**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 more than 30 dams located across different parts of the CRB, and takes into account various dam-specific and system-wide operation objectives. These objectives include flood protection, hydropower generation, as well as meeting irrigation and environmental protection demands of the CRB.

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**How to Run the Program**

The RColSim model has been developed in R programming language. The following steps are necessary to conduct a simulation:

1. **R**

The R programing language needs to be available, however, the model has only used functions and libraries that are available in base-R platform. Therefore, no additional library is needed to execute the program.

## 2. Preparation of to Run RColSim

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. There are two primary methods of obtaining unregulated flow. The first is by 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. However, the second option is only suitable 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, are used to generate the unregulated streamflow input to RColSim.

*Rule Curves*

Rule curves designate a target reservoir water level or volume at different times of 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 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 reservoir refill by their target refill date. The variable refill curve, assured refill curve, critical rule curve, and operating rule curve lower limits all fit into the lower limit category.

The target storage volumes for each rule curve are read from diagrams required storage on the y axis and date on the x axis. A set of curves gives the required storage for different scenario of forecasted inflow. 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 computation procedure is discussed in section X.

*Flow Targets*

Most reservoirs have designated flow targets to reduce the negative impact of dams on the anadromous fish spawning, rearing, and migration. Table 1 summarizes the flow targets included in RColSim.

### 2.1. Using the R scripts to assemble inputs

#### 2.1.1. Script 1

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). Natural streamflow is constructed from the grid-scale runoff and baseflow by routing flow to the inlet of each dam, using an algorithm based on Lohmann et al. (1996). The routed flows are 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. Irrigation demands are 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 source vs groundwater 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 naturalized 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 either 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 *supply\_demand.R* script 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. 1, which represent the incremental drainage area between a downstream dam and the nearest upstream dam(s). Lastly, the script calculates the demand from interruptible water rights along the mainstem Columbia River. These water rights are curtailed only in rare circumstances.

#### 2.1.2. Script 2

After *supply\_demand.R* is run, the second script to run 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. 1. The water demand upstream of a dam is equal to the sum of demand in all upstream incremental drainage areas shown in Fig. 1. The file, *inputs/station\_mapping* lists the drainage area for each upstream location (dam inlet or other control point important for flow targets).

*Variable refill curve*

Some of the reservoirs make use of a variable refill curve that guides refill of the reservoirs. It allows a deeper draft than permitted by the assured refill curve while providing a high level of assurance that the dam will refill by the target date. 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 model can be run in two modes. The power discharge requirement is an assumed release of water from the reservoir. Its value is estimated from Assured Operating Procedure documents (refer to the directory /Documentation/AOPs for these documents). In normal practice, the PDR is a tweaking parameter that is adjusted to by planners to meet a set of criteria for a refill test (see Principles and Procedures, 2003, page 14). It 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 () takes into account 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 the variable refill curve. The first is perfect forecast, in which the target reservoir volumes are computed using known inflows. This is the case when the inflow volumes used in (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. It does not, therefore 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 included, 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 time period, usually April through August, give or take a month. 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, which gives the simulation start year, end date, path to the input file, and the output directory.

*Initial controlled flow*

### 2.2. Main RColSim program

Once the input files have been created, the only required step remaining is to run the script, *RColSim\_main.R*.

*Main program architecture*

The *RColSim\_main.R* script begins by loading the global input file. Then required scripts are loaded that contain functions used by the main program, rule curves (other than the variable refill curve that is contained in the input file), switches, and functions used for generating model output. The following scripts are loaded:

1. *LoadFunctions.R*
2. *Read\_Rule\_Curves.R*
3. *Switches.R*
4. *dataframes.R*
5. *PMFs.R*
6. *VIC\_Data.R*

*LoadFunctions.R*

This script contains all the functions pertaining to the calculation of dam inflows, outflows, rule curves, and hydropower generation for each of the 46 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 very 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*

This script consists of a single function that 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*

A number of options and switches are available to choose from that affect the priority of dam management objectives, and that allow the user to control which variables are written to output. See **Index of switches and controls for a description of the various implemented options**.

*dataframes.R*

The scripts 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.

\*\*\*\*\*\*\*\* *water\_df*, and *energy\_df*, are essential to the code operation and cannot be deleted \*\*\*\*\*\*

*PMFs.R*

Functions for calculating model performance metrics. See **Index of performance metrics for a description of these.**

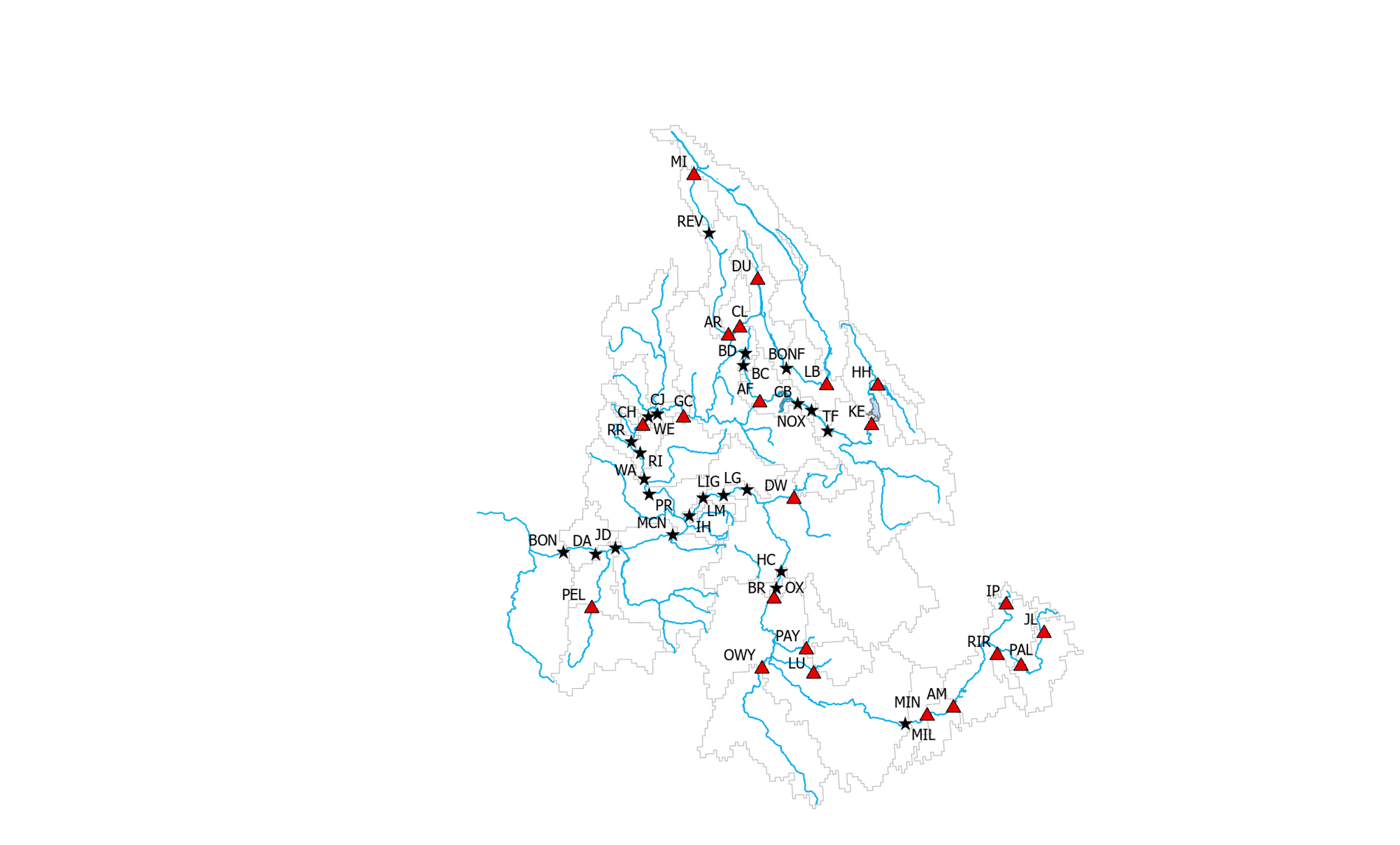
*VIC\_Data.R*

This script 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, 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 executes the first time step of the simulation. The main program executes all the remaining timesteps. At the beginning of each timestep, a set of common variables is initialized. 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 that value that is used by a multiplicity of functions only needs to be calculated once per time step and greatly 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. The final section of the script writes the outputs to file.

### 2.3. Running with future streamflow projections



**Figure 1.** Incremental drainage areas for each dam represented in RColSim.

Weekly surface water demands (withdrawals for municipal water and irrigation, excluding conveyance

Inflow to a downstream dam is calculated as the sum of outflow from immediate upstream dams plus incremental supply with demands removed (Eq. 1). Incremental supply is the difference between supply to a downstream dam and supply to all immediately upstream dams. Water demand corresponds with the same drainage area as incremental supply and is included in the input file. The orientation of dams represented in RColSim is shown in Table 1.

(1)

**Table 1.** Upstream-downstream orientation of dams in RColSim.

|  |  |  |
| --- | --- | --- |
| **Downstream dam alternative names** | **Downstream dam** | **Immediate upstream dam(s)** |
| BO, Bonneville | BONNE | DALLE |
| DA, The Dalles | DALLE | JDAYY |
| JD, John Day | JDAYY | MCNAR |
| MCN, McNary | MCNAR | ICEHA, PRIRA |
| PR, Priest Rapids | PRIRA | WANAP |
| WA, Wanapum | WANAP | RISLA |
| RI, Rock Island | RISLA | ROCKY |
| RR, Rocky Reach | ROCKY | WELLS |
| WE, Wells | WELLS | CHIEF |
| CJ, Chief Joseph | CHIEF | GCOUL |
| GC, Grand Coulee | GCOUL | CORRA, ARROW, BOUND |
| BD, Boundary | BOUND | ALBEN |
| AF, Albeni Falls | ALBEN | CABIN |
| CB, Cabinet Gorge | CABIN | NOXON |
| NOX, Noxon Rapids | NOXON | FLAPO |
| KE, Kerr | FLAPO | COLFA |
| COL, Columbia Falls | COLFA | FLASF |
| CL, Corra Lin | CORRA | DUNCA, BONFE |
| BONFE, Bonners Ferry | BONFE | LIBBY |
| AR, Hugh Keenleyside | ARROW | REVEL |
| REV, Revelstoke | REVEL | MICAA |
| IH, Ice Harbor | ICEHA | LMONU |
| LM, Lower Monumental | LMONU | LGOOS |
| LIG, Little Goose | LGOOS | LGRAN |
| LG, Lower Granite | LGRAN | HCANY, DWORS |
| HC, Hells Canyon | HCANY | OXBOW |
| OX, Oxbow | OXBOW | BROWN |
| BR, Brownlee | BROWN | MILNE |
| MIL, Milner | MILNE | PALIS |

**3- Update the Global Input File**

The global input file has the following values:

* **RColSim\_WD**
  + RColSim working directory indicates where the main RColSim model is located
* **Flow\_Input\_File**
  + Input file to RColSim
* **Output\_Folder**
  + The folder where program stores the output files
* **simulation\_start\_year**
  + The year that simulation starts. The start month cannot be specified because RColSim has to start from August when operation year starts.
* **simulation\_end\_date**
  + The date that simulation ends. Unlike start year, this value has to be an actual date.
* **input\_start\_date**
  + Here, the model user specifies the start date of RColSim input file.
* **input\_end\_date**
  + End date of RColSim input file.

**4- Other Model Inputs**

The users that are only interested in running the baseline scenarios of RColSim do not need to adjust any other input files. However, there are some modeling options that can be specified in “RColSim/Switches.R”. For example, users can specify if they want to conduct the simulation under the perfect forecast condition or predefined refill curves by setting “*PfctForecast\_Refill\_Targ”* or *“*SQuo\_Refill\_Targ*”* valuesto 1. There are also additional inputs that can be potentially changed for specific purposes. Examples of these inputs include rule curves that are available in “RColSim/default\_rule\_curves”.

**Index of Variables**

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

AvgMin – Average minimum release from a dam according to operating rules (cfs).

BotVol – Water storage corresponding with the lower operating limit for a dam (acre-ft).

CombSup() – Total water allocated to meet fish flow and energy objectives (acre-ft/wk).

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

DallesRunoffAprSep – Cumulative April to September unregulated flow at The Dalles (acre-ft/wk).

DemVIC – Surface water demand in the drainage area between upstream and downstream dams (acre-ft/wk). If the unregulated flow input is modified flow (demands already removed), be sure to set all the DemVIC columns to zero in the input file to avoid double-counting irrigation demand).

FullPoolVol – Water storage corresponding with the upper operating limit for a dam (acre-ft).

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

MWhr\_per\_ftAcFt – Conversion factor for converting head times volume to energy output.

FlowVIC – Unregulated flow entering a dam generated from the entire upstream drainage area (acre-ft/wk).

RefillVol1 – Refill curve value for status quo refill (acre-ft).

RefillVol2 – Refill curve value for perfect forecast (acre-ft).

RefillVol – Refill curve value for perfect forecast (acre-ft). Some dams use this name instead of RefillVol2

**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. AvailAfter() will be MIAvailAfter() in the code.

Add\_Space() – Additional flood space (acre-ft) required at Brownlee based on flood conditions at The Dalles (used only if FC\_Option = 1).

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

April\_Evac\_Target() – Expected flood evacuation at the end of April (acre-ft/wk).

AprilUpstreamFloodEvacGC() –Expected flood evacuation at the end of April from all reservoirs upstream of Grand Coulee (acre-ft/wk).

AvailAfter() – Total available volume of water to be allocated (acre-ft).

BelowFCC() – Volume of water stored in all reservoirs in excess of the total volume specified by the flood curves at all reservoirs (acre-ft).

BonnevilleTarget() – Chum flow target at Bonneville dam (cfs).

BONFlowDeficit() – Shortage of flow at Bonneville for meeting Chum flow target (acre-ft/wk).

Chum\_variable\_1() -- Variable minimum flow for Bonneville Chum based upon forecasted inflow to the Dalles, for the period of November to April 9 (cfs).

Chum\_variable\_2() – Base minimum flow for Bonneville Chum based on month (cfs).

ChumSF() – Deficit of flow for meeting winter Chum flow target at Bonneville (acre-ft/wk).

CorrectedDallesRunoff() – Forecasted Apr through August runoff at The Dalles minus the total storage space made available in reservoirs upstream of Grand Coulee (acre-ft/wk).

CriticalCurve() – The energy rule curve value (acre-ft) corresponding with the minimum reservoir storage for a given week of year to meet energy objectives.

Curtail() – Magnitude of curtailment of water rights provisioned on several dams along the Columbia mainstem (acre-ft/wk).

DallesFloodCond() – Index of forecasted April-August flow at The Dalles, scale of 1-11 from low flow to high flow.

DamProtectRel() – Amount of water that must be released (acre-ft/wk) to keep the dam from filling above the full pool volume.

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

ECC() – Energy content curve value (acre-ft) as a function of the critical curve, flood curve, and refill curve. This function combines all the rule curves and outputs the target reservoir level for the dam considering energy and flood control objectives.

ECCEnergyContent() -- Potential energy of water remaining in a reservoir above the Energy Content Curve after removing 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.

ECCSharedWater() – Water remaining in a reservoir above the Energy Content Curve after removing water allocated to minimum release and fish flow objectives (acre-ft/wk). It is the energy allocated specially for hydropower generation.

EnergyContent() -- Potential energy of water remaining in a reservoir above the lower operating limit after removing water allocated to minimum release and fish flow objectives, multiplied by turbine

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

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.

FirmEnergyDeficit() -- Basin-wide deficit of firm energy production (MW-hr).

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

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

FloodSpace() – Additional storage space reserved in several dams in case of high flows at The Dalles (acre-ft).

FlowData() – Reads naturalized flow from the input file.

GCAbsMinQ() – Absolute minimum release from Grand Coulee to support fish flow objects (acre-ft/wk).

GCBdgtForVB() – Release from Grand Coulee to meet fish flow requirement at Vernita Bar (acre-ft/wk).

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

GCLimitedStorage() – Maximum amount of water that can be released to meet target flow at Bonneville and still maintain reservoir levels at the variable draft limit (acre-ft/wk).

GC\_VDL() – Grand Coulee variable draft limit (see McNaryDraftLimit description) for meeting fish flow targets at Bonneville, taking into account flood control and navigation requirements (acre-ft).

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

HHBiOpDraftLimit() – Required water volume in Hungry Horse reservoir after accounting for releases to meet federal Biological flow requirements (acre-ft).

HungryHorseEnergy() -- Actual hydropower generation at Hungry Horse dam (MW-hr).

Inc() – incremental unregulated flow to a dam. Incremental flow is flow at the downstream gauge minus flow at immediate upstream gauge(s).

In() – Preliminary inflow to a dam according to preliminary outflow from upstream dams, incremental flow (minus surface water demands).

Inflow() – Actual inflow to a dam according to actual outflow from upstream dams, incremental flow (minus surface water demands).

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

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

LibbyEnergy() – Actual hydropower generation at Libby Dam (MW-hr).

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

MaxSystemEnergy() -- Actual hydropower generation at all dams (MW-hr).

McNaryDraftLimit() – Minimum reservoir volume after accounting for release to meet McNary fish flow target (acre-ft). Applies to Mica, Arrow, Duncan, Libby, Hungry Horse, and Grand Coulee reservoirs.

McNarySharedWater() – Water allocated for meeting McNary fish flow target (acre-feet/wk).

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

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

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

MIMinRelForAR() – Minimum release of water from Mica to Arrow (acre-ft/wk).

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 used for generating non-firm hydropower (MW-hr).

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

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

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

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

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

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

PreEnergy() -- Initial estimate of energy production (MW-hr), considering only water released for flood protection (MW-hr).

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

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 over a given time step (acre-ft/wk).

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

Req() – Required minimum release based on historical data (acre-ft/wk).

Reservoir() – Reads starting (time t-1) storage volume in a reservoir from the reservoir volume output file (reservoir\_volume.txt). If time t=1, then the reservoir is initialized according to the InitialConditionSwitch.

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).

SharedWater() -- Water remaining in a reservoir above the lower operating limit after removing water allocated to minimum release and fish flow objectives (acre-ft/wk).

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

shortfall\_2() – Shortfall of non-firm hydropower generation (MW-hr).

shortfall\_5() – Shortfall of fish flows at Columbia Falls (acre-ft/wk).

shortfall\_6() – Shortfall of fish flows at Lower Granite (acre-ft/wk).

shortfall\_7() – Shortfall of fish flows at Vernita Bar (acre-ft/wk).

shortfall\_8() – Shortfall of fish flows at McNary (acre-ft/wk).

shortfall\_9() – Elevation of water in Grand Coulee below the target for recreation (ft).

shortfall\_10() – Shortfall of flood protection at the The Dalles (acre-ft/wk).

shortfall\_11() – Shortfall of required flows for navigation at Ice Harbor (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).

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

1931Refill() – Reads the refill curve value based on the 1931 historical refill curve.

**Index of Input Files**

AddSp\_input – Additional flood space available at Brownlee dam in case of high flows at the Dalles (acre-ft).

AFAvgMin\_input – Average required minimum release from Albeni Falls dam (cfs).

APR\_HH\_input – April flood rule curve for Hungry Horse dam (acre-ft).

ARFlood – Weekly flood curve values for Arrow dam (acre-ft).

ARFloodMonth – monthly flood curve values for Arrow dam (acre-ft).

ARFlood\_May5\_i – Wet year flood curve for Arrow dam (acre-ft).

ARFlood\_1May\_input – Dry year flood curve for Arrow dam (acre-ft).

Article\_56 – Minimum required flows for fish at Kerr dam (cfs).

BONNetHead\_input – Approximate monthly difference in elevation between water in Bonneville reservoir and the tailwater (ft).

Chum\_variable\_2\_input – Values used to calculate the Bonneville flow target for Chum (cfs).

BRCurFC\_Cont – Weekly flood curve values for Brownlee dam (acre-ft).

BRForecastFloodStorage – Monthly flood curve values for Brownlee dam (acre-ft).

CLIJCRuleCurve\_input – International Joint Commission rule curve for Corra Linn reservoir. There are no other rule curves for this dam.

DAHighFloodTarget\_input – Flood target at The Dalles when forecasted Apr-Aug runoff at The Dalles is greater than 120 million acre-feet.

DALowFloodTarget\_input -- Flood target at The Dalles when forecasted Apr-Aug runoff at The Dalles is less than 120 million acre-feet.

DUFlood\_input – Weekly flood curve values for Duncan dam (acre-ft).

DU\_JAN\_FAMAJ – January through June monthly flood curve values for Duncan dam (acre-ft).

DWFlood\_input – Weekly flood curve values for Dworshak dam (acre-ft).

DW\_FloodM -- Monthly flood curve values for Dworshak dam (acre-ft).

DWRefillMin\_input – Weekly minimum refill values for Dworshak dam (acre-ft).

DWAvgMin\_input – Average minimum release from Dworshak dam (acre-ft).

DWCriticalCurve\_input – Weekly critical curve values for Dworshak dam (acre-ft).

DW1931Refill\_input – Weekly historical refill curve for Dworshak dam (acre-ft).

FirmFraction\_input -- Adjustment to the average firm energy load throughout the year.

GCRecLimit\_input – Storage volume in Grand Coulee dam required to support recreation (acre-ft).

GCAbsMinQ\_input -- Minimum release from Grand Coulee to support fish flow objects (acre-ft/wk).

GCBdgtForVB\_input -- Required release from Grand Coulee to meet Vernita Bar fish flow target (acre-ft/wk).

HHBaseDraftLimit\_input -- Volume of water in Hungry Horse reservoir that must be maintained after drafting to meet Biological Opinion flows (acre-ft).

HHFlood\_2\_input – Weekly flood curve values for Hungry Horse (used only if FC\_option=1).

HH\_USBRmax\_input – Maximum outflow allowed from Hungry Horse dam (cfs).

HistStor – Historical reservoir volumes, used only for initialization (acre-ft).

LowerGraniteTarget\_input – Target flows for Lower Granite Dam to support fish migration (acre-ft/wk).

MIAssuredReleasedMin\_i – Required minimum release from Mica (cfs).

MIMaxFloodOutflow\_input – Maximum allowable release from Mica (acre-ft/wk).

MSFloodRuleCurve\_input – Flood rule curve for the Middle Snake composite reservoir (acre-feet).

NonFirmFraction\_input – Fraction of the average weekly non-firm energy load, multiplied by average load to get non-firm energy load for a particular week in the year.

PreGCDraftLimit\_input -- Weekly draft limit for Grand Coulee dam to meet Bonneville flow objectives (acre-ft).

**Index of Switches and Controls**

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

CombEfficiency – Estimated combined efficiency for turbines. A different value can be set for each dam, but the default is 0.8 for all.

curtail\_option – Select how mainstem curtailment should be calculated (3 options).

EnergyAllocSafeFactor -- Due to penstock constraints, the energy allocation algorithm may occasionally request water from an upstream dam that is already spilling water. In this case the system wide energy target may be missed by a small amount since no extra energy will be produced at the upstream dam itself. This control increases the energy target by a small amount to ensure that the system wide targets are met despite this allocation decision.

InitialConditionSwitch—Select how to initialized water storage in the reservoir (3 options).

MOPControl – Select whether to write measures of performance to file (binary).

RefillMinSw() – Switch to select alternate minimum release for generating inflow estimates at Grand Coulee and Arrow (2 options).

RefillSwitch() – Choose between status quo dam operations (option 1) and perfect forecast (option 2).

TopRuleSw() -- Switch to select how to determine flood rule (3 options).

ResetStorageSwitch() – Choose whether to reset dam storage each year at a user-specified month (binary).

ResetStorageMonth() – Choose the month of the year to reset storage.

SensitivityFraction -- Factor of safety for meeting flow objectives.

track\_curtailment – Select whether to write curtailment magnitudes to file (binary). Turning off this function could speed up the code because curtailment calls additional functions.

UseAlternateNonFirmTarget – Choose whether to use status quo energy target and fraction (option 0) or use alternative forecast for non-firm energy that uses climate forecast multipliers for the period from August-January (option 1).

UseTotalEnergyContentForFirm() – Choose whether to release only to the ECC curve (option 0) or allow to release to the lower operating limit of the dam (option 1).