**Processing Workflow:**

**Creating layers for pluming:**

**River Nutrient Pollution**

*This workflow combines the NHDPlus national dataset (stream reach spatial locations) with nitrogen/phosphorous that enters the ocean, as predicted by SPARROW models.*

*There are 5 regional sparrow models: Midwest, Northeast, Pacific, Southeast, and Southwest. They predict nitrogen/phosphorous loads in streams based on slightly different parameters for each region. Stars indicate anthropogenic source:*

*Midwest:*

*Nitrogen:*

*-wastewater treatment plants \**

*- farm fertilizer \**

*- manure \**

*- atmospheric deposition*

*- urban land \**

*- nitrogen fixing crops*

*Phosphorus*

*-wastewater treatment plants \**

*- farm fertilizer \**

*- manure \**

*- natural sources*

*- urban land \**

*Northeast:*

*Nitrogen:*

* *Wastewater treatment plants \**
* *Septic system effluent \**
* *Fertilizer \**
* *Crop fixation*
* *Manure \**
* *Deposition*
* *Urban nonpoint sources \**

*Phosphorus:*

* *Wastewater treatment plants \**
* *Fertilizer \**
* *Manure \**
* *Urban nonpoint sources \**
* *Mineral erosion*

*Pacific:*

*Nitrogen:*

* *Scrub and grassland*
* *Atmospheric deposition*
* *Urban land \**
* *Spring discharge*
* *Red alder trees*
* *Fertilizer and manure \**
* *Wastewater treatment plants \**

*Phosphorus:*

* *Channel sources*
* *Weathering of geologic material*
* *Spring discharge*
* *Urban land \**
* *Grazing cattle manure \**
* *Fertilizer and livestock \**
* *Wastewater treatment plants \**

*Southeast:*

*Nitrogen:*

* *Wastewater treatment plants \**
* *Farm fertilizer \**
* *Manure \**
* *Deposition*
* *Urban land \**

*Phosphorus*

* *Natural sources*
* *Manure \**
* *Wastewater treatment plants \**
* *Farm fertilizer \**
* *Mining facility discharge \**
* *Urban land \**
* *Mined areas \**

*Southwest:*

*Nitrogen:*

* *Deposition*
* *Wastewater treatment plants \**
* *Farm fertilizer \**
* *Manure \**
* *Developed Land \**

*Phosphorus:*

* *Channel streams*
* *Developed land \**
* *Farm Fertilizer \**
* *Natural Sources \**
* *Manure \**

***Processing layers for pluming:***

*The NHD plus dataset is first filtered to just include terminal reaches, or the ultimate stream segment before a water body. To only include coastal reaches, as opposed to reaches that outlet to lakes, only reaches within 2km of the coastline were selected. To ensure that the reaches are within the ocean raster’s bounds to guarantee they will work with the plume model, reach geometries were converted to points and then snapped to a 0.5 km negative buffered EEZ. This ensures that points containing the effluent to plume are actually included in the ocean. Snapped points were then joined to river nutrient and flow data from the SPARROW models by COMID, or the specific reach identifier. Points not contained in both datasets were dropped.*

*GIS workflow walkthrough:*

1. Select terminal reaches from the NHDPlus National Dataset
   1. Input NHDPlus dataset
   2. Select only terminal reaches (terminal\_reach = 1)
   3. Reproject into WGS 1984 (EPSG 4326)
2. Convert lines to points
   1. *Feature Vertices to Points* tool
      1. Input = reprojected reaches from step 1
      2. Point type = END
      3. Name = \*\_endpoints
3. Snap points to negative buffered EEZ
   1. *Near* tool
      1. check the location box
      2. input = \*\_endpoints from above
      3. near features = eez\_snapping (0.5km negative buffered EEZ)
4. Select endpoints within 2km of the coast
   1. *Selection* -> *Select by Location*
      1. Target layer = \*\_endpoints
      2. Source layer = eez\_2km\_buffer (2km positive buffered EEZ)
   2. Export data
      1. Data -> export data
         1. Export = selected fearures
         2. Save as \*\_coastal\_ends
5. Create new shapefile with the snapped geometry
   1. Open attribute table of \*\_coastal\_ends
      1. Export
         1. Save as \*\_snapped
   2. Reload shapefile with updated geometry
      1. Load in \*\_snapped as a table
      2. Right click table
         1. Select Display XY Data
            1. X Field = Near X
            2. Y Field = Near Y
            3. MAKE SURE PROJECTION IS WGS 1984
6. Join snapped points to the effluent
   1. Load in sparrow model data
      1. This is either nitrogen (tn) or phosphorous (tp)
      2. There’s an input for each region (5 regions)
   2. Join snapped points to effluent
      1. Right click \*\_snapped\_ends
      2. Joins & Relates –> Joins
         1. COMID (reach ID from NHD)
         2. \*\_sparrow\_model\_output\_tn.txt
         3. Comid (reach ID from sparros)
         4. Check “keep only matching records”
7. Export snapped and joined shapefile
   1. Right click the layer
   2. Export
      1. Save as \*\_snapjoin

**Outfall pollution:**

Raw outfall pollution numbers were downloaded from model outputs from the [U.S. Hypoxia Task Force Nutrient Model](%22https:/echo.epa.gov/trends/loading-tool/hypoxia-task-force-nutrient-model%22). These data are projected lbs/year of phosphorous or nitrogen for each outfall in the United States. The methods vary: total lbs are sometimes predicted based on monitoring information, otherwise lbs pollutant are estimated based on modeling techniques.

Outfall pollutant data were joined to the [spatial locations of ocean outfalls](https://catalog.data.gov/dataset/wastewater-outfalls). This dataset categorizes an ocean outfall as any outfall within 20km of the coastline, or in the ocean. Outfalls that had both pollutant information and a coastal spatial location were retained for pluming. These points were snapped to a -0.5km buffered EEZ, similar to the river nutrient pollution dataset.

**Plume modeling:**

**River nutrients:**

For rivers, ocean plume area is related to the area of the upstream watershed where:

P = c\*A ^Beta

Where P is the plume area, A is the watershed area, c is a plume size factor related to discharge, and b is a constant scaling factor. We use values of c = 0.5 and b = 0.65, both of which are the most commonly found ratios according to [Warrick and Farnsworth, 2017](https://www.sciencedirect.com/science/article/pii/S0079661116300532?via%3Dihub#!).

Plume size for each river plume is calculated based on the upstream watershed area. Effluent is plumed into the ocean starting at the spatial location of each rivermouth. Plumes are expanded iteratively using a four-neighbor rule until the total area of plumed cells exceeds the predicted plume size in the above area. Only cells within the EEZ are included in plume expansion, i.e. cells outside the ocean never contain any of the plume.

Once the spatial extent of a plume is determined, pollutant mass per raster cell is calculated by first dividing the total mass of the pollutant by the number of expansions needed to achieve the calculated plume size. The total mass of pollutant is distributed equally over each expansion, to simulate increasing dilution as the distance from the point source increases.

Example:

In a plume that projects from a point into a perfectly flat “ocean”, the first expansion occupies one cell, where the initial location of the rivermouth is. The plume is expanded so that the second expansion adds 3 adjacent cells: the cell above, below, and to the left of the initial cell (assuming that the left is ocean and the right is land). The third expansion adds 5 cells, the fourth 7 cells, and so on, until the total cell area exceeds the calculated plume area. Then, pollutant mass is divided over the number of expansions and then further divided over the number of new cells in each expansion, so that the amount of pollutant in each expansion is equal. If the pollutant per expansion X = total\_kgs\_pollutant / number of expansions, then each cell in the first expansion contains X/1 kgs pollutant, each cell in the second contains X/3 kgs, the third X/5, the fourth X/7, etc.

**Outfall nutrients:**

Outfall spatial extents are complex and hard to generalize. For our purposes, we recycle the plume relationship calculated for rivers and apply them to outfall plumes. Outfalls have an initial velocity and are subject to more complicated oceanographic conditions than river plumes, however, as a general overview, our methods roughly estimate plume location and extent.

First, because outfalls do not have a watershed size, we first predicted plume area based on the flow rate (CFS) of each river. To do this, we used linear regression using R’s lm() function. The results are as follows…

Coefficients:

Estimate Std. Error t value Pr(>|t|)

(Intercept) 7.4778210 0.9152438 8.17 4.28e-16 \*\*\*

FLOWcfs 0.0145240 0.0001006 144.31 < 2e-16 \*\*\*

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Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 53.48 on 3419 degrees of freedom

Multiple R-squared: 0.859, Adjusted R-squared: 0.8589

F-statistic: 2.083e+04 on 1 and 3419 DF, p-value: < 2.2e-16

Giving us a relationship of:

Plume area = .0145240 \* FLOWcfs + 7.478210

We then apply the same plume model as for river nutrients, where the plume area is calculated, plumes are expanded via a 4-neighbor rule until the area of the plume exceeds the calculated plume area, then the pollutant is distributed to each cell by dividing the same amount of pollutant over all the new cells contained in each expansion.

**Total pollution:**

To calculate total pollution in each cell, we summed the outfall pollutant and the anthropogenic river nutrients for phosphorus, and the outfall pollutants, anthropogenic river nutrients, and [atmospheric deposition nMutrients](https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=830) for nitrogen.

**Relative pollution:**

The relative pollutant load from each cell was calculated by dividing the anthropogenic pollution in each cell by the concentration of either nitrate or phosphate in each cell, according to [BioOracle](https://www.bio-oracle.org/) data. BioOracle data often does not include cells immediately adjacent to coastlines, where the bulk of nutrient loading occurs. To estimate nutrient concentrations in these areas, we interpolated BioOracle data into these cells using a Nearest Neighbor protocol.

**Exclusion Analysis:**

To estimate available space for seaweed aquaculture, we applied the same methodology in [Racine et al., 2021](https://www.sciencedirect.com/science/article/pii/S0308597X21001172) to the entire United States. Available space is calculated based on depth (from [GEBCO](https://www.gebco.net/data_and_products/gridded_bathymetry_data/), 10-100 m is considered suitable), and available marine space. Available marine space is determined by an exclusion analysis that includes [shipping lanes](https://www.fisheries.noaa.gov/inport/item/39986), [MPA’s](https://marineprotectedareas.noaa.gov/dataanalysis/mpainventory/), [submarine cables](https://www.fisheries.noaa.gov/inport/item/57238), [undersea pipelines](https://www.fisheries.noaa.gov/inport/item/54395), [military restricted areas](https://www.fisheries.noaa.gov/inport/item/48876), and oil and gas [platforms](https://www.fisheries.noaa.gov/inport/item/54390) and [wells](https://www.fisheries.noaa.gov/inport/item/54392).