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River Basin Export Reduction Optimization Support Tool (RBEROST-Pacific) User Guide, v2s

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2 List of Acronyms

ACRE	Agricultural Conservation Reduction Estimator
.amp	AMPL Command File Extension
AMPL	A Mathematical Programming Language
BMP	Best Management Practice
COMID	Common Identifier
CPLEX	Optimizer based on the simplex method as implemented in the C programming language
CSV	Comma Separated Values
.dat	AMPL Data File Extension
DEL_FRAC	Delivery Fraction
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
HRU	Hydrologic Response Unit
HSG	Hydrologic Soil Group
HUC	Hydrologic Unit Code
HUC6	6-digit Hydrologic Unit Code
HUC8	8-digit Hydrologic Unit Code
HUC10	10-digit Hydrologic Unit Code
HUC12	12-digit Hydrologic Unit Code
.mod	AMPL Model File Extension
MS4	Municipal Separate Storm Sewer System
N	Nitrogen
NEOS	Network
NHD	National Hydrography Dataset
NHDPlus	National Hydrography Dataset Plus
NLCD	National Land Cover Dataset
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
ORD	Office of Research and Development
ORISE	Oak Ridge Institute for Science and Education
O&M	Operations & Maintenance
P	Phosphorus
PI	Principal Investigator
R	Programming language
RBEROST	River Basin Export Reduction Optimization Support Tool
RMD	R Markdown File
RShiny	R package providing graphical user interface for user inputs and outputs
SE	Standard Error
SPARROW	Spatially Referenced Regressions On Watershed Attributes

STATSGO2	The Digital General Soil Map of the United States
StreamCat	EPA StreamCatchment Dataset
SWAT	Soil and Water Assessment Tool
SWMM	Stormwater Management Model
TDEP	Total Nitrogen Deposition
TN	Total Nitrogen
TP	Total Phosphorus
USGS	United States Geological Survey
WA	Washington State
WMOST	Watershed Management Optimization Support Tool
WWTP	Wastewater Treatment Plant
XML	Extensible Markup Language

3 Model Framework

The River Basin Export Reduction Optimization Support Tool (RBEROST) is a decision support tool designed to support integrated regional watershed planning. The Pacific model is built upon the framework of the earlier Upper Connecticut RBEROST model. The Pacific model encompasses a series of watersheds surrounding the Puget Sound in the state of Washington. The watersheds incorporated into the model do not extend outside of Washington into adjacent U.S. states, nor into Canada. Data inputs into the model vary by year, and more detailed information about data sources may be found in Table 3-2. The tool is designed to help reduce nutrient loading to targeted waterbodies for the least financial cost. This tool optimizes costs for meeting targets for nutrient export at the annual scale and is designed to be used as a screening tool for large watersheds (e.g., HUC 6 - HUC 8 scale). The tool is mathematically similar to the Watershed Management Optimization Support Tool, or WMOST [*Detenbeck et al.*, 2018a; *Detenbeck et al.*, 2018b]. WMOST is built for optimization at the HUC10 or HUC12 scale and can be run on daily or monthly timesteps. In contrast, RBEROST was developed as a regional screening tool to overcome computational challenges with running WMOST at larger spatial watershed scales. All RBEROST scripts were initially written in R version 4.3.2 and updated under R version 4.4. Please note that execution of the RBEROST application is recommended with RStudio version 2023.12.1 Build 402 “Ocean Storm” and may be incompatible with other versions. The R code and instructions on how to execute the code necessary for these installations are included in the documentation below.

RBEROST allows users to screen which locations and choices of Best Management Practices (BMPs) will meet annual loading targets for the least financial cost. There are three main steps within RBEROST including a preprocessing step, an interaction with an online server, and a postprocessing step (Figure 3-1). Additional work may be necessary before beginning RBEROST to collect and format the necessary data. The preprocessing step combines medium-resolution National Hydrography Dataset Plus (NHDPlus v2; *Dewald et al.* [2019]) reach lengths, NHDPlus v2 catchment-level annual nutrient loading, land use data, hydrologic soil group data, nitrogen (N) deposition data, user-defined loading targets, user-selected agricultural (cropland), grazing land, urban, road, point source and riparian buffer BMPs, and data on BMP-specific costs and nutrient removal efficiencies incorporated in RBEROST input files. The preprocessing step then uses this information to write three program files in A Mathematical Programming Language, or AMPL, including a model, data, and command file (Figure 3-1). The AMPL files describe a model that defines a cost-minimization optimization problem subject to meeting downstream annual loading targets. These files are then sent to a free online CPLEX server hosted by the Network-Enabled Optimization System (NEOS) [*Czyzyk et al.*, 1998; *Dolan*, 2001; *Gropp and Moré*, 1997]. CPLEX is a linear solver that will solve the optimization problem defined by the user inputs of loading targets and selected BMPs for the least cost. Once the solution is optimized, the model outputs its decisions of which BMPs to implement, and where to implement them. The final step of RBEROST is the postprocessing step (Figure 3-1). This step parses the output from NEOS into a summary report describing which BMPs were implemented. It also provides csv files for download that describe the BMP choices on the NHDPlus v2 catchment-level scale.

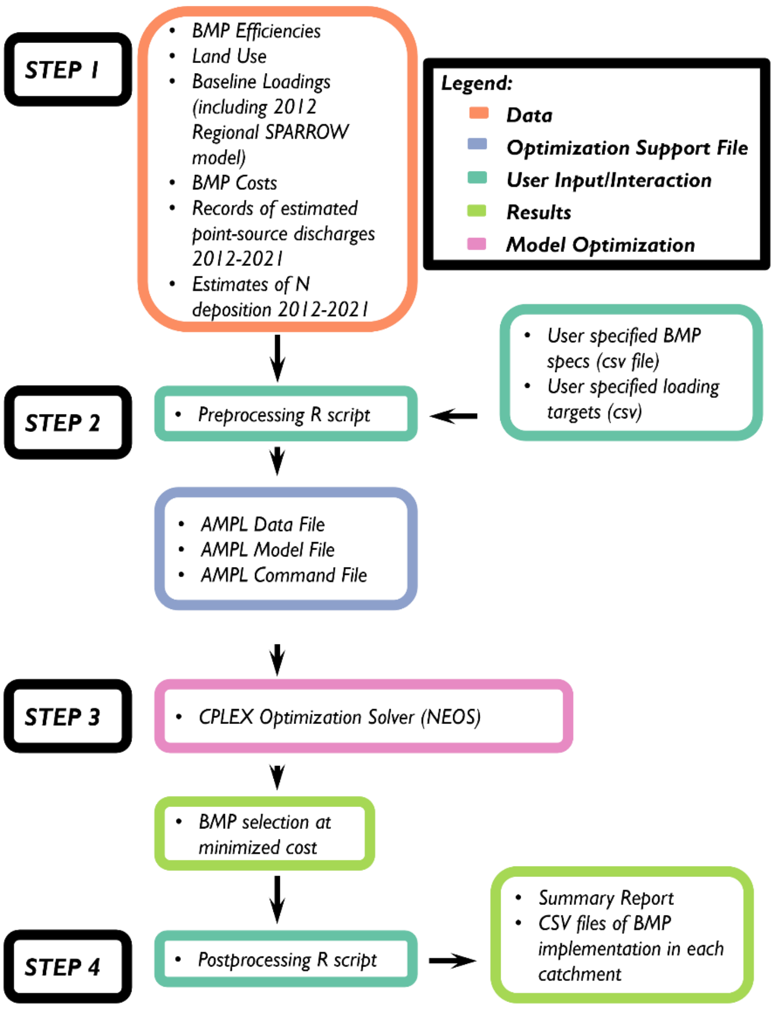


Figure 3-1: Schematic overview of RBEROST, including input data, support files, user determined inputs, result files, and other model components. The preprocessing R script incorporates data from compiled data sets of nutrient loads, land-use, BMP costs and efficiencies, point source loads, and user-selected BMP options and user-specified loading targets to create input files for the user to upload to the NEOS server. The CPLEX optimization solver produces output which describes the least cost management solutions which are formatted by a postprocessing R script in a summary report.

3.1 Optimization Method

RBEROST uses the IBM ILOG CPLEX Optimizer for linear programming that solves a mathematical problem written in AMPL to minimize the total annualized cost of selected BMPs. RBEROST interacts with this solver through the NEOS server, hosted by the University of Wisconsin-Madison. The CPLEX Optimizer was chosen because it accepts XML calls from a program so that RBEROST can interact with it directly, i.e., via the uncertainty module, but users also have the option of manually interacting with the server by submitting input files through the webpage at **https://neos-server.org/neos/solvers/lp:CPLEX/AMPL.html**. Currently, only manual interaction is supported for the main body of the RBEROST program, i.e., users have to submit files to NEOS via the web page.

3.2 Optimization Variables and Constraints

RBEROST includes six categories of BMPs:

1. **Point Source BMPs.** Point source BMP options include 8 different water treatment plant upgrades for 22 facilities to facilitate nutrient removal in wastewater effluent.
2. **Urban BMPs.** Urban BMP options include practices applied to developed land and may serve functions such as increasing evaporation from standing surface water, infiltration of ponded water into soil media, percolation of infiltrated water into groundwater, filtration of particulate matter, denitrification, or outflow through an orifice or weir, among others.
3. **Road BMPs.** Road BMP options include practices applied to roadways to decrease the amount of nutrient pollution infiltration into stormwater by atmospheric deposition and collection in drainages. Options include extended dry detention basins, wet basins, grass swales with under drain, sand filters, various methods of infiltration of rainwater in soil media (trench, basin, chamber), and permeable material use.
4. **Agricultural BMPs.** Agricultural BMP options include practices applied to agricultural cropland and may serve functions such as slowing runoff flow velocities from cropland areas, increasing infiltration into underlying soils, routing runoff through pools and basins, and adjusting fertilizer application or other farming practices to slow and reduce nutrient transport to waterbodies, among others. RBEROST only treats row crop area with agricultural BMPs, and 'ag' throughout the code and documentation refers only to row crop area.
5. **Grazing BMPs.** Currently only one BMP is considered for grazing and pastureland, and that is the installation of off-site water tanks. These tanks provide alternate water supplies to livestock and reduce the amount of time animals spend in the stream.
6. **Riparian Buffer BMPs.** Riparian Buffer BMP options include the conversion of land within riparian areas to either herbaceous/grassed or forested land. Such practices slow water as it approaches the stream or river and increase infiltration. Nutrients may then be removed by plant uptake and soil processes.

RBEROST can consider removal of both total nitrogen (TN) and total phosphorus (TP) simultaneously. Removal of TN and TP contribute to achieving user-defined loading targets, which are applied at the terminal, or furthest downstream, stream reach. Stream reaches are tracked by NHDPlusV2 common identifiers (COMIDs) that are unique to individual stream reaches throughout the model. A single watershed may have one or multiple terminal COMIDs, and each terminal COMID receives water from the reaches upstream from it. Not all terminal COMIDs have targets for both phosphorus and nitrogen, and the number of upstream COMIDs varies.

Table 3-1 summarizes the optimization variables included in the model and their associated constraints. Constraints on the point source BMPs are binary, such that the model chooses to implement or not to implement point source BMPs (in this case, each combination of BMPs is considered separately, though the results presented to the users display the decisions for each individual BMP) based on the associated cost and removal efficiency. Constraints on the urban, grazing, and agricultural BMPs relate to the fraction of each land area that is treated. The model chooses to treat a fraction of urban, pasture, or agricultural land area with each BMP based on the associated cost and removal efficiency; however, the sum of all fractions must be between 0 and 1. No agricultural, grazing, or urban land can be treated by two BMPs. Constraints exist on porous pavement BMPs, as the model will only implement these on roadways and parking lots. Constraints exist on some agricultural BMPs that manipulate tile drainage – these BMPs may only be implemented on tile-drained land. Constraints on riparian buffer BMPs relate to the length (in ft) of stream bank available to be treated, where riparian BMPs can only be implemented on stream lengths that currently have no buffer. Initial conditions for the optimization model reflect current practices, where the selected point source, urban, road, agricultural, grazing, and riparian buffer BMPs have not yet been implemented and the load is set to the baseline annual nutrient load delivered by the upstream reaches to the target waterbodies.

Table 3-1: A summary of RBEROST model variables, constraints, and initial conditions

Optimization Variable Description	Optimization Variable Name in AMPL Model File	Constraint Description	Constraint	Initial Conditions
Point Source BMP	point_dec	Choose whether to implement	Binary (0 or 1). Sum of implementation decisions per catchment <= 1.	0
Per-catchment urban BMP selection	urbanBMP_bin	Choose whether to implement	Binary (0 or 1)	0
Urban BMP fraction	urban_frac	Fraction of urban land treated	Fraction >= User Specified Min * Fraction urban area that is suitable. Fraction <= User Specified Max * Fraction urban area that is suitable. Sum Fractions <= 1. Total area treated per catchment >= 1 acre.	0
Per-catchment agricultural BMP selection	agBMP_bin	Choose whether to implement	Binary (0 or 1)	0
Agricultural BMP fraction	ag_frac	Fraction of row crop land treated	Fraction >= User Specified Min. Fraction <= User Specified Max. Sum Fractions <= 1. Total area treated per catchment >= 1 acre. Sum Fractions for tile drain BMPs <= Fraction cropland that is tile drained.	0
Per-catchment grazing BMP selection	grazBMP_bin	Choose whether to implement	Binary (0 or 1)	0

Optimization Variable Description	Optimization Variable Name in AMPL Model File	Constraint Description	Constraint	Initial Conditions
Grazing BMP fraction	graz_frac	Fraction of pasture land treated	Fraction >= User Specified Min. Fraction <= User Specified Max. Sum Fractions <= 1. Total area treated per catchment >= 1 acre.	0
Riparian Buffer BMP fraction	ripbuf_length	Length of stream reach treated	Length >= 0. Length <= Unbuffered Stream length * User specified max fraction. Removal along all Length <= Riparian loads. Sum all lengths <= total unbuffered bank length	0
Per-catchment road BMP selection	roadBMP_bin	Choose whether to implement	Binary (0 or 1)	0
Road BMP fraction	road_frac	Fraction of road area treated	Fraction >= User specified min fraction. Fraction <= User specified max fraction. Sum fractions <=1. Sum Fractions for pavement BMPs <= Fraction urban area that is roads.	0

3.3 Objective Function

The objective function finds the minimum BMP implementation costs while achieving a reduction in baseline nutrient loadings to the specified targets. Minimized costs are a function of the costs to implement point source, urban, road, agricultural, grazing, and riparian buffer BMPs in the catchments.

$$Cost_{Minimized} = \sum_{i=1}^{p}\left(\sum_{j=1}^{q}\left(Cost_{PointSource,i,j}\right) + \sum_{k=1}^{r}\left(Cost_{Urban,i,k}\right) + \sum_{l=1}^{s}\left(Cost_{Agricultural,i,l}\right) + \sum_{m}^{t}\left(Cost_{Grazing,i,m}\right) + \sum_{n=1}^{u}\left(Cost_{Riparian\ Buffers,i,n}\right) + \sum_{w=1}^{v}\left(Cost_{Roads,i,w}\right)\right) \quad (3.1)$$

In Eq 3.1 and following equations, $i = 1 \ldots p$ are NHDPlus catchments, $j = 1 \ldots q$ are unique combinations of point source BMPs, $k = 1 \ldots r$ are urban BMPs, $l = 1 \ldots s$ are Agricultural BMPs, $m = 1 \ldots t$ are grazing BMPs, $n = 1 \ldots u$ are Riparian Buffer BMPs, and $w = 1 \ldots v$ are road BMPs,. Agricultural/grazing BMP costs are in 2021-2022 USA dollars, urban and road BMPs are in 2020 USA dollars, and point BMP costs are in 2021 USA dollars. Individual parts of Eq. 3.1 are defined below in Eq. 3.2, Eq. 3.3, Eq. 3.4, Eq. 3.5, and Eq. 3.6 .

$$Cost_{PointSource,i,j} = \left(ImplementationDecision_{i,j}\right) * \left(Capital\ Costs_{i,j} + O\&M\ Costs_{i,j}\right) \quad (3.2)$$

$Cost_{PointSource,i,j}$ describes the costs of implementing BMP j in WWTPs. $ImplementationDecision_{i,j}$ is a binary 0-1 that indicates whether a BMP is implemented or not. It is treated as a variable in the optimization problem. $Capital\ Costs_{i,j}$ represent the annualized capital costs of BMP j, and $O\&M\ Costs_{i,j}$ represent the annual operations and maintenance costs of BMP j.

$$Cost_{Urban,i,k} = \left(Urban\ Land\ Area_i\right) * \left(Capital\ Costs_{i,k} + O\&M\ Costs_{i,k}\right) * \left(Fraction\ _{TreatedLand,i,k}\right) \quad (3.3)$$

$Cost_{Urban,i,k}$ describes the cost of treating stormwater runoff from urbanized land in catchment i with stormwater BMP k. $Urban\ Land\ Area_i$ is the area of urbanized land in catchment i (in acres), $Capital\ Costs_{i,k}$ and $O\&M\ Costs_{i,k}$ are annualized capital and annual operations and maintenance costs for urban BMP k respectively. These reflect the weighted average of cost estimates based on land use and soil infiltration characteristics in the catchment. $Fraction_{TreatedLand,I,k}$ ranges 0-1 and is treated as a variable in the optimization problem.

$$Cost_{Agricultural,i,l} = \left(Fraction\ _{TreatedLand,i,l}\right) * \left(Agricultural\ Land\ Area_i\right) * Ag\ Cost\ Adjustment * \left(Capital\ Costs_{i,l} + O\&M\ Costs_{i,l}\right) \quad (3.4)$$

$Cost_{Agricultural,i,l}$ describes the costs of implementing BMP l in row crop agricultural fields. $Fraction\ _{TreatedLand,i,l}$ ranges 0-1 and is treated as a variable in the optimization problem, $Agricultural\ Land\ Area_i$ is the amount of row crop area in catchment i, $Ag\ Cost\ Adjustment$ reflects the difference in Environmental Quality Incentives Program (EQIP) base payments and actual costs of agricultural BMPs, $Capital\ Costs_{i,l}$ represent the annualized capital costs of BMP l, and $O\&M\ Costs_{i,l}$ represent the annual operations and maintenance costs of BMP l.

$$Cost_{Grazing,i,m} = \left(Fraction\ _{TreatedLand,i,m}\right) * \left(Pasture\ Land\ Area_i\right) * Ag\ Cost\ Adjustment * \left(Capital\ Costs_{i,m} + O\&M\ Costs_{i,m}\right) \quad (3.5)$$

$Cost_{Grazing,i,m}$ describes the costs of implementing BMP *m* in pasture fields. $Fraction_{\ TreatedLand,i,m}$ ranges 0-1 and is treated as a variable in the optimization problem, *Pasture Land Area*$_i$ is the amount of pasture area in catchment i, $Ag\ Cost\ Adjustment$ reflects the difference in Environmental Quality Incentives Program (EQIP) base payments and actual costs of agricultural BMPs, *Capital Costs*$_{i,m}$ represent the annualized capital costs of BMP *m*, and *O&M Costs*$_{i,m}$ represent the annual operations and maintenance costs of BMP *m*. Costs may differ by catchment *i* based on state.

$$Cost_{Riparian\ Buffers,i.n} = Length_{\ Treated\ Bank,i,n} * Ag\ Cost\ Adjustment * (Capital\ Costs_{i,n} + O\&M\ Costs_{i,n}) \quad (3.6)$$

Cost$_{Riparian\ Buffers,i,n}$ describes the costs of converting riparian zones into forested or grassed buffers, *Length*$_{TreatedBank,i,n}$ is a variable in the optimization and ranges from 0 ft to twice the length of stream reach (reflecting total bank length in ft) in catchment *i*. *Capital Costs*$_{i,n}$ and *O&M Costs*$_{i,n}$ are base costs from EQIP, and are adjusted with *Ag Cost Adjustment* as in Eqs. 3.4 and 3.5.

$$Cost_{Roads,i,w} = (Road\ Area_i) * \left(Capital\ Costs_{i,w} + O\&M\ Costs_{i,w}\right) * \left(Fraction_{Roads,i,w}\right) \quad (3.7)$$

$Cost_{Roads,i,w}$ describes the cost of treating stormwater runoff from road areas in catchment *i* with stormwater BMP *w*. *Road Area*$_i$ is the area of roads in catchment *i* (in acres), *Capital Costs*$_{i,w}$ and *O&M Costs*$_{i,w}$ are annualized capital and annual operations and maintenance costs for road BMP *k*, respectively. These reflect the weighted average of cost estimates based on land use and soil infiltration characteristics in the catchment. *Fraction*$_{Roads,i,w}$ ranges from 0-1 and is treated as a variable in the optimization problem.

3.4 Optimization Parameters

Table 3-2 summarizes parameters in RBEROST-Pacific and their sources for the Puget Sound case study described later.

Table 3-2: A summary of RBEROST parameters.

Optimization Parameter Description	**Optimization Parameter Name in AMPL Model and Data Files**	**Data Source**
Nitrogen baseline annual average loading data per catchment to each TN target	baseloads_N1…baseloads_Nn	Pacific Regional SPARROW model [*Wise*, 2019] annual average loadings output (pac_sparrow_model_output_tn.txt) modified with pollutant discharge estimates from a report on nitrogen and phosphorus removal at municipal wastewater treatment facilities [*Tetra-Tech*,Inc., 2011] and with N deposition estimates from the National Atmospheric Deposition Program [*National Atmospheric Deposition Program*, 2021]
Phosphorus baseline annual average loading data per catchment to each TP target	baseloads_P1…baseloads_Pn	Pacific Regional SPARROW model [*Wise*, 2019] annual average loadings output (pac_sparrow_model_output_tp.txt) modified with pollutant discharge estimates from a report on nitrogen and phosphorus removal at municipal wastewater treatment facilities [*Tetra Tech*,Inc., 2011]
Total nitrogen load allowed after reduction for all TN targets	loads_lim_N1…loads_lim_Nn	User supplied
Total phosphorus load allowed after reduction for all TP targets	loads_lim_P1…loads_lim_Pn	User supplied
The sum of SPARROW model annual nitrogen average loads delivered to each TN target that are not associated with point sources, urban area, row crop area, or grazing area (e.g., loads from N deposition)	other_loads_N1…other_loads_Nn	Pacific Regional SPARROW model [*Wise*, 2019] average loadings output (pac_sparrow_model_output_tn.txt) modified with N depositional data from the National Atmospheric Deposition Program [*National Atmospheric Deposition Program*, 2021]

Optimization Parameter Description	Optimization Parameter Name in AMPL Model and Data Files	Data Source
The sum of SPARROW model annual phosphorus average loads delivered to each TP target that are not associated with point sources, urban area, row crop area, or grazing area (e.g., loads channel mobilization)	other_loads_P1…other_loads_Pn	Pacific Regional SPARROW model [*Wise*, 2019] annual average loadings output (pac_sparrow_model_output_tp.txt)
Available urban and row crop area per catchment	area	Urban area: Pacific Regional SPARROW Model [*Wise*, 2019] input data (pac_sparrow_model_input.txt) - "developed11_km2" field proportioned by hydrologic soil group: gNATSGO and SSURGO [*Soil Survey Staff et al.*, 2022a,b] Row crop/Agricultural area: Percent cropland data from the 2011 NLCD database (catchment-specific data per state downloaded from StreamCat; [*Hill et al.*, 2016]) - "PctCrop2011Cat" field. Percent pasture data from the 2011 NLCD database (catchment-specific data per state downloaded from StreamCat; [*Hill et al.*, 2016]) - "PctHay2011Cat" field.
Capital costs associated with implementing wastewater treatment plant retrofits for nutrient removal	point_costs_capital	Tetra Tech report for Washington Ecology [*Markus et al.*, 2011]
Operations costs associated with implementing wastewater treatment plant retrofits for nutrient removal	point_costs_operations	Tetra Tech report for Washington Ecology [*Markus et al.*, 2011]

Optimization Parameter Description	Optimization Parameter Name in AMPL Model and Data Files	Data Source
WWTP-specific nitrogen removal efficiency	point_effic_N	Tetra Tech report for Washington Ecology [*Markus et al.*, 2011]
WWTP-specific phosphorus removal efficiency	point_effic_P	Tetra Tech report for Washington Ecology [*Markus et al.*, 2011]
Percent of Urban land that is suitable for BMP implementation.	urban_bmp_implementationpotential	The urban BMP matrix is currently all set to 1.[1]
Weighted capital costs associated with implementing urban BMPs	urban_costs_capital	Calculated by EPA based on following tools and sources, updated to 2020 $: Puget Sound Database, [*Herrera Environmental Consultants*, 2012], Opti-Tool [*Mateleska*, 2016], National Stormwater Calculator [*RTI International and Geosyntec Consultants*, 2015], BMP and LID Whole Life Cost Models Version 2.0 [*WERF*, 2009]
Weighted maintenance costs associated with implementing urban BMPs	urban_costs_operations	Calculated by EPA based on following tools and sources, updated to current $: Puget Sound Database [*Herrera Environmental Consultants*, 2012], Opti-Tool [*Mateleska*, 2016], National Stormwater Calculator [*RTI International and Geosyntec Consultants*, 2015], BMP and LID Whole Life Cost Models Version 2.0 [*WERF*, 2009]

[1] Future RBEROST development may include the ability for users to further limit the available urban area suitable for BMP implementation based on site-specific knowledge.

Optimization Parameter Description	**Optimization Parameter Name in AMPL Model and Data Files**	**Data Source**
Urban nitrogen removal efficiency per BMP option and catchment	urban_effic_N	Estimated by EPA using WMOST supplemented by information from the following sources WMOST [*Detenbeck et al.*, 2018a], SWAT [*Arnold et al.*, 2012], Stormwater Best Management Practice Simplified Sizing Tool [*Herrera Environmental Consultants*, 2010], [*Tetra-Tech, Inc.*, 2015], National Stormwater Calculator [*Rossman and Bernagros*, 2019]
Urban phosphorus removal efficiency per BMP option and catchment	urban_effic_P	Estimated by EPA using WMOST supplemented by information from the following sources WMOST [*Detenbeck et al.*, 2018a], SWAT [*Arnold et al.*, 2012], Stormwater Best Management Practice Simplified Sizing Tool [*Herrera Environmental Consultants*, 2010], [*Tetra-Tech, Inc.*, 2015], National Stormwater Calculator [*Rossman and Bernagros*, 2019]
Parameter to ensure that urban BMPs are implemented on at least some minimum acreage if implemented. Currently set to 1.	urbanBMP_minarea	Not applicable
Minimum allowed percent implementation of urban BMPs per catchment	urban_frac_min	User supplied
Maximum allowed percent implementation of urban BMPs per catchment	urban_frac_max	User supplied

Optimization Parameter Description	Optimization Parameter Name in AMPL Model and Data Files	Data Source
Percent of Agricultural land (cropland) that is suitable for BMP implementation. Tile drainage adjustment is only implemented if the "Drainage Management" BMP is selected. While other Ag BMPs can be applied anywhere, the "Drainage Management" BMP can only be applied on tile drained land.	ag_bmp_implementationpotential	Tile drain grids estimated by *Valayamkunnath et al.* [2020], summarized by NHD plus v2 catchment [*Dewald et al.*, 2019], and compared to StreamCat cropland values [*Hill et al.*, 2016]
Capital costs associated with implementing agricultural rowcrop BMPs	ag_costs_capital	U.S. Department of Agriculture; Environmental Quality Incentives Program state-by-state cost sheets from 2021 [*U.S. Department of Agriculture Staff*, 2021].
Operations and maintenance costs associated with implementing agricultural rowcrop BMPs	ag_costs_operations	U.S. Department of Agriculture; Environmental Quality Incentives Program state-by-state cost sheets from 2021 [*U.S. Department of Agriculture Staff*, 2021].
Agricultural nitrogen removal efficiency per BMP option and HUC12	ag_effic_N	"Grade_Stabilization" BMP: [*Waidler et al.*, 2009] "Diversion" BMP: [*Waidler et al.*, 2009] "Cover_Crops" BMP: [*Christianson et al.*, 2021] "Drainage_Management" BMP: [*Ross et al.*, 2016] "Manure_Injection" BMP: [*Dell et al.*, 2016] for methodology and [*Lund et al.*, 2014] for N loss pathways. Remaining agricultural BMPs: Efficiencies summarized by HUC12 (or if unavailable, HUC10, HUC8, and/or HUC6) based on ACRE database [*White et al.*, 2019]

Optimization Parameter Description	**Optimization Parameter Name in AMPL Model and Data Files**	**Data Source**
Agricultural phosphorus removal efficiency per BMP option and HUC12	ag_effic_P	“Grade_Stabilization” BMP: [*Waidler et al.*, 2009] “Diversion” BMP: [*Waidler et al.*, 2009] “Cover_Crops” BMP: [*Christianson et al.*, 2021] “Drainage_Management” BMP: [*Ross et al.*, 2016] “Manure_Injection” BMP: [*Dell et al.*, 2016] for methodology and [*Lund et al.*, 2014] for N loss pathways. Remaining agricultural BMPs: Efficiencies summarized by HUC12 (or if unavailable, HUC10, HUC8, and/or HUC6) based on ACRE database [*White et al.*, 2019]
Agricultural BMP costs reflected in ag_costs represent base payment costs (75% of actual costs). The agcost_frac parameter reflects 100% of costs (100/75 = 1.33).	agcost_frac	Correspondence with EPA and NRCS state conservationist for Washington
Parameter to ensure that agricultural BMPs are implemented on at least some minimum acreage if implemented. Currently set to 1.	agBMP_minarea	Not applicable
Minimum allowed percent implementation of agricultural BMPs per catchment	ag_frac_min	User supplied
Maximum allowed percent implementation of agricultural BMPs per catchment	ag_frac_max	User supplied

Optimization Parameter Description	**Optimization Parameter Name in AMPL Model and Data Files**	**Data Source**
Capital costs associated with implementing grazing BMPs	graz_costs_capital	U.S. Department of Agriculture; Environmental Quality Incentives Program state-by-state cost sheets from 2021 [*U.S. Department of Agriculture Staff*, 2021].
Operations and maintenance costs associated with implementing grazing BMPs	graz_costs_operations	U.S. Department of Agriculture; Environmental Quality Incentives Program state-by-state cost sheets from 2021 [*U.S. Department of Agriculture Staff*, 2021].
Grazing nitrogen removal efficiency per BMP option	graz_effic_N	[*Franklin et al.*, 2009; *Sheffield et al.*, 1997]
Grazing phosphorus removal efficiency per BMP option and HUC12	graz_effic_P	[*Franklin et al.*, 2009; *Sheffield et al.*, 1997]
Parameter to ensure that grazing BMPs are implemented on at least some minimum acreage if implemented. Currently set to 1.	grazBMP_minarea	Not applicable
Minimum allowed percent implementation of grazing BMPs per catchment	graz_frac_min	User supplied
Maximum allowed percent implementation of grazing BMPs per catchment	graz_frac_max	User supplied

Optimization Parameter Description	Optimization Parameter Name in AMPL Model and Data Files	Data Source
Nitrogen baseline annual riparian loading data per catchment to each TN target	riparianload_N1…riparianload_Nn	Methodology from Pollutant Removal Credits for Buffer Restoration in MS4 Permits Final Panel Report [*Houle et al.*, 2019] using land cover data from the National Landcover Database [*Jin et al.*, 2019; *Yang et al.*, 2018] and river reach shape files from NHDPlus V2 [*Dewald et al.*, 2019]. The methodology was expanded to consider nutrient inputs from cropland– these inputs were estimated to include all cropland inputs from the SPARROW models [*Wise*, 2019]
Phosphorus baseline annual riparian loading data per catchment to each TP target	riparianload_P1…riparianload_Pn	Methodology from Pollutant Removal Credits for Buffer Restoration in MS4 Permits Final Panel Report [*Houle et al.*, 2019] using land cover data from the National Landcover Database [*Jin et al.*, 2019; *Yang et al.*, 2018] and river reach shape files from NHDPlus V2 [*Dewald et al.*, 2019]. The methodology was expanded to consider nutrient inputs from cropland and grazing – these inputs were estimated to include all cropland and grazing inputs from the SPARROW models [*Wise*, 2019]
Length of streambank that is not already buffered per catchment	unbuffered_banklength	Land cover data from the National Landcover Database [*Jin et al.*, 2019; *Yang et al.*, 2018] and river reach shape files from NHDPlus V2 [*Dewald et al.*, 2019]
Total stream bank length (2 x reach length) per catchment	total_banklength	River reach shape files from NHDPlus V2 [*Dewald et al.*, 2019] and reported by the Pacific SPARROW model [*Wise*, 2019]

Optimization Parameter Description	Optimization Parameter Name in AMPL Model and Data Files	Data Source
Capital costs associated with implementing riparian buffer BMPs	ripbuf_costs_capital	U.S. Department of Agriculture; Environmental Quality Incentives Program state-by-state cost sheets from 2021 [*U.S. Department of Agriculture Staff*, 2021].
Operations and maintenance costs associated with implementing riparian buffer BMPs	ripbuf_costs_operations	U.S. Department of Agriculture; Environmental Quality Incentives Program state-by-state cost sheets from 2021 [*U.S. Department of Agriculture Staff*, 2021].
Total nitrogen removal by riparian buffers per catchment for each TN target	riparianremoval_N1…riparianremoval_Nn	Annual removal rates are a function of riparian loading and nutrient removal efficiency of riparian buffers. Loading is dependent on the amount of urbanized land within a 400 ft riparian zone and the amount of grazing and row crop N inputs in the catchment. Efficiency is dependent on slope and hydrologic soil group [*Houle et al.*, 2019]. Land cover data from the National Landcover Database [*Jin et al.*, 2019; *Yang et al.*, 2018]. Agricultural and Grazing inputs from SPARROW [*Wise*, 2019]. River reach shape files from NHDPlus V2 [*Dewald et al.*, 2019] Hydrologic soil group: STATSGO2 [*Soil Survey Staff et al.*, 2021] Slope data from Hydrologic Derivatives for Modeling and Analysis by the USGS [*Verdin*, 2017]

Optimization Parameter Description	**Optimization Parameter Name in AMPL Model and Data Files**	**Data Source**
Total phosphorus removal by riparian buffers per catchment for each TP target	riparianremoval_P1…riparianremoval_Pn	Annual removal rates are a function of riparian loading and nutrient removal efficiency of riparian buffers. Loading is dependent on the amount of urbanized land within a 400 ft riparian zone and the amount of grazing and row crop P inputs in the catchment. Efficiency is dependent on slope and hydrologic soil group [*Houle et al.*, 2019]. Land cover data from the National Landcover Database [*Jin et al.*, 2019; *Yang et al.*, 2018]. Agricultural and Grazing inputs from SPARROW [*Wise*, 2019]. River reach shape files from NHDPlus V2 [*Dewald et al.*, 2019] Hydrologic soil group: STATSGO2 [*Soil Survey Staff et al.*, 2021] Slope data from Hydrologic Derivatives for Modeling and Analysis by the USGS [*Verdin*, 2017]
Minimum allowed percent implementation of riparian buffer BMPs per catchment	ripbuf_frac_min	User supplied
Maximum allowed percent implementation of riparian buffer BMPs per catchment	ripbuf_frac_max	User supplied
Crosswalk of COMIDs available for urban BMP implementation. This parameter enables only urban areas of each COMID to be selected.	urban_comid_xwalk	Based upon information from NHDPlus V2 [*Dewald et al.*, 2019] and NLCD StreamCat [*Hill et al.*, 2016].

Optimization Parameter Description	**Optimization Parameter Name in AMPL Model and Data Files**	**Data Source**
Crosswalk of COMIDs available for road BMP implementation. This parameter enables only road areas of each COMID to be selected.	road_comid_xwalk	Based upon information from NHDPlus V2 [*Dewald et al.*, 2019] and NLCD Impervious Descriptors [*Yang et al.*, 2018]
Available urban area per catchment	urban_area	Urban area: Pacific Regional SPARROW Model [*Wise*, 2019] input data (pac_sparrow_model_input.txt) - “developed11_km2” field proportioned by hydrologic soil group: STATSGO2 [*Soil Survey Staff et al.*, 2021]
Available road area per catchment	road_area	Percent road area derived from 2016 NLCD Imperviousness Descriptors [*Yang et al.*, 2018]
Nitrogen removal efficiency per road BMP option	road_effic_N	Estimated using WMOST supplemented by information from the following sources WMOST [*Detenbeck et al.*, 2018a], SWAT [*Arnold et al.*, 2012], Stormwater Best Management Practice Simplified Sizing Tool [*Herrera Environmental Consultants*, 2010], [*Tetra-Tech, Inc.*, 2015], National Stormwater Calculator [*Rossman and Bernagros*, 2019]
Phosphorus removal efficiency per road BMP option	road_effic_P	Estimated using WMOST supplemented by information from the following sources WMOST [*Detenbeck et al.*, 2018a], SWAT [*Arnold et al.*, 2012], Stormwater Best Management Practice Simplified Sizing Tool [*Herrera Environmental Consultants*, 2010], [*Tetra-Tech, Inc.*, 2015], National Stormwater Calculator [*Rossman and Bernagros*, 2019]

Optimization Parameter Description	Optimization Parameter Name in AMPL Model and Data Files	Data Source
Capital costs associated with implementation of road BMPs	road_costs_capital	Calculated based on following sources, updated to current $: [*Herrera Environmental Consultants*, 2012], Opti-Tool [*Mateleska*, 2016], National Stormwater Calculator [*RTI International and Geosyntec Consultants*, 2015], BMP and LID Whole Life Cost Models Version 2.0 [*WERF*, 2009]
Operations and maintenance costs associated with implementation of road BMPs	road_costs_operations	Calculated based on following sources, updated to 2020 $: [*Herrera Environmental Consultants*, 2012], Opti-Tool [*Mateleska*, 2016], National Stormwater Calculator [*RTI International and Geosyntec Consultants*, 2015], BMP and LID Whole Life Cost Models Version 2.0 [*WERF*, 2009]
Minimum allowed percent implementation of road BMPs per catchment	road_frac_min	User supplied
Maximum allowed percent implementation of road BMPs per catchment	road_frac_max	User supplied

4 Model Use

The RBEROST Pacific model was initially developed in R version 4.3.2 and updated under R version 4.4. The model can be run through RStudio. RBEROST was developed with RStudio version 2023.12.1 Build 402 “Ocean Storm”. To run RBEROST, the user first defines specifications, including the load reduction targets and the potential BMPs to be considered for the optimization model. The user specifications are then run through the R preprocessing code, which develops and formats the AMPL files required to run the optimization on the NEOS server. The user uploads the AMPL files to the NEOS server and accesses the optimization results using information that is e-mailed to the user. Finally, the user runs the R postprocessing code to summarize results of the NEOS optimization. Figure 4-1 summarizes this workflow.

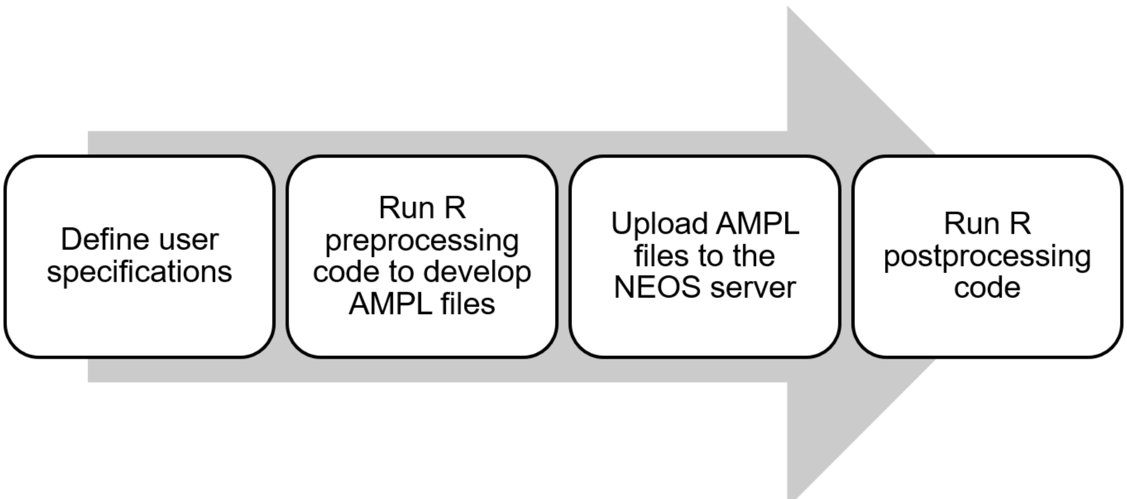


Figure 4-1: User workflow of RBEROST.

4.1 Getting Started

Users can either download or clone the GitHub repository containing the Pacific RBEROST files required for preprocessing (creation of AMPL files) and postprocessing (viewing of NEOS optimization results) to their local drive. It is necessary for the file structure of the zip file as well as naming conventions for Preprocessing inputs and R files to be maintained. Due to the large size of some of the supporting files, github will only include placeholders for the larger files if the zip file is downloaded. Instead, to clone the Pacific RBEROST GitHub repository, navigate to the GitHub webpage for the model. On the GitHub page, find the green “`< > Code`” button and select it as shown in Figure 4-2. A small window will appear and display a URL as well as other information. Select the icon to the right of the URL to copy the URL (Figure 4-3). Next, open RStudio and select “`New Project`” under the “`File`” tab at the top left portion of the window as shown in Figure 4-4. A window will appear that shows several ways to create a new project. Select the “`Version Control`” option (Figure 4-5). Next, select the “`Git`” option that appears in the subsequent window (Figure 4-6). The next window that appears will contain a space to insert the URL copied from the GitHub webpage. Next, name the file as you wish and select a workspace on your device to save the cloned version of the repository. This will create a cloned version of the repository in the selected workspace on your device. Figure 4-7 shows where to paste the GitHub repository URL, as well as where to add a name for your repository and select a location on your device for the RBEROST files.

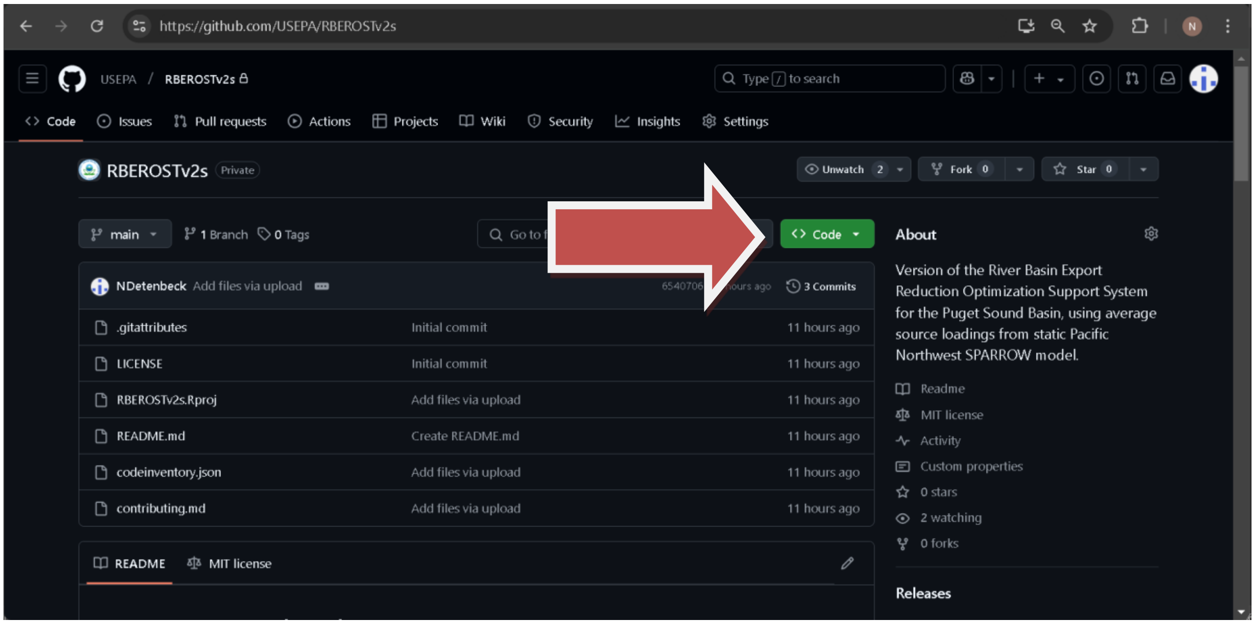


Figure 4-2: Initial step to clone RBEROST repository from GitHub webpage.

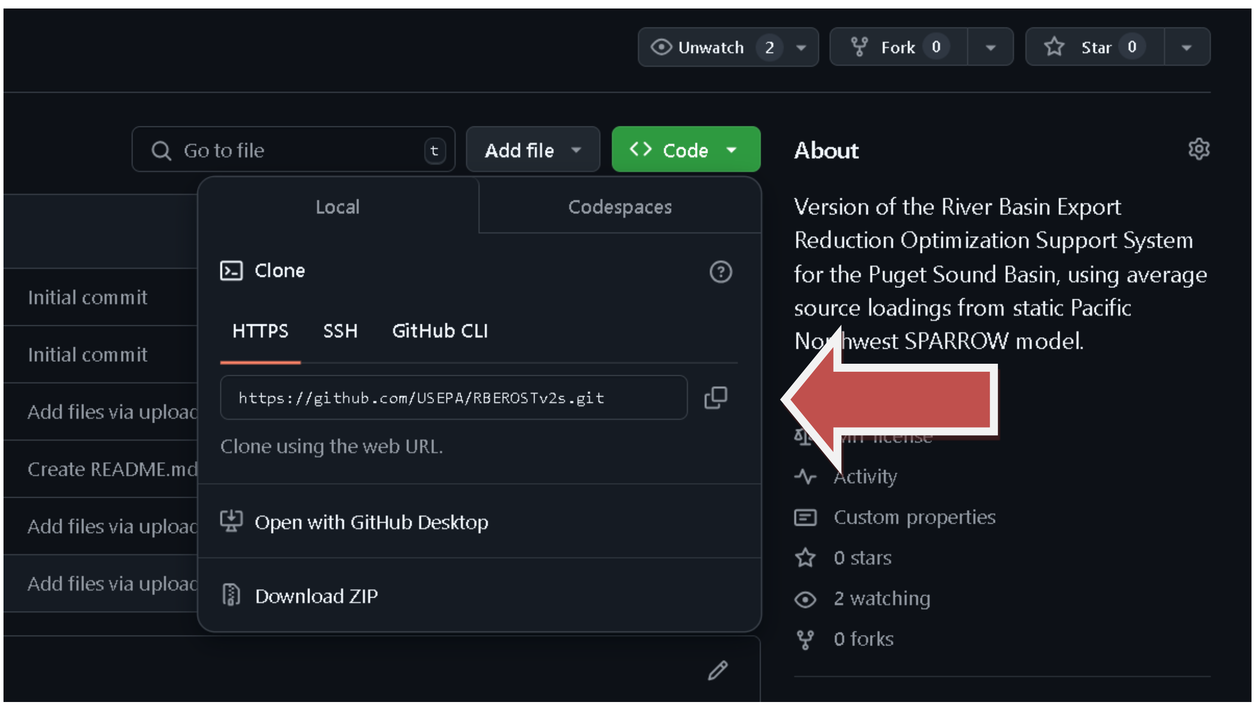


Figure 4-3: Subsequent step to clone RBEROST repository from GitHub webpage.

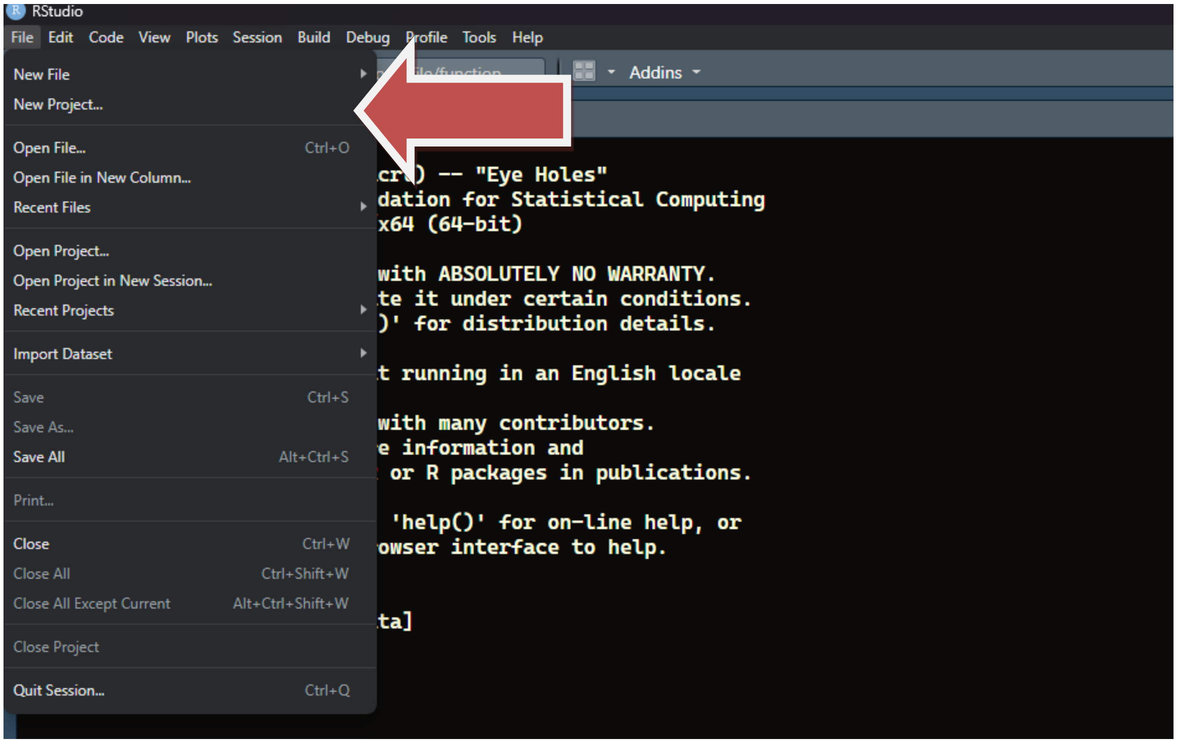


Figure 4-4: Initial step to clone RBEROST repository in RStudio.

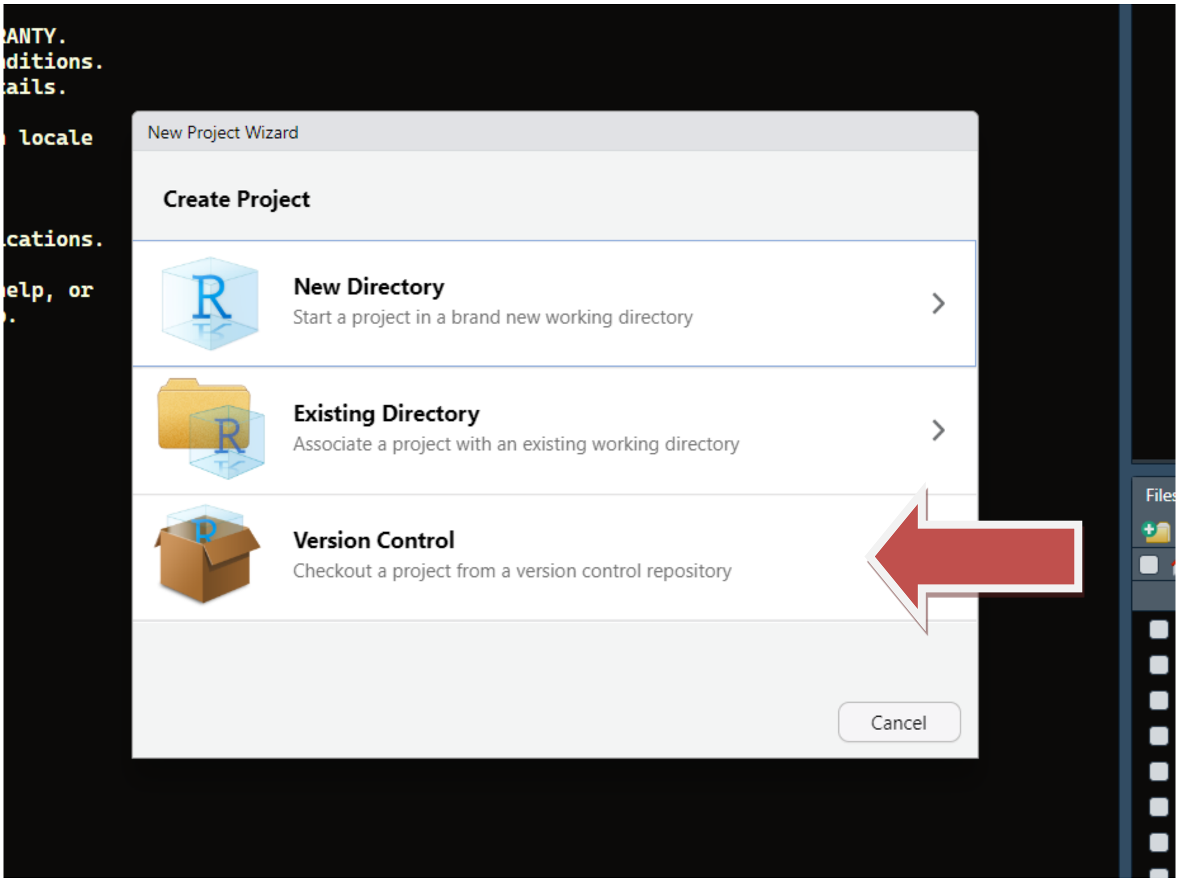


Figure 4-5: Subsequent step to clone RBEROST repository in RStudio.

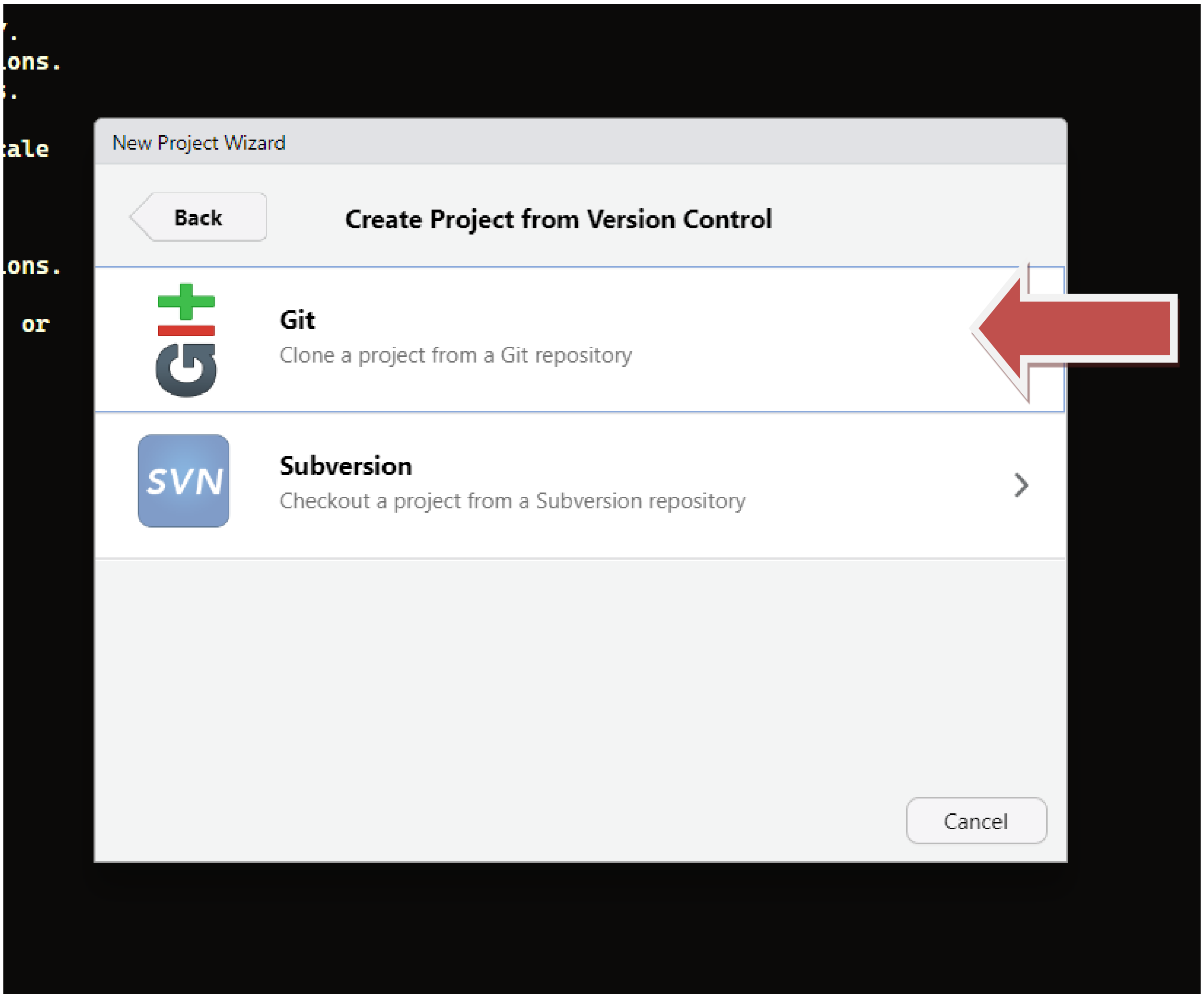


Figure 4-6: Additional subsequent step to clone RBEROST repository in RStudio.

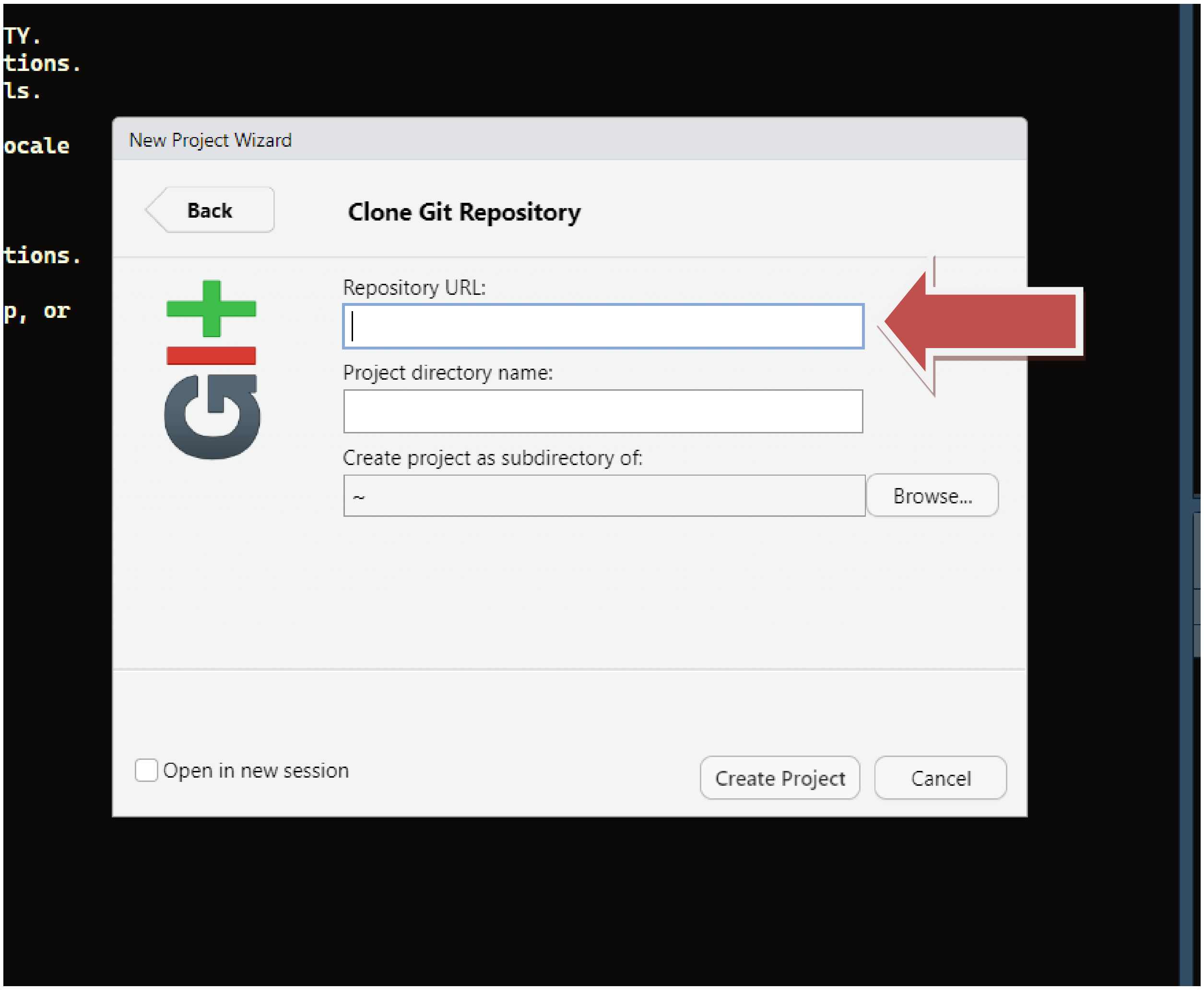


Figure 4-7: Final step to clone RBEROST repository in RStudio.

For the default pathways in RBEROST to work, you will need to open the model via the `RBEROST.Rproj` file. Double click the file in File Explorer to open the project in RStudio. Figure 4-8 shows the file in the unzipped folder. The project should open in RStudio, and the files can be seen on the bottom right. RBEROST can be executed through the `RunRBEROST-Pacific.Rmd` file, which is opened by clicking on it in the `Files` pane of RStudio (Figure 4-9).

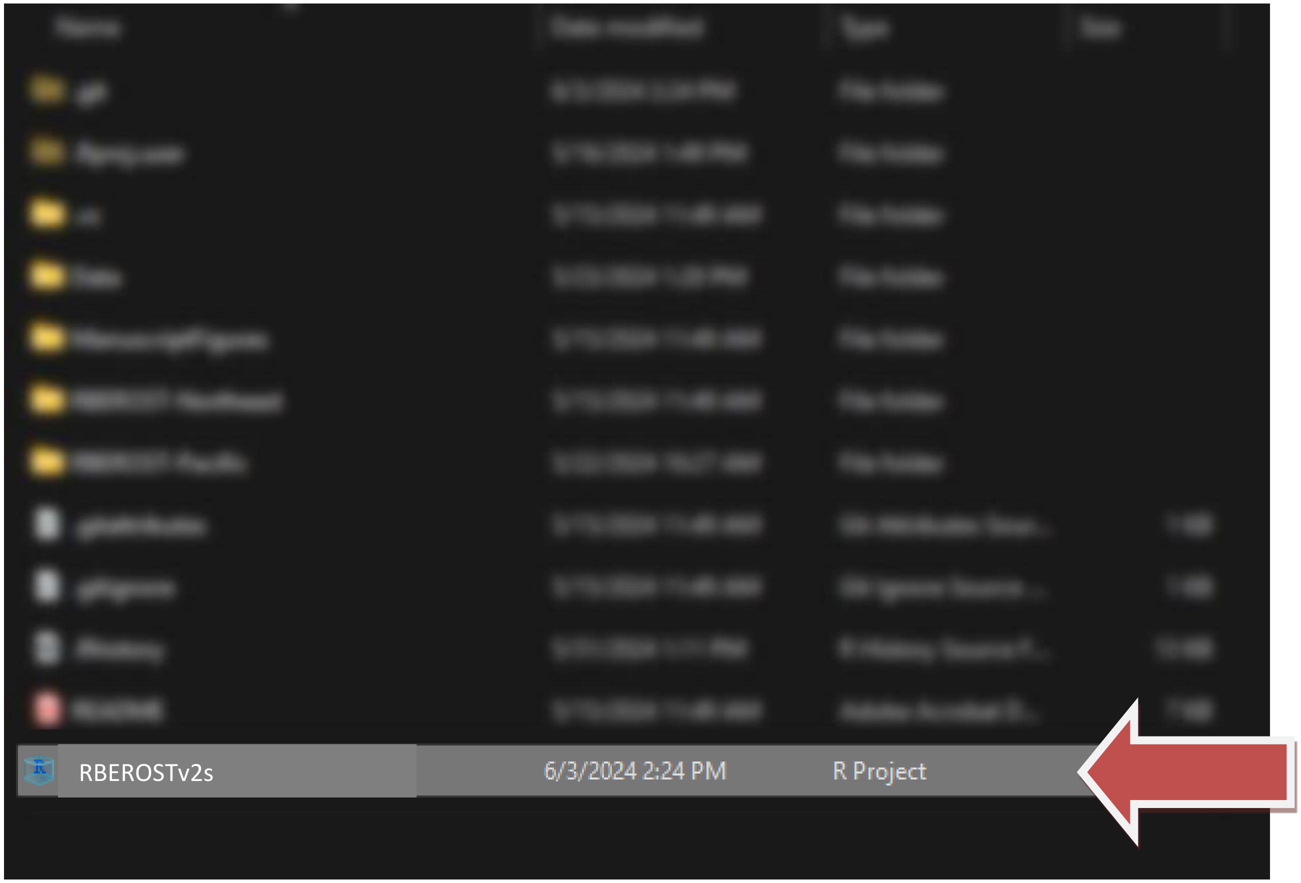


Figure 4-8: RBEROST R Project file.

The folder structure includes R scripts to preprocess the data and postprocess optimization results. All files are accessed through the `RunRBEROST-Pacific.Rmd` file. `RunRBEROST-Pacific.Rmd` will source the necessary scripts to run each part of RBEROST. Scripts used in RBEROST are in the `./R` folder, where `./` refers to the file path of the unzipped folder. All scripts must retain their location and naming to be called by RBEROST. Changing the location of individual files within their folder structure will not allow RBEROST to run properly. Files include:

1) `Optimization_HelperFunctions-Pacific.R` which includes functions used in RBEROST,

2) `01_Optimization_Preprocessing_gateway-Pacific.R` that routes RBEROST to preprocessing either with or without uncertainty,

3) `01_Optimization_Preprocessing-Pacific.R` which creates AMPL files without uncertainty, and

4) `01_Optimization_Preprocessing+Uncertainty-Pacific.R` which creates AMPL files with uncertainty.

The RBEROST-Pacific model currently supports the use of versions both with and without uncertainty. R scripts for the postprocessor include `02_Optimization_RunShiny.R` which sources the `Optimization_ServerFile-Pacific.R`, `Optimization_ServerFunctions_Postprocessor-Pacific.R`, `Optimization_UserInterfaceFile-Pacific.R`, and `Optimization_UI_Postprocessor-Pacific.R` files to build the RShiny application. Users should be aware that parallelization of the RBEROST process is possible but is not implemented in the current version. However, users may pursue implementing parallelization on their own to increase the speed of the model.

RBEROST relies on several R packages to run. The application was developed with tidyverse 2.0.0, reshape2 1.4.4, data.table 1.15.4, stringr 1.5.1, foreach 1.5.2, shiny 1.8.1.1, shinycssloaders 1.0.0, tidygraph 1.3.1, and bit64 4.0.5. If these packages are already installed, it is recommended to update them prior to running RBEROST. RBEROST provides the code necessary to install and/or update all packages in the `RunRBEROST-Pacific.Rmd` file. This code will only need to be run once, the first time that RBEROST is opened, by clicking the green triangle ("run current chunk") on the first code chunk (indicated by the red arrow in Figure 4-10). While the code is running, the green triangle will change to a red square (Figure 4-11). The icon will change back to a green triangle when the code is finished. During the R package installation, you may be prompted with a question "Do you want to install from sources the package which needs compilation?" (Figure 4-12). Select "Yes."

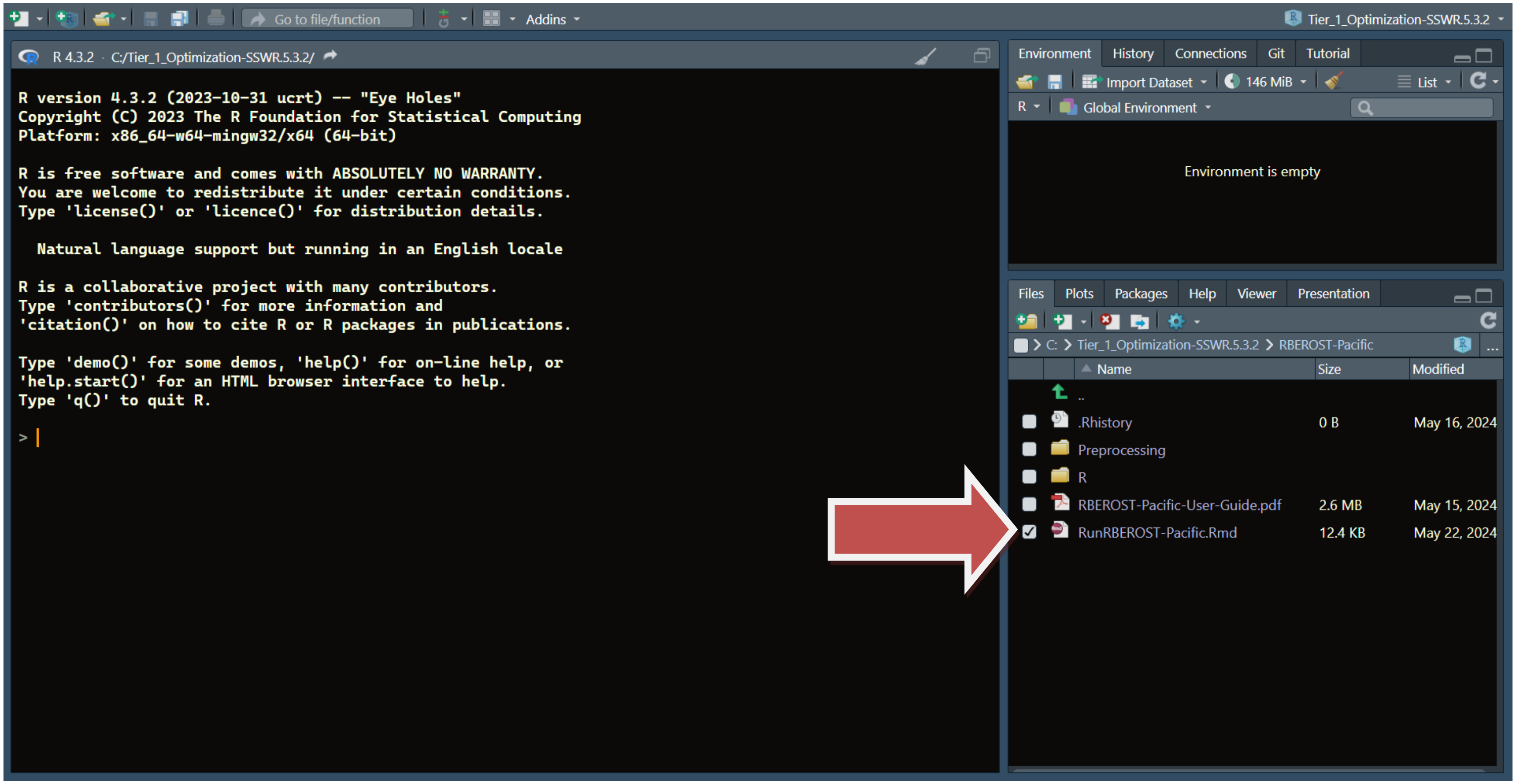


Figure 4-9: Where to find the file 'RunRBEROST.Rmd' to open RBEROST though RStudio.

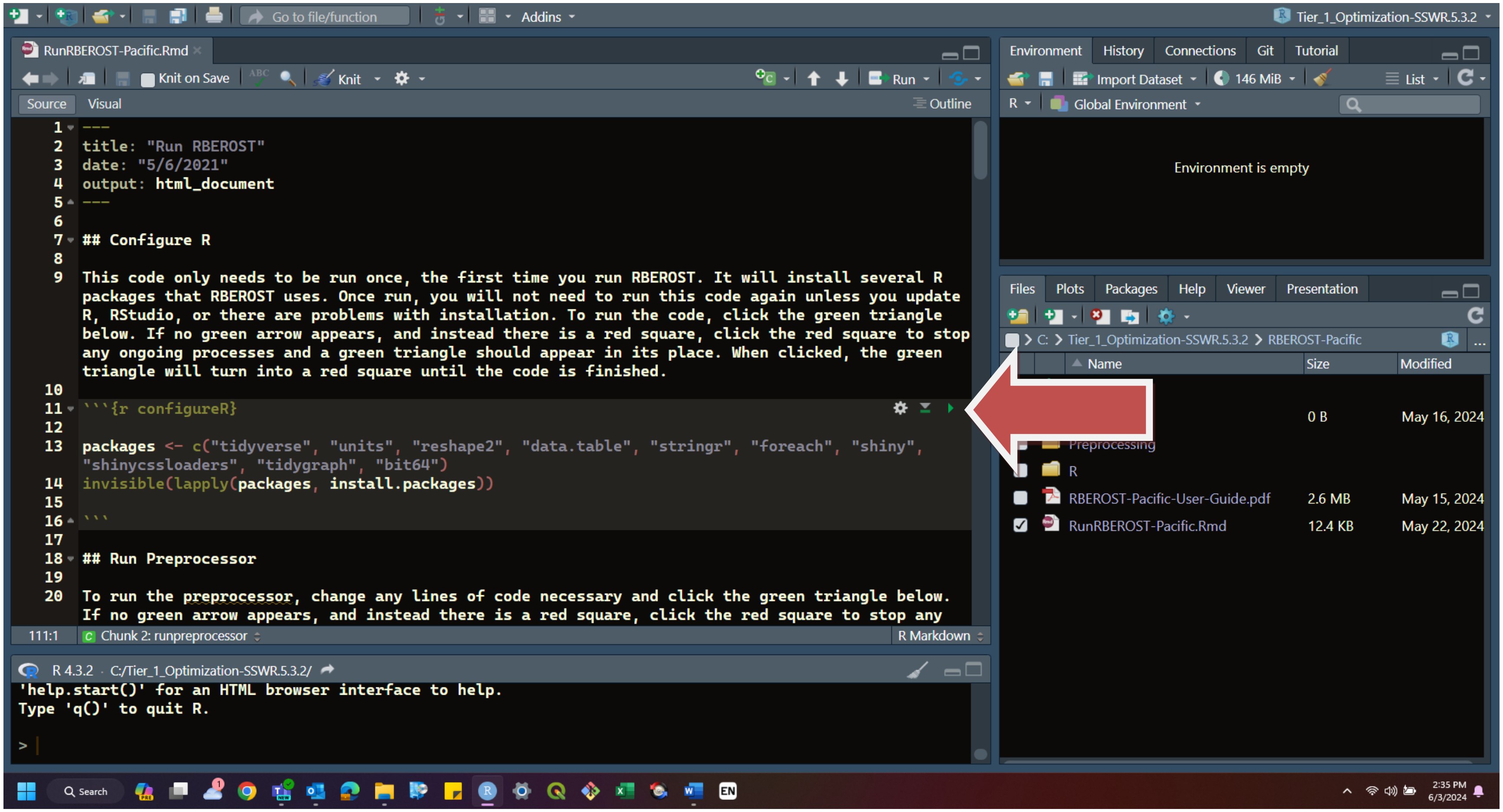


Figure 4-10: Run the package installation code chunk when RBEROST is opened for the first time.

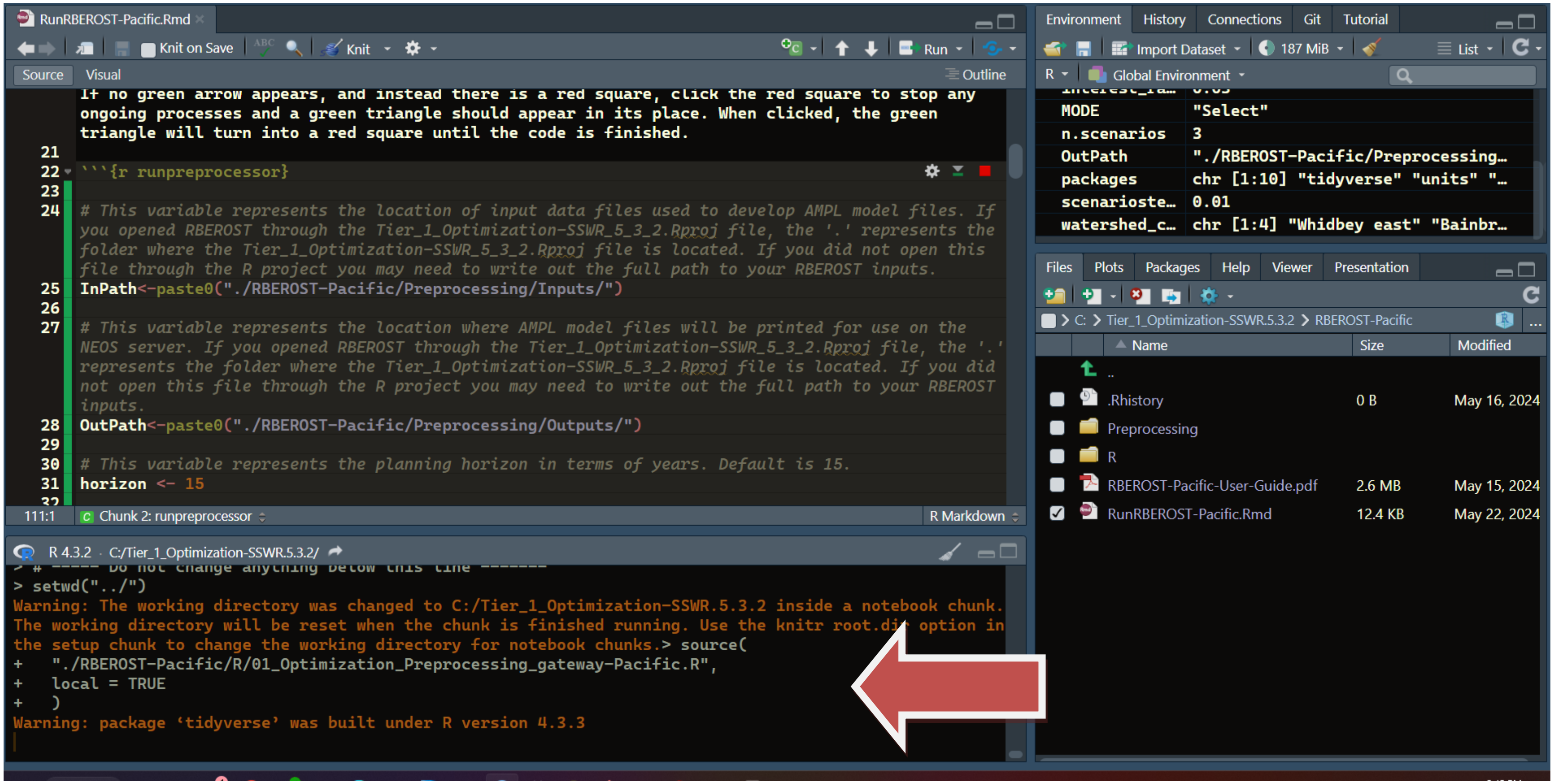


Figure 4-11: An image of what RStudio displays while the code chunk is running.

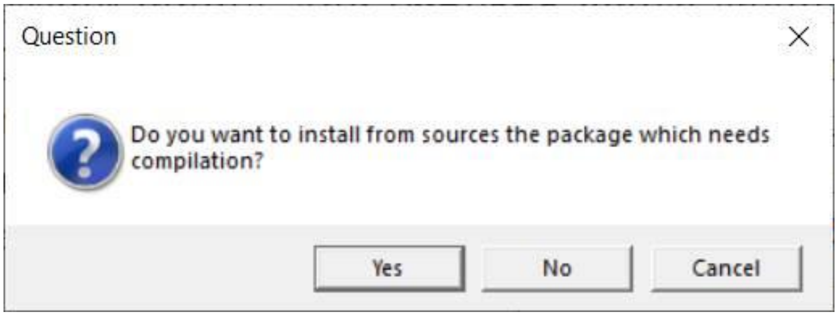


Figure 4-12: A message users may encounter while installing packages.

4.2 Preprocessing

This section details the steps required to develop the AMPL model files that are run through the NEOS server to solve the optimization. The user is required to update the Run Preprocessor section of the code in `RunRBEROST-Pacific.Rmd` as well as the two UserSpecs csv files `01_UserSpecs_BMPs.csv` and `01_UserSpecs_loadingtargets.csv`, which are in the `./RBEROST-Pacific/Preprocessing/Inputs` folder (Figure 4-13). To run the preprocessing step, first edit the UserSpecs files and the available options within `RunRBEROST-Pacific.Rmd`. A more detailed description of the various options available to the user in the `RunRBEROST-Pacific.Rmd` file is available in section 4.2.1. Users may also choose to alter various UserSpec files, such as **01_UserSpec_BMPs.csv**, to better suit their objectives and additional data. Sections 4.2.1 and 4.2.2 as well as Appendix A – Additional Information about Urban and Road BMP Costs and Efficiencies contain additional information on how users may modify files to create their own optimization runs. Once input files and options have been determined, click the green triangle in the upper right of the preprocessing code chunk. The green triangle will turn into a red square until the code is done running, at which point the red square will return to a green triangle. Users may encounter warning messages when running the preprocessor that displays messages about the creation of NA values. These warning messages do not reflect errors in the data and are normal occurrences that may happen when running the preprocessor code.

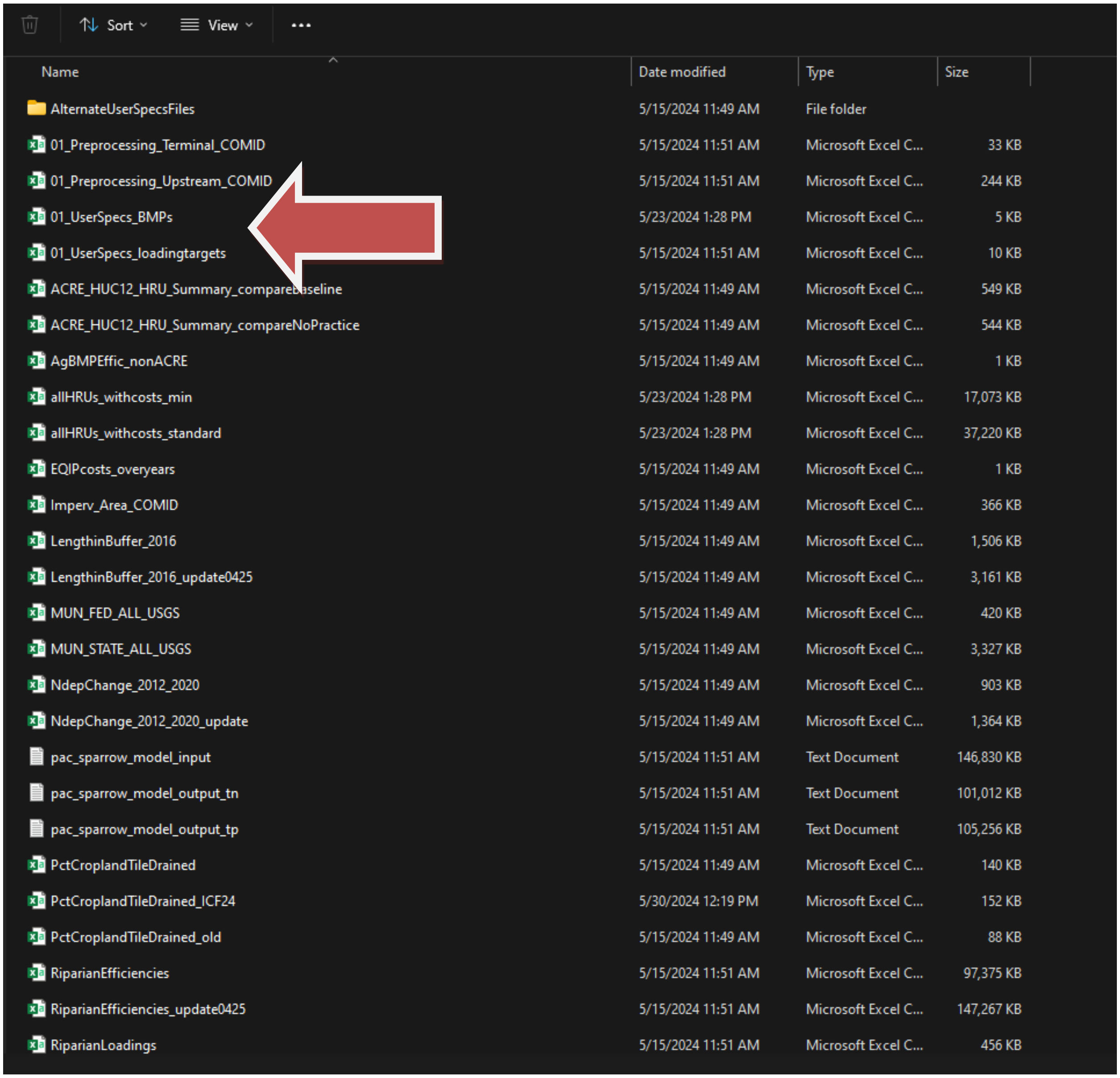


Figure 4-13: Location of the 2 User Specification csv files used in RBEROST.

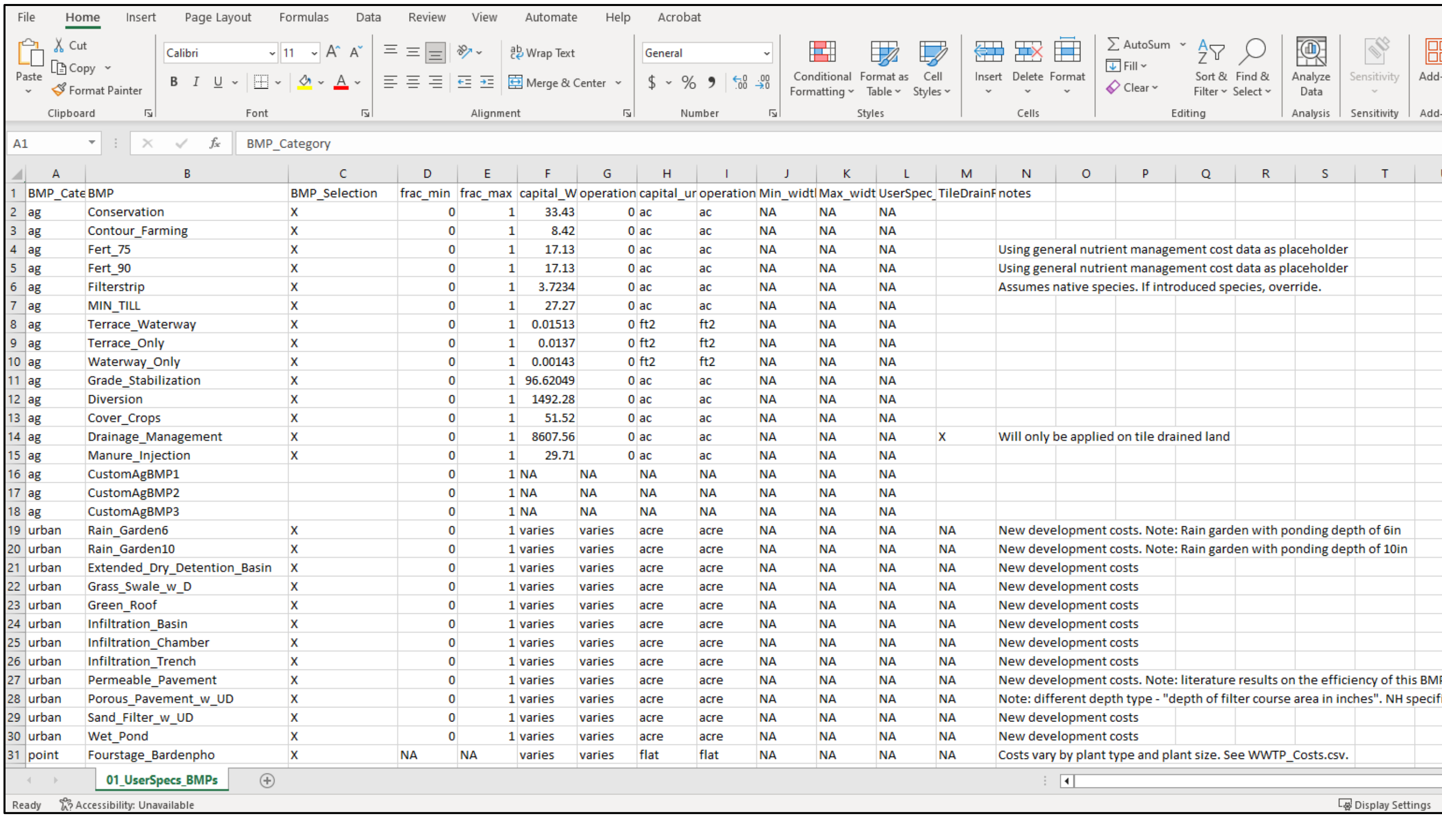
4.2.1 User Specifications

There are ten parameters that users can change in the `RunRBEROST-Pacific.Rmd` file. (See data dictionary in Appendix D.) These include `InPath`, which should point to the folder with the Preprocessing inputs, and `OutPath` which should point to the folder that the AMPL files will be written to. If RBEROST is opened from the `RBEROST.Rproj` file, and if file structure is left intact, these parameters do not need to be changed. However, some users may have RStudio configurations that override the working directory after completing one optimization and choosing a second set of watersheds to run a second optimization. In these rare cases the user will need to re-set the working directory back to the original. The `horizon` parameter describes the planning horizon used to annualize costs. The default value is 15 years.

The parameter `mode` allows the user to either run all available watershed targets by setting the parameter to "`All`", or to run only select watershed targets by setting the parameter to "`Select`". When the `mode` parameter is set to "`Select`", the parameter `watershed_choices` can be set to determine which targets to include. Note, when the "`Select`" option is chosen, a new `01_UserSpecs_loadingtargets_selected.csv` file will be created during preprocessing, which will only include rows from the parent `01_UserSpecs_loadingtargets.csv` file that correspond to the `watershed_choices` that were selected. A new "selected" file will be generated with every new selection of `watershed_choices` and will overwrite the previous selected file. Users can include one target or multiple targets from the list in the comments section of `RunRBEROST-Pacific.Rmd`. Multiple targets can be selected by creating a simple vector of watershed target names. Please note that watershed names are case sensitive. When the `mode` parameter is set to "`All`", the `watershed_choices` parameter is ignored and may be omitted. The default setting for `mode` is "`Select`". The variable `interest_rate` is the expected interest for the project, and the default value is 0.03, or 3%. AgBMPcomparison can be set as "No Practice" or "Baseline" and determines how the efficiencies of agricultural BMPs will be determined. "No Practice" represents the efficiency of a practice in isolation compared to conventional practices, and "Baseline" represents the efficiency of removing existing conservation practices and replacing them with a certain practice.

`IncludeUncertainty` is a logical parameter and can be set as `TRUE` or `FALSE`. Variables `n.scenarios` and `scenariostepchange` only apply when running RBEROST with uncertainty. The variable `n.scenarios` determines the number of scenarios that will be viewed, and the `scenariostepchange` determines the percentage difference in target load between each of the runs. The default value for `n.scenarios` is 3, meaning the model will develop three scenarios of varying uncertainty based on `scenariostepchange`. The default value for the variable `scenariostepchange` is 0.2, meaning that each run varies by 20 percent of the original target load specified. The lines of code to edit are marked with red arrows in Figure 4-14 and Figure 4-15.

Users specify the potential BMP options that will run through RBEROST within the `01_UserSpecs_BMPs.csv` file (



	BMP_Cate	BMP	BMP_Selection	frac_min	frac_max	capital_W	operation	capital_ur	operation	Min_widt	Max_widt	UserSpec_	TileDrainF	notes
2	ag	Conservation	X	0	1	33.43	0	ac	ac	NA	NA	NA		
3	ag	Contour_Farming	X	0	1	8.42	0	ac	ac	NA	NA	NA		
4	ag	Fert_75	X	0	1	17.13	0	ac	ac	NA	NA	NA		Using general nutrient management cost data as placeholder
5	ag	Fert_90	X	0	1	17.13	0	ac	ac	NA	NA	NA		Using general nutrient management cost data as placeholder
6	ag	Filterstrip	X	0	1	3.7234	0	ac	ac	NA	NA	NA		Assumes native species. If introduced species, override.
7	ag	MIN_TILL	X	0	1	27.27	0	ac	ac	NA	NA	NA		
8	ag	Terrace_Waterway	X	0	1	0.01513	0	ft2	ft2	NA	NA	NA		
9	ag	Terrace_Only	X	0	1	0.0137	0	ft2	ft2	NA	NA	NA		
10	ag	Waterway_Only	X	0	1	0.00143	0	ft2	ft2	NA	NA	NA		
11	ag	Grade_Stabilization	X	0	1	96.62049	0	ac	ac	NA	NA	NA		
12	ag	Diversion	X	0	1	1492.28	0	ac	ac	NA	NA	NA		
13	ag	Cover_Crops	X	0	1	51.52	0	ac	ac	NA	NA	NA		
14	ag	Drainage_Management	X	0	1	8607.56	0	ac	ac	NA	NA	NA	X	Will only be applied on tile drained land
15	ag	Manure_Injection	X	0	1	29.71	0	ac	ac	NA	NA	NA		
16	ag	CustomAgBMP1		0	1	NA	NA	NA	NA	NA	NA	NA		
17	ag	CustomAgBMP2		0	1	NA	NA	NA	NA	NA	NA	NA		
18	ag	CustomAgBMP3		0	1	NA	NA	NA	NA	NA	NA	NA		
19	urban	Rain_Garden6	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs. Note: Rain garden with ponding depth of 6in
20	urban	Rain_Garden10	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs. Note: Rain garden with ponding depth of 10in
21	urban	Extended_Dry_Detention_Basin	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
22	urban	Grass_Swale_w_D	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
23	urban	Green_Roof	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
24	urban	Infiltration_Basin	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
25	urban	Infiltration_Chamber	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
26	urban	Infiltration_Trench	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
27	urban	Permeable_Pavement	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs. Note: literature results on the efficiency of this BMF
28	urban	Porous_Pavement_w_UD	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	Note: different depth type - "depth of filter course area in inches". NH specifi
29	urban	Sand_Filter_w_UD	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
30	urban	Wet_Pond	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
31	point	Fourstage_Bardenpho	X	NA	NA	varies	varies	flat	flat	NA	NA	NA	NA	Costs vary by plant type and plant size. See WWTP_Costs.csv.

Figure 4-16). BMP options are specified by placing a capital "X" in the `BMP_Selection` field of the `01_UserSpecs_BMPs.csv` file or removing an existing capital "X" to exclude a given BMP option. Note, a lowercase "x" will not be read by the RBEROST preprocessor. Users can also choose a minimum and/or maximum implementation of each BMP as a fraction of total possible implementation. `01_UserSpecs_BMPs.csv` includes all the BMPs available for model optimization per BMP category (agricultural, urban, point source, grazing, and riparian buffer BMPs), state-specific capital and operations & maintenance costs to implement the BMP, units of the costs, user-specified buffer widths for riparian buffer BMPs, and whether or not Ag BMPs should be restricted to tile-drained areas. When selecting point BMPs, users should note that tertiary filters may only be selected in conjunction with other point BMPs. The model will not consider tertiary filter wastewater treatment plant upgrades alone.

Additionally, there are three custom AgBMPs provided for users to input their own data if they wish to model BMPs that are not included (CustomAgBMP1, CustomAgBMP2, and CustomAgBMP3). The costs may be entered in the `01_UserSpecs_BMPs.csv`, while the efficiency data must be entered into `AgBMPEffic_nonACRE.csv`. Users should be aware that BMP names entered into files utilized in the preprocessor cannot contain spaces, slashes, dashes, or other non-letter characters. The use of such characters will cause errors with the AMPL file and will not allow the optimization to run properly on the NEOS server. BMP names must match the formatting of the current BMPs and only use letter characters, numbers, and underscores.

The data provided covers the geographic extent of the Puget Sound, WA case study. To expand the geographic range of the optimization, data files will need to be expanded to include COMIDs based on the NHDPlus Version 2 reach network [*Dewald et al.*, 2019] located in additional areas.

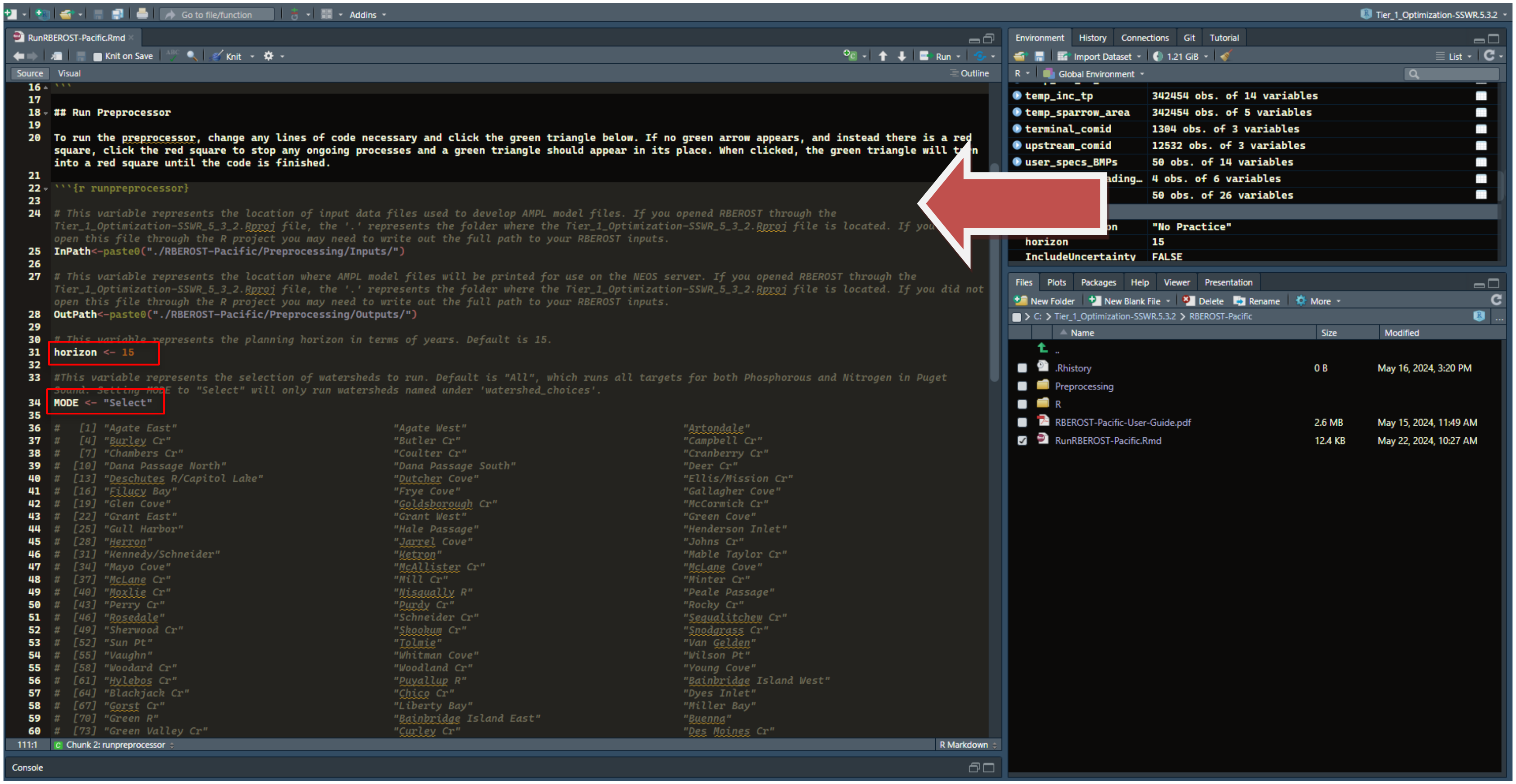


Figure 4-14: Lines of code for the user to edit in the preprocessing step.

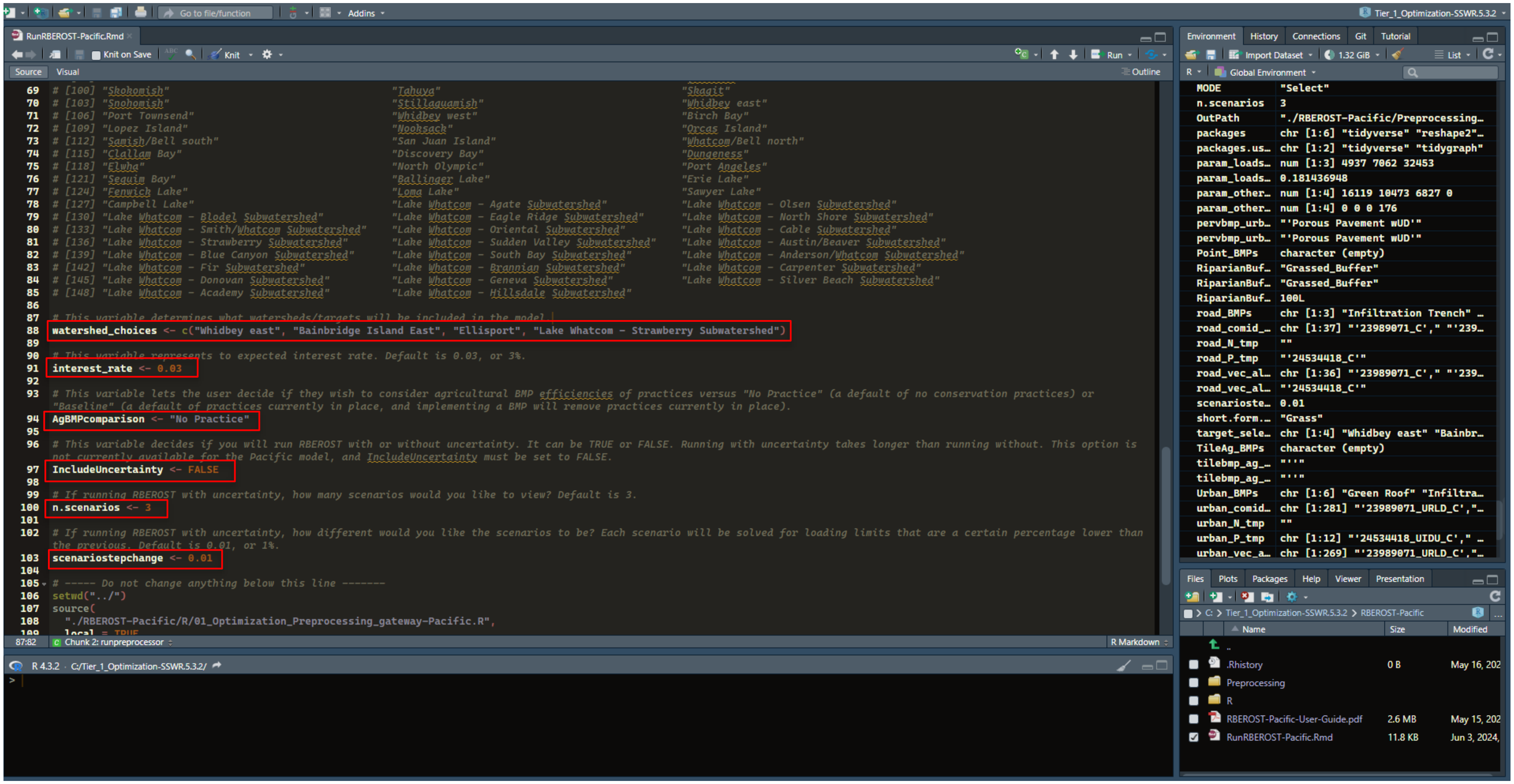
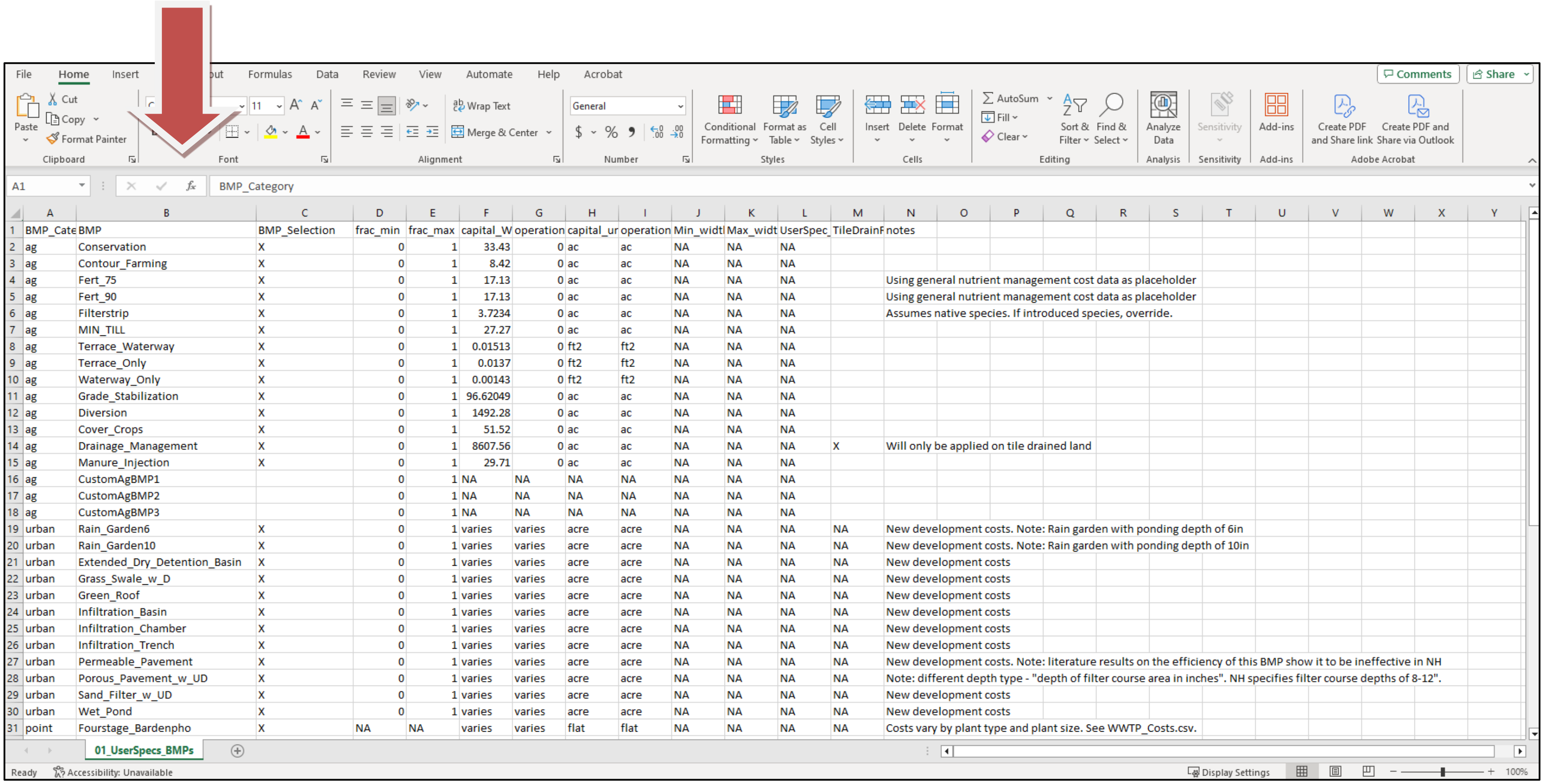


Figure 4-15: Lines of code for the user to edit in the preprocessing step.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	BMP_Cate	BMP	BMP_Selection	frac_min	frac_max	capital_W	operation	capital_ur	operation	Min_widtl	Max_widt	UserSpec_	TileDrainF	notes
2	ag	Conservation	X	0	1	33.43	0	ac	ac	NA	NA	NA		
3	ag	Contour_Farming	X	0	1	8.42	0	ac	ac	NA	NA	NA		
4	ag	Fert_75	X	0	1	17.13	0	ac	ac	NA	NA	NA		Using general nutrient management cost data as placeholder
5	ag	Fert_90	X	0	1	17.13	0	ac	ac	NA	NA	NA		Using general nutrient management cost data as placeholder
6	ag	Filterstrip	X	0	1	3.7234	0	ac	ac	NA	NA	NA		Assumes native species. If introduced species, override.
7	ag	MIN_TILL	X	0	1	27.27	0	ac	ac	NA	NA	NA		
8	ag	Terrace_Waterway	X	0	1	0.01513	0	ft2	ft2	NA	NA	NA		
9	ag	Terrace_Only	X	0	1	0.0137	0	ft2	ft2	NA	NA	NA		
10	ag	Waterway_Only	X	0	1	0.00143	0	ft2	ft2	NA	NA	NA		
11	ag	Grade_Stabilization	X	0	1	96.62049	0	ac	ac	NA	NA	NA		
12	ag	Diversion	X	0	1	1492.28	0	ac	ac	NA	NA	NA		
13	ag	Cover_Crops	X	0	1	51.52	0	ac	ac	NA	NA	NA		
14	ag	Drainage_Management	X	0	1	8607.56	0	ac	ac	NA	NA	NA	X	Will only be applied on tile drained land
15	ag	Manure_Injection	X	0	1	29.71	0	ac	ac	NA	NA	NA		
16	ag	CustomAgBMP1		0	1	NA	NA	NA	NA	NA	NA	NA		
17	ag	CustomAgBMP2		0	1	NA	NA	NA	NA	NA	NA	NA		
18	ag	CustomAgBMP3		0	1	NA	NA	NA	NA	NA	NA	NA		
19	urban	Rain_Garden6	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs. Note: Rain garden with ponding depth of 6in
20	urban	Rain_Garden10	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs. Note: Rain garden with ponding depth of 10in
21	urban	Extended_Dry_Detention_Basin	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
22	urban	Grass_Swale_w_D	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
23	urban	Green_Roof	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
24	urban	Infiltration_Basin	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
25	urban	Infiltration_Chamber	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
26	urban	Infiltration_Trench	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
27	urban	Permeable_Pavement	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs. Note: literature results on the efficiency of this BMP show it to be ineffective in NH
28	urban	Porous_Pavement_w_UD	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	Note: different depth type - "depth of filter course area in inches". NH specifies filter course depths of 8-12".
29	urban	Sand_Filter_w_UD	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
30	urban	Wet_Pond	X	0	1	varies	varies	acre	acre	NA	NA	NA	NA	New development costs
31	point	Fourstage_Bardenpho	X	NA	NA	varies	varies	flat	flat	NA	NA	NA	NA	Costs vary by plant type and plant size. See WWTP_Costs.csv.

Figure 4-16: A screenshot of the BMP UserSpecs file with the specifications for the Pacific RBEROST Model.

4.2.1.1 BMP Costs

Implementation of all BMPs requires both capital and operations & maintenance costs. Default cost dollar years are referenced in the input table column headers. The user can override any of these costs by specifying one or more values that are representative of costs per treated area for agricultural, urban, grazing, and riparian buffer BMPs.

If cost data from additional states beyond the geographic extent of the Puget Sound case study must be included, these are added to the file **`01_UserSpecs_BMPs.csv`**. For each additional state, two columns must be added to this file, following the naming convention of "capital_[two letter state code]" (e.g., capital_WY) and "operations_[two letter state code]". The units for these costs must be the same across all states included, and units are indicated in the "capital_units" and "operations_units" fields. Possible units are "ac (acre)" and "ft2" for agricultural and riparian buffer BMPs, "acre" for urban BMPs, "acre" for road BMPs, and "flat" for point source BMPs. Point source BMP costs are defined as flat because they do not vary by a specific unit and are instead based on the individual size and type of WWTP. Costs for individual WWTPs are stored in the **WWTP_Costs.csv** file.

If optimizations that include uncertainty are performed for geographic ranges that extend to states beyond the ones in the case study, additional columns must also be added to the **`EQIPcosts_overyears.csv`** file. Column headings should follow the naming conventions of "capital_[two letter state code]_[year]" or "operations_[two letter state code]_[year]", and cost units must be consistent across all columns.

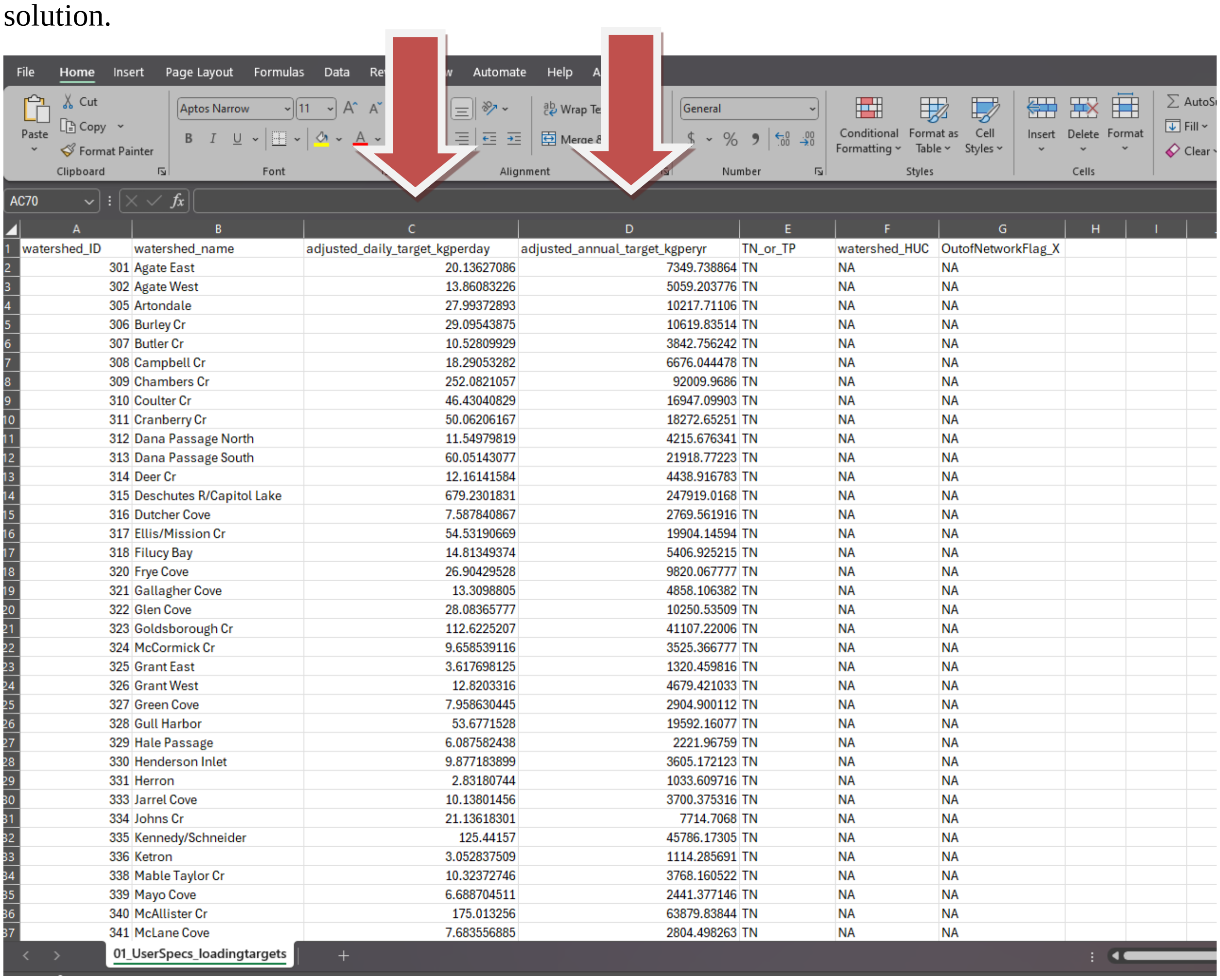
4.2.1.2 Urban BMP Runoff Depth and Riparian Buffer Width

Nutrient removal efficiency resulting from implementation of urban BMPs depends on the BMP design runoff depth. These design depths are assumed to meet standards of Washington Ecology, which are performance-based standards based on volume and flow requirements. Additional information about urban BMP efficiencies methods is included in Appendix A – Additional Information about Urban and Road BMP Costs and Efficiencies. The data provided for the case study includes costs and efficiencies that are weighted averages for each COMID based on the distributions of landcover and hydrologic soil groups in each catchment. The **`01_UserSpecs_BMPs.csv`** therefore does not include space for users to change the design specs of urban BMPs. Additional information on urban BMP efficiencies is included in Appendix A – Additional Information about Urban and Road BMP Costs and Efficiencies.

Specification of riparian buffer width affects the amount of nutrients removed by the buffers. Users can specify buffer widths in the column, **`UserSpec_width_ft`** within the **`01_UserSpecs_BMPs.csv`** file.

4.2.1.3 Load Reduction Goal

After specifying watersheds for analysis with the **`watershed_choices`** variable in the .RMD file, users can specify loading targets within those watersheds by modifying parameters in the RMD file (Figure 4-17). Modifying parameters in the RMD file will result in the model only considering the selected targets in the **`UserSpec_loadingtargets.csv`** file. Targets are defined as the maximum allowable load for a given terminal COMID or set of terminal COMIDs relevant to a given watershed. Some watersheds have only a single terminal COMID, where the loading target applies to the loading at a sole terminal COMID. Other watersheds have multiple terminal COMIDs, where the loading target for the watershed applies to the sum loading of all relevant terminal COMIDs. The RMD file lists potential targets the user can select. 121 of the Puget Sound RBEROST targets (*Agate East* to *Sequim Bay*) are nitrogen targets, while 27 Puget Sound RBEROST targets (*Ballinger Lake* to *Lake Whatcom-Hillsdale Subwatershed*) are phosphorus targets. Maps of the watersheds included in the RBEROST- Pacific model are included in Appendix B – Maps of Pacific Model Spatial Extent. A map of the watersheds relevant for nitrogen targets is show in Figure B - 1. A map of lakes and watersheds relevant for phosphorus targets is show in Figure B - 2. BMP selections at individual COMIDs may simultaneously contribute to reductions in both phosphorus and nitrogen, depending on which targets are selected. RBEROST-Pacific (v2) has been tested up to a watershed size of 2,824 COMIDs. If the NEOS optimizer times out when applied to larger watersheds (or combinations of watersheds) on this scale, users may need to increase the target loads slightly to obtain a solution.



watershed_ID	watershed_name	adjusted_daily_target_kgperday	adjusted_annual_target_kgperyr	TN_or_TP	watershed_HUC	OutofNetworkFlag_X
301	Agate East	20.13627086	7349.738864	TN	NA	NA
302	Agate West	13.86083226	5059.203776	TN	NA	NA
305	Artondale	27.99372893	10217.71106	TN	NA	NA
306	Burley Cr	29.09543875	10619.83514	TN	NA	NA
307	Butler Cr	10.52809929	3842.756242	TN	NA	NA
308	Campbell Cr	18.29053282	6676.044478	TN	NA	NA
309	Chambers Cr	252.0821057	92009.9686	TN	NA	NA
310	Coulter Cr	46.43040829	16947.09903	TN	NA	NA
311	Cranberry Cr	50.06206167	18272.65251	TN	NA	NA
312	Dana Passage North	11.54979819	4215.676341	TN	NA	NA
313	Dana Passage South	60.05143077	21918.77223	TN	NA	NA
314	Deer Cr	12.16141584	4438.916783	TN	NA	NA
315	Deschutes R/Capitol Lake	679.2301831	247919.0168	TN	NA	NA
316	Dutcher Cove	7.587840867	2769.561916	TN	NA	NA
317	Ellis/Mission Cr	54.53190669	19904.14594	TN	NA	NA
318	Filucy Bay	14.81349374	5406.925215	TN	NA	NA
320	Frye Cove	26.90429528	9820.067777	TN	NA	NA
321	Gallagher Cove	13.3098805	4858.106382	TN	NA	NA
322	Glen Cove	28.08365777	10250.53509	TN	NA	NA
323	Goldsborough Cr	112.6225207	41107.22006	TN	NA	NA
324	McCormick Cr	9.658539116	3525.366777	TN	NA	NA
325	Grant East	3.617698125	1320.459816	TN	NA	NA
326	Grant West	12.8203316	4679.421033	TN	NA	NA
327	Green Cove	7.958630445	2904.900112	TN	NA	NA
328	Gull Harbor	53.6771528	19592.16077	TN	NA	NA
329	Hale Passage	6.087582438	2221.96759	TN	NA	NA
330	Henderson Inlet	9.877183899	3605.172123	TN	NA	NA
331	Herron	2.83180744	1033.609716	TN	NA	NA
333	Jarrel Cove	10.13801456	3700.375316	TN	NA	NA
334	Johns Cr	21.13618301	7714.7068	TN	NA	NA
335	Kennedy/Schneider	125.44157	45786.17305	TN	NA	NA
336	Ketron	3.052837509	1114.285691	TN	NA	NA
338	Mable Taylor Cr	10.32372746	3768.160522	TN	NA	NA
339	Mayo Cove	6.688704511	2441.377146	TN	NA	NA
340	McAllister Cr	175.013256	63879.83844	TN	NA	NA
341	McLane Cove	7.683556885	2804.498263	TN	NA	NA

Figure 4-17: A screenshot of the loading targets UserSpecs file with the specifications for the RBEROST- Pacific model.

4.2.2 Preprocess Data Inputs

The data preprocessing section of the code adjusts and formats the input data for AMPL model file development. Input data include baseline nutrient loads, land use information, watershed characteristics, BMP costs, and BMP nutrient removal efficiencies. The provided data cover the geographic extent of the Puget Sound case study only.

4.2.2.1 Baseline Nutrient Loading and Land Use Data

Recent regional SPARROW model outputs from the U.S. Geological Survey provide the basis for RBEROST baseline nutrient loading conditions [*Wise*, 2019]. These models provide catchment-level nutrient loads and land use data. Catchments are specified using common COMIDs based on the NHDPlus v2 reach network [*Dewald et al.*, 2019]. RBEROST also includes 2011 cropland, pastureland and imperviousness land use data from the National Land Cover Database [*Yang et al.*, 2018] provided at the NHDPlus V2 catchment level via StreamCat [*Hill et al.*, 2016]. For modeling that includes states outside of the region presented in the case study, StreamCat files for additional states can be added to the Preprocessing/Inputs folder and renamed according to the same convention as the provided files, e.g., WA_streamcat_2011_cropland and WA_streamcat_2011_imperv.

Data modifications entail classifying incremental baseline SPARROW loadings as point source, urban, road, agricultural, grazing, or "other" loads. Incremental loads in SPARROW are stream loads that originate from the NHDPlus V2 catchment. This is differentiated from total loads in SPARROW which is the sum of incremental load for each catchment and delivered load from upstream. Other loads include loadings from sources that cannot be classified as point, urban, and agricultural (e.g., atmospheric deposition). The model code adjusts baseline point source loading to account for changes in wastewater nutrient effluent and atmospheric nitrogen deposition since 2012. This is done within RBEROST so that the user can potentially include additional locations for baseline loadings adjustments where changes are known to have occurred. This would be done by editing the input files `WWTP_BaselineRemoval.csv`, `WWTP_COMIDs.csv`, `WWTP_Costs.csv`, `WWTP_RemovalEffic.csv` and `NdepChange_2012_2020.csv` to include information for additional COMIDs. Details of these files are available in Table 6-1.

The optimization depends on agricultural, urban, and grazing land area available for BMP implementation. Urban and road acreage data are derived from NLCD, while agricultural and grazing acreage are calculated as the product of incremental acreage available per catchment (from SPARROW; [*Wise*, 2019]) and the percent of area defined as cropland and hayland per catchment (from National Land Cover Data/StreamCat; [*Hill et al.*, 2016]).

Riparian loading depends on the amount of impervious surface cover within the river corridor, as per *Houle et al.* [2019], and the loading from grazing and rowcrop land as per *Wise* [2019]. These estimates must be derived prior to modeling with RBEROST. They are provided in the `RiparianLoadings.csv` file. Riparian loading is a subset of urban, ag, point, grazing, or other loads and does not describe an additional source. Users who wish to use different methodologies to estimate riparian loads (e.g., including agricultural loads) may do so and overwrite the `RiparianLoadings.csv` file with a new file with the same naming conventions and format.

4.2.2.2 Watershed and Target Specifications

The `01_UserSpecs_loadingtargets.csv` file describes the locations of loading targets that will be included in RBEROST. The COMIDs are used to identify upstream contributing reaches to each target. Additional information on methodology for assigning terminal and upstream COMIDs is included in Appendix C – . These contributing reaches are included in the input baseline loading and land use datasets used in calculating inputs to each target waterbody.

The SPARROW regional models specify a delivery fraction (DEL_FRAC) that reflects the fraction of the incremental nutrient loads and upstream inputs that are delivered to a flowline's terminal reach (in most cases, the ocean). RBEROST revises this delivery fraction to recognize each loading target as the specified terminal reach. For instance, if the specified target COMID has a delivery fraction of 92% in the SPARROW regional model dataset, indicating that 92% of the incremental loads associated with the target reach are delivered to the terminal reach, the revised delivery fraction at this location is 100%, indicating that 100% of the incremental loads associated with the target are delivered to the corresponding target reach.

The delivery fractions for all reaches upstream of the target are revised based on the ratio of the revised target delivery fraction to the original terminal reach delivery fraction. For instance, if the SPARROW regional model data indicates that an upstream reach delivers 83% of its incremental load to the terminal reach and that the target reach delivers 92% of its incremental load to the terminal reach, then the revised delivery fraction for the upstream reach to the target reach is (100%/92%)*(83%) = 90%. Delivery fractions typically differ between TN and TP, and these calculations are performed separately for each nutrient target. RBEROST allows nested targets as well, in which case a stream reach that contributes to more than one loading target will be assigned more than one DEL_FRAC value.

4.2.2.3 BMP Costs and Efficiencies

Agricultural, riparian, and grazing BMP costs specified in the `01_UserSpecs_BMPs.csv` file are adjusted to per-acre units for agricultural, grazing, road and urban BMPs. Because point source BMPs are location-specific, the model code merges the wastewater treatment plant (WWTP) costs with each plants' reach location (COMID) prior to developing the AMPL model files. Urban and road BMP costs vary based on the BMP, urban land use type, and hydrologic soil group (HSG). Costs include both capital and operations costs, represented in 2020 U.S. dollars within the `UrbanBMPData.csv` file.

RBEROST assumes a default planning horizon of 15 years and an interest rate for capital costs of 3%. The user can adjust the horizon and interest_rate variables within the `RunRBEROST-Pacific.Rmd` file.

While some BMP efficiencies are BMP-specific, others are also location-specific. For agricultural BMPs with nutrient removal efficiencies that vary based on HUC12, the model code identifies the individual reaches that fall within each HUC12 and assigns the HUC12-specific efficiency to each reach. There are two available agricultural BMP cost datasets that differ based on how they compare the export of nutrients. "No Practice" compares the export of nutrients with a given BMP versus the export of nutrients under conventional practices. "Baseline" compares the export of nutrients with only one given BMP versus the export of nutrients occurring under existing conservation practices. The "Baseline" approach assumes existing conservation practices are removed and only the one BMP is implemented. Point source BMP efficiencies are specific to each WWTP upgrade. Urban BMP efficiencies are based upon the specific BMP being implemented, the land use type, and the HSG. Road BMP efficiencies vary based upon the specific BMP being implemented and the HSG. Riparian buffer BMP efficiencies depend on average infiltration rate, as well as the slope of the riparian buffer.

4.2.3 Write AMPL Model Files

Running the optimization model through the NEOS server depends on the development of three AMPL model files: the command file (.amp), the data file (.dat) and the model file (.mod). The command file contains instructions for the optimization server to solve the mathematical problem and defines what results should be displayed afterwards. The data file contains all the data used in the optimization, including values for each parameter across their geographic range. The model file defines the mathematical problem to be optimized and contains a list of constraints placed on the model during optimization. After running the preprocessing code, the AMPL model files will by default be written to the `./RBEROST-Pacific/Preprocessing/Outputs` folder, unless otherwise specified in the `RunRBEROST-Pacific.Rmd` file (Figure 4-18).

Several messages appear while running RBEROST preprocessor (Figure 4-19). The first indicates when RBEROST has begun and when it has finished determining the list of COMIDs upstream from the loading targets. This step may take a few minutes, so the messages are intended to assure the user that the code is running. The next series of messages indicate whether the provided StreamCat dataset contains additional COMIDs beyond those that are included in SPARROW, or vice versa. The number of messages will match the number of targets. SPARROW COMIDs that are not in StreamCat, or StreamCat COMIDs that are not in SPARROW contribute to the ‘`other_loads`’ parameters. The next messages will indicate when RBEROST has completed writing AMPL scripts. When running RBEROST with uncertainty analysis, AMPL scripts without uncertainty will be written first as part of the preprocessing. These AMPL files without uncertainty may be ignored or saved for further use.

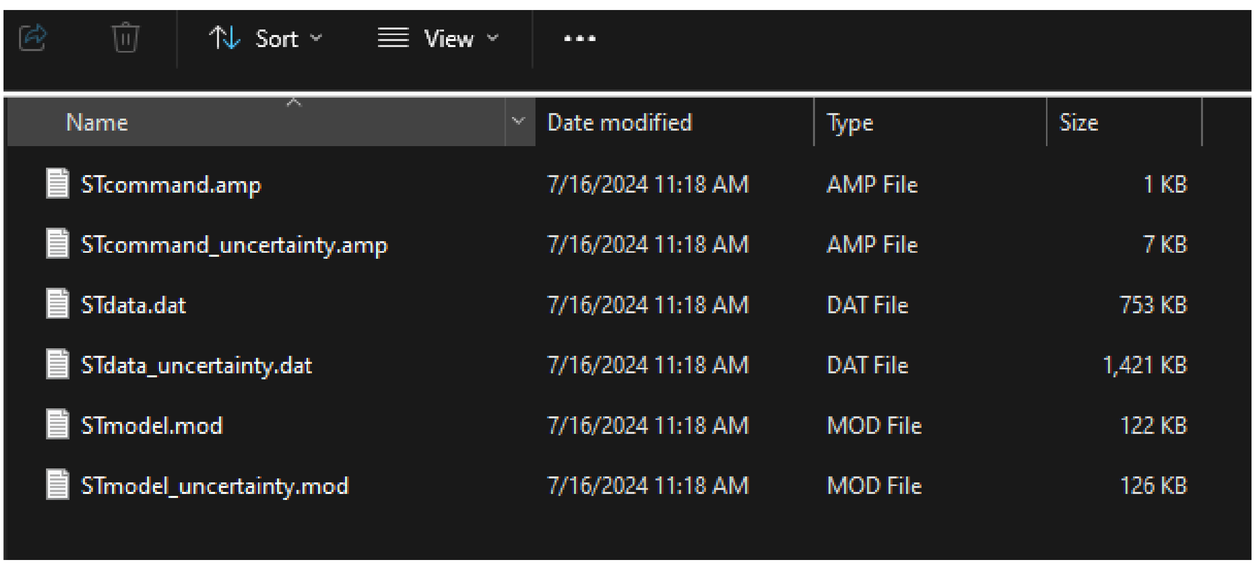


Figure 4-18: Outputs of running RBEROST preprocessor with uncertainty.

4.2.3.1 AMPL Command File

The command file specifies display characteristics of the NEOS optimization results.

4.2.3.2 AMPL Data File

The data file specifies the catchment- and BMP-specific data required for the NEOS optimization run, including:

- Baseline loadings, efficiency, and cost data formatted by the R code;
- Total reduced loading values (loads_lim parameters) calculated based on the specified loading targets;
- Total loading value for loads specified as "other loads" (other_loads parameters) that are not available for BMP loading reduction;
- The fraction of agricultural costs (agcost_frac) that reflect base payment versus actual agricultural BMP costs;

These parameters are described in greater detail in Table 3-2.

4.2.3.3 AMPL Model File

The model file specifies the following:

- COMIDs, BMPs, cost types, and load types that are included in the optimization;
- The bases on which parameters vary (e.g., agricultural efficiencies vary by both reach and BMP);
- Constraints on parameters and variables (e.g., whether a variable represents binary conditions or a fraction less than or equal to 1);
- The total load reduction functions; and
- The cost minimization objective function.

The model file with uncertainty includes the same specifications for parameters that describe standard errors.

4.3 NEOS Server

RBEROST uses the CPLEX Optimizer available through NEOS to solve the optimization. CPLEX will allow XML calls from RBEROST to submit AMPL files to the server, however at the time of current release, only a manual interaction option with the server is available. Users will click on the following link and upload the AMPL model, data, and commands files to the Web Submission Form: **https://neos-server.org/neos/solvers/lp:CPLEX/AMPL.html** (Figure 4-20). Before submitting, the user will specify the e-mail address to receive an update when the model run is complete. Users are also highly encouraged to include a descriptive note of the model in the comments section (Figure 4-21). Please refer to the WMOST User Guide

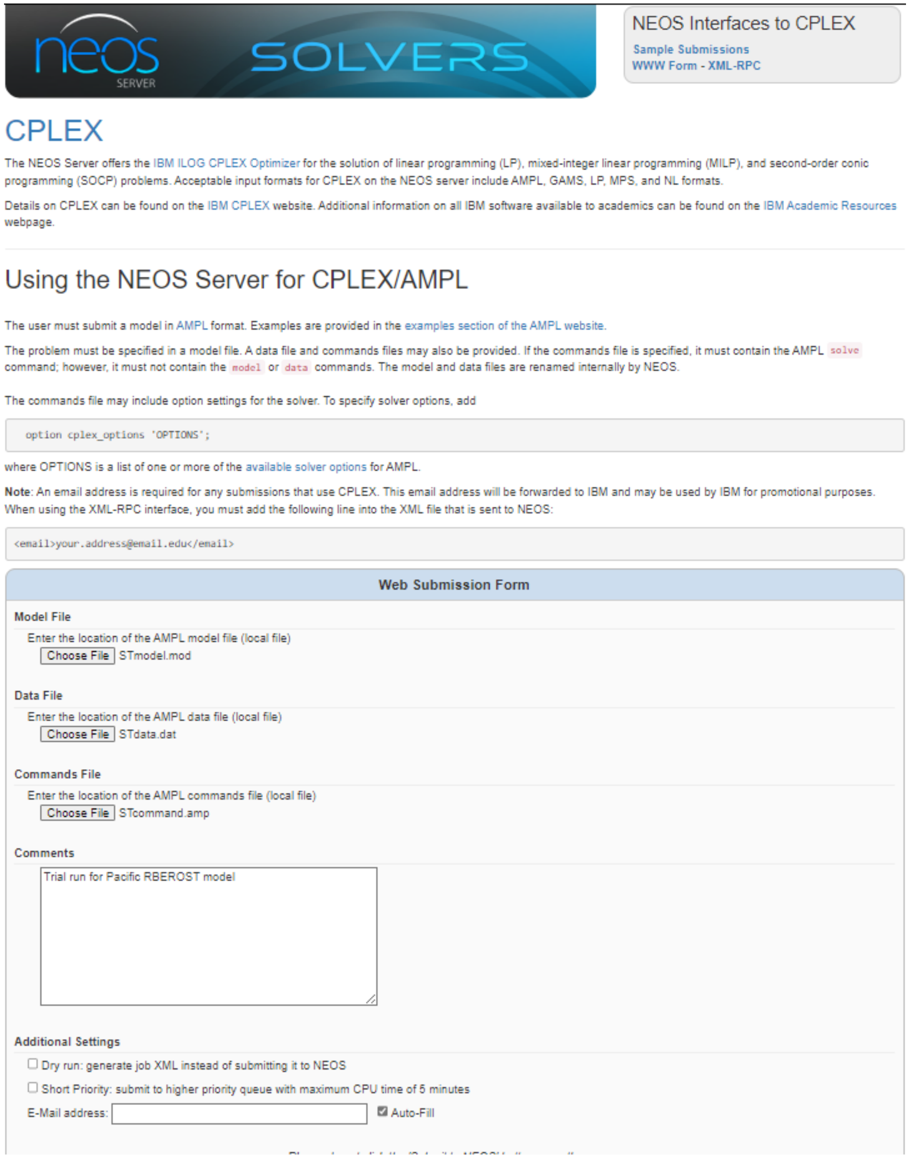
[*Detenbeck et al.*, 2018a] for additional information on how to run optimization models on the NEOS server.

Generally, NEOS can solve models without uncertainty in less than five minutes. Exact times may vary, perhaps greatly, depending on the complexity of the specified problem and the current demands on NEOS and on the CPLEX optimizer. If the optimization can be solved quickly, the results will appear on the screen for the user to copy and save, but if not, the NEOS job will be placed in a queue. In the latter case, once the optimization has solved, users will receive an email from the server (Figure 4-22) with a link, a job number, and a password. Users can retrieve their results from the server with this information (Figure 4-23). Users save the NEOS server optimization results by selecting all text within the results window (CTRL+A), pasting it into a text file (via text editor such as Notepad), and saving it as a text file (.txt) to a location that makes sense for them (Figure 4-24). Example output files are provided in **`.\RBEROST-Pacific\Postprocessor\`** If NEOS was unable to optimize the model, the returned result may be very short, simply stating that optimization failed. This result file may still be submitted to the RBEROST Postprocessor. Inputting a result file to postprocessing when NEOS fails to optimize the model will result in an abbreviated results panel (Figure 4-27).

```
Note: For the 1st TN target, there are fewer reaches in the provided
StreamCat datasets than are included in SPARROW.
Only the reaches that are included in both datasets will be available
for BMP optimization. Loads from the remaining reaches will be included in
the 'other_loads' parameter.
[1] "Based on User Selections, the following combinations of BMPs are considered f
or WWTP upgrades: C. FOURBDP = Fourstage_Bardenpho, C = Chem_add, DNF = Denitrific
ation_filters, F = Tertiary_filters, M = MeOH_addition, MBR = Membrane_bioreactor
s, MLE = Modified_Ludzack_Ettinger, and SBR = Sequencing_batch_reactor."
[1] "Urban costs are assigned based on landuse and hydrologic soil group in each c
omid. They are calculated using specifications that meet design standards. Urban B
MPs with no cost information available are displayed as (1 x e12) to deter the NEO
S server from selecting BMPs with missing data."
[1] "RBEROST has finished writing AMPL scripts without uncertainty at 2024-07-16 1
2:16:17.22362"
[1] "RBEROST is now creating AMPL files with uncertainty analysis at 2024-07-16 1
2:16:17.23158"
Warning: NaNs produced[1] "Based on User Selections, the following combinations of
BMPs are considered for WWTP upgrades: C. FOURBDP = Fourstage_Bardenpho, C = Chem_
add, DNF = Denitrification_filters, F = Tertiary_filters, M = MeOH_addition, MBR =
Membrane_bioreactors, MLE = Modified_Ludzack_Ettinger, and SBR = Sequencing_batch_
reactor."
[1] "RBEROST has finished writing AMPL scripts with uncertainty at 2024-07-16 12:1
7:54.200802"
```

Figure 4-19: Example messages displayed by RBEROST preprocessor.

Figure 4-20: The CPLEX Optimizer hosted by NEOS.



neos SERVER SOLVERS

NEOS Interfaces to CPLEX

Sample Submissions

WWW Form - XML-RPC

CPLEX

The NEOS Server offers the IBM ILOG CPLEX Optimizer for the solution of linear programming (LP), mixed-integer linear programming (MILP), and second-order conic programming (SOCP) problems. Acceptable input formats for CPLEX on the NEOS server include AMPL, GAMS, LP, MPS, and NL formats.

Details on CPLEX can be found on the IBM CPLEX website. Additional information on all IBM software available to academics can be found on the IBM Academic Resources webpage.

Using the NEOS Server for CPLEX/AMPL

The user must submit a model in AMPL format. Examples are provided in the examples section of the AMPL website.

The problem must be specified in a model file. A data file and commands files may also be provided. If the commands file is specified, it must contain the AMPL `solve` command; however, it must not contain the `model` or `data` commands. The model and data files are renamed internally by NEOS.

The commands file may include option settings for the solver. To specify solver options, add

```
option cplex_options 'OPTIONS';
```

where OPTIONS is a list of one or more of the available solver options for AMPL.

Note: An email address is required for any submissions that use CPLEX. This email address will be forwarded to IBM and may be used by IBM for promotional purposes. When using the XML-RPC interface, you must add the following line into the XML file that is sent to NEOS:

```
<email>your.address@email.edu</email>
```

Web Submission Form

Model File

Enter the location of the AMPL model file (local file)

Choose File STmodel.mod

Data File

Enter the location of the AMPL data file (local file)

Choose File STdata.dat

Commands File

Enter the location of the AMPL commands file (local file)

Choose File STcommand.amp

Comments

Trial run for Pacific RBEROST model

Additional Settings

☐ Dry run: generate job XML instead of submitting it to NEOS

☐ Short Priority: submit to higher priority queue with maximum CPU time of 5 minutes

E-Mail address: ☑ Auto-Fill

Figure 4-21: User inputs to CPLEX to run RBEROST.

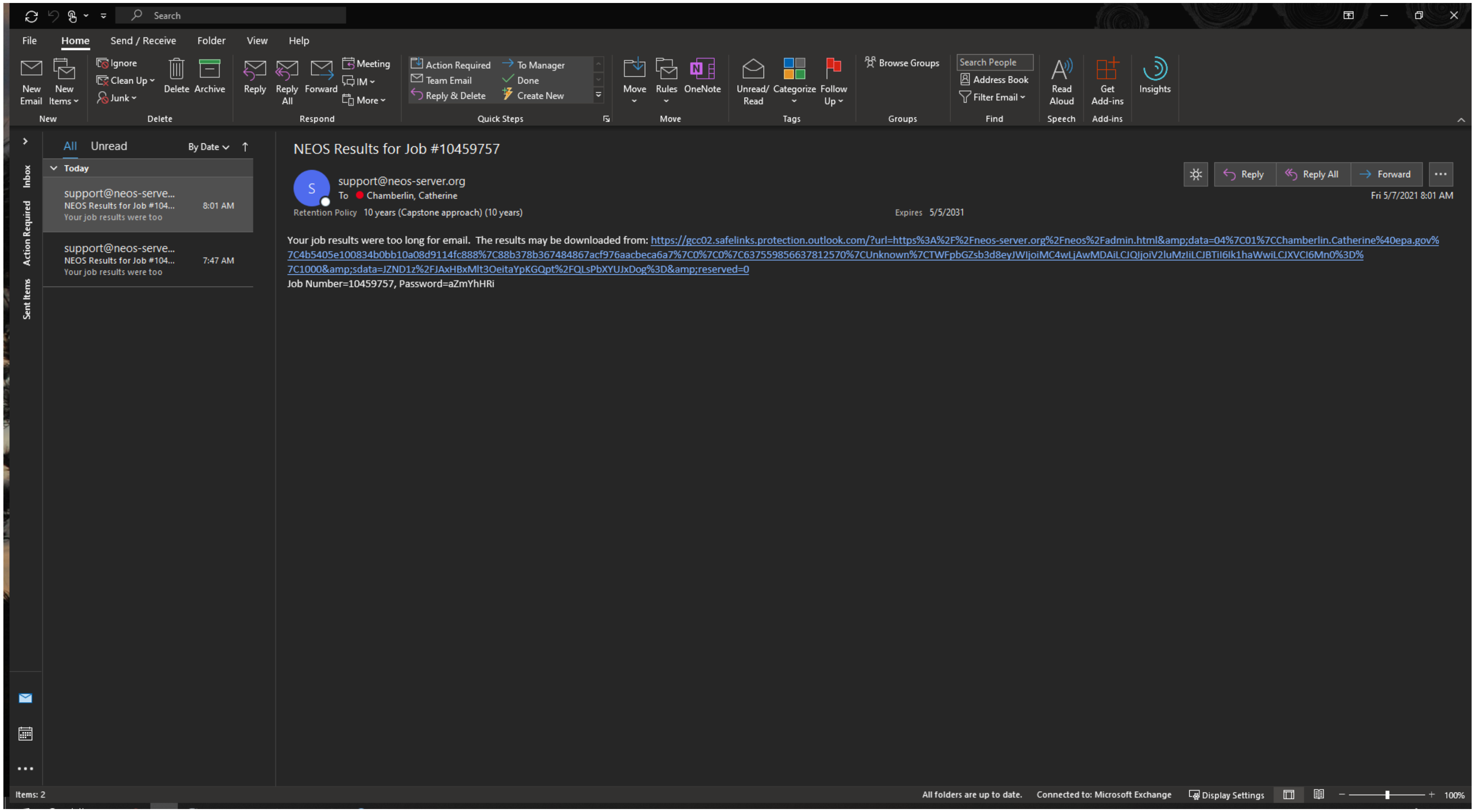


Figure 4-22: Example email from NEOS.

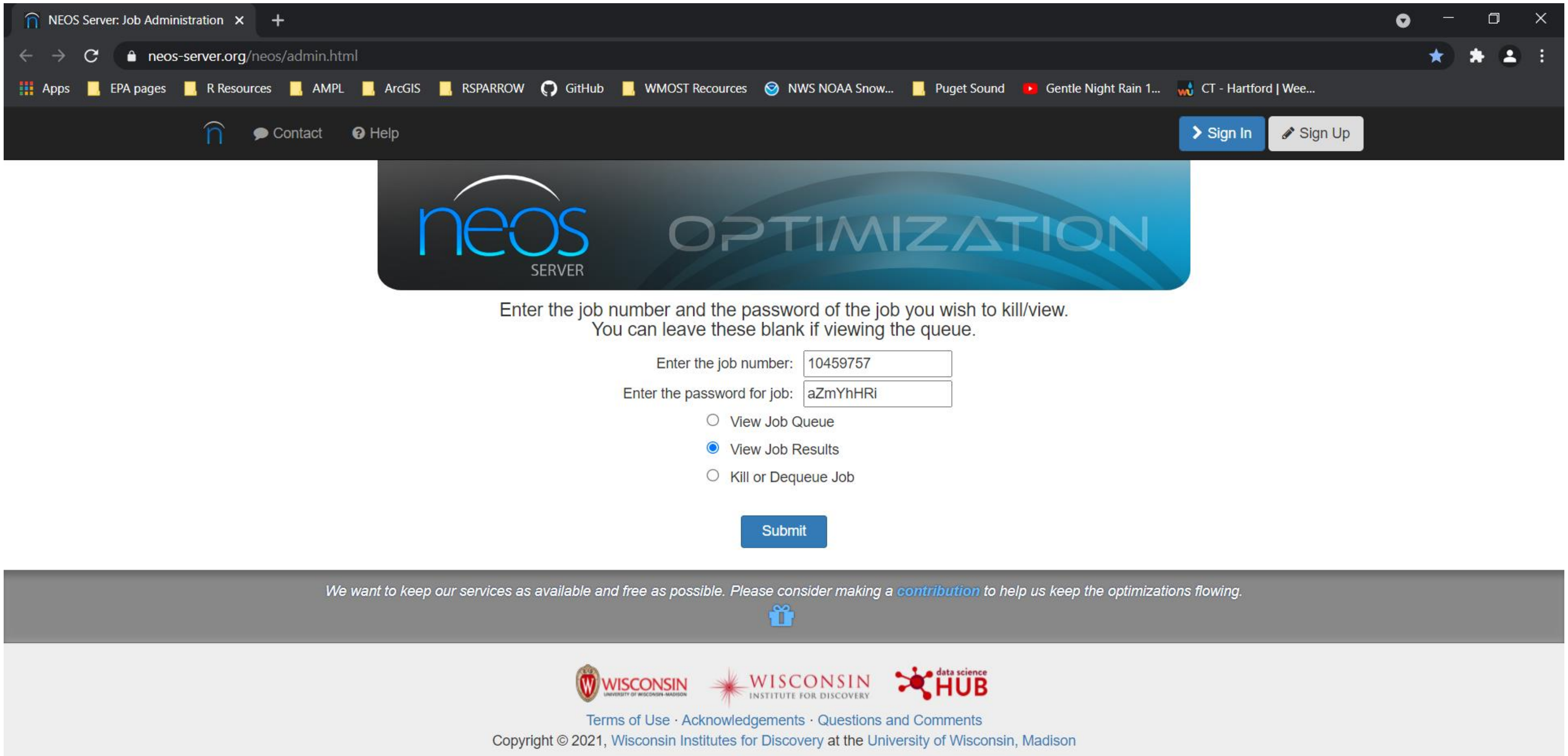


Figure 4-23: Retrieving results through the NEOS Job Administration page.

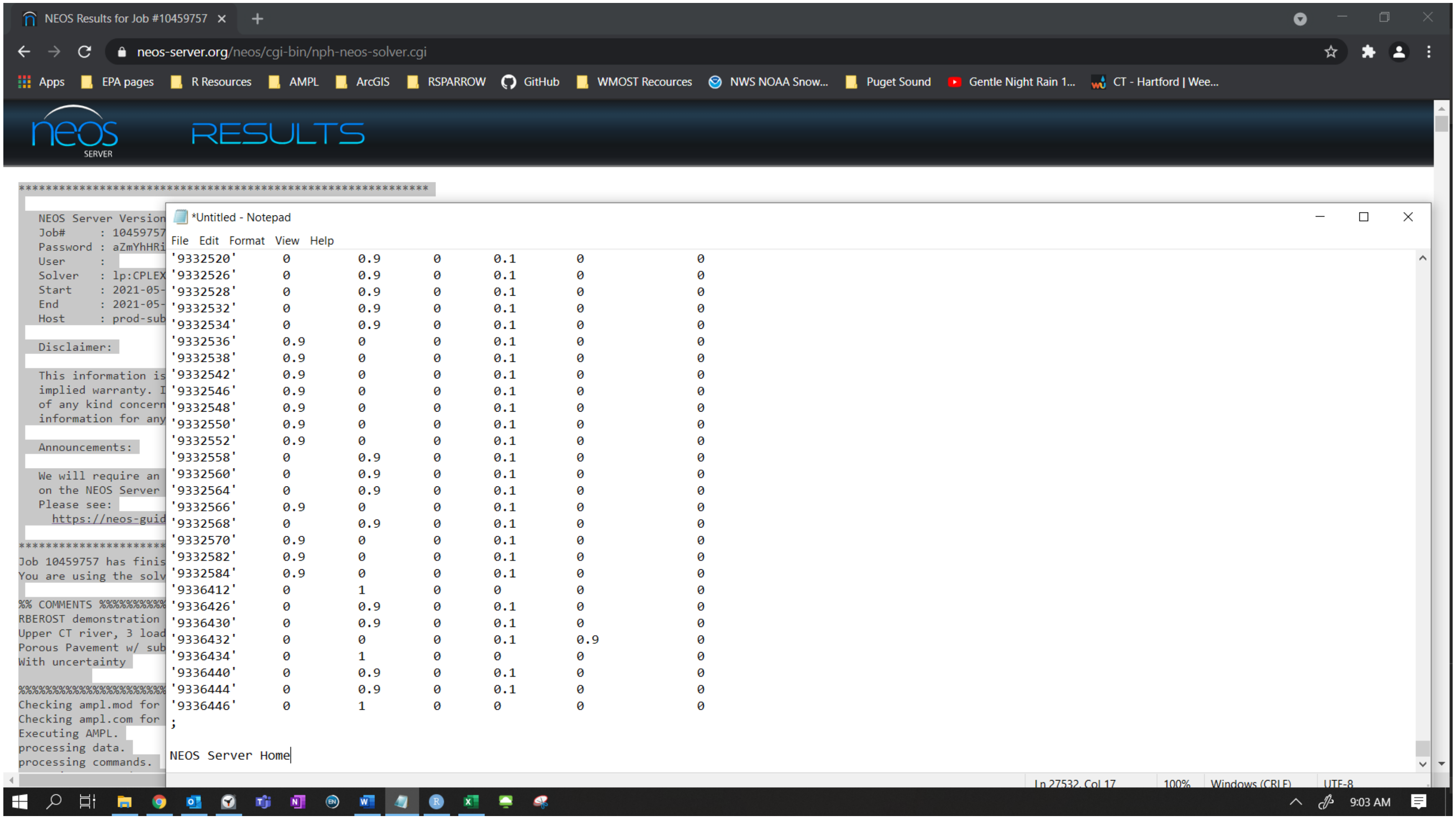


Figure 4-24: Saving NEOS results as a text file.

4.4 Postprocessing

The postprocessing R code combines optimization results from the NEOS server with input data to develop result summaries. The code uses R-Shiny, an R package that produces a summary of RBEROST either within the RStudio interface or in the default web browser.

To run the postprocessing code, users can click the green triangle in the `Run Postprocessor` section of the `RunRBEROST-Pacific.Rmd` file (Figure 4-25). More than one result file can be viewed per session, however the Shiny App will not automatically close if the viewing window is closed. To stop the Shiny App after closing the browser window, click the red square in the `Run Postprocessor` section, and a green triangle will appear that will allow the user to launch the application again.

If RBEROST postprocessor is running within a browser, you may print the results screen to a pdf file for your records.

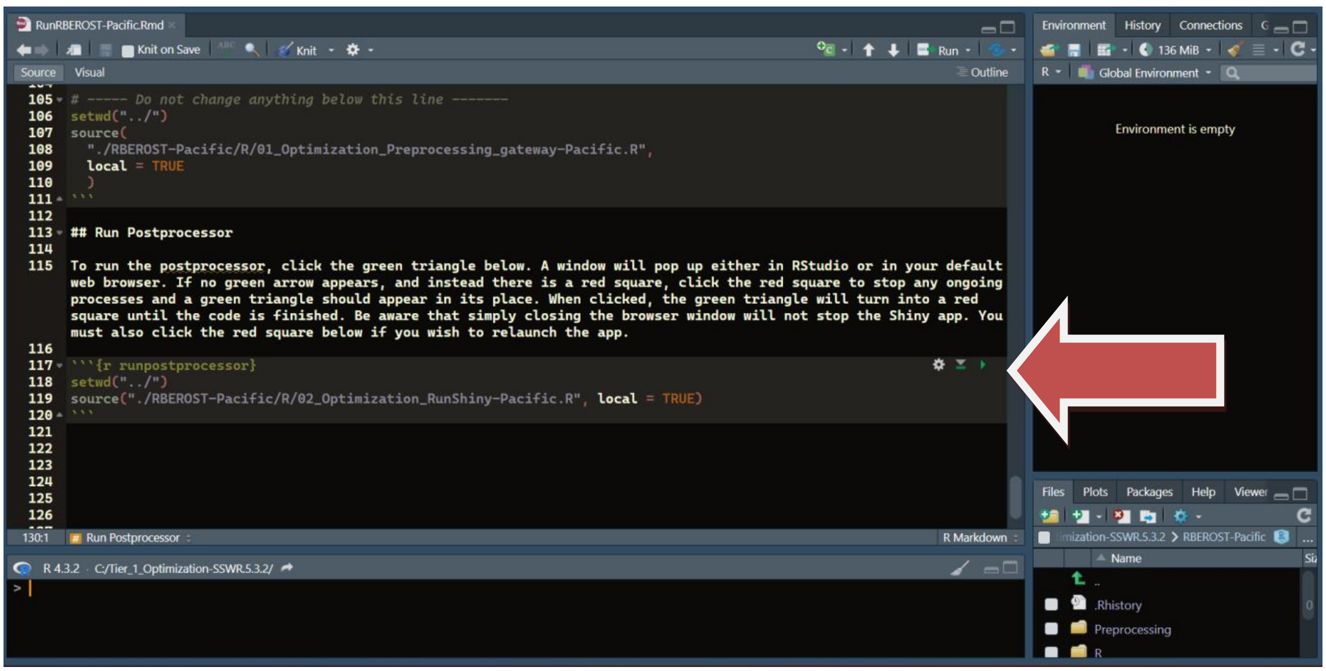


Figure 4-25: Run the RBEROST postprocessor.

4.4.1 Necessary Files

The postprocessor requires an upload of at least seven files and will display warning messages if files are not uploaded to the correct options (Figure 4-26). Note, when the "`All`" mode option is chosen, then the parent `01_UserSpecs_loadingtargets.csv` file should be uploaded to the RShiny application. If the "`Select`" mode option is chosen, then the newly generated `01_UserSpecs_loadingtargets_selected.csv` file should be uploaded to the RShiny application. The upload of StreamCat cropland files accepts all the state cropland files used in the optimization, which may be more than one file. Printing to pdf is the current recommended way of capturing metadata regarding which files are provided to the postprocessor. Required files include a result file from a NEOS optimization run, the list of WWTPs by their COMID locations, the SPARROW input file, the StreamCat files for all states included in the optimization, the UrbanBMPData file, and the road_areas file.

4.4.2 Preview Files

The preview step is not necessary but may be helpful for users to ensure they have selected and uploaded the intended files. To preview files, click the **`Preview Uploads`** button and navigate to the **`File Preview`** tab (Figure 4-28). At any point users can upload new files and preview them by selecting **`Preview Uploads`** again.

4.4.3 Display Results

To view results, click **`View NEOS Results`** and navigate to the **`View Results`** tab (Figure 4-29). Several panels will appear including an option to select the scenario the user wishes to view, the comments entered by the user to NEOS, a summary of the total cost calculated by RBEROST, and a summary of BMP implementations by category. For RBEROST runs without uncertainty, only one scenario is available. For RBEROST runs with uncertainty, more than one scenario may be available, and only one will be displayed at a time. Additional panels displayed for models with uncertainty include a panel showing the expected probability density distribution of costs (Figure 4-29) and a panel showing the probability density distributions of total annual expected loading to the user-specified loading targets (Figure 4-30). The panel displaying the probability density distribution of total expected loadings to user-specified targets will also display a dashed line at the value of the user defined loading target value from the **`01_UserSpecs_loadingtargets.csv`** `or` **`01_UserSpecs_loadingtargets_selected.csv`** file. The user will also have additional information displayed depending on the number of scenarios and level of uncertainty given, such as 20 percent (Figure 4-31) and 50 percent (Figure 4-32). If the model was unable to solve, a message will appear with the following explanation:

> "RBEROST may fail to optimize models for a variety of reasons. Sometimes this may be a result of user error during specification of user inputs (e.g., in the case of nonsensical limits on BMPs) or during NEOS submission (e.g., uploading incorrect files). Other times, this is a result of loading targets that are too restrictive, or a result of not including enough BMPs for the model to use. It is also possible to receive an error for reasons other than those listed above. Please check your user inputs.
>
> If problems persist a user might try running RBEROST again with less restrictive loading targets and/or including more BMPs in the optimization."

In addition, in the event of failure due to AMPL syntax, errors from CPLEX will be displayed. These errors can occasionally occur for a variety of reasons, including if the users have uploaded the AMPL files in the wrong order during job submission.

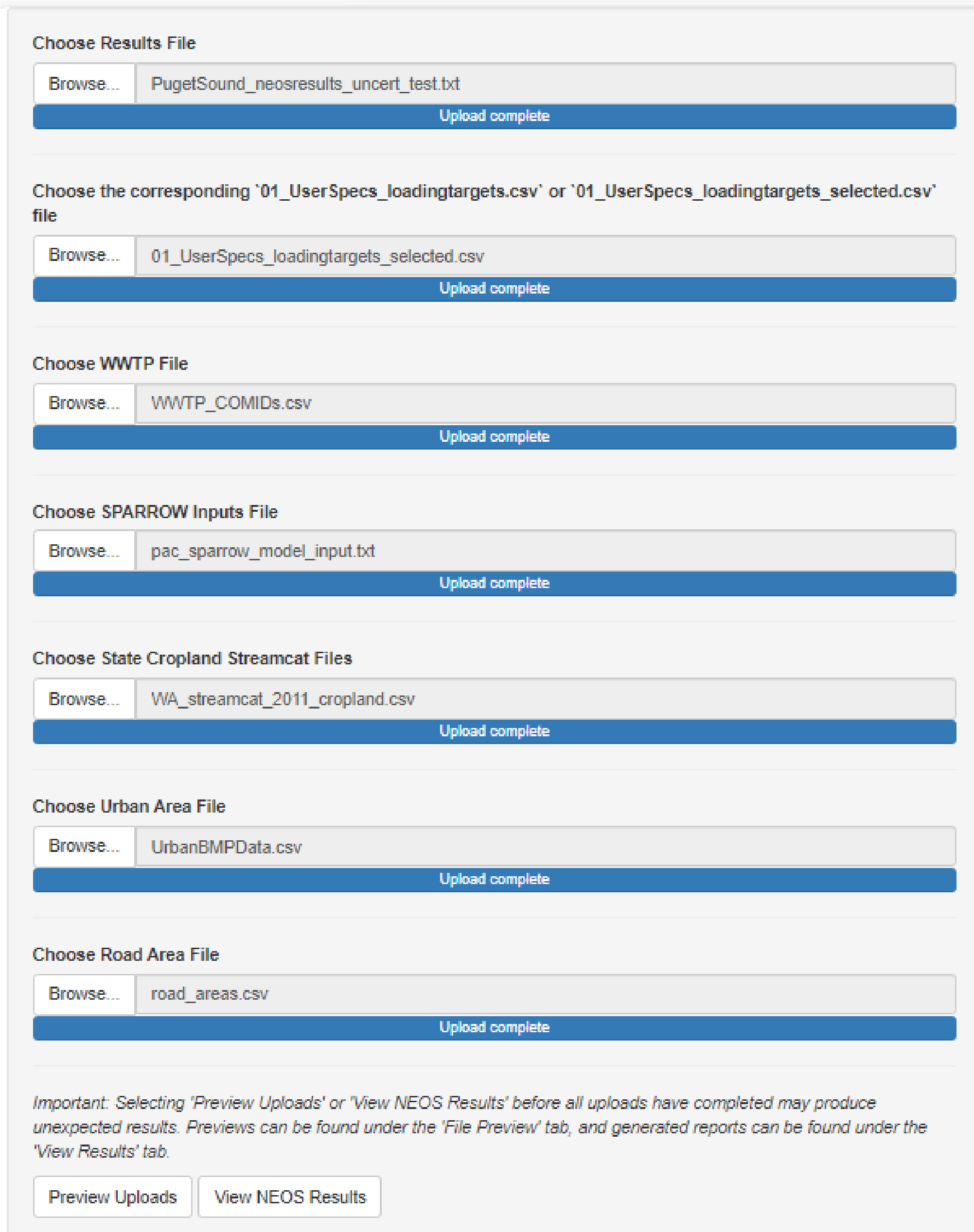


Figure 4-26: Files necessary to run RBEROST post-processor.

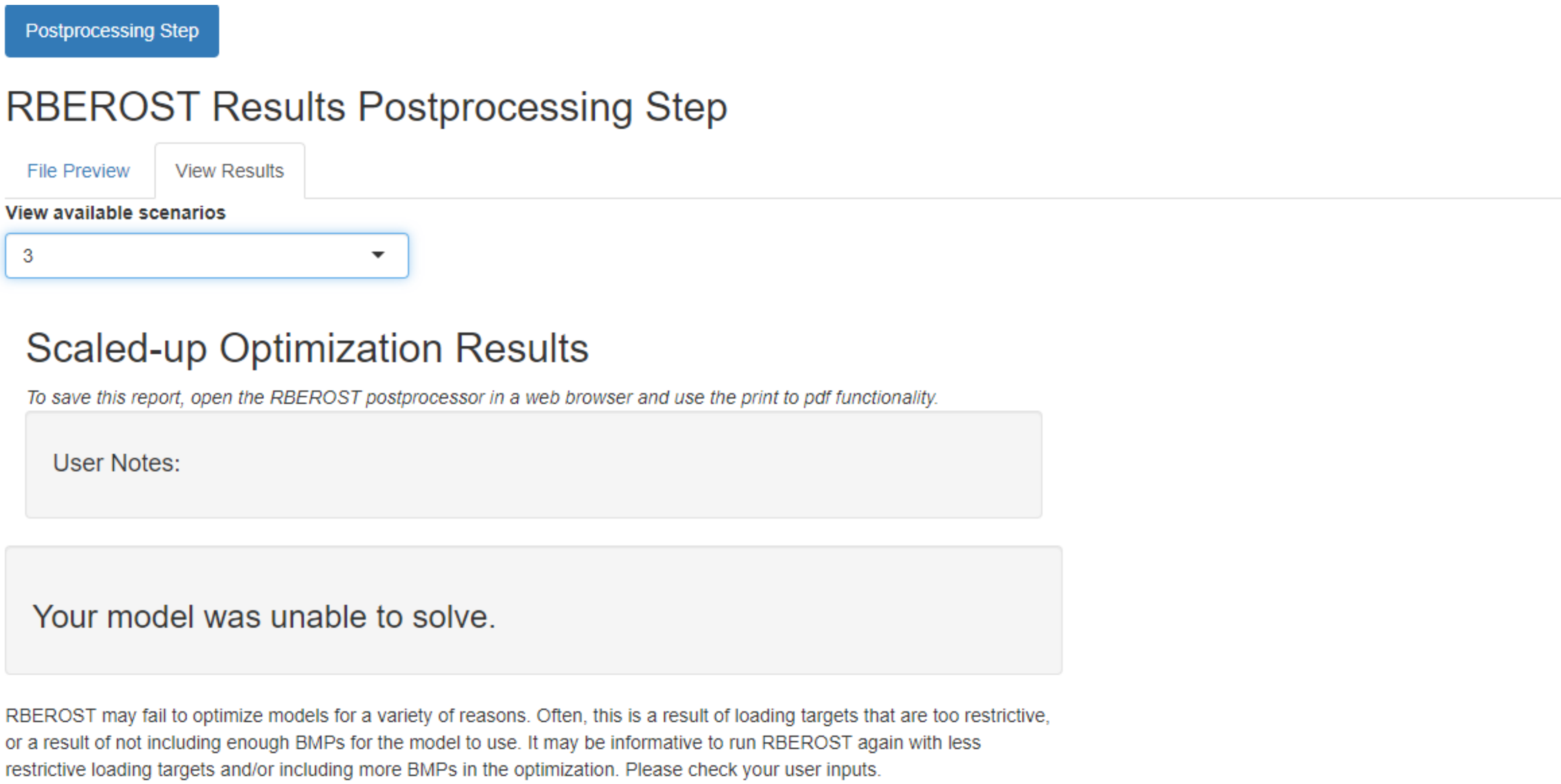


Figure 4-27: Postprocessor results when optimization fails.

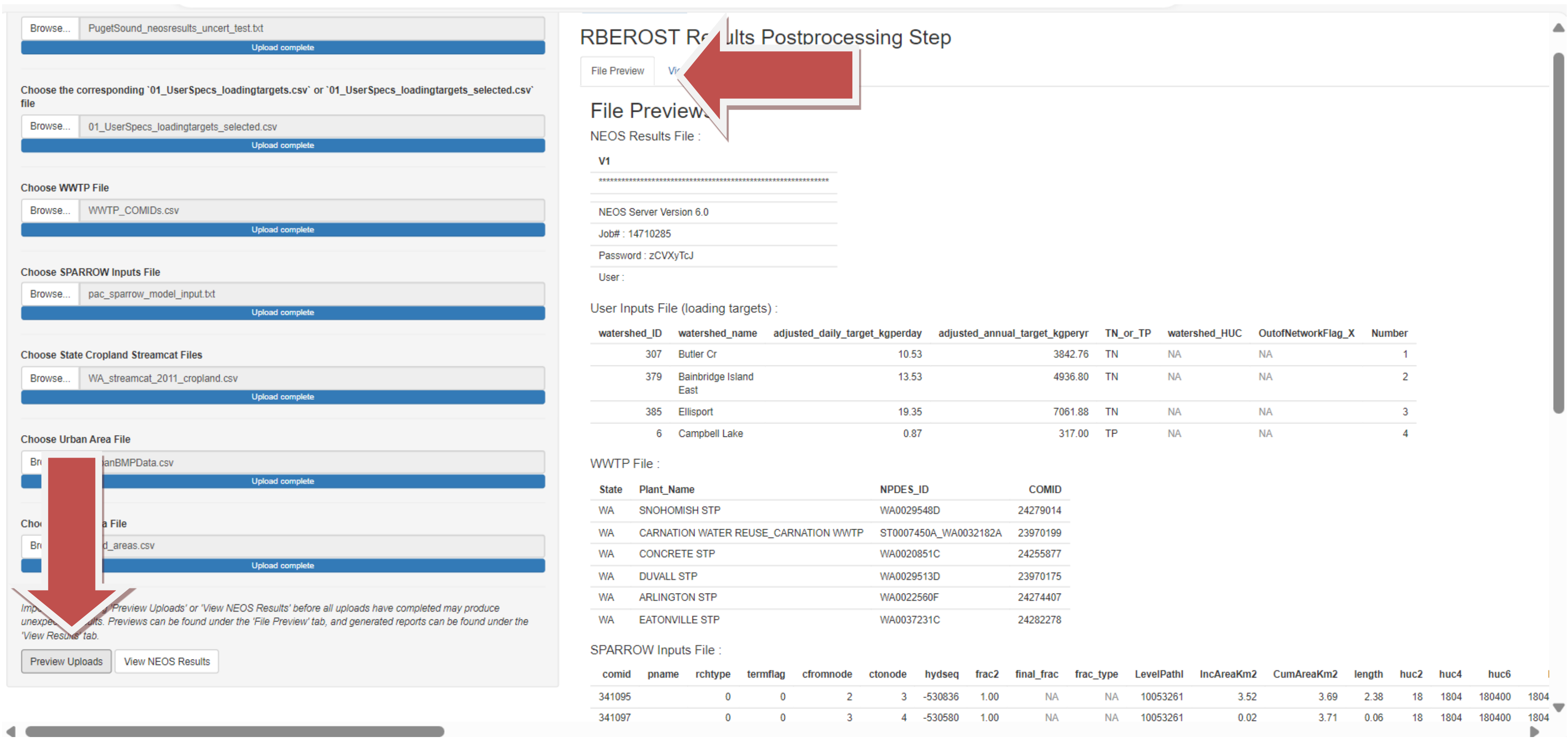


Figure 4-28: Previewing files for RBEROST postprocessor.

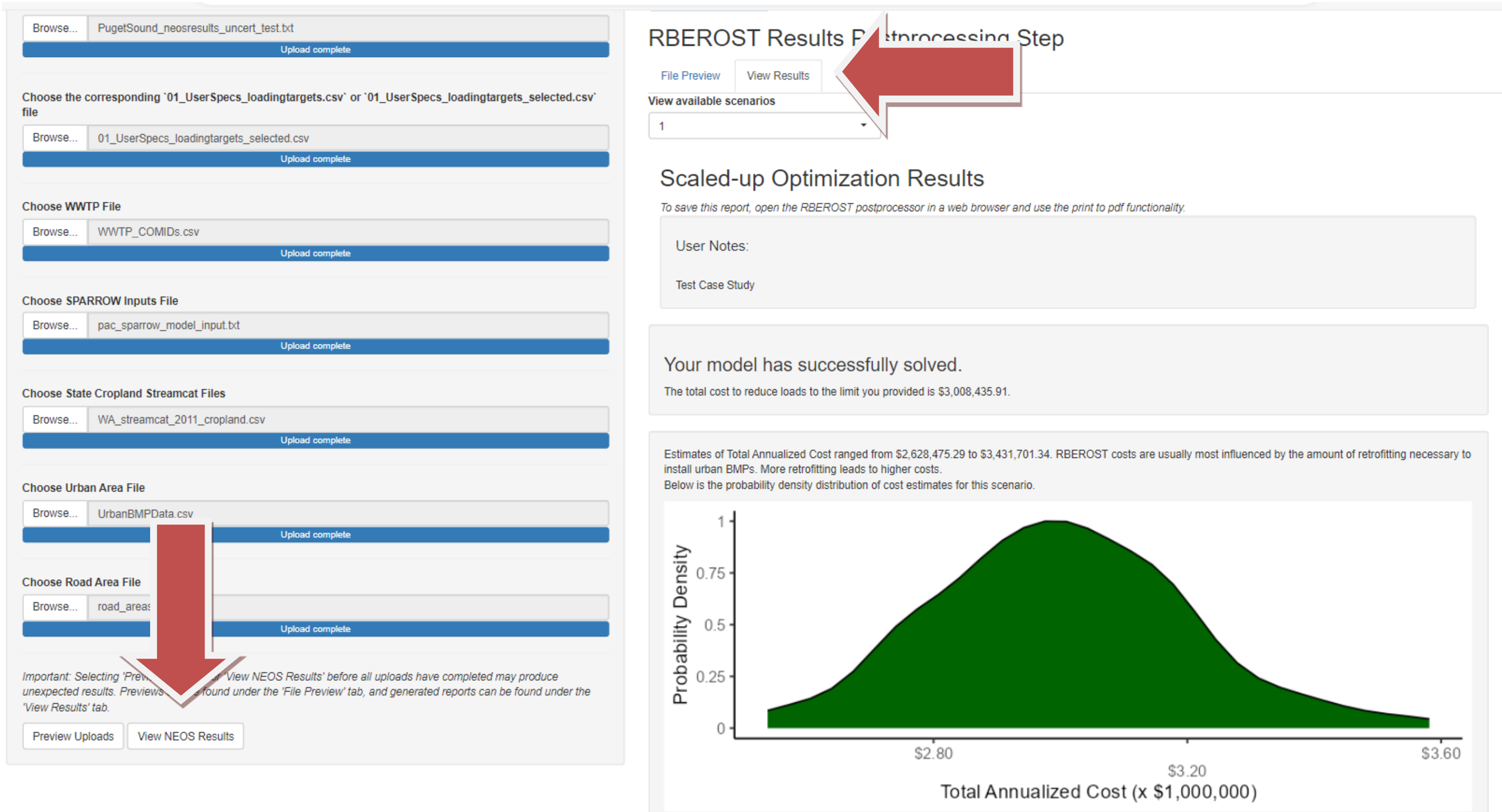


Figure 4-29: Viewing RBEROST results.

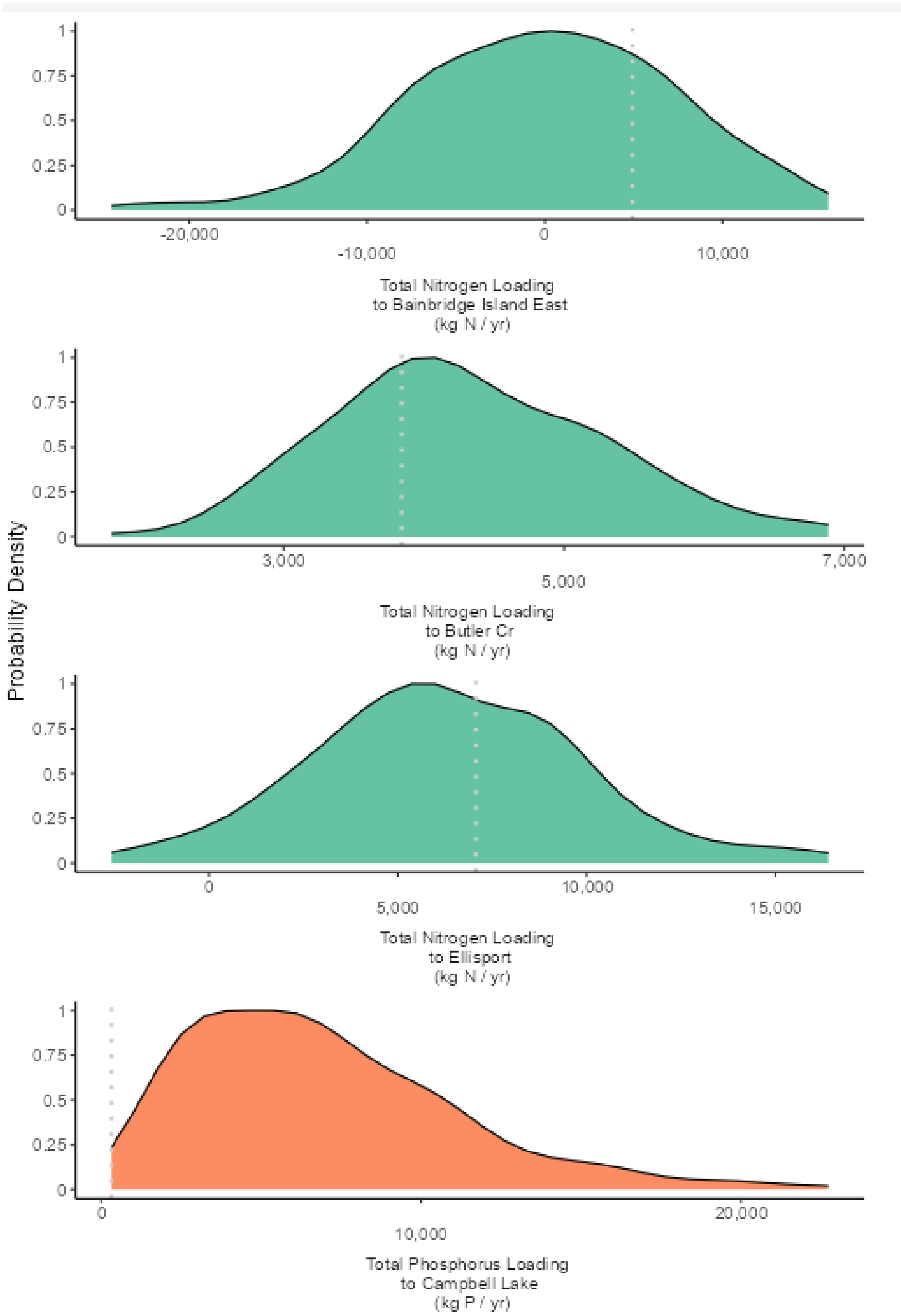
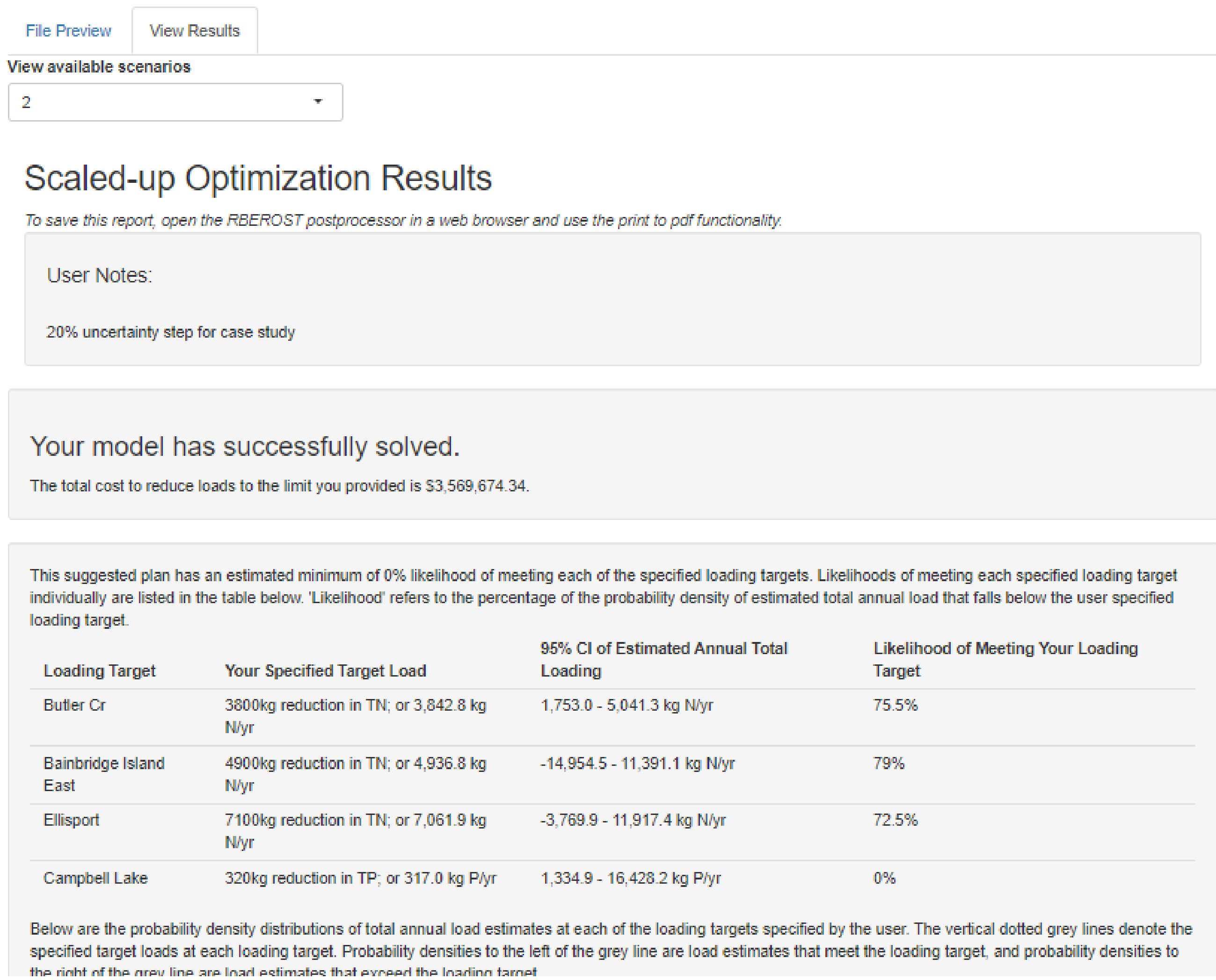


Figure 4-30: Total annual expected loading to targets.



File Preview | View Results

View available scenarios

2

Scaled-up Optimization Results

To save this report, open the RBEROST postprocessor in a web browser and use the print to pdf functionality.

User Notes:

20% uncertainty step for case study

Your model has successfully solved.

The total cost to reduce loads to the limit you provided is $3,569,674.34.

This suggested plan has an estimated minimum of 0% likelihood of meeting each of the specified loading targets. Likelihoods of meeting each specified loading target individually are listed in the table below. 'Likelihood' refers to the percentage of the probability density of estimated total annual load that falls below the user specified loading target.

Loading Target	Your Specified Target Load	95% CI of Estimated Annual Total Loading	Likelihood of Meeting Your Loading Target
Butler Cr	3800kg reduction in TN; or 3,842.8 kg N/yr	1,753.0 - 5,041.3 kg N/yr	75.5%
Bainbridge Island East	4900kg reduction in TN; or 4,936.8 kg N/yr	-14,954.5 - 11,391.1 kg N/yr	79%
Ellisport	7100kg reduction in TN; or 7,061.9 kg N/yr	-3,769.9 - 11,917.4 kg N/yr	72.5%
Campbell Lake	320kg reduction in TP; or 317.0 kg P/yr	1,334.9 - 16,428.2 kg P/yr	0%

Below are the probability density distributions of total annual load estimates at each of the loading targets specified by the user. The vertical dotted grey lines denote the specified target loads at each loading target. Probability densities to the left of the grey line are load estimates that meet the loading target, and probability densities to the right of the grey line are load estimates that exceed the loading target.

Figure 4-31: Optimization postprocessor results when running RBEROST with 20% uncertainty.

View available scenarios

2

Scaled-up Optimization Results

To save this report, open the RBEROST postprocessor in a web browser and use the print to pdf functionality.

User Notes:

50% uncertainty step for case study

Your model has successfully solved.

The total cost to reduce loads to the limit you provided is $4,444,398.47.

This suggested plan has an estimated minimum of 0% likelihood of meeting each of the specified loading targets. Likelihoods of meeting each specified loading target individually are listed in the table below. 'Likelihood' refers to the percentage of the probability density of estimated total annual load that falls below the user specified loading target.

Loading Target	Your Specified Target Load	95% CI of Estimated Annual Total Loading	Likelihood of Meeting Your Loading Target
Butler Cr	3800kg reduction in TN; or 3,842.8 kg N/yr	424.0 - 3,067.8 kg N/yr	99.5%
Bainbridge Island East	4900kg reduction in TN; or 4,936.8 kg N/yr	-18,940.2 - 11,050.1 kg N/yr	83%
Ellisport	7100kg reduction in TN; or 7,061.9 kg N/yr	-8,990.2 - 10,341.7 kg N/yr	84%
Campbell Lake	320kg reduction in TP; or 317.0 kg P/yr	1,297.3 - 16,327.3 kg P/yr	0%

Below are the probability density distributions of total annual load estimates at each of the loading targets specified by the user. The vertical dotted grey lines denote the specified target loads at each loading target. Probability densities to the left of the grey line are load estimates that meet the loading target, and probability densities to the right of the grey line are load estimates that exceed the loading target.

Figure 4-32: Optimization postprocessor results when running RBEROST with 50% uncertainty.

4.4.4 Download Detailed Results

COMID-specific BMP implementation decisions can be downloaded from the Shiny App for any single scenario (Figure 4-33). Point-source decisions are not available for download and are displayed within the Shiny interface. Additional contextual information is included in the downloadable csv files including the HUC12 code and state for each COMID, the size of the catchment, and the total area of agricultural land treated for ag BMPs, urban land for urban BMPs, or grazing land for grazing BMPs, the NPDES permit for WWTP upgrades, or the total river reach length for riparian buffer BMPs.

The model did not implement any WWTP retrofits.

The model chose to implement the total area of the following rowcrop BMPs:

Conservation (ac)
124.9

Download Agricultural (Rowcrop) BMPs by COMID

The model did not implement any grazing BMPs.

The model chose to implement the total area of the following urban BMPs.

'GreenRoof' (ac)	'InfiltrationBasin' (ac)	'PorousPavementwUD' (ac)	'SandFilterwUD' (ac)
689.0	195.9	9,947.8	292.2

Download Urban BMPs by COMID

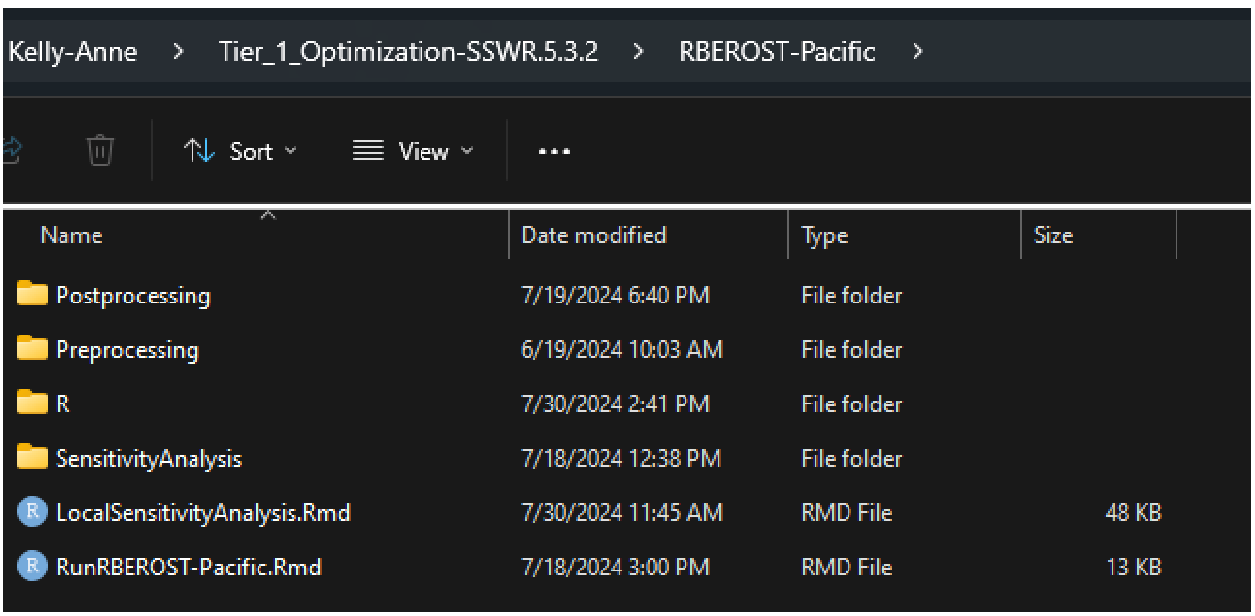
The model did not implement any road BMPs.

The model did not implement any riparian buffer BMPs.

Figure 4-33: Downloading RBEROST results.

5 Model Sensitivity

A local sensitivity analysis was developed for Puget Sound RBEROST which allows evaluation of the effect of uncertainty of individual parameters on model results, independent of other parameters. To run the local sensitivity analysis, open and run the `LocalSensitivityAnalysis.Rmd` file. Before running the file, be sure to update the email in the 'setup' chunk. Additionally, within the `SensitivityAnalysis` folder, ensure that the `AMPLscripts` folder and `NEOSResults` folder are cleared of any previous runs to prevent duplicate files from being created or parsing results from old runs. Additional directions on running specific chunks of the analysis can be found within the code file itself, such as before the 'send AMPL scripts to solver' chunk and 'load & parse sens files' chunk. The local sensitivity analysis will vary each parameter specified in the code by a certain sensitivity range based on expected parameter distribution and run the varied parameter with the original model to evaluate the sensitivity of results to a specific parameter. The global sensitivity module, which allows for simultaneous evaluation of uncertainty of multiple parameters, is still being developed. Please note that unfortunately individual agencies may have firewall settings that interfere with operation of the sensitivity module which automatically sends files to the NEOS server. The NEOS server uses port 3333, which is not a "standard" port and is blocked by some firewalls due to security concerns. Users will either need to request an exception for this application or work with this module outside of the firewall.



RBEROST results are sensitive to provided data and user inputs. Model results are most sensitive to the provided TP baseloads for urban and grazing areas, agricultural cost fraction, capital costs and the TP removal efficiency for the offsite water grazing BMP, and TP removal efficiencies for the following urban BMPs: green roofs, infiltration basins, porous pavement with underdrains, and sand filters with underdrains. "Most sensitive" means that a one percent change or less in *both* the positive and negative direction causes either total costs or spending on individual BMPs to change by more than 10 percent. Other parameters may have been more sensitive in one direction than the other, or generally less sensitive in both directions. RBEROST sensitivity to each individual user input is given in Table 5-1, and sensitivity to each individual data parameter provided in the RBEROST preprocessing input csv files is given in Table 5-2. The `Parameter` columns in Table 5-1 and Table 5-2 are the names of the parameters as they appear in the AMPL model and data scripts. The `Set member` columns generally describe the specific BMP being defined but may also reflect other groupings, such as capital or operations costs, urban or agricultural area, or the source of nutrient loading baselines.

Tolerances are defined as the relative amount of variation in the estimate of each parameter that produces RBEROST results with costs that are within 10 percent of the reference cost, and that produces results with relative amounts of spending on each BMP that are within 10 percent of the amount spent on that BMP in the reference result. The reference result is the RBEROST solution to a problem with all BMPs included and no limits on implementation (sometimes referred to as the 'unconstrained' model. Parameters are considered sensitive if a change of less than 10 percent produces results that are more than 10 percent different from the reference. Parameters are considered highly sensitive if a change of less than one percent produces results that are more than 10 percent different from the reference. The last two columns in Table 5-1 and Table 5-2 describe the sensitivity to parameters as they are decreased from their default value and as they are increased from their default value. Parameters with tolerances marked as "not applicable" either have default values of 0, or already have default values that are at the minimum or maximum of their permitted range.

Table 5-1: RBEROST tolerance to variation in User Specifications

Parameter	Set member (BMP or other)	Tolerance to decreased values	Tolerance to increased values
ag_frac_max	Conservation	sensitive	not applicable
ag_frac_min	Conservation	not applicable	not applicable
graz_frac_max	Offsite_Water	not sensitive	not applicable
graz_frac_min	Offsite_Water	not applicable	not applicable
loads_lim_N1	NA	not sensitive	not sensitive
loads_lim_N2	NA	not sensitive	not sensitive
loads_lim_N3	NA	not sensitive	not sensitive
loads_lim_P4	NA	not sensitive	not sensitive
ripbuf_frac_max	Grassed_Buffer	not sensitive	not applicable
ripbuf_frac_min	Grassed_Buffer	not applicable	not applicable
road_frac_max	Infiltration_Trench	not sensitive	not applicable
road_frac_max	Sand_Filter_w_UD	not sensitive	not applicable
road_frac_max	Wet_Pond	not sensitive	not applicable
road_frac_min	Infiltration_Trench	not applicable	not applicable
road_frac_min	Sand_Filter_w_UD	not applicable	not applicable
road_frac_min	Wet_Pond	not applicable	not applicable
urban_frac_max	Green_Roof	not sensitive	not applicable
urban_frac_max	Infiltration_Basin	not sensitive	not applicable
urban_frac_max	Infiltration_Trench	not sensitive	not applicable
urban_frac_max	Porous_Pavement_w_UD	sensitive	not applicable
urban_frac_max	Sand_Filter_w_UD	not sensitive	not applicable
urban_frac_max	Wet_Pond	not sensitive	not applicable
urban_frac_min	Green_Roof	not applicable	not applicable
urban_frac_min	Infiltration_Basin	not applicable	not applicable
urban_frac_min	Infiltration_Trench	not applicable	not applicable
urban_frac_min	Porous_Pavement_w_UD	not applicable	not applicable
urban_frac_min	Sand_Filter_w_UD	not applicable	not applicable
urban_frac_min	Wet_Pond	not applicable	not applicable

Table 5-2: RBEROST tolerance to variation in parameters in RBEROST data sets

Parameter	Set member (BMP or other)	Tolerance to decreased values	Tolerance to increased values
ag_bmp_ implementationpotential	Conservation	sensitive	not sensitive
ag_costs_capital	Conservation	sensitive	sensitive
ag_costs_operations	Conservation	not sensitive	not sensitive
ag_effic_N	Conservation	not sensitive	not sensitive
ag_effic_P	Conservation	not sensitive	not sensitive
agcost_frac	NA	highly sensitive	sensitive
area	ag	sensitive	sensitive
area	graz	not sensitive	not sensitive
baseloads_N1	ag	not sensitive	not sensitive
baseloads_N1	graz	not sensitive	not sensitive
baseloads_N1	point	sensitive	sensitive
baseloads_N1	road	not sensitive	not sensitive
baseloads_N1	urban	sensitive	sensitive
baseloads_N2	ag	not sensitive	not sensitive
baseloads_N2	graz	not sensitive	not sensitive
baseloads_N2	point	not sensitive	not sensitive
baseloads_N2	road	not sensitive	not sensitive
baseloads_N2	urban	sensitive	not sensitive
baseloads_N3	ag	not sensitive	not sensitive
baseloads_N3	graz	not sensitive	not sensitive
baseloads_N3	point	not sensitive	not sensitive
baseloads_N3	road	not sensitive	not sensitive
baseloads_N3	urban	not sensitive	not sensitive
baseloads_P4	ag	not sensitive	not sensitive
baseloads_P4	graz	not sensitive	highly sensitive
baseloads_P4	point	not sensitive	not sensitive
baseloads_P4	road	not sensitive	not sensitive
baseloads_P4	urban	highly sensitive	not sensitive
graz_costs_capital	Offsite_Water	highly sensitive	not sensitive
graz_costs_operations	Offsite_Water	not sensitive	not sensitive
graz_effic_N	Offsite_Water	not sensitive	not sensitive
graz_effic_P	Offsite_Water	not sensitive	highly sensitive

other_loads_N1	NA	not sensitive	not sensitive
other_loads_N2	NA	not sensitive	not sensitive
other_loads_N3	NA	not sensitive	not sensitive
other_loads_P4	NA	not sensitive	not sensitive
point_costs_capital	C	not sensitive	not sensitive
point_costs_operations	C	not sensitive	not sensitive
point_effic_N	C	not sensitive	not sensitive
point_effic_P	C	not applicable	not applicable
riparianload_N1	NA	not sensitive	not sensitive
riparianload_N2	NA	not sensitive	not sensitive
riparianload_N3	NA	not sensitive	not sensitive
riparianload_P4	NA	not sensitive	not sensitive
riparianremoval_N1	Grassed_Buffer	not sensitive	not sensitive
riparianremoval_N2	Grassed_Buffer	not sensitive	not sensitive
riparianremoval_N3	Grassed_Buffer	not sensitive	not sensitive
riparianremoval_P4	Grassed_Buffer	not sensitive	not sensitive
ripbuf_costs_capital	Grassed_Buffer	not sensitive	not sensitive
ripbuf_costs_operations	Grassed_Buffer	not applicable	not applicable
road_area	road	not sensitive	not sensitive
road_costs_capital	Infiltration_Trench	not sensitive	not sensitive
road_costs_capital	Sand_Filter_w_UD	not sensitive	not sensitive
road_costs_capital	Wet_Pond	not sensitive	not sensitive
road_costs_operations	Infiltration_Trench	not sensitive	not sensitive
road_costs_operations	Sand_Filter_w_UD	not sensitive	not sensitive
road_costs_operations	Wet_Pond	not sensitive	not sensitive
road_effic_N	Infiltration_Trench	not sensitive	not sensitive
road_effic_N	Sand_Filter_w_UD	not sensitive	not sensitive
road_effic_N	Wet_Pond	not sensitive	not sensitive
road_effic_P	Infiltration_Trench	not sensitive	not sensitive
road_effic_P	Sand_Filter_w_UD	not sensitive	not sensitive
road_effic_P	Wet_Pond	not sensitive	not sensitive
total_banklength	NA	not sensitive	not sensitive
unbuffered_banklength	Grassed_Buffer	not sensitive	not sensitive
urban_area	urban	sensitive	sensitive
urban_bmp_ implementationpotential	Green_Roof	not sensitive	not sensitive

urban_bmp_ implementationpotential	Infiltration_Basin	not sensitive	not sensitive
urban_bmp_ implementationpotential	Infiltration_Trench	not sensitive	not sensitive
urban_bmp_ implementationpotential	Porous_Pavement_w_UD	sensitive	not sensitive
urban_bmp_ implementationpotential	Sand_Filter_w_UD	not sensitive	not sensitive
urban_bmp_ implementationpotential	Wet_Pond	not sensitive	not sensitive
urban_costs_capital	Green_Roof	not sensitive	not sensitive
urban_costs_capital	Infiltration_Basin	not sensitive	not sensitive
urban_costs_capital	Infiltration_Trench	not sensitive	not sensitive
urban_costs_capital	Porous_Pavement_w_UD	not sensitive	not sensitive
urban_costs_capital	Sand_Filter_w_UD	not sensitive	not sensitive
urban_costs_capital	Wet_Pond	not sensitive	not sensitive
urban_costs_operations	Green_Roof	not sensitive	not sensitive
urban_costs_operations	Infiltration_Basin	not sensitive	not sensitive
urban_costs_operations	Infiltration_Trench	not sensitive	not sensitive
urban_costs_operations	Porous_Pavement_w_UD	not sensitive	not sensitive
urban_costs_operations	Sand_Filter_w_UD	not sensitive	not sensitive
urban_costs_operations	Wet_Pond	not sensitive	not sensitive
urban_effic_N	Green_Roof	not sensitive	not sensitive
urban_effic_N	Infiltration_Basin	not sensitive	not sensitive
urban_effic_N	Infiltration_Trench	not sensitive	not sensitive
urban_effic_N	Porous_Pavement_w_UD	sensitive	sensitive
urban_effic_N	Sand_Filter_w_UD	not sensitive	not sensitive
urban_effic_N	Wet_Pond	not sensitive	not sensitive
urban_effic_P	Green_Roof	highly sensitive	not sensitive
urban_effic_P	Infiltration_Basin	highly sensitive	not sensitive
urban_effic_P	Infiltration_Trench	not sensitive	not sensitive
urban_effic_P	Porous_Pavement_w_UD	highly sensitive	not sensitive
urban_effic_P	Sand_Filter_w_UD	highly sensitive	not sensitive
urban_effic_P	Wet_Pond	not sensitive	not sensitive

6 Data Dictionary

Table 6-1 lists the input files that are read into the preprocessing and postprocessing R code, describes the contents of the inputs and specific data fields used in the model, units of data, and data sources. Table 6-2 lists the output files that are created by the postprocessing R code, the data units, and the sources of associated data. Appendix D – Data Dictionary for Individual RBEROST Variables lists descriptions for individual variables in each of the preprocessing input datasets.

Table 6-1: Data dictionary of RBEROST input files

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
01_Preprocessing_Terminal_COMID.csv	File containing a list of all terminal NHD COMID's associated with each watershed/user target.	Not Applicable	Not Applicable
01_Preprocessing_Upstream_COMID.csv	File containing a list of all upstream NHD COMID's based on each terminal COMID and associated with individual watersheds/user targets.	Not Applicable	Not Applicable

Input File Name	Input File Description	Data Units (If Applicabl e)	Source(s)
01_UserSpecs_BMPs.csv	User specification file for selection of BMPs to be included in optimization model, BMP capital and operations & maintenance costs, riparian buffer width, and whether or not Ag BMPs treat tile drained land. File includes default capital and operations & maintenance costs as well as default buffer widths. Minimum and maximum buffer widths (Min_width_ft and Max_width_ft) indicate the range between which the user can specify riparian buffer BMP widths. Min_width_ft and Max_width_ft fields are not used in scaled-up optimization model code. Separate columns must be included for the capital and operations & maintenance costs for each state included in the geographic range of optimization. Column titles must follow the naming convention "capital_[two letter state code]" and "operations_[two letter state code]".	Per-area BMP cost units described in file. Buffer width in feet.	BMP cost data sources described in Table 3.2. Minimum and maximum buffer widths from [*Houle et al.*, 2019].
01_UserSpecs_loadingtargets.csv	User specification file for providing loading targets to include in RBEROST. Fields include Waterbody name and adjusted targets. Fields including TN_or_TP, OutofNetworkFlag, and TermFlag are deprecated and no longer utilized.	kg/day; kg/year	Not Applicable

Input File Name	**Input File Description**	**Data Units (If Applicable)**	**Source(s)**
01_UserSpecs_loadingtargets_selected.csv	Modified version of the 01_UserSpecs_loadingtargets.csv file containing only rows that correspond to the watershed_choices when the "Select" mode option is chosen.	kg/day; kg/year	Not Applicable
ACRE_HUC12_HRU_Summary_compareBaseline.csv	Agricultural BMP efficiencies summarized by HUC12 (or if unavailable, HUC10, HUC8 and/or HUC6) based on ACRE database. "HUC" fields represent the hydrologic unit code (HUC12/HUC10/HUC8/HUC6). "Scenario" field represents BMP scenarios, modeled by [*White et al.*, 2019] for the ACRE database. "MeanTN_Effic" field reflects average nitrogen removal efficiency per scenario, with respect to "Baseline" conditions. "MeanTP_Effic" reflects average phosphorus removal. Columns ending in "_se" represent standard errors.	Percent	Original ACRE database from [*White et al.*, 2019]. Data summarized at HUC-levels by RBEROST associated R scripts.

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
ACRE_HUC12_HRU_Summary_compareNoPractice.csv	Agricultural BMP efficiencies summarized by HUC12 (or if unavailable, HUC10, HUC8 and/or HUC6) based on ACRE database. "HUC" fields represent the hydrologic unit code (HUC12/HUC10/HUC8/HUC6). "Scenario" field represents BMP scenarios, modeled by [*White et al.*, 2019] for the ACRE database. "MeanTN_Effic" field reflects average nitrogen removal efficiency per scenario, with respect to "No Practice" conditions. "MeanTP_Effic" reflects average phosphorus removal. Columns ending in "_se" represent standard errors.	Percent	Original ACRE database from [*White et al.*, 2019]. Data summarized at HUC-levels by RBEROST associated R scripts.

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
AgBMPEffic_nonACRE.csv	Agricultural BMP nitrogen removal efficiencies for grade stabilization, diversions, cover crops, drainage management, manure injection and offsite water (do not vary by location). "Category" field reflects the agricultural BMP category within RBEROST, "BMP" field reflects the best management practice considered, and "N_Efficiency" and "P_Efficiency" fields reflects the nitrogen removal efficiency, which is the percent of nutrients removed. Fields ending with "_se" represent standard error. BMPs CustomAg1, CustomAg2, and CustomAg3 may be used by the user if needed, and data should be added to this file.	Percent	Grade_Stabilization" BMP: [*Waidler et al.*, 2009] "Diversion" BMP: [*Waidler et al.*, 2009] "Cover_Crops" BMP: [*Christianson et al.*, 2021] "Drainage_Management" BMP: [*Ross et al.*, 2016] "Manure_Injection" BMP: [*Dell et al.*, 2016] for methodology and [*Lund et al.*, 2014] for N loss pathways. Offsite_Water" BMP: [*Franklin et al.*, 2009; *Sheffield et al.*, 1997]

Input File Name	**Input File Description**	**Data Units (If Applicable)**	**Source(s)**
EQIPcosts_overyears.csv	EQIP costs for agricultural and riparian buffer BMPs for years 2020-2021. "BMP_Category" field reflects whether a BMP is implemented on agricultural (row crop) land, on pasture land, or in riparian buffers. "BMP" field reflects the best management practice considered, "capital_units" reflect the cost units for capital costs as cost / unit area, "operations_units" reflect the cost units for operation costs as cost / unit area. The remaining fields describe the costs from EQIP payment schedules follow the naming convention "[capital or operations costs]_[state]_[year]". At least one year of data must be provided for each state included in the geographic range of optimization.	Dollars per unit area	[*U.S. Department of Agriculture Staff,* 2021]

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
LengthinBuffer_2016.csv	The amount of each stream reach that is in riparian buffers of certain widths, as of 2016. Fields include "comid," "totalbanklength_ft," which is two times the stream reach, "totalbanklength_ft_se" describing the standard error associated with the total bank length, and fields describing the length of stream bank in buffer and the standard error around those values. Naming conventions for the rest of the fields are [Riparian buffer BMP]_["buffer" for estimates, "buffer_se" for standard errors]_[minimum buffer width to be considered "in buffer"]_ft.	Feet	Stream reaches from [*Dewald et al.*, 2019], landcover from *Yang et al.* [2018]. Summaries provided following R scripts and ArcPython model builder scripts associated with RBEROST.
MUN_FED_ALL_USGS.csv	USGS file that includes locational information for federally operated nutrient point sources. File contains information such as facility flow as well as loadings and NPDES permit information.	Flow in million gallons per day (MGD); Loadings in kg/day and kg/month	[*Mohamedali et al.*, 2011]

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
MUN_STATE_ALL_USGS.csv	USGS file that includes locational information for state operated nutrient point sources. File contains information such as facility flow as well as loadings and NPDES permit information.	Flow in million gallons per day (MGD); Loadings in kg/day and kg/month	[*Mohamedali et al.*, 2011]

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
NdepChange_2012_2020.csv / NdepChange_2012_2020_update.csv	Changes in TN deposition. Fields include "comid," "TDEP_TN_2012_arch" (describing annual mass deposition in 2012 with an older deposition model), "TDEP_TN_2017_arch" (describing annual mass deposition in 2017 with an older deposition model), TDEP_TN_2017_cur (describing deposition in 2017 with a newer deposition model), TDEP_TN_2020_cur (describing deposition in 2020 with a newer deposition model), Change_2012_2017 which looks at same-model percent change between 2012 and 2017, Change_arch_cur, which is the percent change between the two methodologies for 2017, Change_2017_2020 which is the percent change between 2017 and 2020, and AdjChange2012_2020, which is the percent change 2012-2020 accounting for the methodological shift. "update" version of file contains updated values for select COMIDs.	kg-N/ha, kg-N/ha, percent	[*National Atmospheric Deposition Program*, 2021]; COMID shapefiles from *Dewald et al.* [2019]; summarized with ArcMap and R scripts for RBEROST

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
pac_sparrow_model_input.txt	Pacific Regional SPARROW Model input dataset. Fields used in scaled-up optimization model include "huc12," "comid," "IncAreaKM2" (incremental area per catchment), and "developed11_km2" (urban area per catchment).	Incremental and urban areas in km2	[*Wise*, 2019]
pac_sparrow_model_output_tn.txt	Pacific Regional SPARROW Total Nitrogen Model output dataset. Fields used in RBEROST include "comid," "il_tn_scg" (incremental load per catchment from scrub brush), "il_tn_atm" (incremental atmospheric deposition load), "il_tn_urb" (incremental urban load), "il_tn_spr" (incremental load from springs), "il_tn_ald" (incremental load from alder trees), "il_tn_fer" (incremental load from fertilizer), "il_tn_wwtp" (incremental load from WWTPs), and "DEL_FRAC" (fraction of incremental load delivered to terminal reach).	Incremental loadings in kg/yr	[*Wise*, 2019]

Input File Name	**Input File Description**	**Data Units (If Applicable)**	**Source(s)**
pac_sparrow_model_output_tp.txt	Pacific Regional SPARROW Total Phosphorus Model output dataset. Fields used in RBEROST include “comid,” “il_tp_chan” (incremental load per catchment from channels), “il_tp_geo” (incremental load from geological sources), “il_tp_spr” (incremental load from springs), “il_tp_urb” (incremental load from urban land), “il_tp_grazing” (incremental load from grazing land), “il_tp_fer” (incremental load from fertilizer), “il_tp_wwtp” (incremental load from WWTPs), and “DEL_FRAC” (fraction of incremental load delivered to terminal reach). each field that is used in RBEROST.	Incremental loadings in kg/yr	[*Wise*, 2019]
PctCroplandTileDrained_ICF24.csv	Percent of cropland per catchment that is tile drained. Fields include “comid” and “pct_tiled_adj”	Percent	[*Hill et al.*, 2016; *Dewald et al.*, 2019; *Valayamkunnath et al.*, 2020]

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
RiparianEfficiencies_update0425.csv	Performance curves describing nutrient removal efficiency in riparian buffers. Fields include "comid," and fields with character entries of functions that RBEROST will parse to calculate efficiency. All functions are functions of buffer width, and the coefficients depend on slope and hydrologic soil group. Naming convention follows [N or P, designating which nutrient removal efficiency is being described]_[type of riparian buffer BMP]_[approximate width of buffer]. Though all equations are a function of buffer width, the slope and hydrologic soil group may differ based on the buffer width which may change the coefficients. Columns that describe uncertainty are designated with "_uncertainty" at the end. Uncertainty columns contain a character string of 10 different equations produced by sampling the slope and hydrologic soil groups of each buffer width. These character strings are parsed within RBEROST.	Percent	Methodology: [*Houle et al.*, 2019.] River reach shape files: [*Dewald et al*., 2019]. Hydrologic soil group: STATSGO2 [*Soil Survey Staff et al.*, 2021]. Slope data: [*Verdin*, 2017]

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
RiparianLoadings_update0425.csv	Nutrient loading to riparian zones. Fields include “comid,” “N_riparian_kgyr” “P_riparian_kgyr,” “N_riparian_kgyr_se,” and “P_riparian_kgyr_se,” where N or P designates the nutrient being described, and _se designates standard errors.	kg-N/yr; kg-P/yr; kg-N/yr; kg-P/yr	Methodology for calculating loading: [*Houle et al.*, 2019]. Land cover data: [*Jin et al.*, 2019; *Yang et al.*, 2018]. River reach shape files: [*Dewald et al.*, 2019]
road_areas.csv	Field containing road areas that can be used for implementing road BMPs. File contains areas for each combination of COMID and hydrologic soil group (HSG).	Area – acres; area_sum – acres; area_port – percent, area_port is a percentage used to calculate road areas for each HSG within a COMID	Not Applicable

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
road_bmps.csv	File containing road BMPs, efficiencies capital costs, and operations costs that vary by COMID and HSG.	Costs - 2020 U.S. Dollars; Area – acres; Efficiencies – percent	Not Applicable
UrbanBMPData.csv	File containing urban BMPs, efficiencies, capital costs, and operations costs that vary by COMID, HSG, and land use type.	Costs - 2020 U.S. Dollars; Efficiencies – percent; Area - acres	Not Applicable
USGS_AgBMP_PugetSound.csv	Information on agricultural BMP areas per COMID used in conjunction with other data during preprocessing to develop ag baseline BMP areas.	Percent	Not Applicable

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
WA_streamcat_2011_cropland.csv	Washington percent cropland, hayfield, Open development, low intensity development, medium intensity development, and high intensity development data from National Land Cover Database, 2011 (catchment-specific data downloaded from StreamCat). Fields used in scaled-up optimization model include "comid," "PctCrop2011Cat," "PctHay2011Cat", "PctOpUrb2011Cat," "PctLowUrb2011Cat," "PctMedUrb2011Cat," and "PctHiUrb2011Cat". *Note: if optimizing a geographic extent that includes states beyond those used in the Puget Sound case study, additional state files may be included. Locating these files in the Preprocessor/Inputs folder and following the naming convention of "[two letter state code]_streamcat_2011_[cropland or imperv].csv" will allow them to be used automatically by RBEROST.	Percent	Percent cropland land data downloaded from NLCD via StreamCat [*Hill et al.*, 2016]

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
WA_streamcat_2011_imperv.csv	Washington percent imperviousness data from National Land Cover Database (catchment-specific data downloaded from StreamCat). Fields used in scaled-up optimization model include "comid" and "PctImp2011Cat." *Note: if optimizing a geographic extent that includes states beyond those used in the Puget Sound Case study, additional state files may be included. Locating these files in the Preprocessor/Inputs folder and following the naming convention of "[two letter state code]_streamcat_2011_[cropland or imperv].csv" will allow them to be used automatically by RBEROST.	Percent	Percent impervious land data downloaded from NLCD via StreamCat [*Hill et al.*, 2016]
WWTP_BaselineRemoval.csv	Loading for each year and comid available in [*U.S. Environmental Protection Agency*, 2012]. RBEROST uses the "Rem_2012oroldest_2021ornewest_load_ch_TN" and "Rem_2012oroldest_2021ornewest_load_ch_TP" columns to adjust the SPARROW loading estimates.	kg/yr, percent	[*U.S. Environmental Protection Agency*, 2012]

Input File Name	Input File Description	Data Units (If Applicable)	Source(s)
WWTP_COMIDs.csv	Crosswalk between the WWTPs included in the scaled-up optimization model example application and their locations along the NHDPlus Version 2 flow network.	Not Applicable	[*Markus et al.*, 2011; *Dewald et al.*, 2019]
WWTP_Costs.csv	Cost estimates of upgrades by BMP combinations. Columns include "COMID", and columns with the naming convention "[BMP(s) implemented in combination separated by '_']_[Capital|OM]_2021dollars[_se], where se indicates that the column describes the standard error of cost.	2021 dollars, 2021 dollars per year	[*Markus et al.*, 2011]
WWTP_RemovalEffic.csv	Estimated nitrogen and phosphorus removal efficiencies based on BioWin modeling. Columns include "COMID", and columns with the naming convention "[BMP(s) implemented in combination separated by '_']_[TN|TP]_Efficiency[_se], where se indicates that the column describes the standard error of cost.	Percent	[*Markus et al.*, 2011]

Table 6-2: Data dictionary of RBEROSR output files

Output File Name	Output File Description	Data Units (If Applicable)
AgBMP_by_ComID_Scenario1.csv (or other scenarios, if not renamed by user)	Agricultural (row crop) BMP implementation by COMID. Fields include “COMID,” “HUC_12” (12 digit hydrologic unit code), “IncAreaKm” (the area of the catchment defined by COMID), “ag_km2” (the area within that COMID defined as ag), “PctCrop2011Cat” (the percent of NLCD 2011 pixels categorized as row crop in the COMID as summarized by StreamCat) and “StateAbbrev” (WA for the Puget Sound case study). Any additional fields follow the naming convention of [BMP name]_[either FracImplement (the fraction of ag area treated with this BMP) or areaac (the total acreage of area treated with this BMP)]	_FracImplement fields as fractions, _areaac fields as acres
GrazingBMP_by_ComID_Scenario1.csv (or other scenarios, if not renamed by user)	Pasture/Grazing BMP implementation by COMID. Fields include “COMID,” “HUC_12” (12 digit hydrologic unit code), “IncAreaKm” (the area of the catchment defined by COMID), “ag_km2” (the area within that COMID defined as ag), “PctCrop2011Cat” (the percent of NLCD 2011 pixels categorized as row crop in the COMID as summarized by StreamCat) and “StateAbbrev” (WA for the Puget Sound case study). Any additional fields follow the naming convention of [BMP name]_[either FracImplement (the fraction of ag area treated with this BMP) or areaac (the total acreage of area treated with this BMP)]	_FracImplement fields as fractions, _areaac fields as acres

Output File Name	Output File Description	Data Units (If Applicable)
Point_by_ComID_Scenario1.csv (or other scenarios, if not renamed by user)	WWTP upgrades implemented by COMID. Fields include "COMID", "NPDES_ID" (the NPDES permit number of the discharger), "State" (WA for the Puget Sound case study), "Plant_Name" (name of the plant(s) in the catchment. If more than one, names are separated by "_"). The following columns list each individual BMP, and each row holds a "0" or "1" to indicate upgrade or no upgrade. If combinations of BMPs were implemented, "1" will appear in multiple columns.	Not applicable
Urban_by_ComID_Scenario1.csv (or other scenarios, if not renamed by user)	Urban BMP implementation by COMID. Fields include "COMID," "HUC_12" (12 digit hydrologic unit code), "Land_Use" (the land use of the area where implemented), and "HSG" (hydrologic soil group where BMP is implemented). Any additional fields follow the naming convention of [BMP name]_[either FracImplement (the fraction of urban area treated with this BMP) or areaac (the total acreage of area treated with this BMP)]	_FracImplement fields as fractions, _areaac fields as acres
RipBufBMP_by_ComID_Scenario1.csv (or other scenarios, if not renamed by user)	Riparian buffer BMP implementation by COMID. Fields include "COMID," "HUC_12" (12 digit hydrologic unit code), "IncAreaKm" (the area of the catchment defined by COMID), "totalbanklength_ft" (the distance of bank within the COMID, or 2 times "riverreachlength_ft"), "StateAbbrev" (WA for the Puget Sound case study), and "riverreachlength_ft" (the length of river). Additional fields follow the naming convention of [BMP name]_LengthImplemented_ft.	Length, in ft

Output File Name	Output File Description	Data Units (If Applicable)
Road_BMP_by_ComID_Scenario1.csv (or other scenarios, if not renamed by user)	Road BMP implementation by COMID. Fields include "COMID," "HUC_12" (12 digit hydrologic unit code), and "HSG" (hydrologic soil group). Any additional fields follow the naming convention of [BMP name]_[either FracImplement (the fraction of urban area treated with this BMP) or areaac (the total acreage of area treated with this BMP)]	_FracImplement fields as fractions, _areaac fields as acres

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Appendix A – Additional Information about Urban and Road BMP Costs and Efficiencies

Puget Sound Case Study Calculation of Stormwater BMP Costs and Efficiencies

Stormwater BMP types

A list of stormwater BMP types of interest was derived from the Western Washington Stormwater Management Manual (DOE 2019). Of the 23 practices of interest, six cannot be readily modeled with SWWM or WMOST so we cannot derive removal efficiencies for these (indicated by strike-outs below):

Downspout BMPs

Roof disconnection w Infiltration Drywell

Roof disconnection w Infiltration Trench

~~Downspout w partial dispersion system~~

Infiltration BMPs

Permeable pavement

Infiltration Basin

Infiltration Trench

Bioretention

Drywell

Filtration BMPS

Sand filter

Biofiltration BMPs

Vegetated filter strip

- **Wetpool BMPs**
- Wet pond
- ~~Wet vault~~
- Constructed wetland
- ~~Combined detention/wetpool~~
- **Manufactured (proprietary)**
- **Other LID**
- Rain gardens
- ~~Tree retention/tree planting~~
- Green roof
- Rainwater harvesting
- **Detention BMPs**
- Detention ponds
- ~~Detention tanks~~
- ~~Detention vaults~~

Estimation of Puget Sound regional build-up/wash off coefficients for use in SWAT

We used WMOST to estimate N and P loadings for representative watersheds across the Puget Sound Basin both with and without BMPs implemented. This required that we generate baseline hydrology and loading time series using SWAT as inputs to WMOST and for that, we required regionally calibrated build-up/wash off coefficients. We estimated regional build-up/washoff coefficients by running SWAT via EPA's HAWQS application (HAWQS 2020) for HUC12s in the Seattle, WA area for which event mean concentrations (EMC) had been derived for small urban catchments (Hobbs et al., 2015). EMC values were combined with discharge to estimate monthly loads which were used to calibrate the SWAT model runs using SWAT-CUP (Abbaspour 2015). Unfortunately, only one of the 15 SWAT calibrations showed a good fit. Parameters related to build-up/washoff can be highly correlated, leading to matrix inversion problems (Tetra-Tech, Inc., 2015). However, the calibrated maximum build-up coefficient for TSS was very similar to that derived for New England by Tetra Tech (Tetra-Tech, Inc., 2015). In addition, the calibrated half-time for build-up was similar to the default value used in HAWQS. However, ratios of TP, TN, and NO3 to sediment in runoff for the Puget Sound region were much higher than HAWQS defaults, possibly due to implementation of pre-existing BMPs for sediment reduction at the test sites.

Estimation of Puget Sound BMP removal efficiencies for N and P

Stormwater BMP removal efficiencies were estimated using WMOST to generate "managed sets" for BMPs of interest on developed HRUs in HUC12s with nearby weather stations, chosen by the state of WA to be representative of western Washington for applications of the Western Washington Hydrology Model (WWHM; Clear Creek Solutions, Inc., 2015). SWAT models were set up in HAWQS to generate input hydrology and loading time series for developed HRUs with unique land-use by hydrologic soil group combinations. Not all combinations were present in each representative HUC12, however. PRISM was used as the source of precipitation data and curve numbers and infiltration rates from the Western Washington Hydrology Model were assigned.

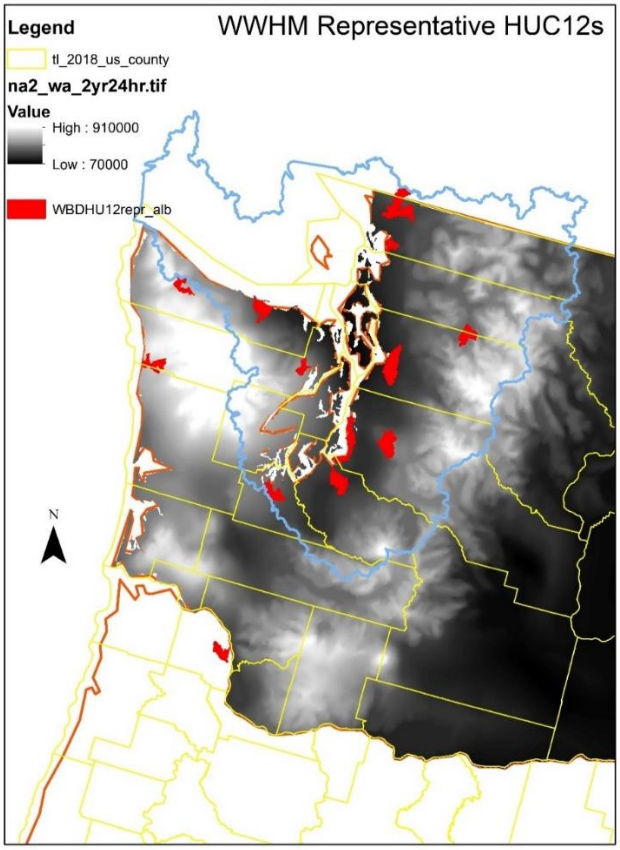

Figure A - 1: Western Washington Hydrology Model Representative HUC12's in the Puget Sound Region.

Total loads from managed sets over the period 1985 – 2018 were compared to baseline loads for the same time period to estimate long-term N and P reduction efficiencies for each BMP x LU x soil hydgrp combination. Two sets of WMOST models were set up, one using flow-volume storage depth targets established by WA state for one subset of BMPs: roof disconnection with drywell or infiltration trench, permeable pavement, infiltration basin or trench, bioretention, drywell, wet pond, constructed wetland, *green roof**, *rainwater harvesting**, *detention ponds/tanks/vaults**. Those listed in italics are meant to be used for controlling flow volume only, not water quality targets. Flow volume targets can be based on requirements either based on limited changes in flow duration curves or the requirement to treat 91% of runoff. We chose the latter requirement for ease of implementation. We evaluated cumulative runoff time series by storm magnitude to establish the event volume associated with 91% of cumulative runoff. Cumulative runoff was estimated using a curve number approach, with curve numbers chosen to be representative of western WA. A second set of WMOST analyses was set up using water-quality volume storage depth targets established by WA state for another subset of BMPs: permeable pavement, infiltration basin/trench, bioretention, drywell, sand filter, vegetated filter strip, biofiltration swale, wet pond, constructed wetland. WA state establishes water quality volume targets based on the 6-month 24hr precipitation event, which in turn can be estimated as 72% of the 2yr 24 hr event. NOAA has derived maps of the latter precipitation metric (NOAA 2022). We evaluated storage volume requirements differently for infiltration BMPs vs depression BMPs. For infiltration BMPs, we calculated the cumulative infiltration excess runoff totals to estimate required storage volumes. For depressional BMPs, we calculated maxima of running 2-day runoff averages, assuming BMPs would be designed to drain within 48 hours.

Estimation of Puget Sound BMP costs

Four different sources or methods for BMP cost estimation were applied, with order of preference listed from left to right in the following table. Of the four tools listed, only the National Stormwater Calculator (NSC) provides both capital and operation and maintenance (O&M) costs, allows cost adjustments for project complexity, and allows for regional cost adjustments. Neither the WERF calculator nor the Puget Sound database provide adjustments for complexity. OptiTool provides adjustments for project complexity but is currently tailored for costs specific to the New England area.

Table A - 1: Additional information about stormwater BMPs for the Puget Sound Region

Stormwater BMP	National Stormwater Calculator BMP (Rossman and Bernagros 2019)	WERF Model BMP (including operation costs; WERF 2009)	Puget Sound BMP Cost Database (Herrera Environmental Consultants 2012)	OptiTool (Tetra-Tech, Inc. 2016)
Roof disconnection w Infiltration Drywell				
Roof disconnection w Infiltration Trench			X	
Permeable pavement	X	X		2 types
Infiltration Basin	X			
Infiltration Trench			X	
Bioretention	X	X		
Drywell				
Sand filter				**X**
Vegetated filter strip			**X**	
Biofiltration swale		**X**		
Wet pond			**X**	X
Constructed wetland				**X**
Manufactured (proprietary)				
Green roof		X	X	
Rainwater harvesting		**X**	X	
Detention ponds			X	

The NSC complexity spreadsheet was applied to assign the following complexity classes to each land-use x hydrologic soil group combination:

Table A - 2: Complexity classes for the Puget Sound region.

NLCD Land Use	SWAT Land Use	Soil	Cost Curve
Developed - Open Space	URLD	A	Simple
Developed - Open Space	URLD	B	Simple
Developed - Open Space	URLD	C	Simple
Developed - Open Space	URLD	D	Simple
Low Density Residential	URMD	A	Simple
Low Density Residential	URMD	B	Simple-Typical
Low Density Residential	URMD	C	Typical-Complex
Low Density Residential	URMD	D	Typical-Complex
High Density Residential	URHD	A	Typical
High Density Residential	URHD	B	Typical
High Density Residential	URHD	C	Typical-Complex
High Density Residential	URHD	D	Complex
Industrial	UIDU	A	Complex
Industrial	UIDU	B	Typical-Complex
Industrial	UIDU	C	Complex
Industrial	UIDU	D	Complex

For NSC calculations, separate cost curve equations were applied for each complexity class (RTI International and Geosyntec Consultants. 2015). Cost methods produced an estimate of cost/unit impervious area. For BMPs described in the Kitsap County BMP methods for the Puget Sound Lowlands, capture ratios (area BMP per area impervious area) were derived from those equations as a function of annual average precipitation from the PRISM grid 30-year climate normal (1991 - 2020) (Herrera Environmental Consultants 2010). Otherwise design depths described above were used in conjunction with storage volumes to calculate capture ratios.

Interpolation of BMP efficiencies and costs for NHDPlus catchments in Puget Sound Basin

Quadratic equations were derived using PROC REG in SAS to interpolate BMP N and P reduction efficiencies and both capital and O&M costs as a function of annual average precipitation and maximum 2-day runoff (water quality targets) or as a function of annual average precipitation and cumulative excess infiltration runoff (flow-volume targets). Four models were compared for each case, i.e., both first and second order equations involving each parameter (precipitation or runoff metric) and that parameter squared. The best model fit was assessed using the Aikake's Information Criterion (AIC) as well as visual examination of residuals for patterns of nonlinearity. In addition, mean reduction efficiencies and costs were calculated for cases showing no significant variation as a function of precipitation or runoff. Models for reduction efficiencies were calculated for each BMP x Hydgrp combination, while models for costs were calculated for each BMP x Landuse x Hydgrp combination. Application of quadratic equations for predictions yielded negative estimates in some cases. Thus, for first order equations we forced a y-intercept of zero. For second-order equations, we substituted minimum costs associated with the required minimum area of LID installations for western WA for any costs below those thresholds. The equations are presented below. The same equations were used for modeling minimum implementation levels. To determine whether costs estimated from the original model should be used or the minimum implementation model, the largest of the costs were selected as capital or operations cost value.

Additionally, thresholds for the costs per N/P removal efficiency were applied to remove any unreasonable costs and efficiencies. We calculated the capital and operation and maintenances costs per one percent of N or P removed. For example, the following equation was used to calculate capital costs per one percent of P removed.

$$capital_p = capital_{cost}/(effic_p * 100)$$

This was repeated for operation and maintenance costs as well as N efficiencies. Then, the threshold was set to the third quarter of the overall distribution of those newly calculated variables. So, observations were dropped that had values:

- greater than the third quantile value of capital costs per one percent of P removed and
- greater than the third quantile value of capital costs per one percent of N removed and
- greater than the third quantile value of operation and maintenance costs per one percent of P removed and
- greater than the third quantile value of operation and maintenance costs per one percent of N removed.

Capital cost equations

Model 1: Cost as a function of annual average precipitation

$$Cost_{capital} = Intercept + (Annav\_capcost_{coef} * Annavprecipin)$$

Model 2: Cost as a function of two-day average runoff

$$Cost_{capital} = Intercept + (ro2d\_capcost_{coef} * ro2d\_in)$$

Model 3: Cost as a function of annual average precipitation and annual average precipitation squared

$$Cost_{capital} = Intercept + \left(Annav\_capcost_{coef} * Annavprecipin\right) + \left(Annav2\_capcost_{coef} * (Annavprecipin)^2\right)$$

Model 4: Cost as a function of two-day average runoff and two-day average runoff squared

$$Cost_{capital} = Intercept + \left(ro2d\_capcost_{coef} * ro2d\_in\right) + \left(ro2d2\_capcost_{coef} * (ro2d\_in)^2\right)$$

Operation and maintenance cost equations

Model 1: Cost as a function of annual average precipitation

$$Operations_{cost} = Intercept + (Annav\_omcost_{coef} * Annavprecipin)$$

Model 2: Cost as a function of two-day average runoff

$$Operations_{cost} = Intercept + (ro2d\_omcost_{coef} * ro2d\_in)$$

Model 3: Cost as a function of annual average precipitation and annual average precipitation squared

$$Operations_{cost} = Intercept + \left(Annav\_omcost_{coef} * Annavprecipin\right) + \left(Annav2\_omcost_{coef} * (Annavprecipin)^2\right)$$

Model 4: Cost as a function of two-day average runoff and two-day average runoff squared

$$Operations_{cost} = Intercept + \left(ro2d\_omcost_{coef} * ro2d\_in\right) + (ro2d2\_omcost_{coef} * (ro2d\_in)^{2})$$

Variable	Description
$Cost_{capital}$	Capital costs per acre for BMPs by land use and soil group type
$Cost_{operations}$	Operation and maintenance costs per acre for BMPs by land use and soil group type
$Annav\_capcost_{coef}$	Capital cost coefficient on annual average precipitation
$Annav2\_capcost_{coef}$	Capital cost coefficient on annual average precipitation squared
$Annavprecipin$	Average annual precipitation
$ro2d\_capcost_{coef}$	Capital cost coefficient on average two-day runoff
$ro2d2\_capcost_{coef}$	Capital cost coefficient on average two-day runoff squared
$ro2d\_in$	Average two-day runoff
$Annav\_omcost_{coef}$	Operation and maintenance cost coefficient on annual average precipitation
$Annav2\_omcost_{coef}$	Operation and maintenance cost coefficient on annual average precipitation squared
$ro2d\_omcost_{coef}$	Operation and maintenance cost coefficient on average two-day runoff
$ro2d2\_omcost_{coef}$	Operation and maintenance cost coefficient on average two-day runoff squared

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Addendum: Summary Statistic Tables for BMP Reduction Efficiencies and Costs

capcostparam_statsflow - Summary statistics for capital costs for BMPs based on flow-volume targets and regression coefficients for prediction based on best of four competing models by BMP, land-use, and soil hydrologic group

omcostparam_statsflow - Summary statistics for O&M costs for BMPs based on flow-volume targets and regression coefficients for prediction based on best of four competing models by BMP, land-use, and soil hydrologic group

capcostparam_statswq - Summary statistics for capital costs for BMPs based on wq-volume targets and regression coefficients for prediction based on best of four competing models by BMP, land-use, and soil hydrologic group

omcostparam_statswq - Summary statistics for O&M costs for BMPs based on wq-volume targets and regression coefficients for prediction based on best of four competing models by BMP, land-use, and soil hydrologic group

nparam_statsflow – Summary statistics for N removal efficiencies for BMPs based on flow-volume targets and regression coefficients for prediction based on best of four competing models by BMP and soil hydrologic group

pparam_statsflow – Summary statistics for P removal efficiencies for BMPs based on flow-volume targets and regression coefficients for prediction based on best of four competing models by BMP and soil hydrologic group

nparam_statswq – Summary statistics for N removal efficiencies for BMPs based on wq-volume targets and regression coefficients for prediction based on best of four competing models by BMP and soil hydrologic group

pparam_statswq – Summary statistics for P removal efficiencies for BMPs based on wq-volume targets and regression coefficients for prediction based on best of four competing models by BMP and soil hydrologic group

Each file contains the following parameters:

BMP – best management practice

Land_Use – developed land-use class

Hydgrp – soil hydrologic group

FREQ

n_<depparam> - number of observations for dependent parameter

mean_<depparam> - mean of observations for dependent parameter

min_<depparam> - minimum of observations for dependent parameter max_<depparam> - maximum of observations for dependent parameter

std_<depparam> - standard deviation of observations for dependent parameter

MODEL - Model number (1 – 4)

DEPVAR - dependent variable

RMSE - root mean squared error

Intercept – equation intercept

AnnavPrecipin – coefficient for annual average precipitation

operations_2020USDacryr – coefficient for

ro2d_in – coefficient for two-day average runoff

AnnavPrecipin2 - coefficient for annual average precipitation^2

ro2d_in2 - coefficient for two-day average runoff^2

_IN_

_P_ - number of parameters

EDF - estimated degrees of freedom

RSQ - r squared

AIC - Aikake's Information Criterion

AIC1 – AIC for model 1

AIC2 – AIC for model 2

AIC3 – AIC for model 3

AIC4 – AIC for model 4

bestAIC – AIC for best model (minimum AIC)

bestmodel – number of best model

PrecOrder – order of prediction equations including annual average precipitation predictors, 0 = average only, 1 first order, 2 second order based on significance of coefficients ($p < 0.05$)

Ro2dOrder – order of prediction equations including 2 day average runoff predictors, 0 = average only, 1 first order, 2 second order based on significance of coefficients ($p < 0.05$)

cuminfexcroOrder – order of prediction equations including cumulative infiltration excess runoff predictors, 0 = average only, 1 first order, 2 second order based on significance of coefficients ($p < 0.05$)

Model 1: depparam = f(Annavprecip)

Model 2: depparam = f(2dro or cuminfexcro)

Model 3: depparam = f(Annavprecip, Annavprecip^{2})

Model 4: depparam f(2dro, 2dro^{2} OR cuminfexcro, cuminfexcro^{2})

If bestAIC = . or both Order variables 0 then use mean value, otherwise apply coefficients for best model

Table 3 Summary Statistics for BMP Costs and Efficiencies

BMP Type	Land Use	HSG	Avg. N Effic.	Avg. P Effic.	Avg. Capital Cost ($/acre treated)	Avg. OM Cost ($/acre treated)
Green_Roof	UIDU	A	1	1	323,689.30	5,539.19
Green_Roof	UIDU	B	1	1	323,689.30	5,539.19
Green_Roof	UIDU	C	1	1	490,665.70	17,059.02
Green_Roof	UIDU	D	1	1	490,665.70	17,059.02
Green_Roof	URHD	A	1	1	105,333.52	1,121.95
Green_Roof	URHD	B	1	1	105,333.52	1,121.95
Green_Roof	URHD	C	1	1	220,546.37	3,657.33
Green_Roof	URHD	D	1	1	335,759.22	11,263.46
Green_Roof	URLD	A	1	1	5,889.11	134.63
Green_Roof	URLD	B	1	1	5,889.11	134.63
Green_Roof	URLD	C	1	1	5,889.11	134.63
Green_Roof	URLD	D	1	1	5,889.11	134.63
Green_Roof	URMD	A	1	1	14,783.05	595.66
Green_Roof	URMD	B	1	1	36,638.00	595.66
Green_Roof	URMD	C	1	1	126,515.01	1,941.71
Green_Roof	URMD	D	1	1	126,515.01	1,941.71
Infiltration_Basin	UIDU	A	0.77432	0.75227	1,632,877.99	20,312.60
Infiltration_Basin	UIDU	B	0.77432	0.75227	1,632,877.99	34,782.85
Infiltration_Basin	UIDU	C	0.77432	0.75227	1,451,549.00	61,535.78
Infiltration_Basin	UIDU	D	0.77432	0.75227	299,486.91	23,251.79
Infiltration_Basin	URHD	A	0.99906	0.99895	10,705.73	59.39
Infiltration_Basin	URHD	B	0.99906	0.99895	715,475.12	2,857.62
Infiltration_Basin	URHD	C	0.99906	0.99895	1,237,308.96	21,972.18
Infiltration_Basin	URHD	D	0.99906	0.99895	372,124.35	22,824.23

Infiltration_Basin	URLD	A	0.99971	0.99985	3,287.48	8.38
Infiltration_Basin	URLD	B	0.99971	0.99985	53,377.82	410.09
Infiltration_Basin	URLD	C	0.99971	0.99985	58,768.53	452.27
Infiltration_Basin	URLD	D	0.99971	0.99985	193,577.34	1,490.01
Infiltration_Basin	URMD	A	0.99917	0.99862	5,114.38	35.41
Infiltration_Basin	URMD	B	0.99917	0.99862	334,223.03	1,757.35
Infiltration_Basin	URMD	C	0.99917	0.99862	942,705.82	16,740.61
Infiltration_Basin	URMD	D	0.99917	0.99862	424,576.67	8,158.68
Infiltration_Trench	URLD	A	0.99876	0.01159	48,170.56	2,056.79
Infiltration_Trench	URLD	B	0.99876	0.01159	244,443.44	12,221.86
Infiltration_Trench	URLD	C	0.99876	0.01159	357,001.84	17,850.33
Infiltration_Trench	URLD	D	0.99876	0.01159	708,119.15	35,405.80
Infiltration_Trench	URMD	A	0.99677	0.00326	213,111.67	8,723.53
Infiltration_Trench	URMD	B	0.99677	0.00326	1,134,025.75	56,701.12
Infiltration_Trench	URMD	C	0.99677	0.00326	1,335,540.02	66,776.95
Infiltration_Trench	URMD	D	0.99677	0.00326	1,839,846.83	91,992.43
Porous_Pavement_w_UD	UIDU	A	0.993	0.99183	-	-
Porous_Pavement_w_UD	UIDU	B	0.993	0.99183	22,042.68	1,321.87
Porous_Pavement_w_UD	UIDU	C	0.993	0.99183	28,273.05	1,413.65
Porous_Pavement_w_UD	UIDU	D	0.993	0.99183	96,288.10	4,814.54
Porous_Pavement_w_UD	URHD	A	1	1	-	22.19
Porous_Pavement_w_UD	URHD	B	1	1	24,328.27	1,216.42
Porous_Pavement_w_UD	URHD	C	1	1	20,676.94	1,033.84
Porous_Pavement_w_UD	URHD	D	1	1	75,448.04	3,772.31
Porous_Pavement_w_UD	URLD	A	1	1	-	5.32
Porous_Pavement_w_UD	URLD	B	1	1	5,239.01	261.94
Porous_Pavement_w_UD	URLD	C	1	1	5,740.11	287.00
Porous_Pavement_w_UD	URLD	D	1	1	18,907.21	998.93
Porous_Pavement_w_UD	URMD	A	1	1	-	13.24
Porous_Pavement_w_UD	URMD	B	1	1	13,221.05	661.04
Porous_Pavement_w_UD	URMD	C	1	1	13,994.89	699.76
Porous_Pavement_w_UD	URMD	D	1	1	47,989.71	2,399.41
Sand_Filter_w_UD	UIDU	A	0.89573	0.89339	13,985.69	699.28
Sand_Filter_w_UD	UIDU	B	0.89573	0.89339	74,331.88	4,458.47
Sand_Filter_w_UD	UIDU	C	0.89573	0.89339	95,341.80	4,767.09
Sand_Filter_w_UD	UIDU	D	0.89573	0.89339	153,143.59	7,657.25
Sand_Filter_w_UD	URHD	A	0.99981	0.99976	13,985.69	699.28
Sand_Filter_w_UD	URHD	B	0.99981	0.99976	81,999.50	4,099.98
Sand_Filter_w_UD	URHD	C	0.99981	0.99976	69,726.35	3,486.32
Sand_Filter_w_UD	URHD	D	0.99981	0.99976	140,864.54	7,043.24
Sand_Filter_w_UD	URLD	A	1	1	6,992.84	349.64

Sand_Filter_w_UD	URLD	B	1	1	8,129.26	406.47
Sand_Filter_w_UD	URLD	C	1	1	8,067.01	403.36
Sand_Filter_w_UD	URLD	D	1	1	18,771.37	724.72
Sand_Filter_w_UD	URMD	A	0.99988	1	13,985.69	699.28
Sand_Filter_w_UD	URMD	B	0.99988	1	45,722.02	2,286.08
Sand_Filter_w_UD	URMD	C	0.99988	1	47,326.14	2,366.30
Sand_Filter_w_UD	URMD	D	0.99988	1	124,075.05	6,203.70
Wet_Pond	URLD	B	0.08732	0.08732	3,081.32	154.07
Wet_Pond	URLD	C	0.01237	0.01333	3,057.73	152.89
Wet_Pond	URLD	D	0.00716	0.00716	6,680.14	231.97
Wet_Pond	URMD	B	0.07085	0.08266	17,330.54	866.53

Additional Puget Sound Case Study Calculations for Road BMP Costs and Efficiencies

Road-specific BMP costs and efficiencies are estimated from the urban BMP costs and efficiencies by taking those values from the most developed land use category (UIDU – Industrial), while still allowing the values to vary by soil group type. Therefore, the road BMP costs and efficiencies both vary by COMID and soil group type, but not by land use.

8 Appendix B – Maps of Pacific Model Spatial Extent

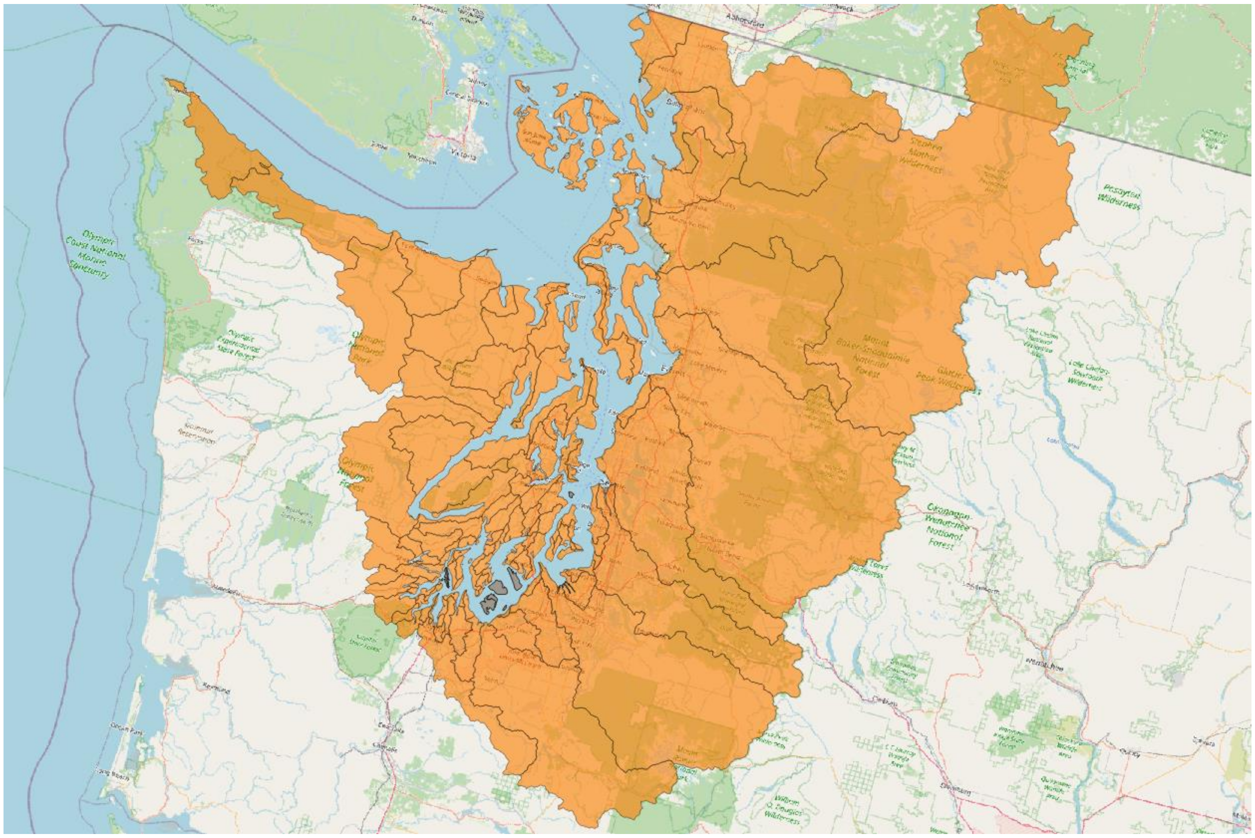

Figure B - 1: A map of the watersheds relevant to the Pacific RBEROST model for nitrogen. Included watersheds are shown in orange while watersheds not included in the model, primarily small islands in the southern end of the sound, are shown in gray.

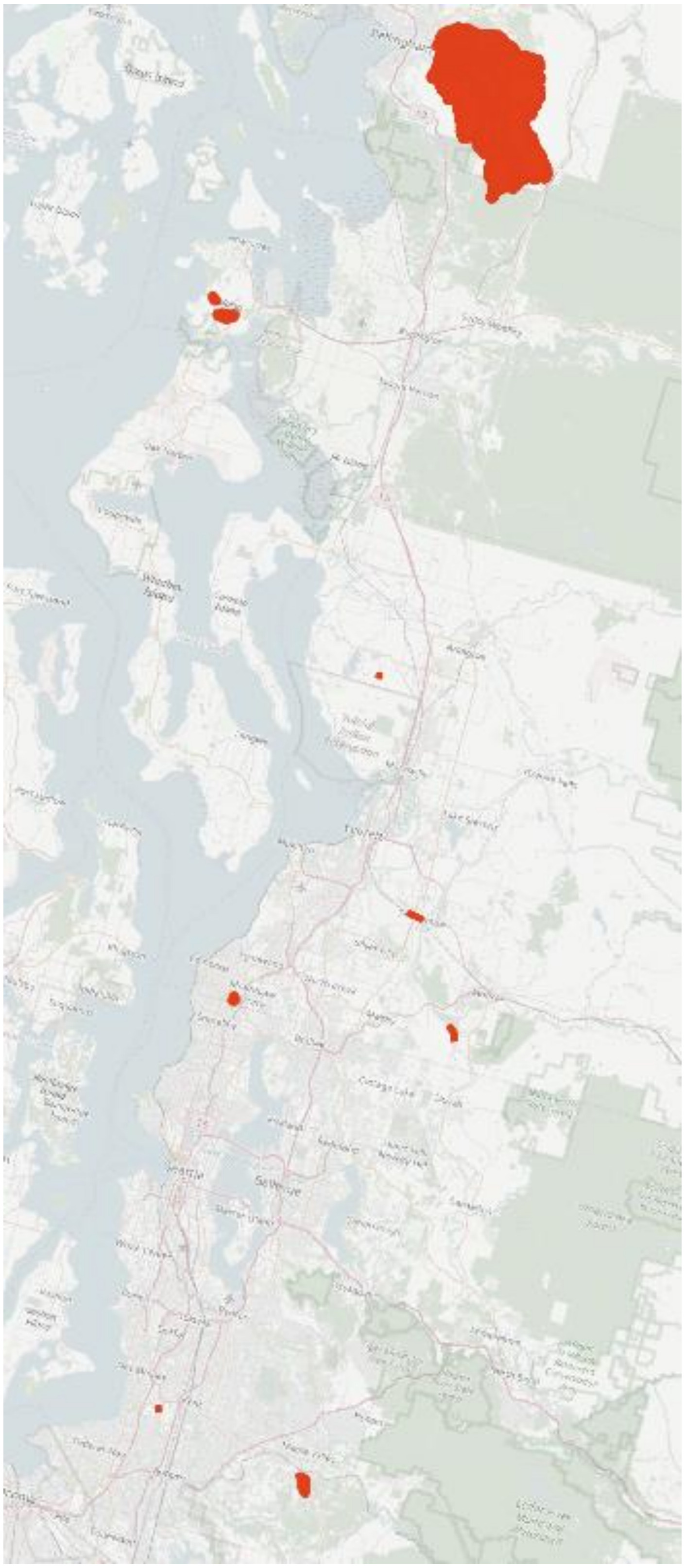

Figure B - 2: A map of the watersheds relevant to the Pacific RBEROST model for phosphorus. The lakes and watersheds are highlighted in red.

9 Appendix C – Water Quality Target Locations and Data Sources

The input files folder contains lists of both terminal and upstream COMIDs. These lists of COMIDs are combined with additional information from the 01_Preprocessing_UserSpec_loadingtargets.csv file to run the model. Additional information describing how targets, terminal COMIDs, and upstream COMIDs are related is included below. Loading target data for lake phosphorus targets originated from Washington State Dept. of Ecology documents detailing the establishment of lake TMDL's for phosphorus (Appendix E). Placeholder loading target data for estuarine nitrogen targets also originated from the Washington State Dept. of Ecology and were estimated based on putting all marine WWTPs at a monthly average effluent TN of 3 mg/L and all watershed reductions at 65% of current estimated anthropogenic loads. Interim and/or final target loads have not yet been established. Internal communications with Dustin Bilhimer also served as a source of loading target information.

Nitrogen targets are based upon Salish Sea Model (SSM) watersheds data such that one target exists for each watershed. The Salish Sea Model contained 138 watersheds, 130 of which are available in RBEROST. Terminal COMIDs were determined for each watershed through spatially joining NHDPlusV2 data for region 17, which contains the state of Washington & Puget Sound, and data from the Salish Sea Model. Eight watersheds, all of which represent small islands in the far southern portion of Puget Sound, do not overlap with NHDPlusV2 data and subsequently are not represented in the model. Of the 130 watersheds that are represented in the model, some contain only a single terminal COMID, and others contain multiple terminal COMIDs. For those with multiple COMIDs, the watershed's target nitrogen load is applied to the sum load of all terminal COMIDs in the watershed. Each terminal COMID serves as terminus that accounts for the loads that flow down from reaches further upstream. Each upstream COMID represents a stream reach that flows into to another reach and so on, until a terminal COMID is reached. Each upstream COMID also represents the land area surrounding the stream reach with which it shares its COMID. The list of upstream COMIDs begins at each terminal COMID and continues upstream until one of three scenarios occurs. First, the upstream path may reach a watershed extent or the US-Canadian border and no COMIDs further upstream are counted. Second, the previously counted COMID may have no COMIDs further upstream that flow to it. Third, the sum of all included COMIDs in the string reaches a total length of 9999 kilometers.

Phosphorus targets, such as those for isolated lakes as well as the sub watersheds of Lake Whatcom, include only the COMIDs directly adjacent to the water bodies. These COMIDs were determined through a spatial analysis to determine which NHDPlusV2 catchments overlapped with each waterbody.

10 Appendix D – Data Dictionary for Individual RBEROST Variables

Table D - 1: Data Dictionary for individual RBEROST preprocessing variables

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	01_Preprocessing_Terminal_COMID.csv	watershed_name	Name of larger watershed area based on boundaries from the Salish Sea Model (SSM).
Pacific	01_Preprocessing_Terminal_COMID.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	01_Preprocessing_Upstream_COMID.csv	catchment_comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	01_Preprocessing_Upstream_COMID.csv	watershed_name	Name of larger watershed area based on boundaries from the Salish Sea Model (SSM).
Pacific	01_Preprocessing_Upstream_COMID.csv/01_Preprocessing_Terminal_COMID.csv	N/A	Terminal flag is marked if a COMID is in both the terminal list and upstream list to mark it as a terminal flag going forward while using the upstream list
Pacific	01_UserSpecs_BMPs.csv	BMP_Category	Pollution category that the BMP addresses
Pacific	01_UserSpecs_BMPs.csv	BMP	BMP Name, or name of the WWTP.
Pacific	01_UserSpecs_BMPs.csv	BMP_Selection	"X" if the BMP is to be included in the RBEROST run.
Pacific	01_UserSpecs_BMPs.csv	frac_min	Minimum fraction of area available to implement BMP
Pacific	01_UserSpecs_BMPs.csv	frac_max	Maximum fraction of area available to implement BMP
Pacific	01_UserSpecs_BMPs.csv	capital_WA	Capital cost to implement BMP, WA
Pacific	01_UserSpecs_BMPs.csv	operations_WA	operational cost to implement BMP, WA
Pacific	01_UserSpecs_BMPs.csv	capital_units	Capital cost units
Pacific	01_UserSpecs_BMPs.csv	operations_units	operational cost units
Pacific	01_UserSpecs_BMPs.csv	Min_width_ft	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	01_UserSpecs_BMPs.csv	Max_width_ft	n/a
Pacific	01_UserSpecs_BMPs.csv	UserSpec_width_ft	n/a
Pacific	01_UserSpecs_BMPs.csv	TileDrainRestricted	n/a
Pacific	01_UserSpecs_BMPs.csv	notes	Additional notes
Pacific	01_UserSpecs_loadingtargets.csv	watershed_ID	Numeric ID of larger watershed area based on the boundaries from the Salish Sea Model (SSM).
Pacific	01_UserSpecs_loadingtargets.csv	watershed_name	Name of larger watershed area based on boundaries from the Salish Sea Model (SSM).
Pacific	01_UserSpecs_loadingtargets.csv	adjusted_daily_target_kgperday	Target value for Salish Sea Model (SSM) watershed discharge per day, adjusted based on the ratio of cumulative land area of relevant NHD catchments to the ratio of land area in the SSM watershed
Pacific	01_UserSpecs_loadingtargets.csv	adjusted_annual_target_kgperyr	Target value for Salish Sea Model (SSM) watershed discharge per year, adjusted based on the ratio of cumulative land area of relevant NHD catchments to the ratio of land area in the SSM watershed
Pacific	01_UserSpecs_loadingtargets.csv	TN_or_TP	Binary designator to designate if the target value is for total nitrogen or total phosphorus.
Pacific	01_UserSpecs_loadingtargets.csv	watershed_HUC	Unused variable carried over from previous version of 01_UserSpecs_loadingtargets.csv
Pacific	01_UserSpecs_loadingtargets.csv	OutofNetworkFlag_X	Unused variable carried over from previous version of 01_UserSpecs_loadingtargets.csv
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	HUC6	6-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	HUC8	8-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	HUC10	10-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	HUC12	12-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	Scenario	BMP Scenario, such as terraces, ponds, conservation, filterstrip, etc.
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	MeanTP_Effic	Average total phosphorus removal efficiency

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	MeanTN_Effic	Average total nitrogen removal efficiency
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	MeanTP_Effic_se	Average total phosphorus removal efficiency standard error
Pacific	ACRE_HUC12_HRU_Summary_compareBaseline.csv	MeanTN_Effic_se	Average total nitrogen removal efficiency standard error
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	HUC6	6-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	HUC8	8-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	HUC10	10-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	HUC12	12-digit Hydrologic Unit Code
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	Scenario	BMP Scenario, such as terraces, ponds, conservation, filterstrip, etc.
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	MeanTP_Effic	Average total phosphorus removal efficiency
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	MeanTN_Effic	Average total nitrogen removal efficiency
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	MeanTP_Effic_se	Average total phosphorus removal efficiency standard error
Pacific	ACRE_HUC12_HRU_Summary_compareNoPractice.csv	MeanTN_Effic_se	Average total nitrogen removal efficiency standard error
Pacific	AgBMPEffic_nonACRE.csv	Category	BMP category
Pacific	AgBMPEffic_nonACRE.csv	BMP	BMP name
Pacific	AgBMPEffic_nonACRE.csv	N_Efficiency	Nitrogen BMP efficiency
Pacific	AgBMPEffic_nonACRE.csv	P_Efficiency	Phosphorous BMP efficiency
Pacific	AgBMPEffic_nonACRE.csv	N_Efficiency_se	Nitrogen BMP efficiency standard error
Pacific	AgBMPEffic_nonACRE.csv	P_Efficiency_se	Phosphorous BMP efficiency standard error
Pacific	LengthinBuffer_2016.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	LengthinBuffer_2016.csv	Grass_buffer_20ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_40ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_60ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_80ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_100ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_20ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_40ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_60ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_80ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_100ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_se_20ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_se_40ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_se_60ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_se_80ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Grass_buffer_se_100ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_se_20ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_se_40ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_se_60ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_se_80ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	Forest_buffer_se_100ft_ft	n/a
Pacific	LengthinBuffer_2016.csv	totalbanklength_ft	Twice the length of the stream reach to account for both sides of the stream
Pacific	LengthinBuffer_2016.csv	totalbanklength_ft_se	Standard error associated with the total bank length
Pacific	MUN_FED_ALL_USGS.csv	NPDES_ID	National Pollutant Discharge Elimination System (NPDES) permit ID number
Pacific	MUN_FED_ALL_USGS.csv	Permit_Name	Name of NPDES permit holder
Pacific	MUN_FED_ALL_USGS.csv	State_Water_Body	n/a
Pacific	MUN_FED_ALL_USGS.csv	Latitude	Latitude value
Pacific	MUN_FED_ALL_USGS.csv	Longitude	Longitude value
Pacific	MUN_FED_ALL_USGS.csv	Flow_mgd	Facility flow in million gallons per day
Pacific	MUN_FED_ALL_USGS.csv	TN	n/a
Pacific	MUN_FED_ALL_USGS.csv	TP	n/a
Pacific	MUN_FED_ALL_USGS.csv	TN_load_kg_day	Nitrogen load in kilograms per day
Pacific	MUN_FED_ALL_USGS.csv	TP_load_kg_day	Phosphorus load in kilograms per day
Pacific	MUN_FED_ALL_USGS.csv	year	Year

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	MUN_FED_ALL_USGS.csv	month	Numeric value for month (1-12)
Pacific	MUN_FED_ALL_USGS.csv	TN_load_kg_month	Sum nitrogen load for that month of that year
Pacific	MUN_FED_ALL_USGS.csv	TP_load_kg_month	Sum phosphorus load for that month of that year
Pacific	MUN_FED_ALL_USGS.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment where the facility is located.
Pacific	MUN_STATE_ALL_USGS.csv	PermitNumb	National Pollutant Discharge Elimination System (NPDES) permit ID number
Pacific	MUN_STATE_ALL_USGS.csv	Flow_mgd	Facility flow in million gallons per day
Pacific	MUN_STATE_ALL_USGS.csv	TN	n/a
Pacific	MUN_STATE_ALL_USGS.csv	TP	n/a
Pacific	MUN_STATE_ALL_USGS.csv	permitfaci	Name of NPDES permit holder
Pacific	MUN_STATE_ALL_USGS.csv	PermitteeW_data	n/a
Pacific	MUN_STATE_ALL_USGS.csv	WaterBodyN_data	n/a
Pacific	MUN_STATE_ALL_USGS.csv	FeatureDes	n/a
Pacific	MUN_STATE_ALL_USGS.csv	MPorFeat_Lat	Latitude value
Pacific	MUN_STATE_ALL_USGS.csv	MPorFeat_Long	Longitude value
Pacific	MUN_STATE_ALL_USGS.csv	TN_load_kg_day	Nitrogen load in kilograms per day
Pacific	MUN_STATE_ALL_USGS.csv	TP_load_kg_day	Phosphorus load in kilograms per day
Pacific	MUN_STATE_ALL_USGS.csv	year	Year
Pacific	MUN_STATE_ALL_USGS.csv	month	Numeric value for month (1-12)
Pacific	MUN_STATE_ALL_USGS.csv	day	Day as numeric value
Pacific	MUN_STATE_ALL_USGS.csv	TN_load_kg_month	Sum nitrogen load for that month of that year
Pacific	MUN_STATE_ALL_USGS.csv	TP_load_kg_month	Sum phosphorus load for that month of that year

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	MUN_STATE_ALL_USGS.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment where the facility is located.
Pacific	NdepChange_2012_2020.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	NdepChange_2012_2020.csv	TDEP_TN_2012_arch	2012 Nitrogen atmospheric deposition from older model/data
Pacific	NdepChange_2012_2020.csv	TDEP_TN_2017_arch	2017 Nitrogen atmospheric deposition from older model/data
Pacific	NdepChange_2012_2020.csv	TDEP_TN_2017_cur	2017 Nitrogen atmospheric deposition from newer model/data
Pacific	NdepChange_2012_2020.csv	TDEP_TN_2020_cur	2020 Nitrogen atmospheric deposition from newer model/data
Pacific	NdepChange_2012_2020.csv	Change_2012_2017	Percent change from 2012-2017 based on older data
Pacific	NdepChange_2012_2020.csv	Change_arch_cur	Percent change from old 2017 model/data to new 2017 model/data
Pacific	NdepChange_2012_2020.csv	Change_2017_2020	Percent change from 2017 to 2020 based on new data
Pacific	NdepChange_2012_2020.csv	AdjChange2012_2020	Adjusted percent change from 2012 to 2020 that adjusts for the discrepancies between models
Pacific	NdepChange_2012_2020_update.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	NdepChange_2012_2020_update.csv	TDEP_TN_2012_arch	2012 Nitrogen atmospheric deposition from older model/data
Pacific	NdepChange_2012_2020_update.csv	TDEP_TN_2017_arch	2017 Nitrogen atmospheric deposition from older model/data
Pacific	NdepChange_2012_2020_update.csv	TDEP_TN_2017_cur	2017 Nitrogen atmospheric deposition from newer model/data

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	NdepChange_2012_2020_update.csv	TDEP_TN_2020_cur	2020 Nitrogen atmospheric deposition from newer model/data
Pacific	NdepChange_2012_2020_update.csv	Change_2012_2017	Percent change from 2012-2017 based on older data
Pacific	NdepChange_2012_2020_update.csv	Change_arch_cur	Percent change from old 2017 model/data to new 2017 model/data
Pacific	NdepChange_2012_2020_update.csv	Change_2017_2020	Percent change from 2017 to 2020 based on new data
Pacific	NdepChange_2012_2020_update.csv	AdjChange2012_2020	Adjusted percent change from 2012 to 2020 that adjusts for the discrepancies between models
Pacific	pac_sparrow_model_input.txt	comid	Unique reach identifier (negative ComID = closed catchment) taken from NHDPlusV2 source data item; NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	pac_sparrow_model_input.txt	pname	stream name from Flowline Geographic Names Information System Identifier (GNIS) taken from original source data where available.
Pacific	pac_sparrow_model_input.txt	rchtype	type of reach (stream or impoundment)
Pacific	pac_sparrow_model_input.txt	termflag	terminal reach indicator
Pacific	pac_sparrow_model_input.txt	cfromnode	Modified from original NHDPlusV2 node identifier, FROMNODE
Pacific	pac_sparrow_model_input.txt	ctonode	Modified from original NHDPlusV2 node identifier, TONODE
Pacific	pac_sparrow_model_input.txt	hydseq	hydrologic sequence number
Pacific	pac_sparrow_model_input.txt	frac2	Fraction of flow remaining in reach after accounting for natural diversions
Pacific	pac_sparrow_model_input.txt	final_frac	Fraction of flow remaining in reach after accounting for irrigation diversions and other permanent losses
Pacific	pac_sparrow_model_input.txt	frac_type	Type of loss associated with final_frac values

Model	**RBEROST Source File**	**RBEROST Variable Name**	**Modification**
Pacific	pac_sparrow_model_inpu t.txt	LevelPathI	Level path value (identifies reaches on the same primary flow path)
Pacific	pac_sparrow_model_inpu t.txt	IncAreaKm2	Incremental catchment area, km2
Pacific	pac_sparrow_model_inpu t.txt	CumAreaKm2	Cumulated upstream watershed area, km2
Pacific	pac_sparrow_model_inpu t.txt	length	stream reach length
Pacific	pac_sparrow_model_inpu t.txt	huc2	2-digit Hydrologic Unit Code
Pacific	pac_sparrow_model_inpu t.txt	huc4	4-digit Hydrologic Unit Code and name
Pacific	pac_sparrow_model_inpu t.txt	huc6	6-digit Hydrologic Unit Code
Pacific	pac_sparrow_model_inpu t.txt	huc8	8-digit Hydrologic Unit Code and name
Pacific	pac_sparrow_model_inpu t.txt	huc12	12-digit Hydrologic Unit Code
Pacific	pac_sparrow_model_inpu t.txt	RAreaHLoad	Reciprocal hydraulic load (yr/m)
Pacific	pac_sparrow_model_inpu t.txt	flow_per	indicator of perennial stream reach (0:no,1:yes)
Pacific	pac_sparrow_model_inpu t.txt	flow_int	indicator of intermittent stream reach (0:no,1:yes)
Pacific	pac_sparrow_model_inpu t.txt	station_id_wb	streamflow model calibration station id
Pacific	pac_sparrow_model_inpu t.txt	mean_dflow_predpd	Mean daily streamflow, cfs
Pacific	pac_sparrow_model_inpu t.txt	inflow1	Interbasin water transfers (between stream reaches on different primary flow paths, cfs)
Pacific	pac_sparrow_model_inpu t.txt	inflow2	Local water transfers (between stream reaches on the same primary flow path, cfs)
Pacific	pac_sparrow_model_inpu t.txt	springs	Discharge from springs, cubic feet per second
Pacific	pac_sparrow_model_inpu t.txt	wwtp_flow_cfs	mean discharge from NPDES wastewater facilities to surface water in 2012 (cfs)
Pacific	pac_sparrow_model_inpu t.txt	irrigation	area of irrigated land in 2012 (sqkm)
Pacific	pac_sparrow_model_inpu t.txt	mn_runoff_cfs	Precipitation minus actual evapo-transpiration (mean for the water years 2000-2014, cfs)

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_input.txt	ln_aet_pet_00_14	Natural log of unmet evapotranspiration (PET-AET,mean for water years 2000-2014,mm)
Pacific	pac_sparrow_model_input.txt	mean_impervious	Natural log of mean impervious surface (percent)
Pacific	pac_sparrow_model_input.txt	LN_PERM	natural log of mean soil permeability (in/hr)
Pacific	pac_sparrow_model_input.txt	gw_use	Natural log of ground water use normalized by catchment area (2010, cfs/sqkm)
Pacific	pac_sparrow_model_input.txt	wb_rchdecay	Natural attenuation of streamflow in intermittent streams (based on reach time of travel)
Pacific	pac_sparrow_model_input.txt	nonmuni_rem	Attenuation of streamflow due to irrigation diversions and groundwater loss
Pacific	pac_sparrow_model_input.txt	muni_rem	attenuation of streamflow due to diversions for municipal water supply
Pacific	pac_sparrow_model_input.txt	RAreaHLoad_yr_m	Reciprocal hydraulic load values used to estimate sediment loss in impoundments that were adjusted to reflect predictions from streamflow model (yr/m)
Pacific	pac_sparrow_model_input.txt	WB_inv_resid2_hat	Calibration weight related to station_id_wb used in streamflow model that represents the ratio of nested area to total area (unitless)
Pacific	pac_sparrow_model_input.txt	inc_run_mm_yr	Incremental water yield estimated by streamflow model (mm/yr)
Pacific	pac_sparrow_model_input.txt	wbm_meanq	cumulative mean annual flow adjusted to reflect predictions from streamflow model (cfs)
Pacific	pac_sparrow_model_input.txt	wbm_vel_fps	Mean water velocity adjusted to reflect predictions from streamflow model (ft/sec)
Pacific	pac_sparrow_model_input.txt	wbm_rchtot	reach time of travel adjusted to reflect predictions from streamflow model (days)
Pacific	pac_sparrow_model_input.txt	wbm_rhload_nat	Reciprocal hydraulic load values adjusted to reflect predictions from streamflow model (yr/m)

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_input.txt	station_id_tn	total nitrogen model calibration station id
Pacific	pac_sparrow_model_input.txt	flux_600_final	Mean annual total nitrogen load related to station_id_tn for water years 2000-2014 detrended to water year 2012, kg/yr
Pacific	pac_sparrow_model_input.txt	grass_scrub11_km2	area of grass and scrub land (2011,km2)
Pacific	pac_sparrow_model_input.txt	cmaq_td	Total atmospheric nitrogen deposition (mean annual value for 2010-2012, kg/yr)
Pacific	pac_sparrow_model_input.txt	developed11_km2	area of developed land (2011,km2)
Pacific	pac_sparrow_model_input.txt	const_springs	Spring discharge that is scaled so estimated coefficient is expressed as mg/l (cfs)
Pacific	pac_sparrow_model_input.txt	red_alder_m2	Basal area of red alder trees (2012)
Pacific	pac_sparrow_model_input.txt	tot_fert_n	Nitrogen from commercial fertilizer and livestock manure applied to farmland (2012, kg/yr)
Pacific	pac_sparrow_model_input.txt	ps_tn	Total nitrogen loads from NPDES wastewater and aquaculture facilities discharged to surface water in 2012 (kg)
Pacific	pac_sparrow_model_input.txt	ln_wb_runoff	Log of local water yield estimated by streamflow model (mm/yr)
Pacific	pac_sparrow_model_input.txt	ln_CAT_OM1	Natural log of soil organic matter content (percent)
Pacific	pac_sparrow_model_input.txt	ln_clay	Natural log of soil clay content, percent
Pacific	pac_sparrow_model_input.txt	tn_rchdecay	Natural attenuation of total nitrogen in intermittent streams (based on reach time of travel, days)
Pacific	pac_sparrow_model_input.txt	station_id_tp	total phosphorus model calibration station id
Pacific	pac_sparrow_model_input.txt	flux_665_final	Mean annual total phosphorus load related to station_id_tp for water years 2000-2014 detrended to water year 2012, kg/yr
Pacific	pac_sparrow_model_input.txt	tp_length_var	Phosphorus from perennial and intermittent streams (km)

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_input.txt	NATL_P_area	Phosphorus from upland geologic sources expressed as incremental area x soil P content (sqkm*mg/mg*0.001)
Pacific	pac_sparrow_model_input.txt	grazing_p_kg	phosphorus from grazing livestock manure (2012, kg/yr)
Pacific	pac_sparrow_model_input.txt	total_p_fert_kg	Phosphorus from livestock manure and commercial fertilizer applied to farm land (kg/yr)
Pacific	pac_sparrow_model_input.txt	ps_tp	Total phosphorus loads from NPDES wastewater and aquaculture facilities discharged to surface water in 2012 (kg)
Pacific	pac_sparrow_model_input.txt	natp_str	Natural log of natural P content of soil and rock (acting exclusively on stream channel source (mg/mg)
Pacific	pac_sparrow_model_input.txt	ln_snow_ice	Natural log of area of snow and ice (2011, percent)
Pacific	pac_sparrow_model_input.txt	tp_ln_wildfire	Natural log of cumulative area disturbed by wildfire from total phosphorus model (2005-2012, percent)
Pacific	pac_sparrow_model_input.txt	station_id_ss	suspended sediment model calibration station id
Pacific	pac_sparrow_model_input.txt	final_ss_flux	Mean annual suspended sediment or TSS load for water years 2000-2014 detrended to water year 2012, kg/yr
Pacific	pac_sparrow_model_input.txt	ss_length_var	stream channel length
Pacific	pac_sparrow_model_input.txt	forest1	area of aggregated NLCD forest land in the U.S. underlain by andesitic, basaltic, igneous, metamorphic, and ryholitic rocks (2011)
Pacific	pac_sparrow_model_input.txt	agland1	area of aggregated NLCD agricultural land in the U.S. underlain by andesitic, basaltic, igneous, metamorphic, and ryholitic rocks (2011)
Pacific	pac_sparrow_model_input.txt	devland1	Area of aggregated NLCD developed land in the U.S. underlain by andesitic, basaltic, igneous, metamorphic, and ryholitic rocks (2011)

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_input.txt	ln_graz_dens	Natural log of grazing cattle density (2012, animals/sqkm)
Pacific	pac_sparrow_model_input.txt	ss_ln_wildfire	Natural log of cumulative area disturbed by wildfire from suspended sediment model (2000-2012, percent)
Pacific	pac_sparrow_model_input.txt	ss_rchdecay1	Sediment loss in Blacktail Creek restoration zone (based on reach time of travel, days)
Pacific	pac_sparrow_model_input.txt	ss_rchdecay3	Sediment loss in perennial streams (based on reach time of travel, days)
Pacific	pac_sparrow_model_input.txt	RAreaHLoad0	Reciprocal hydraulic load values used to estimate sediment loss in impoundments that were adjusted to reflect predictions from streamflow model (yr/m)
Pacific	pac_sparrow_model_input.txt	SS_inv_resid2_hat	Calibration weight related to station_id_ss used in the suspended sediment model that represents the ratio of nested area to total area (unitless)
Pacific	pac_sparrow_model_output_tn.txt	CumAreaKM2	Cumulated upstream watershed area, km2
Pacific	pac_sparrow_model_output_tn.txt	IncAreaKm2	Incremental catchment area, km2
Pacific	pac_sparrow_model_output_tn.txt	al_tn	Accumulated total nitrogen load, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	al_tn_scg	Accumulated total nitrogen load from scrub and grassland, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	al_tn_atm	Accumulated total nitrogen load from atmospheric deposition, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	al_tn_urb	Accumulated total nitrogen load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	al_tn_spr	Accumulated total nitrogen load from spring discharge, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	al_tn_ald	Accumulated total nitrogen from red alder trees, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	al_tn_fer	Accumulated total nitrogen load from fertilizer and livestock manure applied to crop land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	al_tn_wwtp	Accumulated total nitrogen load from wastewater treatment facility discharge, kg/yr

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_output_tn.txt	il_tn	Incremental total nitrogen load, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	il_tn_scg	Incremental total nitrogen load from scrub and grassland, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	il_tn_atm	Incremental total nitrogen load from atmospheric deposition, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	il_tn_urb	Incremental total nitrogen load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	il_tn_spr	Incremental total nitrogen load from spring discharge, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	il_tn_ald	Incremental total nitrogen from red alder trees, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	il_tn_fer	Incremental total nitrogen load from fertilizer and livestock manure applied to crop land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	il_tn_wwtp	Incremental total nitrogen load from wastewater treatment facility discharge, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	DEL_FRAC	Fraction of load leaving a reach that is delivered to a downstream target, fraction
Pacific	pac_sparrow_model_output_tn.txt	comid	Unique reach identifier (negative ComID = closed catchment) taken from NHDPlusV2 source data item; NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	pac_sparrow_model_output_tn.txt	alse_tn	Standard error for accumulated total nitrogen load, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	alse_tn_scg	Standard error for accumulated total nitrogen load from scrub and grassland, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	alse_tn_atm	Standard error for accumulated total nitrogen load from atmospheric deposition, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	alse_tn_urb	Standard error for accumulated total nitrogen load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	alse_tn_spr	Standard error for accumulated total nitrogen load from spring discharge, kg/yr

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_output_tn.txt	alse_tn_ald	Standard error for accumulated total nitrogen from red alder trees, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	alse_tn_fer	Standard error for accumulated total nitrogen load from fertilizer and livestock manure applied to crop land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	alse_tn_wwtp	Standard error for accumulated total nitrogen load from wastewater treatment facility discharge, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn	Standard error for incremental total nitrogen load, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn_scg	Standard error for incremental total nitrogen load from scrub and grassland, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn_atm	Standard error for incremental total nitrogen load from atmospheric deposition, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn_urb	Standard error for incremental total nitrogen load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn_spr	Standard error for incremental total nitrogen load from spring discharge, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn_ald	Standard error for incremental total nitrogen from red alder trees, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn_fer	Standard error for incremental total nitrogen load from fertilizer and livestock manure applied to crop land, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	ilse_tn_wwtp	Standard error for incremental total nitrogen load from wastewater treatment facility discharge, kg/yr
Pacific	pac_sparrow_model_output_tn.txt	SE_DEL_FRAC	Fraction of load leaving a reach that is delivered to a downstream target standard error, fraction
Pacific	pac_sparrow_model_output_tp.txt	comid	Unique reach identifier (negative ComID = closed catchment) taken from NHDPlusV2 source data item; NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_output_tp.txt	CumAreaKM2	Accumulated upstream watershed area, km2
Pacific	pac_sparrow_model_output_tp.txt	IncAreaKm2	Incremental catchment area, km2
Pacific	pac_sparrow_model_output_tp.txt	al_tp	Accumulated total phosphorus load, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	al_tp_chan	Accumulated total phosphorus load from channel sources, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	al_tp_geo	Accumulated total phosphorus from weathering of upland geologic material, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	al_tp_spr	Accumulated total phosphorus from spring discharge, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	al_tp_urb	Accumulated total phosphorus load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	al_tp_graz	Accumulated total phosphorus load from grazing cattle manure applied to pasture and rangeland, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	al_tp_fer	Accumulated total phosphorus load from fertilizer and livestock manure applied to cropland, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	al_tp_wwtp	Accumulated total phosphorus load from wastewater treatment facility discharge, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	il_tp	Incremental total phosphorus load, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	il_tp_chan	Incremental total phosphorus load from channel sources, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	il_tp_geo	Incremental total phosphorus from weathering of upland geologic material, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	il_tp_spr	Incremental total phosphorus from spring discharge, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	il_tp_urb	Incremental total phosphorus load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	il_tp_graz	Incremental total phosphorus load from grazing cattle manure applied to pasture and rangeland, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	il_tp_fer	Incremental total phosphorus load from fertilizer and livestock manure applied to cropland, kg/yr

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_output_tp.txt	il_tp_wwtp	Incremental total phosphorus load from wastewater treatment facility discharge, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	DEL_FRAC	Fraction of load leaving a reach that is delivered to a downstream target, fraction
Pacific	pac_sparrow_model_output_tp.txt	alse_tp	Standard error for accumulated total phosphorus load, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	alse_tp_chan	Standard error for accumulated total phosphorus load from channel sources, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	alse_tp_geo	Standard error for accumulated total phosphorus from weathering of upland geologic material, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	alse_tp_spr	Standard error for accumulated total phosphorus from spring discharge, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	alse_tp_urb	Standard error for accumulated total phosphorus load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	alse_tp_graz	Standard error for accumulated total phosphorus load from grazing cattle manure applied to pasture and rangeland, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	alse_tp_fer	Standard error for accumulated total phosphorus load from fertilizer and livestock manure applied to cropland, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	alse_tp_wwtp	Standard error for accumulated total phosphorus load from wastewater treatment facility discharge, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp	Standard error for incremental total phosphorus load, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp_chan	Standard error for incremental total phosphorus load from channel sources, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp_geo	Standard error for incremental total phosphorus from weathering of upland geologic material, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp_spr	Standard error for incremental total phosphorus from spring discharge, kg/yr

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp_urb	Standard error for incremental total phosphorus load from urban land, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp_graz	Standard error for incremental total phosphorus load from grazing cattle manure applied to pasture and rangeland, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp_fer	Standard error for incremental total phosphorus load from fertilizer and livestock manure applied to cropland, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	ilse_tp_wwtp	Standard error for incremental total phosphorus load from wastewater treatment facility discharge, kg/yr
Pacific	pac_sparrow_model_output_tp.txt	SE_DEL_FRAC	Fraction of load leaving a reach that is delivered to a downstream target standard error, fraction
Pacific	PctCroplandTileDrained_ICF24.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	PctCroplandTileDrained_ICF24.csv	pct_tiled_adj	n/a
Pacific	RiparianEfficiencies_update0425.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_20ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_40ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_60ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_80ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_100ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_20ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_40ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_60ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_80ft	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_100ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_20ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_40ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_60ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_80ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_100ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_20ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_40ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_60ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_80ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_100ft	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_20ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_40ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_60ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_80ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Forest_100ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_20ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_40ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_60ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_80ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	N_Grass_100ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_20ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_40ft_uncertainty	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_60ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_80ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Forest_100ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_20ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_40ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_60ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_80ft_uncertainty	n/a
Pacific	RiparianEfficiencies_update0425.csv	P_Grass_100ft_uncertainty	n/a
Pacific	RiparianLoadings_update0425.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	RiparianLoadings_update0425.csv	N_riparian_kgyr	Riparian nitrogen load in kilograms per year
Pacific	RiparianLoadings_update0425.csv	P_riparian_kgyr	Riparian phosphorus load in kilograms per year
Pacific	RiparianLoadings_update0425.csv	N_riparian_kgyr_se	Standard error for nitrogen load
Pacific	RiparianLoadings_update0425.csv	P_riparian_kgyr_se	Standard error for phosphorus load
Pacific	road_areas.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	road_areas.csv	HSG	Hydrologic soil group
Pacific	road_areas.csv	Area	Area (in acres) within the given COMID of a given HSG
Pacific	road_areas.csv	area_sum	The total area of the COMID in acres
Pacific	road_areas.csv	area_port	The proportion of the given COMID that is the given HSG. Must be between 0 and 1.
Pacific	road_bmps.csv	BMP	BMP name
Pacific	road_bmps.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	road_bmps.csv	HSG	Hydrologic soil group

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	road_bmps.csv	area_port	The proportion of the given COMID that is the given HSG. Must be between 0 and 1.
Pacific	road_bmps.csv	effic_N	Nitrogen efficiency
Pacific	road_bmps.csv	effic_P	Phosphorus efficiency
Pacific	road_bmps.csv	capital_2020USD	Capital cost 2020 dollars
Pacific	road_bmps.csv	operations_2020USD	Operations cost 2020 dollars
Pacific	UrbanBMPData.csv	BMP	BMP name
Pacific	UrbanBMPData.csv	Land_Use	Additional information about land density. URLD = urban low development, URHD = urban high development, URMD= urban medium development, UIDU = Urban Industrial
Pacific	UrbanBMPData.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	UrbanBMPData.csv	HSG	Hydrologic soil group
Pacific	UrbanBMPData.csv	Area	Area (in acres) within the given COMID of a given HSG
Pacific	UrbanBMPData.csv	effic_N	Nitrogen efficiency
Pacific	UrbanBMPData.csv	effic_P	Phosphorus efficiency
Pacific	UrbanBMPData.csv	capital_2020USD	Capital cost 2020 dollars
Pacific	UrbanBMPData.csv	operations_2020USD	Operations cost 2020 dollars
Pacific	USGS_AgBMP_PugetSound.csv	comid	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	USGS_AgBMP_PugetSound.csv	TOT_IMPV12_PERC	n/a
Pacific	WA_streamcat_2011_cropland.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	WA_streamcat_2011_cropland.csv	CatAreaSqKm	Catchment area, square kilometer
Pacific	WA_streamcat_2011_cropland.csv	WsAreaSqKm	watershed area, square kilometer
Pacific	WA_streamcat_2011_cropland.csv	CatPctFull	catchment percent full
Pacific	WA_streamcat_2011_cropland.csv	WsPctFull	watershed percent full
Pacific	WA_streamcat_2011_cropland.csv	PctOw2011Cat	catchment percent open water, 2011

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WA_streamcat_2011_cropland.csv	PctIce2011Cat	catchment percent ice, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbOp2011Cat	catchment percent urban open, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbLo2011Cat	catchment percent low density urban, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbMd2011Cat	catchment percent medium density urban, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbHi2011Cat	catchment percent high density urban, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctBl2011Cat	catchment percent barren land, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctDecid2011Cat	catchment percent deciduous forest, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctConif2011Cat	catchment percent coniferous forest, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctMxFst2011Cat	catchment percent mixed forest, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctShrb2011Cat	catchment percent shrub/scrub, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctGrs2011Cat	catchment percent grassland/herbaceous, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctHay2011Cat	catchment percent pasture/hay, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctCrop2011Cat	catchment percent row crop, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctWdWet2011Cat	catchment percent woody wetland, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctHbWet2011Cat	catchment percent herbaceous wetland, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctOw2011Ws	watershed percent open water, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctIce2011Ws	watershed percent ice, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbOp2011Ws	watershed percent urban open, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbLo2011Ws	watershed percent low density urban, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbMd2011Ws	watershed percent medium density urban, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctUrbHi2011Ws	watershed percent high density urban, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctBl2011Ws	watershed percent barren land, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctDecid2011Ws	watershed percent deciduous forest, 2011

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WA_streamcat_2011_cropland.csv	PctConif2011Ws	watershed percent coniferous forest, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctMxFst2011Ws	watershed percent mixed forest, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctShrb2011Ws	watershed percent shrub/scrub, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctGrs2011Ws	watershed percent grassland/herbaceous, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctHay2011Ws	watershed percent pasture/hay, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctCrop2011Ws	watershed percent row crop, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctWdWet2011Ws	watershed percent woody wetland, 2011
Pacific	WA_streamcat_2011_cropland.csv	PctHbWet2011Ws	watershed percent herbaceous wetland, 2011
Pacific	WA_streamcat_2011_imperv.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	WA_streamcat_2011_imperv.csv	CatAreaSqKm	Catchment area, square kilometer
Pacific	WA_streamcat_2011_imperv.csv	WsAreaSqKm	watershed area, square kilometer
Pacific	WA_streamcat_2011_imperv.csv	CatPctFull	Catchment percent full
Pacific	WA_streamcat_2011_imperv.csv	WsPctFull	watershed percent full
Pacific	WA_streamcat_2011_imperv.csv	PctImp2006Cat	Percent of catchment that is impervious, 2006
Pacific	WA_streamcat_2011_imperv.csv	PctImp2006Ws	Percent of watershed that is impervious, 2006
Pacific	WA_streamcat_2011_imperv.csv	PctImp2008Cat	Percent of catchment that is impervious, 2008
Pacific	WA_streamcat_2011_imperv.csv	PctImp2008Ws	Percent of watershed that is impervious, 2008
Pacific	WA_streamcat_2011_imperv.csv	PctImp2011Cat	Percent of catchment that is impervious, 2011
Pacific	WA_streamcat_2011_imperv.csv	PctImp2011Ws	Percent of watershed that is impervious, 2011
Pacific	WA_streamcat_2011_imperv.csv	PctImp2001Cat	Percent of catchment that is impervious, 2011
Pacific	WA_streamcat_2011_imperv.csv	PctImp2001Ws	Percent of watershed that is impervious, 2001
Pacific	WA_streamcat_2011_imperv.csv	PctImp2013Cat	Percent of catchment that is impervious, 2013

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WA_streamcat_2011_imperv.csv	PctImp2013Ws	Percent of catchment that is impervious, 2013
Pacific	WA_streamcat_2011_imperv.csv	PctImp2019Cat	Percent of watershed that is impervious, 2019
Pacific	WA_streamcat_2011_imperv.csv	PctImp2019Ws	Percent of watershed that is impervious, 2019
Pacific	WA_streamcat_2011_imperv.csv	PctImp2016Cat	Percent of catchment that is impervious, 2016
Pacific	WA_streamcat_2011_imperv.csv	PctImp2016Ws	Percent of watershed that is impervious, 2016
Pacific	WA_streamcat_2011_imperv.csv	PctImp2004Cat	Percent of catchment that is impervious, 2004
Pacific	WA_streamcat_2011_imperv.csv	PctImp2004Ws	Percent of watershed that is impervious, 2004
Pacific	WWTP_BaselineRemoval.csv	State	State Name
Pacific	WWTP_BaselineRemoval.csv	Plant_Name	Plant name
Pacific	WWTP_BaselineRemoval.csv	NPDES_ID	National Pollutant Discharge Elimination System (NPDES) permit ID number
Pacific	WWTP_BaselineRemoval.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2012	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2012	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2013	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2013	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2014	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2014	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2015	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2015	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2016	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2016	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2017	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2017	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2018	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2018	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2019	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2019	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2020	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2020	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Nitrogen_2021	n/a
Pacific	WWTP_BaselineRemoval.csv	load_kgyr_Phosphorus_2021	n/a
Pacific	WWTP_BaselineRemoval.csv	Rem_2012oroldest_2021ornewest_load_ch_TN	n/a
Pacific	WWTP_BaselineRemoval.csv	Rem_2012oroldest_2021ornewest_load_ch_TP	n/a
Pacific	WWTP_COMIDs.csv	State	State
Pacific	WWTP_COMIDs.csv	Plant_Name	Name of wastewater treatment plant and NPDES_ID permit holder
Pacific	WWTP_COMIDs.csv	NPDES_ID	National Pollutant Discharge Elimination System (NPDES) permit ID number
Pacific	WWTP_COMIDs.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment where the WWTP is located.
Pacific	WWTP_Costs.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment where the WWTP is located.
Pacific	WWTP_Costs.csv	C_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	C_F_Capital_Cost_2021dollars	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WWTP_Costs.csv	FOURBDP_M_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	FOURBDP_M_C_F_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_C_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	C_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	C_F_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	FOURBDP_M_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	FOURBDP_M_C_F_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_C_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	C_M_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	M_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	C_M_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	M_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_C_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_C_F_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_C_F_M_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_M_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_C_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_C_F_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_C_F_M_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_M_OM_Cost_2021dollars	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_C_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_C_Capital_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_C_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_C_OM_Cost_2021dollars	n/a
Pacific	WWTP_Costs.csv	C_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	C_F_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_M_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_M_C_F_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_C_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	C_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	C_F_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_M_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_M_C_F_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_C_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	C_M_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	M_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	C_M_OM_Cost_2021dollars_se	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WWTP_Costs.csv	M_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_C_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_C_F_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_C_F_M_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_M_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_C_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_C_F_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_C_F_M_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	SBR_DNF_M_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_C_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_C_Capital_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	FOURBDP_MBR_M_C_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_Costs.csv	MLE_MBR_C_OM_Cost_2021dollars_se	n/a
Pacific	WWTP_RemovalEffic.csv	COMID	NHD (National Hydrography Dataset) Common Identifier number, identifies a particular stream reach/catchment.
Pacific	WWTP_RemovalEffic.csv	MLE_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_TP_Efficiency	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WWTP_RemovalEffic.csv	MLE_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	C_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_C_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_C_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	C_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_C_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_C_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_C_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_C_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_C_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_C_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	C_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_C_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_C_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	C_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_C_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_C_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_C_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_C_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_C_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_C_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	C_F_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	C_F_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_C_F_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_C_F_TP_Efficiency	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WWTP_RemovalEffic.csv	SBR_C_F_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_C_F_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	C_F_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	C_F_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_C_F_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_M_C_F_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_C_F_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_C_F_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	MLE_MBR_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_M_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_M_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_M_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_M_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_C_F_M_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_C_F_M_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_C_F_M_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	SBR_DNF_C_F_M_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	C_M_TN_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	M_TN_Efficiency	n/a

Model	RBEROST Source File	RBEROST Variable Name	Modification
Pacific	WWTP_RemovalEffic.csv	C_M_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	M_TP_Efficiency	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	FOURBDP_MBR_M_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	C_M_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	M_TN_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	C_M_TP_Efficiency_se	n/a
Pacific	WWTP_RemovalEffic.csv	M_TP_Efficiency_se	n/a
Pacific (uncertainty)	EQIPcosts_overyears.csv	BMP_Category	BMP category
Pacific (uncertainty)	EQIPcosts_overyears.csv	BMP	BMP name
Pacific (uncertainty)	EQIPcosts_overyears.csv	capital_WA_2022	Capital cost to implement BMP, WA 2022
Pacific (uncertainty)	EQIPcosts_overyears.csv	capital_WA_2021	Capital cost to implement BMP, WA 2021
Pacific (uncertainty)	EQIPcosts_overyears.csv	operations_WA_2022	Operational cost to implement BMP, WA 2022
Pacific (uncertainty)	EQIPcosts_overyears.csv	operations_WA_2021	Operational cost to implement BMP, WA 2022
Pacific (uncertainty)	EQIPcosts_overyears.csv	capital_units	Capital cost units
Pacific (uncertainty)	EQIPcosts_overyears.csv	operations_units	operational cost units

11 Appendix E – Sources of Information for Upstream Nutrient Loading Targets in Puget Sound Watershed.

Table E-1. Source of information on upstream nutrient loading targets in Puget Sound watershed.

Project Name	Parameters	Report
Campbell Lake Total Phosphorus TMDL	Total Phosphorus	https://fortress.wa.gov/ecy/publications/summarypages/9710201.html
Fenwick Lake Total Phosphorus TMDL	Total Phosphorus	https://fortress.wa.gov/ecy/publications/summarypages/9310203.html
Lake Ballinger Total Phosphorus TMDL	Total Phosphorus	https://fortress.wa.gov/ecy/publications/summarypages/9310202.html
Erie Lake Total Phosphorus TMDL	Total Phosphorus	https://fortress.wa.gov/ecy/publications/summarypages/9710202.html
Lake Sawyer Total Phosphorus TMDL	Total Phosphorus	https://fortress.wa.gov/ecy/publications/summarypages/9310201.html
Lake Whatcom Watershed Multiparameter TMDL	Total Phosphorus, Bacteria, Dissolved Oxygen	https://fortress.wa.gov/ecy/publications/SummaryPages/1310012.html
Snohomish River Estuary Multiparameter TMDL	Ammonia-N, CBOD, Dissolved Oxygen	https://fortress.wa.gov/ecy/publications/summarypages/9957.html
Snoqualmie River Watershed Multiparameter TMDL	Bacteria, Dissolved Oxygen, Ammonia-N, pH	https://fortress.wa.gov/ecy/publications/summarypages/9471.html
Loma Lake STI	Total Phosphorus, Bacteria	n/a