**RColSim**

The Columbia Simulation model written in R programing language (RColSim) is an open-source river system model that simulates the operation of dams and water systems in the Columbia River Basin (CRB). RColSim simulates 45 dams located across different parts of the CRB, and takes into account various dam-specific and system-wide operational objectives. These objectives include flood protection, hydropower generation, as well as meeting irrigation demands and environmental flow requirements of the CRB.

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# 1. Getting started

## 1.1. Accessing the code

The RColSim code and directories can be downloaded from GitHub. There are two primary methods to download a GitHub repository. The first is to clone the repository using Git (<https://git-scm.com/downloads>).

Open the Git terminal. Now, create a directory where the code will be stored, and change into that directory.

> mkdir ~/Documents/RColSim\_tutorial

> cd ~/Documents/RColSim\_tutorial

Now clone the RColSimV1 repository.

> git clone <https://github.com/myourek/RColSimV1.git>

Alternatively, the repository can be downloaded using a browser. Go to the following URL: <https://github.com/myourek/RColSimV1>. Click on the green ‘<> Code’ tab, then click on ‘Download Zip’.

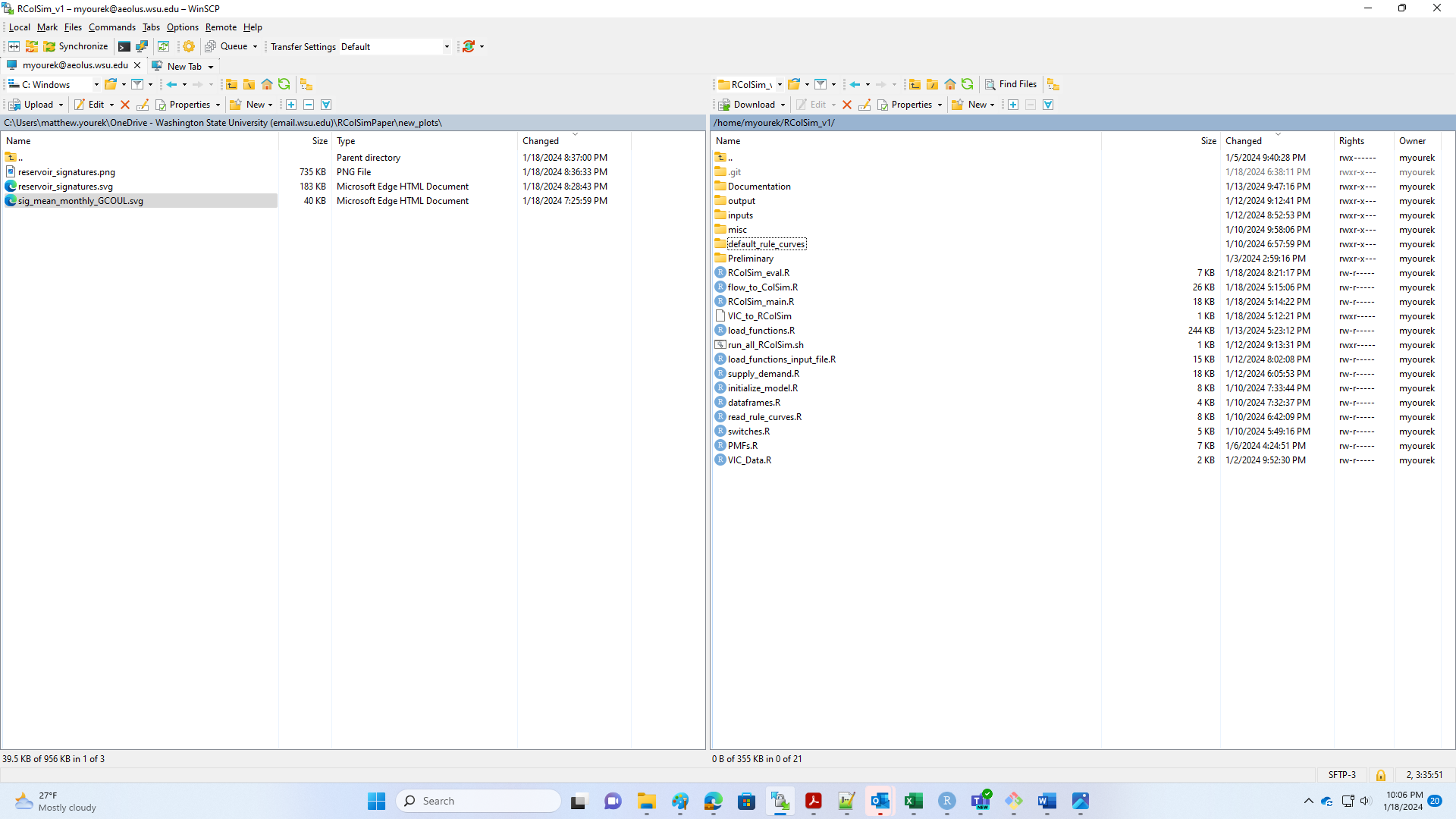
## 1.2. File structure

Fig. 1 shows the basic file structure of RColSim. All the R scripts used by the model are in the RColSimV1 parent directory. These are:

1. *VIC\_data.R* – Reads the input file at the beginning of each timestep and assigns the values from the RColSim input file (e.g. *ToRColSim\_scenario\_baseline\_supply\_and\_demand.txt*) to each of the variables listed in section A.1.
2. *switches.R* – Provides switches and controls the user can change to adjust the priority of objectives and customize model output (see section A.5).
3. *supply\_demand.R* – Aggregates the streamflow and water demand input data for further processing and assembling of the main RColSim input file.
4. *read\_rule\_curves.R* – Reads in the input rule curve and flow target input files.
5. *RColSim\_main.R* – The script that runs the RColSim model.
6. *RColSim\_eval.R* – Generates plots for model evaluation.
7. *PMFs.R* – Functions for computing performance metrics that indicate the degree to which reservoir objectives were or were not satisfied.
8. *load\_functions\_input\_file.R* – Functions for preparing the RColSim input file.
9. *load\_functions.R* – Functions called by the main RColSim program (see section A.4).
10. *initialize\_model.R ­*– Executes the first timestep of the RColSim model.
11. *flow\_to\_ColSim.R* – Generates the RColSim input file and the global input file.
12. *dataframes.R* – Initializes dataframes of output variables.

In addition to the R scripts, there are 6 subdirectories. These are:

1. Preliminary – Contains the routed flow and bias-corrected flow outputs determined from runoff and baseflow simulated by the VIC model and irrigation demands simulated by the VIC-CropSyst model. It also stores the outputs generated by the *supply\_demand.R* script.
2. output – The directory to which RColSim outputs are written.
3. misc – Contains miscellaneous files for reference.
4. inputs – Contains the input text files required by the *supply\_demand.R* and *flow\_to\_ColSim.R* scripts.
5. Documentation – Reservoir operational, procedural, planning, and regulatory documents upon which the RColSim model is based.
6. default\_rule\_curve – Rule curve and flow target input files.



**Fig. 1.** File structure of the RColSim model.

# 2. How to run the program

The RColSim model runs as a sequence of scripts written in R programming language. The R application is required to execute these scripts and is free to download at <https://www.r-project.org/>.

The RColSim model only uses base-R functions and libraries, with the exception of the *xts* package, which is required to run *supply\_demand.R* and *flow\_to\_ColSim.R*. The *xts* package will need to be installed. This is done with the install.packages() function. To install the *xts* package, begin an R session and type:

> install.packages(“xts”)

Packages need only to be installed once; however, they need to be loaded into the R environment at the beginning of each session. The command, load(xts), at the beginning of the R scripts does this.

## 2.1. Running RColSim on a desktop or laptop computer

When working in R, RStudio provides a convenient user interface for editing scripts, executing code, visualizing plots, navigating files, and performing many other tasks. It can be downloaded here: https://posit.co/download/rstudio-desktop/.

The RColSim program architecture is illustrated in Fig.2. There are three R scripts that need to be executed. The first script converts the monthly, bias-corrected VIC flows and daily water demands to weekly natural streamflow and weekly water demands, adjusted for curtailment. The second script in the workflow takes the output from *supply\_demand.R*, combined with rule curve data from the *default\_rule\_curves* subdirectory, and creates the global input and RColSim input file. The third and final step in the workflow is the main RColSim program, which simulates reservoir operation.

The program takes command line arguments, so it should be run from the command line. If you are running in RStudio, click on the “Terminal” tab. The forcing data set for this example is called “Historical\_baseline”, indicating that we want to use the streamflow and irrigation demands simulated using gridded historical climate data. The second argument indicates whether the streamflow inputs account for surface water withdrawals. The *supply\_only* option uses natural streamflow (no water withdrawals). The *supply\_and\_demand ­*option uses unregulated streamflow (flow after removing consumptive water demand). Running an RColSim simulation from the command line requires the following 4 lines:

1 > cd ~/Documents/RColSim\_tutorial/RColSimV1

Line 1 changes the directory to the parent directory for the RColSim program. \*Replace ~ with your home directory.

2 > Rscript supply\_demand.R "Historical\_baseline" "supply\_and\_demand"

Line 2 executes the *supply\_demand.R* script and writes output to the *Preliminary/output/* folder.

3 > Rscript flow\_to\_ColSim.R "Historical\_baseline" "supply\_and\_demand"

Line 3 executes the *flow\_to\_ColSim.R* scripts and writes output to *inputs/*.

4 > Rscript RColSim\_main.R "Historical\_baseline" "supply\_and\_demand"

Line 4 executes the main RColSim routines and writes output to *output/*.

5(optional) > Rscript RColSim\_eval.R

Line 5 is an optional line of code that creates plots of observed vs. simulated reservoir outflow and saves them to the *output/plots/* folder.

## 2.2. Running RColSim on a computing cluster

The following BASH code shows how to simultaneously run multiple climate scenarios in a cluster computing environment. The example uses the TORQUE resource manager to batch process a baseline scenario and a climate scenario using the bcc-csm1-1 global circulation model (GCM). The inputs for each scenario are included in the *Preliminary* subdirectory.

1 > run\_type=supply\_and\_demand

2 > declare -a scr\_list=(Historical\_baseline bcc-csm1-1\_rcp45 bcc-csm1-1\_ rcp85 bcc-csm1-1\_historical)

3 > for scr\_name in ${scr\_list[@]} # loop over the scenarios

4 > do

5 > export SCR=$scr\_name RUN=$run\_type # export variables to computing node

6 > qsub –V VIC\_to\_RColSim # submit job

7 > done

The file *VIC\_to\_RColSim* in the parent directory is the script that each computing node executes. It’s core contents mirror command line arguments from section 2.1.

A diagram of a flowchart

Description automatically generated

**Fig. 2.** Structure of the RColSim model. Moving from top to bottom, the supply\_demand.R script harmonizes water demand and natural streamflow inputs to the same (weekly) timestep and to the same drainage areas. The flow\_to\_ColSim.R script combines output from supply\_demand.R with reservoir rule curves and flow targets to generate the RColSim input files. Finally, RColSim\_main.R executes the core RColSim program.

## 2.3. Description of the RColSim model

The following inputs are required for RColSim to run:

1. Unregulated streamflow
2. Rule curves
3. Flow targets

*Unregulated streamflow*

Unregulated streamflow is flow that has not been altered by the operation of dams but that has been affected by water withdrawals. One method of obtaining unregulated flow, and the one used in this tutorial, is computer simulation. As an alternative, there are streamflow products available through the Bonneville Power Administration (BPA) for which the influence of dams have been removed. These are called modified flows. However, the modified flow data product is only available for historical time periods. Streamflow simulations are needed for climate change studies that require streamflow predictions during future time periods. In this tutorial, we show how simulated runoff and baseflow from the large-scale hydrology model, VIC, can be used in conjunction with irrigation demand from the cropping systems model, CropSyst, to generate the unregulated streamflow input to RColSim.

*Rule Curves*

Rule curves designate a target reservoir water level or volume throughout the year to achieve objectives such as flood control, irrigation, and hydropower generation. Generally, a rule curve is either an upper limit or a lower limit. The upper limit guides flood control operation, ensuring that enough storage space is available to reduce flood volumes. The lower limits help maintain enough water in the reservoir so that firm energy loads can be met throughout the year and the reservoirs refill by their target refill dates. The variable refill curve, assured refill curve, critical rule curve, and operating rule curve lower limits all fit into this category.

The target storage volumes for each rule curve are read from diagrams of required storage on the y axis and date on the x axis. A set of curves gives the required storage for different forecasted inflow conditions. An example is the storage reservation diagrams used for guiding the evacuation of reservoirs for flood control. The Army Corps of Engineers, Columbia Basin Water Management Division maintains a repository of such diagrams at https://www.nwd-wc.usace.army.mil/cafe/forecast/SRD/srd.htm.

In RColSim, the rule curves are supplied in the form of text files in which rows represent week of the year and columns represent the volume of water stored in the reservoir. In transcribing the storage reservation diagrams, we interpolated between the months to derive weekly values, and we converted from required storage space to water stored in the reservoir by subtracting storage space from the full pool volume. Unlike the other rule curves, the variable refill curve is computed using forecasted inflows and assumed releases. The procedure for computing variable refill curves is discussed in section 2.1.2.

*Flow Targets*

Most reservoirs have designated flow targets to reduce negative impact of dams on navigation or anadromous fish spawning, rearing, and migration. The flow targets included in RColSim are listed in Table 1.

**Table 1.** Flow targets included in the RColSim model.

|  |  |  |
| --- | --- | --- |
| Flow target | Purpose | Reference |
| McNary | fall Chinook salmon | 2008 FCRPS BiOp (NMFS, 2008) |
| Priest Rapids | Upper Columbia River steelhead | 2000 FCRPS BiOp (NMFS, 2000) |
| Lower Granite | Snake River salmon and steelhead | 2000 FCRPS BiOp (NMFS, 2000) |
| Bonneville | fall Chinook and chum salmon | 2000 FCRPS BiOp (NMFS, 2000) |
| Libby | sturgeon and bull trout | 2006 FWS BiOp (FWS, 2006) |
| Libby | salmonids | 2008 FCRPS BiOp (NMFS, 2008) |
| Hungry Horse | bull trout | 2000 FCRPS BiOp (NMFS, 2000) |
| Columbia Falls | bull trout | 2000 FCRPS BiOp (NMFS, 2000) |
| Hungry Horse | salmonids | 2008 FCRPS BiOp (NMFS, 2008) |
| Kerr | not specified | Kerr FERC License No. 5 |
| Vernita Bar | fall chinook | Hanford Reach Fall Chinook Protection Program (Douglas County P.U.D., 2004) |
| Grand Coulee | kokanee salmon | 2009 Columbia River Management Plan (BPA/USBR/USACE, 2009) |
| Johnson Bar | Navigation | Hells Canyon Complex FERC No. 1971 |
| Lime Point | Navigation | Hells Canyon Complex FERC No. 1971 |
| Brownlee | fall chinook | Hells Canyon Complex FERC No. 1971 |
| Dworshak | salmonids | 2008 FCRPS BiOp (NMFS, 2008) |

### 2.3.1. Script 1: Assembling the inputs

The first script that should be run when preparing an RColSim simulation is *supply\_demand.*R. This script converts model-simulated irrigation demand and runoff to a weekly timeseries of surface water consumptive demand and natural streamflow (i.e., flow without the influenced dams or water withdrawals). The natural streamflow input was constructed from the grid-scale runoff and baseflow simulations of VIC by routing flow to the inlet of each dam, using an algorithm based on Lohmann et al. (1996). The routed flows were subsequently bias corrected to the no regulation no irrigation dataset (NRNI) provided by the Bonneville Power Administration and produced by the Army Corps of Engineers. The bias correction procedure is described in Snover et al. (2003).

The consumptive water demand is assumed to come from two primary sources, agriculture (i.e. irrigation) and residential use. Irrigation demands were simulated using VIC CropSyst, which provides “top-of-crop” water demands (i.e. water that is actually delivered to the field). The fraction of irrigation water coming from a surface water vs groundwater source is estimated from water rights data, watershed plans, and other literature. Refer to Yourek et al. (2023) for a more detailed discussion of how water demand and natural streamflow were derived for the Columbia River Basin. The grid-scale top-of-crop irrigation demands and residential water demands were aggregated to drainage areas that correspond with a flow target control point, an irrigation project, or the drainage area between an upstream dam and the nearest downstream dam. A crosswalk between grid cell and drainage area is included in the file, *misc/station\_matches\_for\_pod\_file\_2023.txt* for reference. The file, *misc/all\_drainages.csv* gives metadata for these drainage areas.

The *supply\_demand.R* script also calculates curtailment of water rights in tributaries of Washington State with an instream flow rule and adjusts water demand accordingly. Interruptible curtailment of water rights occurs whenever streamflow falls below regulatory minimum flows that are set primarily for the benefit of fish. When this occurs, those with a water right junior to the flow rule are prohibited from diverting until the streamflow once again exceeds the minimum flow. Next, the script aggregates the demand in each drainage to the drainages shown in Fig. 3, which represent the incremental drainage areas between a downstream dam and the nearest upstream dam(s). Refer to the file, *inputs/station\_mapping* for a mapping of the RColSim drainages (first column) to the demand drainages (second column). Lastly, the script calculates the demand from interruptible water rights along the mainstem Columbia River. These water rights are curtailed only in rare circumstances.

### 2.3.2. Script 2: Generating the RColSim input file

After *supply\_demand.R* is run, the second script to execute is *flow\_to\_ColSim.R*. This script compiles the RColSim input file, which consists of the following primary components:

1. Unregulated streamflow
2. Variable refill curve
3. Residual inflow/Cumulative runoff volume

*Unregulated streamflow*

Weekly timeseries of unregulated streamflow is calculated by subtracting the surface water demands from the natural streamflow at the inlet of each of the dams shown in Fig. 3. The water demand upstream of a dam is equal to the sum of demand in all upstream incremental drainage areas (light gray boundaries) in Fig. 3.

*Variable refill curve*

Some of the dams have a variable refill curve that guides reservoir refill. The variable refill curve allows a deeper draft than permitted by the assured refill curve, while assuring that the dam will refill by its target date with a high degree of confidence. The computation of a variable refill curve in the *flow\_to\_ColSim.R* script consists of recursively solving the storage volume, beginning at the target refill date and working backward. The target storage volume at a previous timestep () is computed using the following formula:

(1)

where is the reservoir storage, is the inflow,  is the forecast error, is the power discharge requirement, and is the required refill of upstream dams, all at timestep *t*. The forecast error provides a hedge in case the forecasted inflow volume is less than expected. The power discharge requirement is an assumed release of water. Its value is estimated from Assured Operating Procedure documents (see */Documentation/AOPs* for these documents). In normal practice, the PDR is a tweaking parameter that is adjusted by planners until refill test criteria are met. See */Documentation/Principles\_and\_Procedures.pdf* (CRT Operating Committee, 2003). The PDR is therefore used as a calibration parameter in *flow\_to\_ColSim.R* to improve the fit of simulated vs. observed reservoir volumes. The upstream required refill volume () considers that a portion of will be used to fill upstream reservoirs and will therefore not make it to the inlet of the downstream reservoir.

There are two possible modes for calculating variable refill curves. The first uses a perfect forecast, in which the target reservoir volumes are computed with known inflows. This is the case when the inflow volumes used in Eq. (1) are the same unregulated flows used to drive the reservoir model. The second is normal operation, in which is the streamflow forecast generated by the Army Corps of Engineers or Bureau of Reclamation. The forecast in normal operating mode does equal the unregulated streamflow driving the reservoir model. The forecast errors in perfect forecast mode are set equal to zero, since the unregulated flows are known, and no hedges are needed. The PDRs are set equal to the minimum project outflows. The perfect forecast option therefore calculates the minimum reservoir levels that still guarantee the reservoir refills by the target refill date. The streamflow predictions used by Bureau of Reclamation and U.S.A.C.E. have not yet been included in the model, so the normal operating mode has not been fully implemented. The normal operating mode currently available is a hybrid, in which the forecast errors and normal PDRs are utilized, but is the simulated unregulated streamflow.

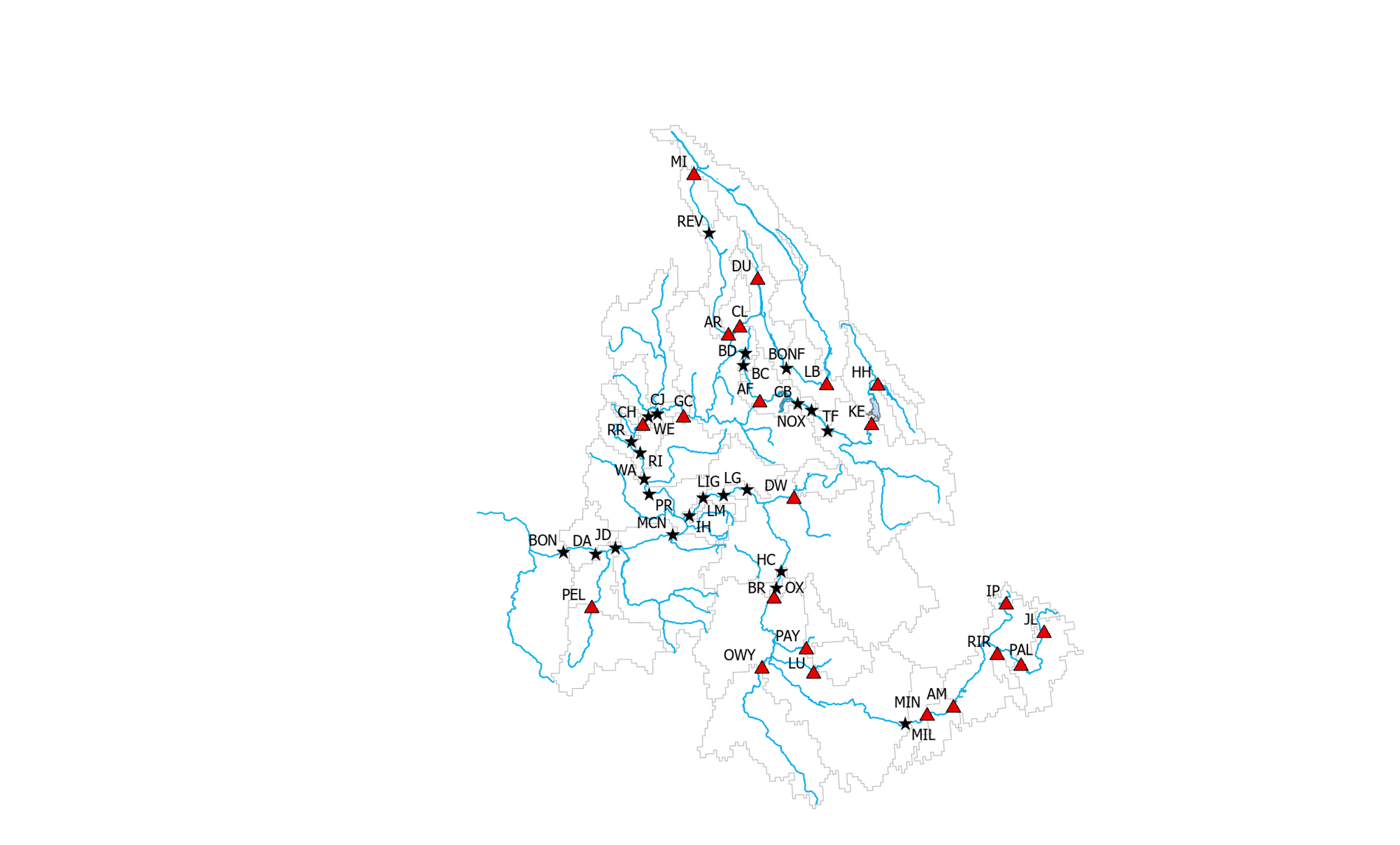
*Residual inflow/Cumulative runoff volume*

The flood control curves utilize either residual inflow or cumulative runoff volume to select the curve representing the appropriate relationship between reservoir volume and week of the year. Residual inflow is the remaining volume of unregulated flow to enter the reservoir by the target refill date. It is calculated as summed over all the timesteps from *t* to the refill date. Cumulative runoff volume is the total unregulated streamflow volume that has been forecasted to enter the reservoir over a specified period, usually April through August. Residual inflow is used primarily in conjunction with the Upper and Middle Snake River reservoirs, while cumulative runoff volume is used in conjunction with the other reservoirs.

In addition to the primary RColSim inputs discussed above, *flow\_to\_ColSim.R* generates the irrigation demands for the Upper Snake drainages, which are used for estimating irrigation withdrawals for the Minidoka, Boise, Payette, and Upper Snake irrigation projects in Southern Idaho. The input file also includes interruptible demands and instream flow rules for computing curtailment along the Columbia mainstem, and return flows from the Columbia Basin Project entering near Wanapum, Priest Rapids, and McNary dams. Finally, the script generates the global input file. The global input file has the following values:

1. RColSim\_WD – The parent directory for the RColSim model.
2. Flow\_Input\_File – The main input file for RColsim.
3. Output\_Folder – The folder where the program writes the output files.
4. simulation\_start\_year – The first year of the simulation. The program always begins the first week in August.
5. Simulation\_end\_date – The date the simulation ends. This value needs to be an actual date given in the format: yyyy-mm-dd.

The *flow\_to\_ColSim.R* script automatically populates the global input file. The user may either change the script or edit the file to change these variables.



**Fig. 3.** Incremental drainage areas for each dam simulated in RColSim. The red triangles mark the location of dams with reservoirs, and the black stars indication the location of run-of-river dams. The light gray boundaries delineate the incremental drainage area between downstream and immediately upstream dam(s).

### 2.3.2. Script 3: Main RColSim program

Once the input files have been created, the only required step remaining is to run the script, *RColSim\_main.R*. The *RColSim\_main.R* script begins by loading the global input file. Then, required scripts are loaded. These are:

1. *load\_functions.R*
2. *read\_rule\_curves.R*
3. *switches.R*
4. *dataframes.R*
5. *PMFs.R*
6. *VIC\_Data.R*

*load\_functions.*R - Functions pertaining to the calculation of dam inflows, outflows, rule curves, and hydropower generation for each of the 45 dams simulated in RColSim. Each dam has its own set of functions, which depends on its unique management objectives. The typical storage reservoir has functions governing both its storage volume at a given week of the year, as well as the release required to meet environmental flow and hydropower targets. Run-of-river dams have comparatively few functions because they have limited or no storage. It is assumed that for run-of-river dams, inflow equals outflow.

*read\_rule\_curves.R* – Reads in the text file inputs from the *default\_rule\_curves* subdirectory. These text files give the rule curve and target flow values for each week of the year under various flow conditions. The main program uses the cumulative runoff volumes and residual inflows from the input file to interpolate between different flow conditions (represented by columns) in the rule curve text files.

*switches.R –* Switches and controls that affect the priority of dam operational objectives and allow the user to control which variables are written to output. See section A.5 for a description of the implemented options.

*dataframes.R* - Initializes the output dataframes. The user can add/remove columns to a given dataframe, define a new dataframe, or delete an existing dataframe to customize the output. **Note that *water\_df*, and *energy\_df*, are essential to the code and should not be deleted.**

*PMFs.*R - Functions for calculating model performance metrics.

*VIC\_Data.R -* Reads the variables from the input file at each time step into the local environment.

Once the necessary scripts are loaded into the R environment, an option is presented to begin a new simulation. If NEW\_SIMULATION == TRUE on line 96, then the output files will be overwritten. The default is set to TRUE. Next, the main program begins the simulation. In the first time step, the *initialize\_model.R* script is executed. This script initializes the storage volume of all reservoirs and runs the first timestep of the simulation. The main program executes all the remaining timesteps. At the beginning of each timestep, a set of common variables is initialized (L120-124). These variables are shared among many functions. They are calculated by the first function that invokes them and treated as a constant by subsequent function calls that use their value for calculating other variables. This ensures that values used by multiple functions only need to be calculated once per time step, which significantly enhances computational speed.

The core section of the main program computes reservoir releases and regulated inflows for each of the storage reservoirs, and inflow/outflows for each of the run-of-river dams. Inflow to a downstream dam () is calculated as the sum of outflow from immediately upstream dams () and incremental flow () (see Eq. 2). Incremental flow is the unregulated streamflow generated between the downstream dam and all immediately upstream dams (Eq. 3). Table 2 gives the upstream/downstream positioning of the dams simulated in RColSim.

(2)

(3)

Most dams simulated in RColSim produce hydroelectricity. The energy generated depends on the dam’s hydraulic capacity, turbine efficiency (), net head (), and outflow (). Since only water discharged through turbines generates electricity, hydropower generation is limited by the hydraulic capacity of the penstock (). Weekly hydropower energy production () is calculated as

(4)

where *c* is a unit conversion factor that converts from ft\*acre-ft/week to MW-hr/wk. It has a value of 1.02246e-3, which is equal to the specific weight of water (metric) \* 9.56e6. The final section of *RColSim\_main.R* script writes variables to the output folder specified in the global input file.

**Table 2.** Upstream-downstream orientation of dams in RColSim.

|  |  |  |  |
| --- | --- | --- | --- |
| Downstream dam - full name | Downstream dam | Upstream dam | River of downstream dam |
| Bonneville | BON | DA | Lower Columbia |
| The Dalles | DA | JD, PEL | Lower Columbia |
| John Day | JD | MCN | Lower Columbia |
| McNary | MCN | IH, PR | Lower Columbia |
| Priest Rapids | PR | WA | Middle Columbia |
| Wanapum | WA | RI | Middle Columbia |
| Rock Island | RI | RR | Middle Columbia |
| Rocky Reach | RR | WE, CH | Middle Columbia |
| Wells | WE | CJ | Middle Columbia |
| Chief Joseph | CJ | GC | Middle Columbia |
| Grand Coulee | GC | CL, AR, BD | Middle Columbia |
| Boundary | BD | BC | Pend Oreille |
| Box Canyon | BC | AF | Pend Oreille |
| Albeni Falls | AF | CB | Pend Oreille |
| Cabinet Gorge | CB | NOX | Clark Fork |
| Noxon Rapids | NOX | TF | Clark Fork |
| Thompson Falls | TF | KE | Clark Fork |
| Kerr | KE | HH | Flathead |
| Corra Linn | CL | DU, BONF | Kootenai |
| Bonner's Ferry | BONF | LB | Kootenai |
| Hugh Keenleyside | AR | REV | Upper Columbia |
| Revelstoke | REV | MI | Upper Columbia |
| Ice Harbor | IH | LM | Lower Snake |
| Lower Monumental | LM | LIG | Lower Snake |
| Little Goose Falls | LIG | LG | Lower Snake |
| Lower Granite | LG | HC, DW | Lower Snake |
| Hells Canyon | HC | \*OX=BR | Middle Snake |
| Brownlee | BR | LUC, MIL, PAY, OWY | Middle Snake |
| Milner | MIL | MIN | Upper Snake |
| Minidoka | MIN | AM | Upper Snake |
| American Falls | AM | IP, PAL, RIR | Upper Snake |
| Palisades | PAL | JL | Upper Snake |

\*The bias-corrected flow into Oxbow is equal to the bias-corrected inflow to Brownlee in the NRNI dataset.

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# A.1. Index of variables

\* **These input variables are read from the RColSim input file and called by the *VIC\_Data()* function.**

**Note:** Many of the variable names are used for multiple dams, and they will include the dam short name in the variable name (e.g. FlowMI is unregulated flow into Mica Dam).

CorrectedDARunoffAprAug – Forecasted April through August unregulated inflow volume to The Dalles, minus the upstream storage space available (acre-ft).

Curt – Irrigation demand for interruptible water rights along the Columbia mainstem (acre-ft/wk).

DallesRunoffAprSep – Forecasted April through September unregulated inflow volume to The Dalles (acre-ft).

Dem – Surface water demand for irrigation districts in Southern Idaho (Upper Snake basin).

Flow – Unregulated inflow to a reservoir (acre-ft/wk).

FullPoolVol – The normal maximum storage volume for a reservoir (acre-ft).

Iflow – Columbia River instream flow rule at several dams along the mainstem (acre-ft/wk).

InitialControlledFlow – Target flow at The Dalles to prevent excessive flooding of the Lower Columbia River flood plain. The first controlled flow of the runoff season is called the initial controlled flow (acre-ft/week).

MinRefillCurve – Minimum reservoir storage that guarantees refill by the target refill date (acre-ft).

OperatingRuleCurve – Required reservoir storage to meet all of the dam’s management objectives (acre-ft).

ResidualInflowJanJul – The portion of forecasted January through July unregulated flow volume that has yet to enter the reservoir (acre-ft).

Ret – Return flow from withdrawals made by the Columbia Basin Project (acre-ft/wk).

start\_refill\_wk – The official start to the flood control refill period, defined as 20 days before unregulated flow at The Dalles is forecasted to exceed 450,000 cfs (USACE, 2003).

Start\_refill\_wk\_GC – The beginning of the refill period at Grand Coulee, defined as one day before unregulated flow at The Dalles is forecasted to exceed the initial controlled flow (BPA/USBR/USACE, 2022).

VariableRefillCurve – Storage volume from the variable refill curve (acre-ft).

# A.2. Index of input files

**\*These input files are in the *default\_rule\_curves* subdirectory and called by the *Read\_Rule\_Curves()* function.**

Article\_56\_input – Input file with tabulated values of project minimum flows for Kerr dam, according to Article 56 of FERC license No. 5.

AssuredRefill\_input – Input file with values of the 1931 assured refill curve. The assured refill curve provides minimum storage volumes required to refill reservoir by the target end date with a 95% level of confidence. Assured refill curves are developed from 1931 inflows, representing the second lowest flow over the period 1929 – 1958.

AssuredRelease\_input – Input file with minimum target outflows from Mica (MIAssuredRelease\_input) or Arrow (ARAssuredRelease\_input) reservoir.

BiOpDraftLimit\_input – The storage volume to which the reservoir should be drafted in summer to meet BiOp flow targets. There are separate input files for Hungry Horse (HHBiOpDraftLimit\_input), Libby (LibbyBiOpDraftLimit\_input), and Dworshak (DWBiOpDraftLimit\_input).

BonnevilleFlowTarget\_input – Text file with weekly minimum flow targets at Bonneville to meet Federal BiOp requirements. High flow (DARunoffJanJul < 85 MAF) and low flow (DARunoffJanJul > 105 MAF) are designated.

BRFallChinookDraft\_input – The storage volumes to which Brownlee reservoir is required to be drafted September through December to support spawning of fall Chinook, according to the FERC No. 1971 License Application.

CHFlow\_percentiles – Historical flow percentiles (20th and 80th) for flow into Chelan dam. Used to calculating the MinReq() for Chelan. These minimum releases were established by the Chelan Settlement Agreement of FERC project number P-637-022 (2003).

CriticalCurve\_input – Input file with values of the critical curve. The critical curve represents the minimum storage volume necessary to meet hydropower firm energy load throughout the year. Four curves are given, corresponding with the years 1-4 of a four-year critical period (refer to *Documentation/Principles\_and\_Procedures.df*) for a full discussion of the critical period. The critical curves typically get progressively lower with successive years in the critical period.

elev\_input – Relationship between water elevation and volume in a reservoir. A separate input file is provided for each reservoir.

FirmFraction\_input – Gives the seasonal distribution of firm hydropower load in the form of firm load / annual average firm load.

Flood\_input – Input text file with flood curve values. Rows represent week of year, and columns represent different conditions of forecasted inflow or residual inflow. The flood curve designates upper operating limits to ensure the reservoir does not refill too quickly during flood season.

GCBdgtForVB\_input – Input file that gives the date to April 10 discharge volume from Grand Coulee required to meet the target flow at Vernita Bar as part of the Hanford Reach fall Chinook protection program.

GCResidualInflow\_input – The 85% exceedance flow volume for the date to April 10 regulated inflow volume to Grand Coulee (acre-ft). Flow volumes are based on historical records of regulated flow at Grand Coulee from 1961 through 2022. Beginning in January 1 of each year, the total remaining volume of water that would enter Lake Roosevelt behind Grand Coulee is calculated for each week, up to April 10.

GCSummerDraft\_input – Input file that gives storage volume (acre-ft) to which Lake Roosevelt behind Grand Coulee dam should be drafted to support salmon migration. If forecasted inflow to The Dalles >= 92 MAF, the target elevation of Lake Roosevelt is 1280 ft, otherwise the target elevation is 1278 ft.

ICF\_adj\_input – Tabulated values of Chart 3 from the *Flood Control Operating Plan* (USACE, 2003). The rows represent percentage of storage space filled in Grand Coulee and Arrow reservoirs. The columns represent three flow conditions: CorrectedDARunoffAprAug < 40 MAF (million acre- feet), CorrectedDARunoffAprAug = 50 MAF, and CorrectedDARunoffAprAug > 60 MAF. Units are cfs.

LimePointTarget\_input – Gives the minimum flow requirement (cfs) at Lime Point (75 miles downstream of Hells Canyon dam). Flows are required to be 13,000 cfs at least 95% of the time July through September (FERC License No. 1971, Article 43).

LowerGraniteFlowTarget\_input – FCRPS BiOp (2000) target flows at Lower Granite dam to protect ESA- listed fish species. The flow objective is 85-100 kcfs from April 2 to June 20 and 50-55 kcfs from June 21 to August 31. The target varies based on forecasted April through July runoff at Lower Granite.

lower\_limit\_input – Input file with rule curve lower limit values. Rows represent week of year, and columns represent different reservoirs. The lower limit is a guide that helps prevent excessive drawdown of reservoirs during the flood evacuation period.

McNaryFlowTarget\_input – FCRPS BiOp (2000) target flows McNary dam to protect ESA-listed fish species. Between April 20 and June 30, minimum flows vary between 220 and 260 kcfs. Minimum flows are 200 kcfs from July 1 to August 31. Interpolation between 220 and 260 kcfs is based on forecasted Jan through July flow at The Dalles. Two flow conditions are given in the input file, low (DARunoffJanJul < 85 MAF) and high (DARunoffJanJul > 105 MAF).

NonFirmFraction\_input – Gives the seasonal distribution of non-firm hydropower load in the form of non-firm load / annual average non-firm load.

PEL\_target\_min – The minimum target flows for Pelton Complex according to the FERC license for the Pelton Complex (FERC P-2030). The values are used by PELMinReq().

PRInc\_inflow\_input – The 75% exceedance flow volume for the date to April 10 regulated inflow volume to Priest Rapids (acre-ft). Flow volumes are based on historical records of regulated flow into Priest Rapids from 1961 through 2022. Beginning in January 1 of each year, the total remaining volume of water that would enter Priest Rapids is calculated for each week, up to April 10.

VernitaBarFlowTarget\_input – input file that gives the required minimum flow at Vernita Bar.

# A.3. Index of constants

AvgMin – Minimum required release from a reservoir (cfs).

BotVol – The normal minimum storage volume for a reservoir (acre-ft).

cfsTOafw – Conversion factor for converting flow in cubic feet per second to flow in acre-ft per week (1 cfs = 13.8838 acre-ft/wk).

CombEfficiency – Estimated turbine efficiency (%).

MWhr\_per\_ftAcFt – Conversion factor for converting water level and discharge (ft \* acre-ft/wk) to energy output (MW\*hr/wk).

PenCap – Maximum flow rate of the penstock (cfs).

ResInitFractionFull – Initial reservoir storage, as a fraction of the full pool volume.

TailElev – Dam tailwater elevation (ft).

week\_counter – Current timestep (1..2..3, etc.)

week\_in\_year – Week of the year (1-52)

year\_counter – Which year of the simulation we are in (1..2..3, etc.)

# A.4. Index of functions

**Note:** Many of the functions are used for multiple dams, and they will be prefixed with the dam’s short name in the code. (e.g. AvailWater() will be MIAvailWater() in the code.

AgReq() – Water released to satisfy irrigation demands downstream of a reservoir (acre-ft/wk). Applies only to reservoirs in the Snake River Basin (Jackson Lake, Palisades, Island Park, Ririe, American Falls, the Boise system, the Payette system, and Owyhee.

AlbeniFallsGroupEnergy() – Actual hydropower generation at Boundary, Albeni Falls, and Box Canyon dams (MW-hr).

Article\_56() – Reads the minimum release requirement (cfs) for Kerr dam from the *Article\_56\_input* file (see section A.2).

AssuredRefill() – Reads the assured refill curve value from AssuredRefill\_input (see section A.2).

AvailWater() – Total available reservoir storage that can be released to meet the objective of a given dam (acre-ft).

AvgFirmLoad() – Average firm hydropower load of the Pacific Northwest (MW-hr/wk). Obtained using the results from Step 1 studies (see Assured Operating Plans in *Documentation/AOPs* subdirectory).

AvgNonFirmLoad() – Non-firm hydropower load of the Pacific Northwest (MW-hr/wk). Calculated as the capacity of the Pacific Northwest – to Pacific Southwest Intertie \* 0.8 (average load / peak load).

BoiseAgReq() – Water released from reservoirs in the Boise System to meet agricultural water demands and maintain streamflow (acre-ft/wk).

BONDraftLimit() – Storage volume after drafting a reservoir to the extent permissible to meet the BiOp flow target at Bonneville for chum salmon (acre-ft).

BONFlowDeficit() – Amount that preliminary outflow is under the chum flow target at Bonneville (acre-ft/wk).

BonnevilleFlowMOP() – Amount that Bonneville outflow is under the chum flow target at Bonneville (acre\_feet/wk).

BonnevilleFlowTarget() – Federal BiOp minimum flow requirement for chum salmon from November 1 through April 10 (cfs). High flow (DARunoffJanJul < 85 MAF) and low flow (DARunoffJanJul > 105 MAF) are designated. Values are interpolated between the low and high flow conditions if necessary.

BRFallChinookDraft() – The storage volume to which Brownlee reservoir should be drafted to support spawning of fall Chinook. Values are interpolated from the *BRFallChinookDraft\_input* file (see section A.2).

BRRelForJBandLP() – The release from Brownlee required to meet Lime Point and Johnson’s Bar flow objectives (acre-ft/wk).

BRRelForLimePoint() – The release from Brownlee required to meet the Lime Point flow objective

(acre-ft/wk). See *LimePoint\_input* file in section A.2.

calc\_refill\_curve() – Computes the variable refill curve for dams without upstream storage.

calc\_refill\_with\_upstream\_storage() – Computes the variable refill curve for dams with upstream storage.

Cat4FilledStorPerc() – The fraction of storage space that has been refilled in the category 4 reservoirs (Grand Coulee and Arrow).

ColFallsFlowMOP() – Shortfall of environmental flow at Columbia Falls (acre-ft/wk).

ColFallsTarget() – Minimum flow requirement (cfs) at Columbia Falls gauge to protect ESA-listed fish species according to the 2000 FCRPS BiOp.

CombSup() – Total water allocated for satisfying environmental flow and energy objectives (acre-ft/wk).

CombUpProtect() – Release of water from all upstream dams to prevent overflow (acre-ft/wk).

CombUpSup() – Total water allocated for satisfying environmental flow and energy objectives in all upstream reservoirs (acre-ft/wk).

ControlledFlow() – Calculates controlled flow at The Dalles (cfs) based on the initial controlled flow and initial controlled flow adjustment (see ICF() and ICF\_adj() descriptions in this section).

CriticalCurve() – Reads the year 1 critical curve value from the critical curve input text file (see *CriticalCurve\_input* in section A.1).

CriticalCurveMin() – Draft limit in years when the reservoir needs to be drafted below the critical curve to meet the firm hydropower load. The user can choose which curve is used as a limit (see *CriticalCurveSw* in section A.5).

Curtail() – Magnitude of curtailment for interruptible water rights along the Columbia mainstem (acre-ft/wk).

DACorrectedResidualInflow() – Calculates the residual forecasted inflow to The Dalles, corrected for upstream storage space (acre-ft).

DallesFloodMOP() – Shortfall of flood protection at the The Dalles (acre-ft/wk).

DamProtectExcess() – Release of water to prevent a dam from overflowing, in excess of that required to meet all other objectives (acre-ft/wk).

DamProtectRel() – Water storage that must be released (acre-ft/wk) to keep the dam from overflowing.

DAPreOutflow() – Outflow from The Dalles before accounting for the controlled flow (acre-ft/wk).

DAResidualInflow() – Calculates the residual inflow volume to The Dalles, corrected for upstream storage (acre-ft).

DownstreamHead() – The total head of water stored in all downstream reservoirs (ft).

DworshakGroupEnergy() – Actual hydropower generation at Little Goose, Dworshak, Lower Monumental, Lower Granite, and Ice Harbor dams (MW-hr).

Elev\_ft() – Calculates the surface water elevation of a reservoir (ft) from the storage volume. Values are interpolated from the *elev\_input* file (see section A.2).

EnergyContent() – Potential energy of water stored in a reservoir in excess of the normal minimum storage volume after removing water allocated for minimum release and fish flow objectives, multiplied by turbine efficiency.

EnergyProduction() – The hydropower generated from discharging water through the penstocks (MW-hr).

EnergySup() – Water to be released from a reservoir to satisfy firm and non-firm power requirements (acre-ft/wk).

ExtraSpace() – Difference between the maximum volume allowed by flood curves and the volume actually stored in all reservoirs (acre-feet).

FirmEnergyDeficit() – The basin-wide shortfall of firm energy based on preliminary outflows (MW-hr). See Prelim().

FirmEnergyMOP() – Shortfall of firm hydropower production (MW-hr).

FirmEnergyTarget() – Hydropower firm energy target for each week (MW-hr/wk).

FirmEngSup() – Power generation (MW-hr) from a dam required to meet the firm energy target.

FirmEngSupReq() – Required release of water (acre-ft/wk) to meet firm energy target.

FirmFraction() – Reads the weekly ratio of firm load to average annual firm load from the *FirmFraction\_input* file (see section A.2).

FishSup() – Additional release (above preliminary release) for meeting all fish flow targets (acre-feet/wk).

FishSupEnergy() – Energy generated from releasing water to meet fish flow objectives in excess of the preliminary release (MW-hr). See Prelim().

FloodCurve() – Calculates the upper limit of reservoir storage (acre-ft) for flood protection.

FloodFrac() – Fraction of the total FloodSpace() provided by Mica, Arrow, Libby, Hungry Horse, and Ground Coulee, respectively.

FloodRelFrac() – Fraction of the total FloodRelSharedWater() supplied by Arrow and Grand Coulee dams, respectively.

FloodRelSharedWater() – Volume of water above the operating rule curve that can be released (acre-ft) to prevent the reservoir from refilling too quickly during the flood control refill period. Applies only to category 4 reservoirs (Arrow and Grand Coulee).

FloodSpace() – Additional storage space reserved in several reservoirs (Mica, Arrow, Libby, Hungry Horse, and Grand Coulee) in case of high flows at The Dalles (acre-ft).

FlowData() – Reads unregulated inflow from the input file.

GCBdgtForVB() – Reads the remaining discharge volume (acre-ft) from the *GCBdgtForVB\_input* file (see section A.2).

GCBeginRefill() – First week of the flood control refill period.

GCBONSharedWater() – Water allocated at Ground Coulee for meeting the chum flow target at Bonneville (acre-feet/wk).

GCBONSup() – Allocated water released from Grand Coulee to satisfy the chum flow target at Bonneville (acre-feet/wk).

GCFerryLimit() – The required volume (acre-ft) behind Grand Coulee dam required for the Gifford- Inchelium ferry to operate.

GCResidualInflow() – The 85% exceedance flow volume for the remaining date to June 30 regulated inflow volume to Grand Coulee (acre-ft). See also *GCResidualInflow\_input* in section A.2.

GCVariableDraftLimit() – The variable draft limit is the lower rule curve from January 1 to April 10. It is the minimum storage volume needed to refill Grand Coulee to its April 10 target volume with 85% assurance. See section 7.4 of the 2022 Draft Water Management Plan (BPA/USBR/USACE, 2022).

GC\_VDL() – Calculates the variable draft limit for Grand Coulee (acre-ft), accounting for the lower limit and flood curve (see also GCVariableDraftLimit()).

GCFerryLimit() – Water volume in Grand Coulee required for ferry travel (acre-ft).

GCRecLimit() – The required storage volume of Lake Roosevelt from 30 June to Labor Day.

GCRecMOP() – Elevation of water in Grand Coulee below the target for recreation (ft).

GCSummerDraftLimit() – Reads the *GCSummerDraft\_input* file to determine the storage volume to which Lake Roosevelt (reservoir of Grand Coulee dam) should be drafted by late summer to meet fish flow objectives (see section A.2).

GCSupForVernitaBar() – The water allocated for satisfying the Vernita Bar flow target (acre-ft/wk)

GCVernitaBarAvailWater() – Reservoir storage that can be released from Grand Coulee to meet the Vernita Bar flow target.

get\_columns() – Determines which columns of the water demand input file to sum for calculating unregulated streamflow from natural streamflow and water demand.

get\_ICF() – Calculates the initial controlled flow at The Dalles (cfs).

get\_iflow\_mainstem() – Converts instream flow rules to a timeseries.

get\_rule\_curves() – Computes reservoir rule curves. This function is called by the RuleCurve\_df() function.

GrandCouleeGroupEnergy() – Actual hydropower generation at Chief Joseph, Grand Coulee, Priest Rapids, Rock Island, Rocky Reach, Wanapum, and Wells dams (MW-hr).

HHBiOpDraftLimit() – The storage volume to which Hungry Horse should be drafted in late summer to protect ESA-listed fishes according to the 2008 FCRS BiOp. (acre-ft).

HHColFallsmax() – Maximum release of water from Hungry Horse dam to prevent flooding at Columbia Falls (acre-ft/wk).

HHRelForColFalls() – Water released from Hungry Horse dam to satisfy the Columbia Falls flow requirement (acre-ft/wk).

ICF() – Computes the initial controlled flow (cfs) (see *InitialControlledFlow* in section A.1).

ICF\_adj() – Calculates an adjustment to the initial controlled flow based on the fraction of storage space that has been refilled in the category 4 reservoirs (Arrow and Grand Coulee). The adjustment is interpolated between columns of the *ICF\_adj* file (see section A.2).

IHNavMOP() – Shortfall of required flow for navigation at Ice Harbor (acre-ft/wk).

In() – Anticipated inflow to a dam based on preliminary outflow from upstream dams and incremental flow

Inc() – incremental flow to a dam. Incremental flow is calculated as the unregulated inflow to the downstream dam minus unregulated inflow to immediately upstream dam(s).

Inflow() – Actual inflow to a dam. It’s equal to actual outflow from upstream dam(s) plus incremental flow.

Init() – Initial reservoir storage volume (acre-ft).

InstreamShortfall() – Columbia River flow deficit measured at several dams along the mainstem (acre-ft/wk).

JohnsonBarFlowTarget() – A minimum flow of 5000 cfs must be maintained at Johnson Bar (17 miles downstream of Hells Canyon). The target is met by releases from Brownlee.

KerrGroupEnergy() – Actual hydropower generation at Cabinet Gorge, Kerr, and Noxon Rapids dams (MW-hr).

LB\_sturgeon\_flow() – Minimum outflows from Libby dam to protect sturgeon. Flows come from the 2006 Fish and Wildlife Service BiOp for Libby dam.

LB\_trout\_flow() – Minimum outflows from Libby dam to protect trout. Flows come from the 2006 Fish and Wildlife Service BiOp for Libby dam.

LGDraftLimit() – Maximum storage volume to which the reservoir can be drafted to satisfy the Lower Granite fish flow target (acre-ft). Applies to Dworshak and Brownlee.

LibbyBiOpDraftLimit() – The storage volume to which Libby should be drafted in late summer to protect ESA-listed fishes according to the 2008 FCRS BiOp.

LimePointFlowTarget() – Reads the flow target at Lime Point from the *LimePointTarget*\_*input* file (see section A.2). The target is met by releases from Brownlee.

LowerColumbiaEnergy() – Actual hydropower generation at Bonneville, Dalles, John Day, and McNary dams (MW-hr).

LowerGraniteFlowMOP() – Shortfall of environmental flows at Lower Granite (acre-ft/wk).

LowerGraniteFlowTarget() – Reads the target minimum flow for Lower Granite from the *LowerGraniteFlowTarget\_input* file (see section A.2).

LowerLimit() – Reads the storage volume (acre-ft) for the current week of year from the *lower\_limit\_input* file (see section A.2).

MaxSystemEnergy() – Actual hydropower generation at all dams, excluding the Upper Snake dams (MW-hr).

McNaryDraftLimit() – Storage volume after drafting a reservoir to the extent permissible to meet the FCRPS BiOp flow target at McNary Dam (acre-ft). Applies to Mica, Arrow, Duncan, Libby, Hungry Horse, and Grand Coulee reservoirs.

McNaryFlowMOP() – Environmental flow shortfall at McNary (acre-ft/wk).

McNarySharedWater() – Volume of water allocated for meeting the FCRPS BiOp flow target at McNary Dam after accounting for minimum required releases (acre-feet/wk).

McNarySup() – Water released to meet McNary BiOp flow target (acre-ft/wk).

McNarySupEnergy() – Hydropower generated by releasing water to meet McNary fish flow target (MW-hr).

Mica() – The storage volume in Mica reservoir at the beginning of the timestep (acre-ft).

MicaGroupEnergy() – Actual hydropower generation at Mica and Revelstoke dams (MW-hr).

MinFloodRelReq() – Additional water released (above that necessary to satisfy all other objectives) from category 4 reservoirs (Arrow and Grand Coulee) to match the controlled flow (acre-ft/wk). This helps those reservoirs from refilling too quickly during high flow years.

MinidokaAgReq() – Agricultural water withdrawals for Minidoka Irrigation Project (acre-ft/wk).

MinReq() – Minimum required release of water from a reservoir (acre-ft/wk).

MinRefill() – Minimum storage volume that will allow reservoir to refill and meet minimum project outflow criteria.

MITarget() – Average target release of water from Mica (acre-ft/wk). It is based on the time of year and the storage volume of Arrow reservoir.

MITargetMin() – Reads the minimum target release of water from Mica (acre-ft/wk) from the *MIAssuredRelease\_input* file (see section A.2).

NetHead() – Difference in elevation between water stored in the reservoir and the tailwater (ft).

NFEnergyContent() – Energy content of water stored in a dam that could be converted to non-firm hydropower (MW-hr).

NonFirmEnergyDeficit() – Basin-wide deficit of non-firm energy production (MW-hr).

NonFirmEnergyMOP() – Shortfall of non-firm hydropower generation (MW-hr).

NonFirmEngSup() – Power generation (MW-hr) from a dam required to meet the non-firm energy target.

NonFirmFraction() – Reads the ratio of weekly non-firm hydropower load to average annual non-firm hydropower load from the *NonFirmFraction\_input* file.

NonFirmSupReq() – Required release (acre-ft/wk) to meet non-firm energy target.

ORC() – Calculates the operating rule curve storage volume (acre-ft) for a given week of the year based on the critical curve, flood curve, assured refill curve, variable refill curve, operating rule curve lower limits, and any other applicable storage volume constraint.

ORC\_EnergyContent() – Potential energy of the water stored in a reservoir in excess of the Operating Rule Curve storage volume after releasing water allocated to minimum release and fish flow objectives, multiplied by turbine efficiency (MW-hr). The function calculates the amount of electricity that could be generated by release of this storage through the dam’s turbines and the turbines of all downstream dams.

ORC\_SharedWater() – water stored in a reservoir in excess of the Operating Rule Curve storage volume after releasing water allocated to minimum release and fish flow objectives (acre-ft/wk). It is the water allocated specially for hydropower generation.

Out() – Outflow from a run-of-river dam (acre-ft/wk).

Outflow() – Actual outflow from a reservoir (acre-ft/wk).

OWYAgReq() – Water released from Owyhee dam to satisfy demands of the Owyhee Irrigation District and maintain adequate streamflow (acre-ft/wk).

PayetteAgReq() – Water released from reservoirs in the Payette System to meet agricultural water demands and maintain streamflow (acre-ft/wk).

PenLimit() – Maximum flow rate through turbines (acre-ft/wk).

PreEnergy() – Initial estimate of energy production (MW-hr), considering only the minimum required releases (MW-hr).

PreInflow() – Inflow before accounting for controlled flow at The Dalles (acre-ft/wk).

Prelim() – Preliminary release based on the required minimum release (acre-ft/wk).

PRIncInflow() – The 75% exceedance incremental flow between Grand Coulee and Priest Rapids (acre-ft/wk). See also *PRInc\_inflow\_input* in section A.2.

RefillCurve() – Reads the refill curve value (acre-ft) corresponding with the reservoir storage for a given week to ensure the reservoir refills by the end of the year.

Release() – Actual release of water from a reservoir after accounting for all objectives (acre-ft/wk).

RelLimit() – Maximum allowable release from a reservoir (acre-ft/wk).

RelReducReq() – Water stored rather than released in case of high flow at The Dalles (acre-ft/wk).

RuleCurve\_df() – Creates a timeseries of rule curve values. The operating rule curve created by this function is provisional and used only for computing the upstream refill requirement.

RuleReq() – Minimum amount of water that must be released over a given timestep to ensure the reservoir storage does not exceed the maximum allowable storage (acre-ft/wk).

runoff\_remaining() – Calculates the residual inflow volume for a reservoir (acre-ft). Residual inflow is the forecasted runoff volume from the date of the forecast to the target refill date.

SharedWater() – Water remaining in a reservoir above the normal minimum storage volume after removing water allocated to minimum release and fish flow objectives (acre-ft/wk).

SumFloodTarget() – Sum of flood curve values for all reservoirs (acre-ft).

TopVol() – Maximum allowable water storage at a given time step (acre-ft).

TotalGCHead() – The total head of water in Grand Coulee and all downstream reservoirs (ft).

TotalRelForLowerGranite() – Total volume of water released to meet the Lower Granite flow objective (acre-ft/wk).

TotalSysStorage() – Total volume of water in all reservoirs (acre-ft).

UpSnakeAgReq() – Agricultural water withdrawals upstream of American Falls dam (acre-ft/wk).

VariableRefill() – Minimum reservoir storage in the variable operating period (usually Jan. through July) that ensures the reservoir will refill by the target refill date.

VernitaBarFlowTarget() – reads the *VernitaBarFlowTarget\_input* file (see section A.2).

VernitaFlowMOP() – Shortfall of environmental flow at Vernita Bar (acre-ft/wk).

VIC\_Data() – Loads input data for the current timestep from the RColSim input file.

# A.5. Index of switches

**\* The user can set the value for each of the switches in the *switches.R* script.**

Chum\_Q\_Switch() – Choose whether water will be released from Grand Coulee to meet the Bonneville flow target for chum salmon (binary). Default is 1 (TRUE).

CriticalCurveSw – Select which year of the 4-year critical period is the lower limit for drafting to meet the firm energy load (1-4). Default is 3 (third-year curve) for Mica and Duncan and 1 (first-year curve) for all other reservoirs.

curtail\_option – Select how mainstem curtailment should be calculated (3 options). Default is 3 (do not calculate).

FishOverRefillSw() – Choose whether to prioritize meeting fish flow targets over refilling the reservoirs (binary). Default is 0 (FALSE).

Fish\_Pool\_Alternative – Option for how far to draft reservoir to meet fish flow objectives. Default = 1.

GuranteeRefillSw() – Choose whether to use the minimum refill curve (see *MinRefillCurve* in section A.1) or only the critical rule curve (see *CriticalCurve* in section A.1) as the lower storage limit for firm energy production (i.e. the proportional draft point). Option 1 selects the former and option 2 selects the latter. Option 2 is the default.

MIFloodMult – Adjustment factor for how much storage space should be made available at Mica and Arrow reservoirs in case of high flow at The Dalles. Default = 1.25.

MOPControl – Select whether to write measures of performance to file (binary). Default is 1 (TRUE).

NonFirmEnergySw() – Select whether to allow release of water for non-firm hydropower production (1) or not (0). Default is 1.

RefillSwitch() – Select whether to use only the assured refill curve to guide reservoir refill (option 1) or use both the assured and variable refill curves (option 2). Default is 2.

refill\_cat4 – Options for refilling category 4 reservoirs (Grand Coulee and Arrow). Option 0 prevents use of outflow from upstream dams to fill category 4 reservoirs. Option 1 allows outflow from upstream reservoirs to refill category 4 reservoirs to CriticalCurveMin() (see section A.4). Option 2 allows upstream releases to refill category 4 reservoirs to their operating rule curves. Default is 1.

SensitivityFraction – Factor of safety for meeting flow objectives. Default is 0.001.

TopRuleSw() – Select how to determine the upper rule curve (3 options). Option 0 is to use the flood rule curve as the upper rule curve. Option 1 is to not evacuate any storage for flood control. Option 2 is to use the highest flood rule curve at all times. Default is 0.

track\_curtailment – Select whether to write curtailment magnitudes to file (binary). Default is 0, do not write.

UseAllStorForMCNLG – Select whether to make all active storage available for meeting the fish flow targets at McNary and Lower Granite. Options are 1=TRUE or 0=FALSE. Default is 0.

UseTotalEnergyContentForFirm() – Choose whether to release only to the operating rule curve (option 0) or allow release below the operating rule curve (option 1). Default is 1.