RColSim User Manual

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 need to execute the program.

2- Preparation of a weekly streamflow and surface water demand input file for RColSim:

The current version of RColSim works at a weekly time step. Therefore, the streamflow inputs to the model need to be aggregated to a weekly time step. An example input streamflow dataset is included in the following repository:

"RColSim/inputs/Supply_to_RColSim/ToRColSim_scenario_baseline_with_curtailment.txt"

The unregulated water supply input columns are designated by the "PriVIC" prefix. These flows should be routed to each of the dams if you are including your own water supply data. Alternatively, the no-regulation, no-irrigation (NRNI) dataset from the Bonneville Power Administration (BPA) can be used.

Weekly surface water demands (withdrawals for municipal water and irrigation, excluding conveyance losses) are also included in the RColSim input file. The aggregation area for these demands corresponds with the drainage areas between the dam indicated after the "DemVIC" prefix and the nearest upstream dam. The water demand in the DemVIC columns was calculated from VIC-CropSyst simulated irrigation demands, not including conveyance losses, as well as surface water municipal demands where those

data were available. The model subtracts water demand from naturalized flow in the incremental drainage area between each dam and its nearest upstream neighbors. These drainage areas are shown in Figure 1. If the user wishes to run RColSim with naturalized flows (demands already removed), the demand columns in the input file need to be replaced with zeros to avoid double-counting water demand. The grid coordinates for each grid in each aggregation area is included in the following repository:

"RColSim/drainage_ids.txt"

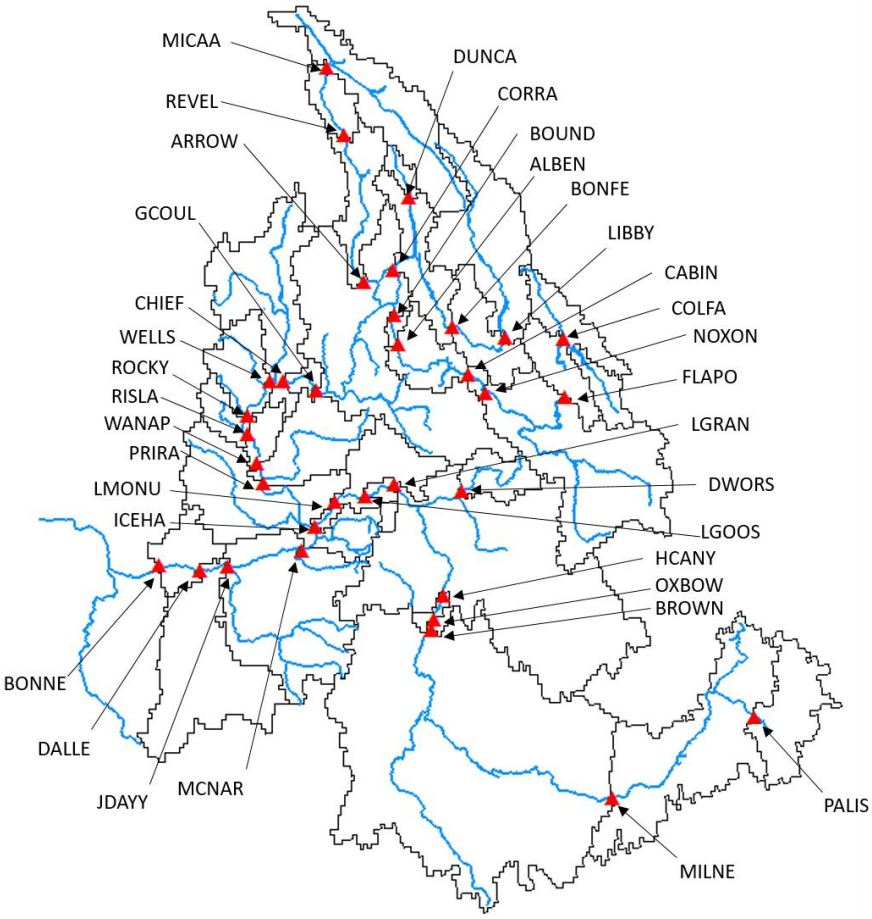

Figure 1. Incremental drainage areas for each dam represented in RColSim.

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.

$$\mathrm{Inflow}_{\mathrm{Down}} = \mathrm{Flow}_{\mathrm{Inc}} - \mathrm{Demand}_{\mathrm{Inc}} + \sum \mathrm{Outflow}_{\mathrm{Up}} \quad (1)$$

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

A global input file exists in the "RColSim/inputs" folder which needs to be updated. The current file is called "*Global_Input_File_Historical_baseline"*, however, users can update the name and address of this

file and correct line 36 of the "*RColSim.R"* file accordingly. The current global input file can be found here: "*RColSim/inputs/Global_Input_File_Historical_baseline.txt*"

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*"* values to 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., PRIVICMI 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.

PriVIC – 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).


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