Methods for Model Development

Objective and Model Assumptions

Our initial model development began with the goal of answering three guiding questions:

1. What are the ranges of concentrations of metals in common feedstocks such as basalt and peridotite (used as a proxy for deployments using olivine)?
2. What are the baseline concentrations of metals in agricultural soils?
3. What are soil threshold values for metals in global regulations?

The goal of this model was to understand which metals from which commonly-used peridotite and basalt feedstocks might warrant deeper investigation due to their risk of potential accumulation from ERW deployments. As such, our modeling approach contains simplified dynamics that are **maximally conservative**. The key assumptions include:

a. Full, instantaneous dissolution of the feedstock over one application event with no partial metal release from the feedstock or time component to dissolution.
b. No export of metals from soil after deposition (e.g., by plant uptake or transport through the soil column into the lower vadose zone).
c. Homogenous vertical and lateral soil metal concentrations throughout the deployment site.

Data Collection

Metals Evaluated: We collected feedstock and soil metal concentration data on the following metals: Nickel (Ni), Antimony (Sb), Beryllium (Be), Silver (Ag), Selenium (Se), Barium (Ba), Chromium (Cr), Copper (Cu), Manganese (Mn), Vanadium (V), Cobalt (Co), Zinc (Zn), Arsenic (As), Cadmium (Cd), Lead (Pb), and Mercury (Hg). We chose to evaluate 16 metals based on the availability of data and inclusion in the US EPA's Eco-SSL program.

Feedstock Data: Feedstock data was pulled from the GEOROC (Geochemistry of Rocks of the Oceans and Continents) database for both basalt and peridotite formations and was filtered to exclude formations currently in oceanic settings. We chose to constrain our analysis to basalt and peridotite because they are currently the most common ERW feedstock types in existing deployments and trials. The GEOROC data points were globally distributed and provided representative insights into the metal content of basalt and peridotite feedstocks found worldwide. It is worth noting that some of the feedstocks included in this search were likely not highly suitable for ERW deployments (e.g., low Ca/Mg content which would mean a low CDR potential).

Soil Data: Soil data was pulled from the United States Geological Survey (USGS) for the U.S. and the Forum of the European Geological Surveys (FOREGS) for Europe. We also gathered data for Brazil (Campos et al., 2003), China (Wang et al., 2020), and India (Kumar et al., 2021). We constrained results to agricultural soils so that the data most accurately reflects soils that would be used for ERW deployments. We searched for soil data across many geographies but were limited to publicly available repositories and supplemental information from open-access peer-reviewed literature, which narrowed the scope of data available. If there are additional soil databases that are relevant but are not included here, please reach out to us at metals@cascadeclimate.org so that we can add them to our dataset.

Regulatory Data: We collected total threshold values from different countries and regulatory agencies, the selection of which was guided by data availability. We concentrated our search primarily on regulations in English and in countries with ongoing or planned ERW deployments. These search parameters may lead to some gaps, and if we have missed a relevant regulation, please email us at metals@cascadeclimate.org.

Maximally Conservative Mass Balance Function

The basic mass-balance equation underlying the ERW-MAC is:

$$HM_{concentration(baseline\ soil)} + \frac{HM_{concentration\ (feedstock)} * application\ rate * number\ of\ application\ events}{soil\ depth * soil\ bulk\ density} = HM_{concentration\ (final\ soil)}$$

The key variables in the function are defined as follows:

$HM_{concentration\ (baseline\ soil)}(mg/kg)$ = the concentration of a metal in the baseline soil;

$HM_{concentration\ (feedstock)}\ (mg/kg)$ = concentration of metal in feedstock;

$application\ rate\ (kg/m^2/application\ event)$ = application rate of the feedstock;

$soil\ depth(m)$ = the soil depth at which the feedstock will be incorporated;

$soil\ bulk\ density\ (kg_{soil}/m^3)$ = the bulk density of the soil the feedstock is being deployed on;

$HM_{concentration\ (final\ soil)}(mg/kg)$ = the calculated concentration of a metal after complete dissolution of the feedstock and accumulation into the soil.

For each metal, a modeled distribution was fit to the feedstock baseline values from GEOROC and to the collected global soil baseline values; a uniform distribution was created for common ranges of soil tillage depth (5-30 cm), and a truncated normal distribution was created for soil bulk density (mean = 1.25, SD = 0.25; all values between 0.8 and 1.7 g/cm^3). A Monte Carlo simulation randomly sampled 10,000 values from each of these distributions and used these as inputs to the mass balance model (see equations above). For each metal, model results were compiled to show a distribution of post-deployment metal concentration for each of the 10,000 modeled scenarios and each of the 5 deployment scenarios (0, 25, 50, 75, 100 and 125 cumulative tons of basalt; 0, 5, 10, 15, 20, 25 cumulative tons of peridotite). These deployment scenarios were chosen based on average deployment volumes in established literature for each feedstock.