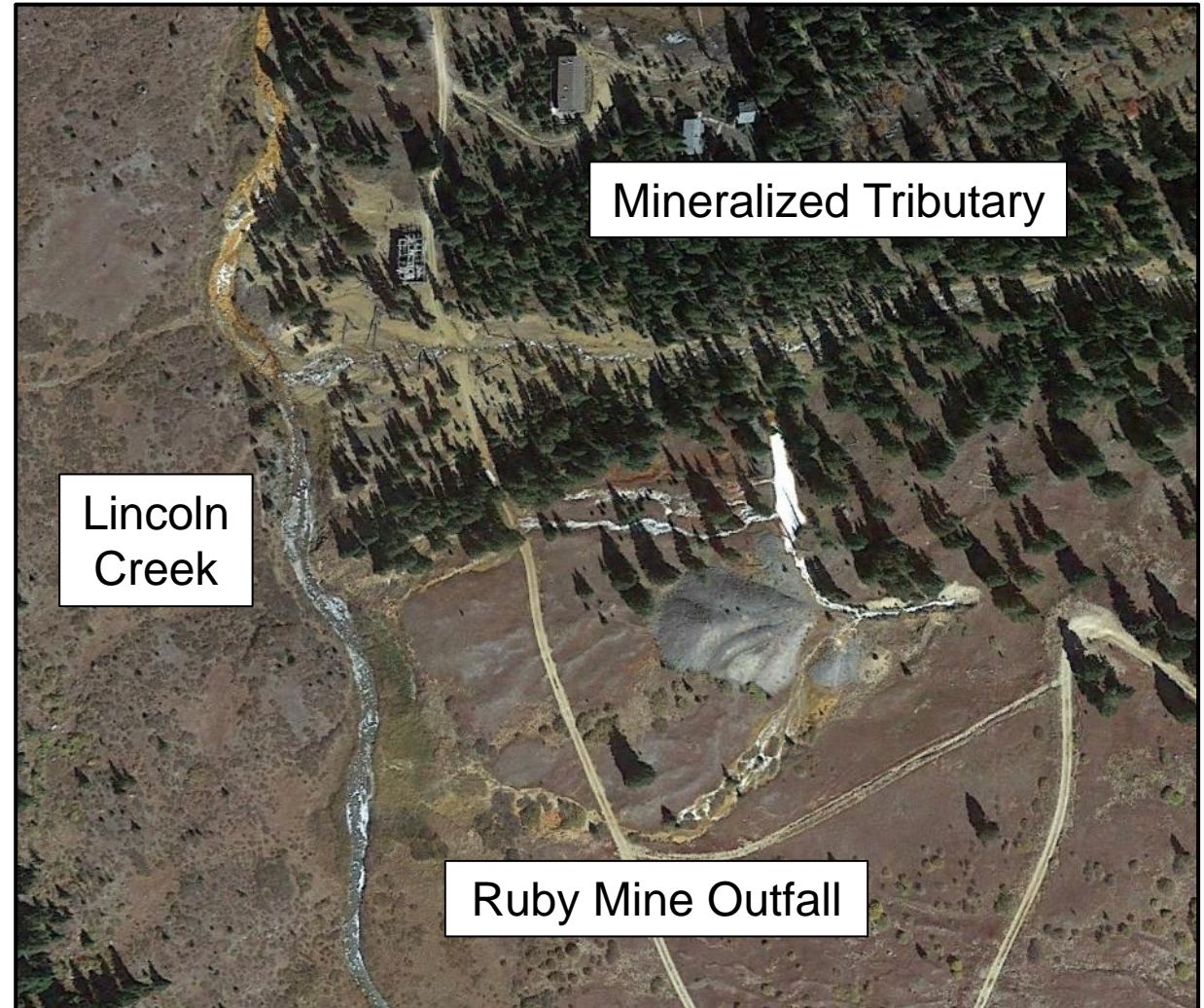
# Next Steps – Benthic Macroinvertebrates

- Analyze functional feeding groups and families to help quantify stream health
- Digest and analyze the BMIs to determine concentration of trace metals and REEs being assimilated



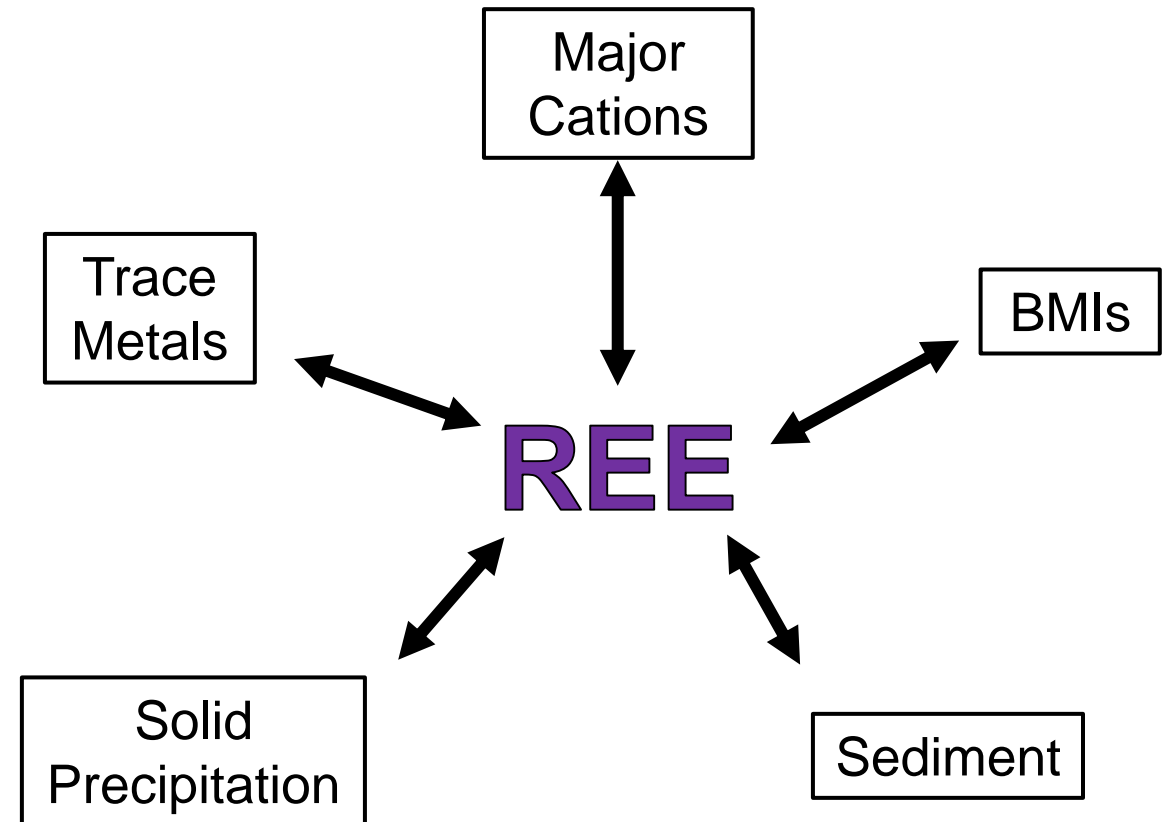
# Impacts of CU's study - Local

- Increase understanding of metal contamination of Lincoln Creek
- Detection is necessary to determine the feasibility of REE extraction



# Impacts of this study – Scientific Community

- The fate of REEs in aquatic systems is not well understood.
  - We are hoping to aid in changing that
- Increase knowledge of REE toxicity to aquatic biota – namely benthic macroinvertebrates
- Examine interactions between Rare Earth Elements and other cations in aquatic systems





Thank You!

**Questions?**

