A Reservoir Operation and Sediment MANagement (ROSMan) Routine

User's Manual

2021

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1. INTRODUCTION

The Reservoir Operation and Sediment MANagement (ROSMan) routine (Shrestha et al. 2020; Shrestha et al. 2020) is a new reservoir routine implemented in SWAT (Soil and Water Assessment Tool). SWAT is a physically-based hydrological model initially developed for large complex catchments (Arnold et al. 1998) by the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS), and used to assess impacts of impoundments, best management practices (BMPs), climate change, or land use change on streamflow and/or pollutant and sediment transport of catchments world-wide.

The SWAT has capabilities to simulate and predict inflow and sediment yields to the reservoirs under various climatic conditions and land use changes. Even though the SWAT model has been successfully applied in many studies for different purposes such as for predicting sediment yields, assessing climate change impacts on surface runoff, and simulating hydrology in different catchments, hydropower reservoir operation methods and sediment management techniques have not yet been implemented within the framework of the SWAT. Therefore, the ROSMan routine has been introduced into the SWAT to simulate reservoir operations and sediment management techniques under different operation policies.

2. OVERVIEW OF A ROSMan

The ROSMan has fundamentally two capabilities: 1) hydropower reservoir operations without considering sedimentation (HydROR) (Shrestha et al. 2020) and 2) accumulation and removal of sediment under hydropower reservoir operations and sediment management techniques (ResSMan) (Shrestha et al. 2020) (Figure 1). Thus, the user can choose between the HydROR and ResSMan. If the main purpose of simulation is to predict energy generation and impacts on the hydrologic regime of a river due to operation of hydropower reservoirs under different policies at the river basin scale, then it is suggested to simulate with the HydROR. The HydROR calculates the water balance of a reservoir and energy generation of a hydropower plant using predefined rule curves and plant efficiency without considering the impacts of sedimentation on the storage capacity. On the other hand, if the main objective of the study is to assess the accumulation of sediment and its impact on reservoir storage capacity, then the user must simulate with the ResSMan. The ResSMan routine has capabilities to predict the accumulation of trapped sediment, its impacts on the storage-capacity of a reservoir, and losses in hydropower generation under user-specified operation policies. Furthermore, it allows to compute the restoration of storage volume due to the removal of sediment by flushing (removal of sediment from a reservoir by passing water and sediment through flush gates located at the low level of a dam) and sluicing (passing sediment before suspended sediment solids have settled down in reservoirs).

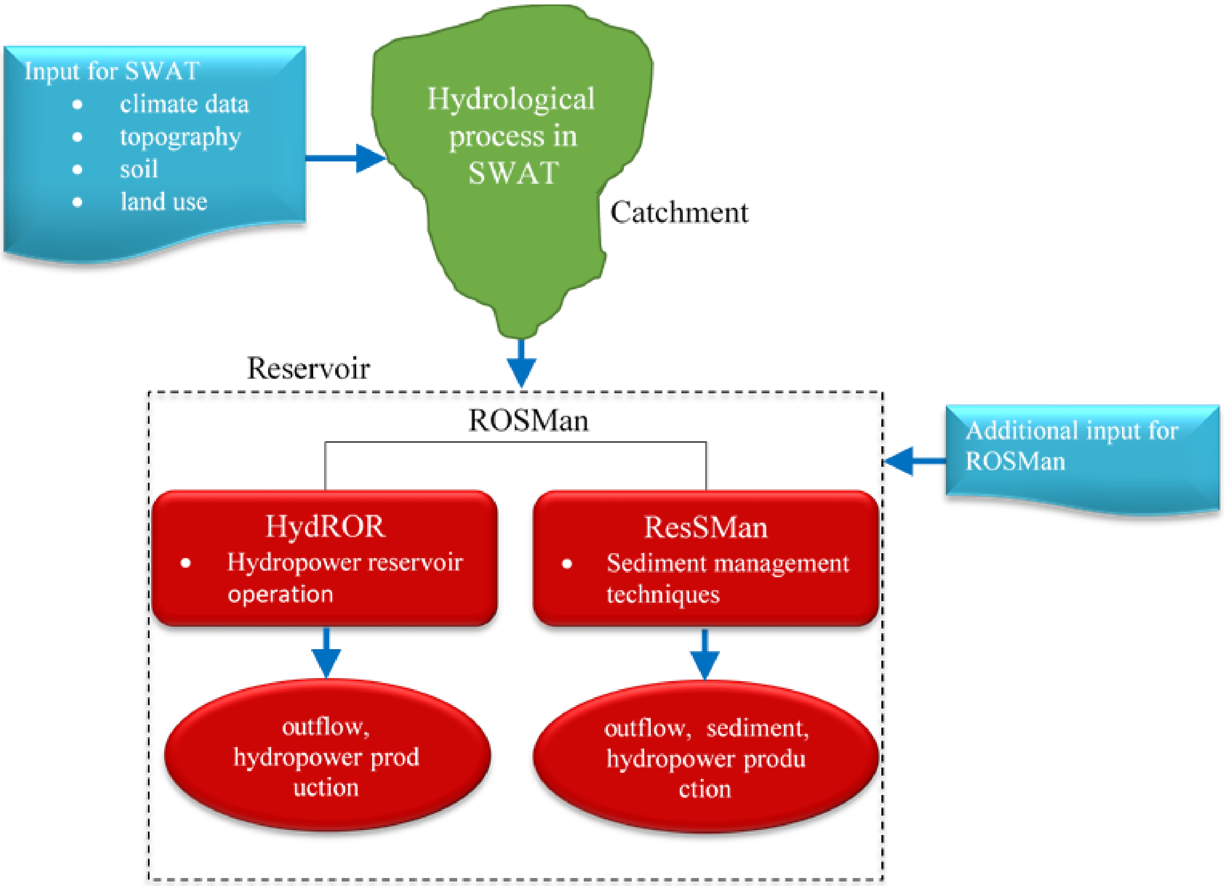


Figure 1: Framework and capabilities of the ROSMan

2.1 Hydropower Reservoir Operation Routine (HydROR)

The HydROR has capabilities to operate hydropower reservoirs, to compute water balance of a reservoir and energy generation using the predefined rule curves. The HydROR neglects the effect of sedimentation on storage capacity of reservoirs, however, it uses the existing sediment routing method of the SWAT to compute sediment in and out from the reservoir. The water inflow to the reservoir, precipitation on the reservoir surface area and potential evapotranspiration from the reservoir surface area are generated by a hydrologic component of the SWAT model. Additional data are needed to estimate hydropower production and to operate the reservoir under the predefined operational policy. These additional data such as area-elevation, volume-elevation curve, maximum/minimum operating level, rule/guide curves, plant efficiency, and design flow of plant are separately entered.

The reservoir routing is accomplished by the following steps in the HydROR. Firstly, the volume of the total outflow ($V_{flowout}$) of a reservoir is estimated using the level pool routing method (Modified Puls Method), which calculates outflows by solving the continuity equation (eq. 1-4) of mass balance (Chow 1964) for every time step of the simulation. The right hand side (unknown) term of equation 3 can be found by interpolation of the Storage Indication (2V/Δt+Q) vs Outflow curve (Figure 2c)), which is created by combining the Outflow curve and the Volume-Elevation curve. Hence, additional data such as Volume-Elevation curve and Outflow curve (spillway rating curve) for a reservoir must be entered separately for every reservoir in the basin. The relationship between water level and reservoir volume can be derived by using a topographic map of the reservoir. The outflow rating curve of the spillway is derived from hydraulic equations relating discharge and head of the spillways.

$$I - Q = \frac{\Delta V}{\Delta t} \tag{1}$$

$$\frac{I_{t-1} - I_t}{2} - \frac{Q_{t-1} - Q_t}{2} = \frac{V_{t-1} - V_t}{2} \tag{2}$$

$$[i_{t-1} - i_t] + \left[\frac{2V_{t-1}}{\Delta t} - q_{t-1}\right] = \left[\frac{2V_t}{\Delta t} - q_t\right] \tag{3}$$

$$V_{flowout} = Q_t \times \Delta t \tag{4}$$

Where, I and Q are average inflow and outflow in m^3/s, i_{t-1} and i_t are inflows to the reservoir at simulation time steps $t-1$ and t in m^3/s, Q_{t-1} and Q_t are outflows from the reservoir for simulation time steps $t-1$ and t in m^3/s, ΔV is change in storage capacity in the reservoir in m^3, and $V_{flowout}$ is the volume of outflow at time t in m^3.

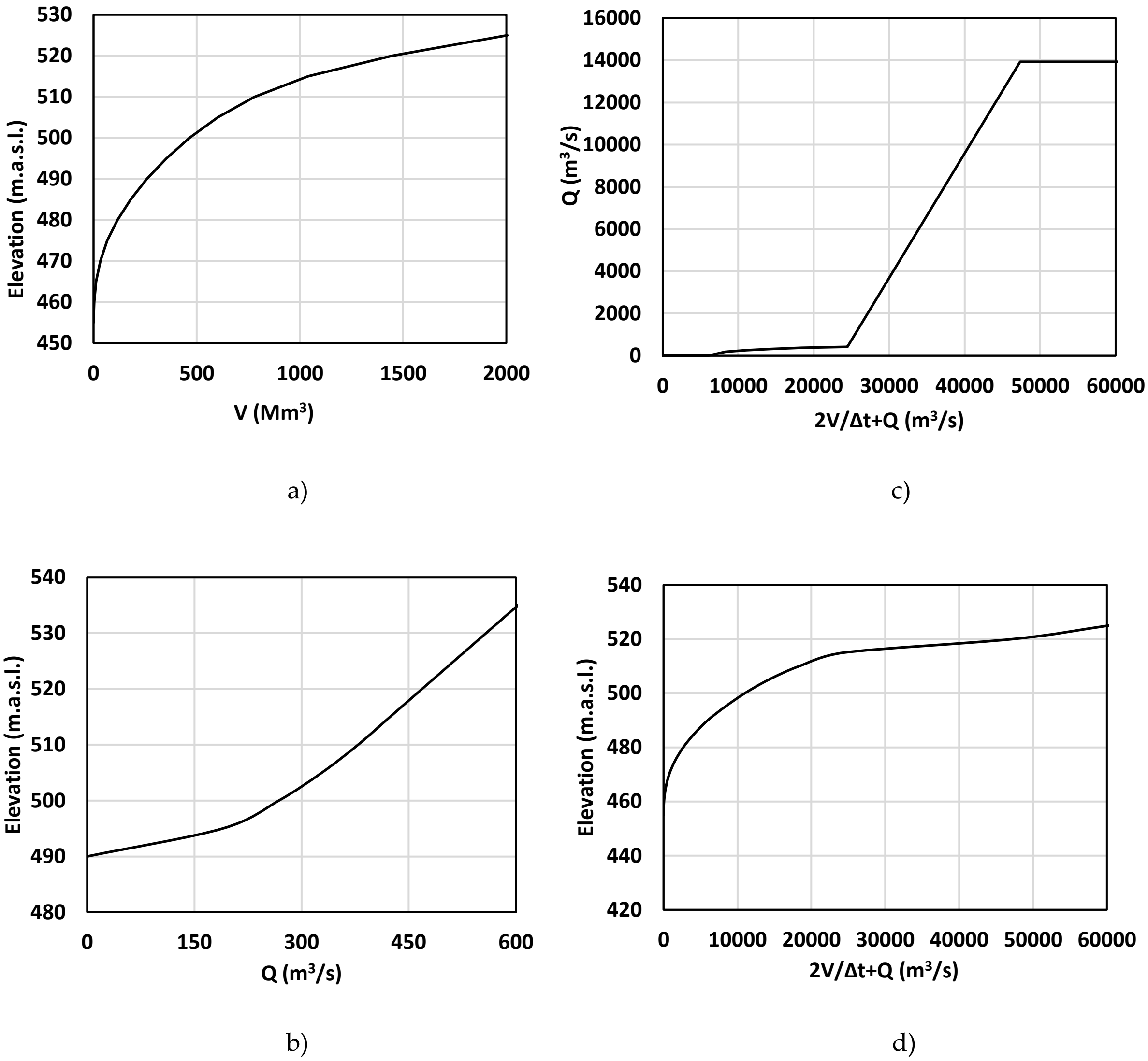


Figure 2: a) Volume-Elevation Curve, b) Outflow rating curve, c) Storage Indication (2V/Δt+Q) vs outflow curve and d) Storage Indication (2V/Δt+Q) vs elevation curve for a reservoir

Secondly, the final outflow (Equations (5)–(8)) of the reservoir is determined based on the operating policy using a user-defined rule curve of the reservoir. In HydROR, the rule curve is defined by specifying a target water level for the first day of each month and the routine calculates daily target water levels by linear interpolation.

$$V_t = V_{t-1} + V_{flowin} - V_{outflow} + V_{pcp} - V_{evap} - V_{seep} \quad (5)$$

$$V_{check} = V_{t-1} + V_{flowin} + V_{pcp} - V_{evap} - V_{seep} - V_{rule} \quad (6)$$

$$\text{IF } (V_{check} \leq 0), \text{then } V_{final\_outflow} = 0 \quad (7)$$

$$\text{IF}(V_{check} \leq V_{outflow}), \text{then } V_{final\_outflow} = V_{check} \quad (8)$$

$$\text{IF}(V_{check} > V_{outflow}), \text{then } V_{final\_outflow} = V_{outflow} \quad (9)$$

Where, V_t is the volume of water in the reservoir at the simulation time step t (m^3), V_{t-1} is the volume of water stored in the reservoir at the simulation time step t-1 (m^3), V_{flowin} is volume of water entering the reservoir (m^3), $V_{outflow}$ is volume of water flowing out of the reservoir (m^3), V_{pcp} is volume of precipitation falling on the reservoir (m^3), V_{evap} is volume of evaporated water from the reservoir (m^3) and V_{seep} is volume of water lost from the reservoir by seepage (m^3), V_{rule} is volume of the reservoir as indicated by the rule curve for a simulation time step and V_{check} is the difference in total water volume (*V*) and V_{rule}. $V_{final\_outflow}$ is the final outflow from the reservoir. This final outflow includes the outflows from different outlets of a reservoir:

$$V_{final\_outflow} = V_{spill} + V_{tur} \quad (10)$$

Where, V_{spill} is the volume of water spilling from the spillway (m^3) and V_{tur} is the volume of water flowing through a turbine (or turbines) for power generation (m^3). The discharge through a spillway is allocated using the outflow rating curve of the spillway. The turbine flow for hydropower generation depends on the design discharge for hydropower plants and operation rules.

Thirdly, power generation from the hydropower plant for every time step of simulation is calculated as in Equations (11) and (12).

$$P = \frac{\eta \times \gamma \times Q_{tur} \times H_{net}}{1000} \quad (11)$$

$$E = \frac{P \times hr}{1000} \quad (12)$$

where Q_{tur} is the flow through turbine in m^3/s, η is the efficiency of power plant, γ is the specific gravity of water in KN/m^3, H_{net} is net head for power plant in m, hr is time in hour, *P* is power production in MW and *E* is energy generation in GWh. The net head is calculated by taking the difference between reservoir water level and the tailrace level/turbine level of the power plant, which should be entered by a user.

Lastly, the HydROR updates reservoir water volume using the mass balance equation and updates water level and surface area from the volume-area-elevation curve of the reservoir and writes the results (reservoir volume, level, outflow and power generation) to an output file.

2.2 Reservoir Sediment Management routine (ResSMan)

The REServoir Sediment MANagement routine (ResSMan) is a hydropower reservoir routine specifically developed for integration into the SWAT. The main functions of the ResSMan are to simulate reservoir routing and sediment management techniques such as flushing and sluicing. Typical features of a reservoir to be assessed with ResSMan contains a spillway at the dam crest level, hydropower intakes to divert flow for hydropower generation, low level outlets for sediment management purposes and the storage capacity is divided into two parts by the full supply level (FSL) and minimum operating level (MOL) into the active and dead storage (Figure 3).

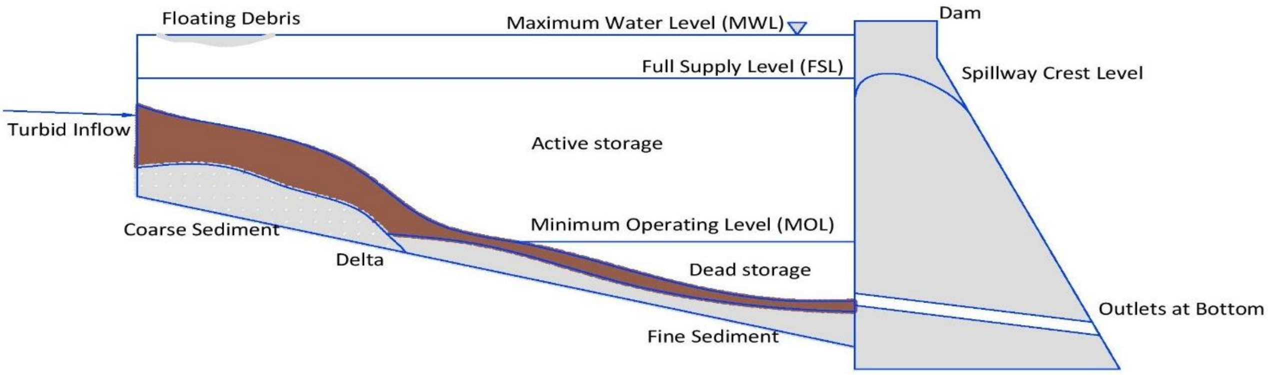


Figure 3: Typical features of a reservoir in the ResSMan

The water and sediment inflow to the reservoir, precipitation onto the reservoir surface area, seepage loss from the reservoir bottom and evapotranspiration from the reservoir surface area are computed by a hydrologic module of the SWAT model. Furthermore, the ResSMan predicts the accumulation of trapped sediment using the Brune curve (Brune 1953), its impacts on the storage capacity of a reservoir, and hydropower generation under user-specified operation policies. When the user specifies to simulate with sediment management techniques, the routine computes the outflow of the removed sediment, restoration of storage capacity and energy production. The ResSMan uses the following empirical equations to estimate the trapping efficiency as proposed by Gill (1979) for coarse-grained, medium and fine-grained sediments:

$$TE = \frac{\Delta T^2}{(0.994701 \times \Delta T^2 + 0.006297 \times \Delta T + 0.3 \times 10^{-5})} \tag{13}$$

$$TE = \frac{\Delta T}{(0.012 + 1.02 \times \Delta T)} \tag{14}$$

$$TE = \frac{\Delta T^3}{(1.02655 \times \Delta T^3 + 0.02621 \times \Delta T^2 - 0.133 \times 10^{-3} \times \Delta T + 0.1 \times 10^{-5})} \tag{15}$$

$$\Delta T = \left(\frac{V}{I}\right)/365 \tag{16}$$

Where, *TE* is trapping efficiency, ΔT is the residence time in days, *V* is storage capacity of the reservoir in m^3, *I* is average daily inflow volume in m^3/s/day. Furthermore, the ResSMan computes the settled sediment mass using the sediment mass balance equation.

$$Set_t = Sed_{flowin} \times TE \tag{17}$$

$$Conc_t = \frac{\left(Conc_{t-1} \times V_{t-1} + (Sed_{flowin} - Set_t)/\rho\right)}{(V_{t-1} + V_{flowin})} \tag{18}$$

$$Sed_{outflow} = (Conc_t) \times V_{final\_outflow} + Sed_{flushed} \tag{19}$$

$$dep_{\mathrm{t}} = dep_{\mathrm{t-1}} + Set_t - Sed_{flushed} \tag{20}$$

Where, $Conc_{t-1}$ and $Conc_t$ are the sediment concentration of suspended solids (ton/m^3) at time step *t-1* and *t* respectively; Sed_{flowin}, $Sed_{outflow}$, Set_t and $Sed_{flushed}$ are sediment mass inflow, outflow, settled sediment mass and sediment mass removed due to flushing (ton) respectively; $dep_{\mathrm{t-1}}$ and dep_{t} are deposited sediment mass (ton) at the time step *t-1* and *t*; ρ is the density of sediment mass (ton/m^3) and the other symbols are as described above. The final reservoir outflow ($V_{final\_outflow}$) and final reservoir storage volume is calculated by using the mass balance equation of water (Eq. 23) of a reservoir.

$$V_{check} = V_{t-1} + V_{flowin} + V_{pcp} - V_{evap} - V_{seep} - V_{rule} - Set_t/\rho \tag{21}$$

$$V_{final\_outflow} = Min\left[Max(V_{check}, 0), V_{tot\_outlet}, Max\left\{\left(V_{t-1} + V_{flowin} + V_{pcp} - V_{evap} - V_{seep}\right), 0\right\}\right] \tag{22}$$

$$V_t = V_{t-1} + V_{flowin} - V_{final\_outflow} + V_{pcp} - V_{evap} - V_{seep} - Set_t/\rho \tag{23}$$

Where, V_{rule} is the volume of the reservoir (m^3) as indicated by the rule curve for the simulation time step, V_{check} is the initial estimate of the volume (m^3) to meet the storage target according to the specified rule curve and V_{tot_outlet} is the sum of outflow capacities of all the outlets (m^3) which is determined on the basis of the water surface level, storage volume and outlet capacity rating curve.

2.2.1 Flushing Process

The process of flushing in the ResSMan routine comprises three phases: drawdown of water surface level, removal of sediment due to occurrence of the flushing, and refilling the reservoir (Figure 4). The drawdown initiates on or after the user specified initiation date of drawdown and meets the criterion of minimum reservoir inflow. The flushing gates, which are usually installed at the bottom of a dam, are opened at their full capacity to achieve the complete drawdown of the reservoir. The routine assumes the gates are opened as soon as drawdown is initiated and closed once flushing is completed. Further, during the flushing process, there is no energy generation from the hydropower plants. Thus, water flow to the turbines is considered nil. However, other outlets such as spillways are in full function to release the water. The operation policy of reservoir routing during the drawdown phase is to achieve river-like flow emptying the reservoir. The total water release from a given reservoir results from reservoir inflow, water storage during drawdown, the maximum drawdown capacity and sum of release capacity of all opened outlets.

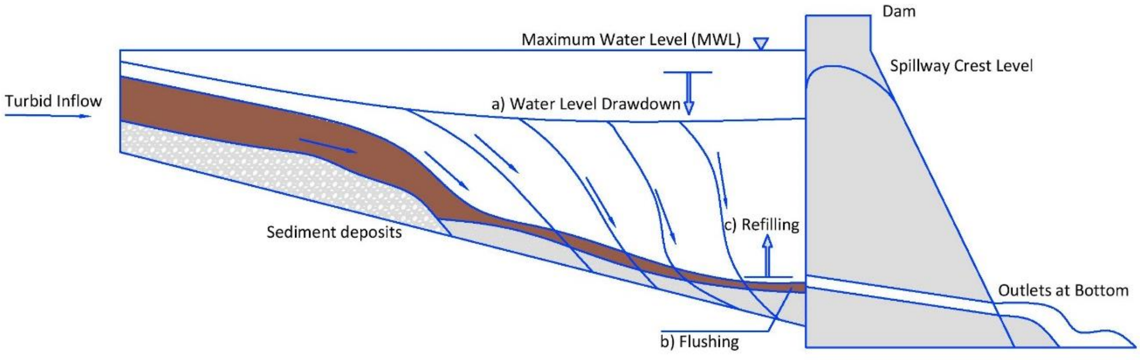


Figure 4: Flushing process to remove reservoir sediment deposits (a) water level drawdown, (b) flushing, (c) refilling reservoir.

It is considered that all the sediment entering the reservoir to remain in suspension during the flushing process. So, the trapping of sediment equals zero and concentration of the suspension sediment rises. Thus, flow with high sediment concentration is passed during release of water through outlets. However, previously deposited sediment mass cannot be removed until the criteria for occurrence of flushing have been satisfied. The following two criteria should be satisfied for successful flushing to take place, as mention in the SedSim model user manual (Wild and Loucks 2012):

i) The water surface level should not exceed the maximum flushing water surface elevation as specified by the user.

ii) The water release from flushing gates should be greater than the required minimum flushing flow.

The first criterion suggests to maintain the water surface level as low as possible, and to achieve the river-like flow and in order to increase the efficiency of the flushing (Lai and Shen 1996; Wen Shen 1999). Furthermore, Wen Shen (1999) suggested that the drawdown water level should not exceed the original river normal flow level. Yet in the ResSMan, it is assumed that the water level can drop up to the original river bed level at the time of flushing. After the complete drawdown of the reservoir, the outflow through the flushing gates equals the runoff of the river and it depends on hydrological condition of the catchment and time of operation of flushing. Thus, the user can define the required minimum flushing flow by analysing the historical hydrological data of the river flow.

After fulfilling both criteria, there will be occurrence of flushing on a particular day and if one of these criteria is not satisfied then the routine waits one more day to achieve successful flushing. Once flushing has successfully taken place for a specified duration, the flushing phase is completed, flushing gates will be closed and refilling of the reservoir begins. The outflow from the reservoir is zero until the water level rises above the MOL of the reservoir. Once the reservoir water level rises above MOL, the reservoir runs in the normal operating policy using the specified rule curve.

During the flushing process, the trapping efficiency of the reservoir is assumed to be zero, thus increases the concentration of suspended sediment of the reservoir. The amount of removed sediment during drawdown phase is equal to the concentration of sediment multiplied by the volume of water outflow. During the flushing phase, deposited sediment is assumed to be removed from portions of the volume-area-elevation curve in the same way in which the distribution of sediment deposition in the reservoir was assumed. The steps of estimating volume of sediment removed during the flushing phase is outlined as below (Wild and Loucks 2012):

1. Determine the original (initial) long term capacity ratio (LTCR) as explained in the 'The feasibility of flushing sediment from reservoirs' (Atkinson 1996). LTCR is defined as the ratio of the sustainable reservoir capacity to the original capacity of a reservoir. The sustainable reservoir capacity is the storage capacity of a reservoir that can be sustained due to flushing in the long term.

The calculation of LTCR can be described by a simplified geometry of a reservoir. Figure 5 represents the simplified cross section of a reservoir immediately upstream of a dam. In the figure, the outer trapezoid (A_r) represents the cross section of the reservoir and the inner trapezoid represents the cross-sectional area (A_f) of the flushing channel that can be sustained by flushing. Using these definitions, the initial LTCR is expressed by the following equation:

$$LTCR_o = \frac{A_f}{A_r} \tag{24}$$

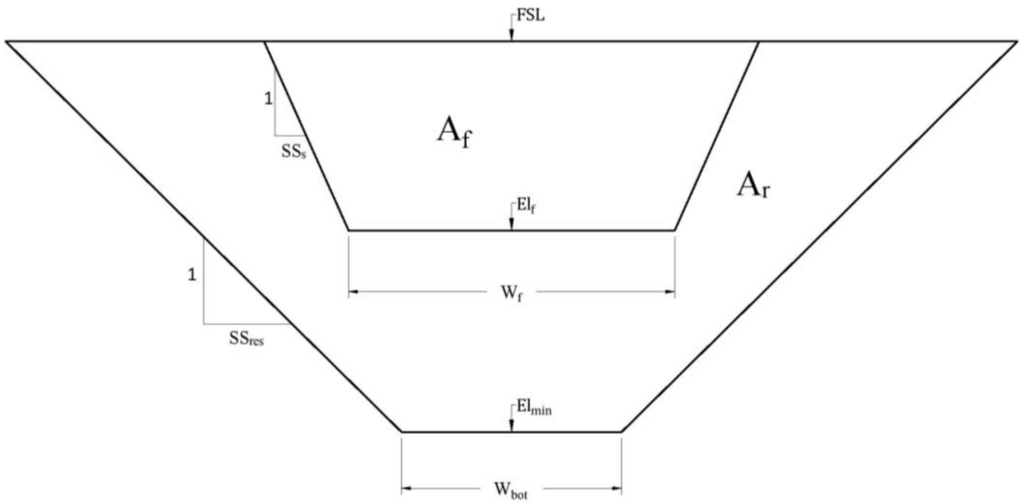


Figure 5: A simplified reservoir geometry and the flushing channel (inner trapezoid) cross section immediately upstream of a dam.

Depending on the combination of different side slopes of the reservoir and the flushing channel, the formation of different cross sectional configurations of the reservoir are possible. For instance, if the flushing channel side slope is steeper than reservoir side slope, then the flushing channel sides will meet the top of the reservoir as shown in Figure 5. The flushing channel side slopes depend on the sediment properties, the degree of consolidation, the depth of deposits and water level fluctuation during flushing (Atkinson 1996). The flushing channel side slope (SS_s) is predicted by using the following simplified equation:

$$SS_s = \frac{10 \times 5}{31.5 \times \rho^{4.7}} \tag{25}$$

Further, the areas of A_r and A_f for the above case are calculated as follows:

$$W_f = 12.8 \times \sqrt{Q_f} \tag{26}$$

$$W_f = Min(W_f, W_{bot}) \tag{27}$$

$$W_{res} = W_{bot} + 2 \times SS_{res} \times (El_f - El_{min}) \tag{28}$$

$$W = Min(W_f, W_{res}) \tag{29}$$

$$W_{tf} = W + 2 \times SS_s \times (FSL - El_f) \tag{30}$$

$$W_l = W_{bot} + 2 \times SS_{res} \times (FSL - El_{min}) \tag{31}$$

$$A_r = 0.5 \times (W_l + W_{bot}) \times (FSL - El_{min}) \tag{32}$$

$$A_f = 0.5 \times (W_{tf} + W) \times (FSL - El_f) \tag{33}$$

Where, Q_f is minimum discharge for flushing (m^3/s), W_f is flushing channel bottom width (m), W_{bot} is representative bottom width of the reservoir (m), SS_{res} is reservoir side slope, El_f is invert level of the bottom outlet (m.a.s.l.), $El_{\mathrm{min}}$is original river bed level immediately upstream from the dam (m.a.s.l.), W_{res} is representative width of the reservoir in the reach upstream from the dam at the flushing water surface elevation (m), W is the representative width of flow for flushing conditions (m), W_{tf} is top width of flushing channel at the top water level (m) and W_l is reservoir width at the top water level (m).

2. Determine the average depth of the settled sediment for every time step (t) of simulation:

$$ressa = \frac{V_o}{FSL - El_{min}} \tag{34}$$

$$D_t = \frac{(Set_t/\rho)}{ressa} \tag{35}$$

Where, V_o is the initial storage capacity of the reservoir at the FSL, and El_{min} is the reservoir bottom level, D_t is average depth of the settled sediment layer (m) and Set_t is settled sediment mass in ton (derived from eq. 17) due to trapping at the time *t*.

3. The routine assumes that sediment deposits uniformly within the reservoir cross section. When the ratio (eq. 36) of the sustainable long-term storage capacity (V_t), which can be maintained due to successful flushing, to the initial storage capacity (V_o) is equal to

its initial LTCR ($i.e. LTCR_o = LTCR_t$), all deposited sediment can be removed by flushing.

$$LTCR_t = \frac{V_o}{V_t} \tag{36}$$

Where, $LTCR_t$ is LTCR at time step *t*, V_t is the sustainable reservoir storage capacity at time step *t* and V_o is the initial storage capacity.

4. If a reservoir has not reached its sustainable storage capacity, the amount of removed sediment is equal to the settled sediment multiplied by the ratio of the flushing channel top width (FCT_t) to the top width of deposited sediment in the reservoir (RST_t) at simulation time step *t* can be given by the equations (see also Figure 6):

$$FCL_{\mathrm{t}} = FCL_{\mathrm{t-1}} + D_t \tag{37}$$

$$FCT_t = Min[W_{tf}, \{W_f + 2 \times SS_s \times (FCL_t - El_f)\}] \tag{38}$$

$$RST_t = Min[W_t, \{W_{bot} + 2 \times SS_{res} \times (FCL_t - El_{min})\}] \tag{39}$$

$$Sed_{flushed} = Sed_t \times \frac{FCT_t}{RST_t} \tag{40}$$

Where, $FCL_{\mathrm{t}}$and $FCL_{\mathrm{t-1}}$are the flushing channel top level at the sediment deposit at the *t* and *t-1* simulation time steps (m.a.s.l.), FCT_t is flushing channel top width at *t*, RST_t is the top width of deposited sediment in the reservoir at *t*, and $Sed_{flushed}$ is sediment removal volume (m^3) at *t*.

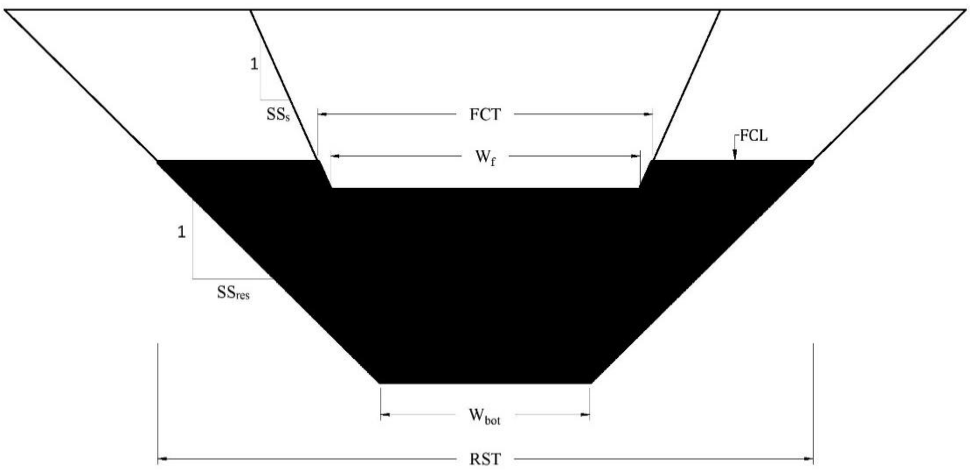


Figure 6: The outer trapezoid is the simplified geometry of a reservoir and the inner trapezoid is the sustainable channel formed by flushing. The shaded area represents deposited sediment in the reservoir up to time period t.

2.2.2 Sluicing Process

Sluicing is the process of passing suspended sediment solids before they settle in reservoirs. In the ResSMan, the drawdown for sluicing initiates either on the user specified initiation date of drawdown or when the criterion of minimum reservoir inflow is met. Thus, the initiation of drawdown depends on which criterion has been specified by the user. Once the drawdown is started, the routine will try to achieve and keep the reservoir water level at target sluicing level releasing water through the low level outlets. However, drawdown on a day should not exceed the user-specified maximum drawdown rate. This criterion is implemented to maintain downstream floods to be lower than peak floods. During the sluicing period, sediment trapping efficiency is estimated by the Churchill Curve. Daily trapping efficiency values are computed using the equations 41 and 42. During reservoir drawdown process, reservoirs are hydrologically smaller than during normal operations. Therefore, the Churchill Curve can approximate more accurately passing of sediments for this condition than the Brune Curve method. Normally, hydropower is generated during sluicing, however a user can specify whether to generate hydropower or not during this time period. Sluicing will end either if the duration of sluicing has been completed or if the reservoir inflow is less than the user-specified minimum reservoir inflow. After the completion of sluicing, the reservoir begins to refill and returns back to its normal operation. But the refilling rate per day is restricted to the user-specified maximum refill rate.

$$SI = \frac{\left({}^{V}/_{I}\right)^2}{L} \tag{41}$$

$$TE = 112 - 800 \times (0.3048 \times SI)^{-0.2} \tag{42}$$

Where, *SI* is Sedimentation Index, *V* is storage capacity of the reservoir (m^3), *I* is average daily inflow in m^3/s, *L* is the length of the reservoir measured from the dam wall to the most upstream impounded water at dam storage capacity (m).

3. MODIFICATION OF THE SWAT SOURCE CODE

The ROSMan is programmed in the Fortran programming language in order to seamlessly integrate the code into the SWAT. To introduce the ROSMan into the official SWAT model version SWAT2012 Rev. 670 (released on the 1st October, 2018), several modifications to the source code were carried out. In the source code files, a comment "!! edited by JPS" has been mentioned wherever the original code lines have been modified; therefore, the code changes can be found by searching for the text "JPS”. However, the ROSMan does not affect the original other simulation processes of the SWAT and if desired a user can still simulate reservoirs using the existing original reservoir simulation methods in the SWAT. The following SWAT source code files have been modified:

i. modparm.f
ii. allocate_parms.f
iii. readfile.f
iv. header.f
v. headout.f
vi. readfig.f
vii. routres.f
viii. res.f
ix. writem.f
x. stdaa.f
xi. std1.f
xii. std2.f
xiii. std3.f
xiv. subaa.f
xv. biofilm.f

xvi. writea.f

xvii. writed.f

xviii. writem.f

xix. pestw.f

xx. print_hyd.f

xxi. rchday.f

xxii. rchaa.f

xxiii. rchmon.f

xxiv. rchyr.f

The following additional subroutines and modules of source code files have been added to simulate with the ROSMan:

3.1 Read_ROSMan.f

This subroutine reads input data from additional input files (described detail in sections below), stores and initializes variables to simulate with the ROSMan.

3.2 ResApp.f

This Fortran module contains several other subroutines and functions which allows for interpolation, simple computation and date conversion. These functions and subroutines are called by the main ROSMan subroutine whenever required for these applications. The ResApp module contains the following functions:

3.2.1 Subroutine Add1DAY

This subroutine is used to add a one day to a given date1 and computes date2 in yyyymmdd format.

3.2.2 Subroutine jtodate

This subroutine converts Julian day (1 to 365/366 days) of a given year (yyyy) into a date in the form of yyyymmdd.

3.2.3 Subroutine to_date

This subroutine converts year (yyyy), month (mm) and day (dd) into a date in the form of yyyymmdd.

3.2.4 Subroutine int_date

This subroutine is opposite to the subroutine to_date, so that it segregates date into year, month and day.

3.2.5 Subroutine xDAYS

To calculate the number of days between two dates, this subroutine is used.

3.2.6 Subroutine rulecurve

This subroutine is used to interpolate daily reservoir water elevation and volume using monthly rule curve and volume-elevation-area curve data provided by the user at specified date (according to given year, month and day) for the given reservoir.

3.2.7 Subroutine interpolate_only

This subroutine gives the interpolated value (y) for the given value (x) from its location array (a) and respective value array (b) using the method of two point formula.

3.2.8 Subroutine read_all_outlet

This subroutine is called whenever it required data of outlet rating curves (spillway, hydropool and low level outlet rating curves). It extracts data from these outlet curves for the specified reservoir.

3.2.9 Subroutine storage_indication

This subroutine is only called by the HydROR routine. This subroutine generates values of the array for the Storage Indication (2*volume/time + outflow) vs outflow curve, combining the outlet capacity curve and Volume-Elevation-Area Curve. This array is used to estimate the outflow of the reservoir using the Modified Puls Method.

3.2.10 Subroutine levelpool

This is the main subroutine is used by the HydROR routine. This subroutine estimates the reservoir outflow using the Modified Puls Method (Level Pool Routing) for the specified reservoir.

3.3 ResSMan.f

This is the main subroutine for simulation with the ResSMan. This routine will be executed for simulation of every reservoir which is specified by the user to simulate with the ResSMan (IRESCO = 7). This routine outputs reservoir storage capacity, water level, water outflow, sediment outflow accumulated sediment and energy generation of the hydropower scheme.

4. INPUT/OUTPUT FILES

4.1 Input files

All the input files are in an ASCII or text file format. The names of input files, their extensions and formats must be the same as described below.

4.2 SWAT reservoir input file (.res)

This is the main input file for reservoir data created by the SWAT model. The user does not need to create this file separately but needs to modify some values of variables. SWAT creates a reservoir input file (.res) for each of the reservoirs assigned within the subbasin (Arnold et al. 2013; Neitsch et al. 2011). The name of this file such as "000020000.res" is given based on the location of the reservoir in the subbasin. The example reservoir is located at the outlet of the subbasin number 2, thus its file name is given as the "000020000.res". To simulate with the ROSMan, first of all, the user must specify "IRESCO" with a number "6" or "7" in the reservoir input file (.res). For simulation with the HydROR, specify IRESCO with 6 and for simulation with the ResSMan, specify IRESCO with 7 (Note: Important) (Figure 7). Then, the user have to assign other variables such as MORES, IYRES, RES_VOL, RES_SED and RES_K according to the original SWAT user manual document. However, the ROSMan ignores all other remaining variables (such as RES_ESA, RES_PVOL etc.) in this file.

```
000020000.res - Notepad
File  Edit  Format  View  Help
Reservoir data:           .res file Subbasin: 2 24/10/2019 12:00:00 AM ArcSWAT 2012.10_4.21
               2    | RES_SUB : Number of the subbasin the reservoir is in
               0    | MORES : Month the reservoir became operational (1-12)
            1980    | IYRES : Year of the simulation the reservoir became operational
               0    | RES_ESA : Reservoir surface area when the reservoir is filled to the  emergency spillway [ha]
             0.0    | RES_EVOL : Volume of water needed to fill the reservoir to the emergency spillway (104 m3)
             0.0    | RES_PSA : Reservoir surface area when the reservoir is filled to the principal spillway [ha]
             0.0    | RES_PVOL : Volume of water needed to fill the reservoir to the principal spillway [104 m3]
             0.0    | RES_VOL : Initial reservoir volume [104 m3]
          4000.0    | RES_SED : Initial sediment concentration in the reservoir [mg/l]
          4000.0    | RES_NSED : Normal sediment concentration in the reservoir [mg/l]
            10.0    | RES_D50 : Median particle diameter of sediment [um]
             0.0    | RES_K : Hydraulic conductivity of the reservoir bottom [mm/hr]
               6    | IRESCO : Outflow simulation code
OFLOWMX: maximum daily outflow for January - June [m3/s]
       0.0       0.0       0.0       0.0       0.0       0.0
OFLOWMX: maximum daily outflow for July - December [m3/s]
       0.0       0.0       0.0       0.0       0.0       0.0
OFLOWMN: minimum daily outflow for January - June [m3/s]
       0.0       0.0       0.0       0.0       0.0       0.0
OFLOWMN: minimum daily outflow for July - December [m3/s]
       0.0       0.0       0.0       0.0       0.0       0.0
             0.0    | RES_RR : Average daily principal spillway release rate [m3/s]
                    | RESMONO : Name of monthly reservoir outflow file
```

Figure 7: An example of a SWAT reservoir input file (.res)

4.3 Hydroplant characteristics file (hydroplant.hpl)

The hydroplant characteristics input file “hydroplant.hpl” is the main input file which stores the properties of hydropower plants and reservoirs in the catchment. The name of this file must be the same as described above with extension of “.hpl” in the text file format. Each row of this file corresponds to the reservoir assigned in the SWAT model at the time of catchment delineation. In this file, the user have to include all the assigned reservoirs in the study catchment, even the reservoir is not used for simulation. As shown in Figure 8, for the ResSub 15 is not used for simulation, thus the most of properties can be filled with 0 and assigned the “SimRes” column with 0.

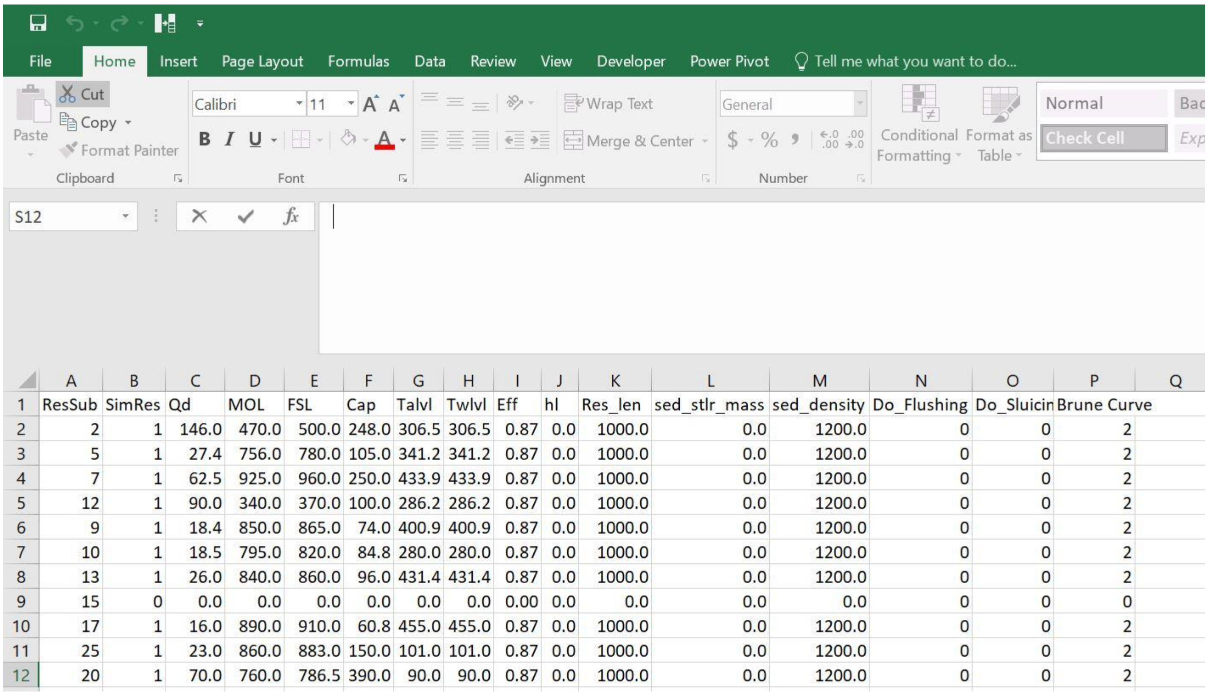
The first line of the file is used for a header or user comments. From 2nd line, it contains 16 columns with data values and each column is spaced by a single tab. The format of the file should match as described and shown in figures here, any distortions in file format may cause errors in simulation. To easily prepare input files, one can store all the data in Excel (Figure 9) and then paste into the text file (Figure 8).

hydroplant.hpl - Notepad

File Edit Format View Help

ResSub	SimRes	Qd	MOL	FSL	Cap	Talvl	Twlvl	Eff	hl	Res_len	sed_stlr_mass	sed_density	Do_Flushing	Do_Sluicing	Brune Curve
2	1	146.0	470.0	500.0	248.0	306.5	306.5	0.87	0.0	1000.0	0.0	1200.0	0	0	2
5	1	27.4	756.0	780.0	105.0	341.2	341.2	0.87	0.0	1000.0	0.0	1200.0	0	0	2
7	1	62.5	925.0	960.0	250.0	433.9	433.9	0.87	0.0	1000.0	0.0	1200.0	0	0	2
12	1	90.0	340.0	370.0	100.0	286.2	286.2	0.87	0.0	1000.0	0.0	1200.0	0	0	2
9	1	18.4	850.0	865.0	74.0	400.9	400.9	0.87	0.0	1000.0	0.0	1200.0	0	0	2
10	1	18.5	795.0	820.0	84.8	280.0	280.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2
13	1	26.0	840.0	860.0	96.0	431.4	431.4	0.87	0.0	1000.0	0.0	1200.0	0	0	2
15	0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0	0	0
17	1	16.0	890.0	910.0	60.8	455.0	455.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2
25	1	23.0	860.0	883.0	150.0	101.0	101.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2
20	1	70.0	760.0	786.5	390.0	90.0	90.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2

Figure 8: An example file of hydroplant.hpl



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	ResSub	SimRes	Qd	MOL	FSL	Cap	Talvl	Twlvl	Eff	hl	Res_len	sed_stlr_mass	sed_density	Do_Flushing	Do_Sluicin	Brune Curve
2	2	1	146.0	470.0	500.0	248.0	306.5	306.5	0.87	0.0	1000.0	0.0	1200.0	0	0	2
3	5	1	27.4	756.0	780.0	105.0	341.2	341.2	0.87	0.0	1000.0	0.0	1200.0	0	0	2
4	7	1	62.5	925.0	960.0	250.0	433.9	433.9	0.87	0.0	1000.0	0.0	1200.0	0	0	2
5	12	1	90.0	340.0	370.0	100.0	286.2	286.2	0.87	0.0	1000.0	0.0	1200.0	0	0	2
6	9	1	18.4	850.0	865.0	74.0	400.9	400.9	0.87	0.0	1000.0	0.0	1200.0	0	0	2
7	10	1	18.5	795.0	820.0	84.8	280.0	280.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2
8	13	1	26.0	840.0	860.0	96.0	431.4	431.4	0.87	0.0	1000.0	0.0	1200.0	0	0	2
9	15	0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0	0	0
10	17	1	16.0	890.0	910.0	60.8	455.0	455.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2
11	25	1	23.0	860.0	883.0	150.0	101.0	101.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2
12	20	1	70.0	760.0	786.5	390.0	90.0	90.0	0.87	0.0	1000.0	0.0	1200.0	0	0	2

Figure 9: Hydropower plant characteristics stored in MS-Excel file

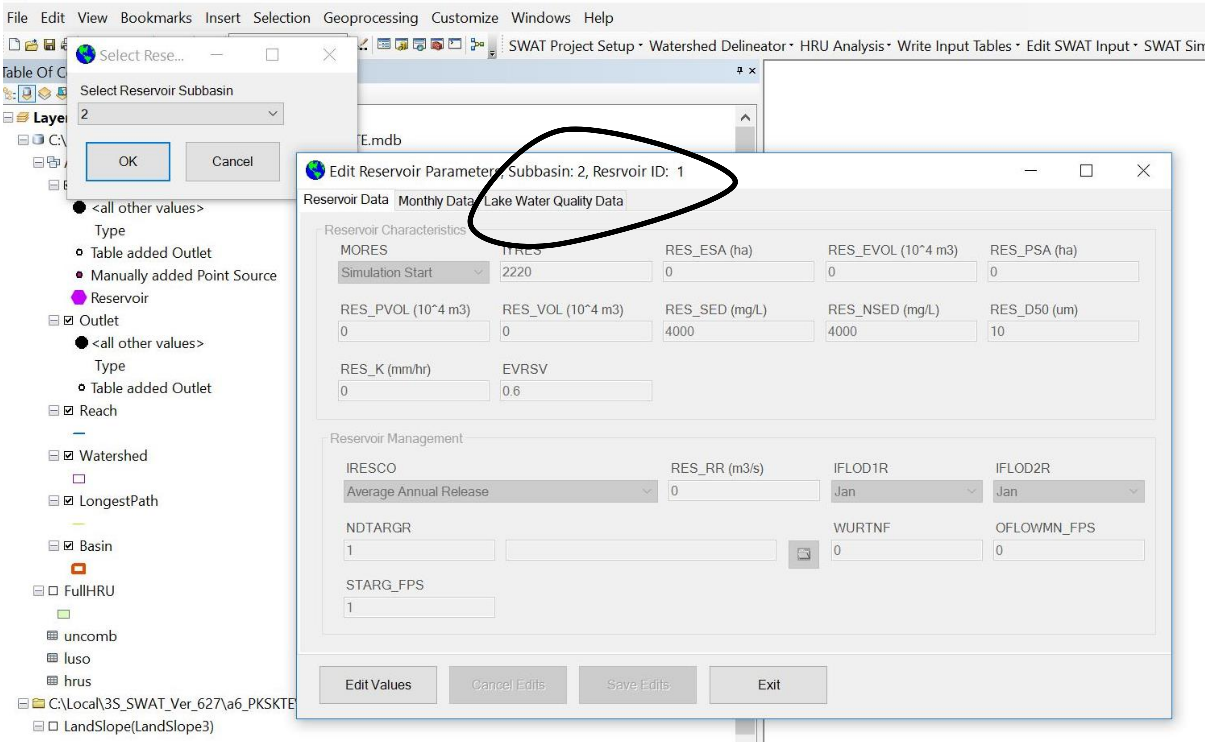


Figure 10: Reservoir ID determination using ArcSWAT

4.3.1 Reservoir subbasin number (integer)

The first column of ".hpl" file stores the subbasin number (integer) of the reservoir. The subbasin number stored in each row must be identical to the subbasin as defined in the ".res" reservoir input file. Again, the sequence of each reservoir must be according to the Reservoir

ID (Figure 10), because the SWAT simulate the reservoir in the order of this unique ID. The Reservoir ID (Figure 10) can be found from ArcSWAT model setup as shown in Figure 10. In the given example, the reservoir ID with 1 is located in the subbasin number 2 and thus it is stored in the 1st row of the data. The simulation sequence of reservoirs is very critical information.

4.3.2 Simulate reservoir or not (integer)

The user must enter 1 in the 2nd column if the specific reservoir is simulating. If the user has specified 0 for any reservoirs, then these reservoirs will not be simulated and any values of other columns will not be used for any purposes and respective other files also will not be read.

4.3.3 Design discharge (m^3/s)

The 3rd column of this file is the design discharge in m^3/s of corresponding hydropower plant of the reservoir. The user must provide this data in the real format, if the information is not known then must leave with 0.0.

4.3.4 Minimum operating level (m.a.s.l.)

This column represents the minimum operating water level (MOL) in meter above sea level (m.a.s.l.) of the active storage of the reservoir. The ResSMan uses this level to compute the dead and active storage volume of the reservoir. The model assumes that dead storage and active storage volume is separated by this level and dead storage is below this level. The dead storage zone is only used for storing settled sediment mass and the storage capacity within this zone cannot be used for hydropower generation.

4.3.5 Full Supply level (m.a.s.l.)

The 5th column of this file stores the information of the full supply level (FSL) of the reservoir. The FSL represents the upper limit of the active storage volume of the reservoir and used to compute the dead and active storage volume of the reservoir (Figure 3). The active storage volume fluctuates between FSL and MOL and specifically used for hydropower generation.

4.3.6 Installed capacity (MW)

This column represents the installed capacity (MW) of the hydropower plant for each reservoir. This is the maximum capacity that the hydropower plant can produce at simulation period. If the reservoir has not facility to generate hydropower, then the user must assign to 0.

4.3.7 Turbine axis level (m.a.s.l.) and Tailwater level (m.a.s.l.)

The information in 7th and 8th column is stored with turbine axis level and Tailwater level of the hydropower plant. These data are used to compute the head of hydropower plant to estimate the power production. The model assumes constant Tailwater level during the simulation period. The user must provide these information. If one of these information is not known, then can be assigned as equal values but assigning 0.0 will effect on computation of hydropower production.

4.3.8 Hydropower Plant efficiency (factor)

The 9th column specifies the combined efficiency of the hydropower plant in the form of a factor. This efficiency is combination of turbines and generators and assumes to be constant during simulation period.

4.3.9 Headloss coefficient (factor)

In this column, specify headloss coefficient (fraction) of the hydropower plant. This headloss coefficient includes all possible losses such as frictional loss, entry loss and exit loss of hydropower plant and assumes constant during simulation period. If user assigns this column with 0.0, then model ignores headloss.

4.3.10 Reservoir Length (m)

This column represents the reservoir length at the FSL. This input is used only to simulate with the sluicing technique. During sluicing, the ResSMan computes reservoir trapping efficiency using the Churchill Method (1948). Thus, reservoir length is required to compute the Sedimentation Index (SI), ultimately this index is used to estimate trapping efficiency. If the user is not simulating with sluicing, then this value can be assigned with 0.0.

4.3.11 Initial settled sediment mass (Ton)

The 12th column represents the amount of sediment mass in metric tonne (Ton) deposited in the bottom of the reservoir at the beginning of the simulation period. This value accounts only quantity of deposit sediment and can be assigned as 0.0, if the initial reservoir volume is 0. The initial suspended sediment concentration (mg/l) is assigned in .res file which is represented as RES_SED. The sediment outflow depends on the concentration of suspended sediment at the beginning of the simulation. If the initial volume of reservoir is zero then, it can be assigned as 0.0. The variable RES_NSED (mg/l) is the equilibrium sediment concentration in the reservoir which is required to simulate with existing SWAT reservoir routine. The SWAT assumes that suspended sediment will be settled when the concentration of suspend sediment exceeds this value. However, the ResSMan predicts the settle sediment implementing the Brune Curve method. Hence, whatever value assigned for the RES_NSED, the ResSMan will not use this value for any calculations.

4.3.12 Sediment density (kg/m^3)

The 13th column represents the density of sediment in kg/m^3. The volume of settled sediment mass is calculated using this value. This value must provide if the particular reservoir is simulated with the ResSMan.

4.3.13 Simulate with flushing or not (integer)

The 14th column is used to specify whether the reservoir is simulating with flushing or not. The value of this column must be “1” or “0”. If the specific reservoir is simulating with the flushing technique, then the user must assign 1, if not then the user must assign 0.

4.3.14 Simulate with sluicing or not (integer)

Same as column 15th, if the specific reservoir is simulating with the sluicing technique, then the user must assign 1, if not then the user must assign 0.

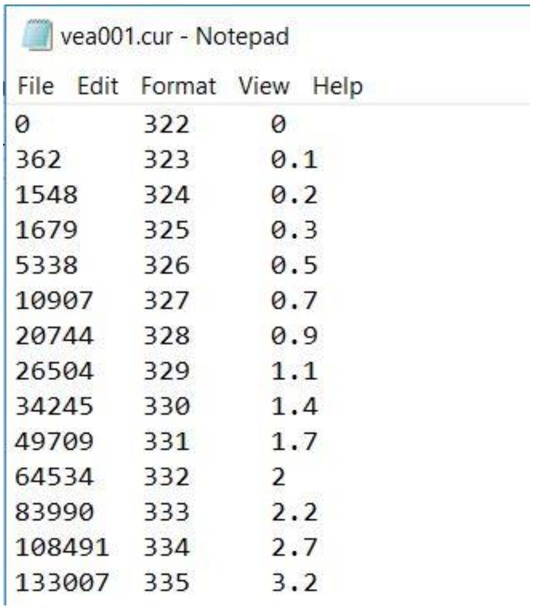
4.3.15 Brune Curve Type (integer)

In the ResSMan, the sediment trapping efficiency is calculated by Brune Curve method. Brune (1953) developed a trapping efficiency curve as related to reservoir capacity-inflow ratio by using data of 40 normally ponded reservoirs and 4 other types of reservoirs in the USA. Brune has classified these curves into three category: 1) lower trapping efficiency curve for fine grained sediment; 2) original median trap curve for median grained sediment and 3) higher trapping efficiency curve for coarse sediment. In this column, the user can specify one of these curves assigning 1 for lower curve, 2 for median curve and 3 for higher curve.

4.4 Volume-elevation-area curve (.cur) file

The ".cur" file contains volume (m^3), elevation (m.a.s.l.) and surface area (ha) of a reservoir (Figure 11). The data start from from 1st line of the file without any headers and comments. The 1st row of volume and surface area data should be 0 and its respective elevation. This file should be created for each of the reservoirs which will be simulated with the ROSMan (both HydROR and ResSMan). The name of file should be in "vea001.cur", "vea002.cur", "vea015.cur". Where, the corresponding file of reservoir ID 1 is vea001.cur, corresponding file of reservoir ID 2 is vea002.cur and corresponding file of reservoir ID 15 is vea015.cur respectively. The naming order of other input files must be also in the same order as described here.

The volume-elevation-area curve of the reservoir can be obtained from the topographic map of the reservoir. This curve is used to estimate active and dead storage volume, water surface level and surface area. The hydropower production capacity and accumulation of sediment on the bottom of reservoir depend on the active and dead storage volume. The water surface elevation is used to calculate the head of the hydropower plant, while the surface area is used to estimate the amount of precipitation and evaporation on and from the reservoir surface area respectively.


vea001.cur - Notepad

File Edit Format View Help

0	322	0
362	323	0.1
1548	324	0.2
1679	325	0.3
5338	326	0.5
10907	327	0.7
20744	328	0.9
26504	329	1.1
34245	330	1.4
49709	331	1.7
64534	332	2
83990	333	2.2
108491	334	2.7
133007	335	3.2

Figure 11: An example of volume-elevation-area curve (.cur) file

4.5 Rule curve (.rul) file

Reservoir operation is accomplished by a predefined rule curve in the ROSMan. The rule curves can be generated on the basis of maximum hydropower production, flood control, and environmental criteria such as water quality for fish and wildlife preservation, and downstream flow regulation.

The ".rul" file of 1st column contains month number (integer) and 2nd column contains water surface elevation (m.a.s.l.) corresponding to the 1st day of respective month (Figure 12). The data start from 1st line of the file without any headers and comments. The names of files should be as rulecurve001.rul, rulecurve002.rul…………..in the order of reservoirs as in the hydroplant.hpl file. Using this monthly rule curve, the ROSMan interpolates water elevation and storage volume for each day of simulation.

```
rulecurve001.rul - Notepad
File  Edit  Format  View  Help
1       492.1
2       488.4
3       484.1
4       479.7
5       474.9
6       470
7       474.9
8       481.5
9       487.4
10      493.1
11      498.1
12      496.1
```

Figure 12: An example of rule curve (.rul) file

4.6 Spillway rating curve (.out) file

The file names for spillway rating curves should be as spillway001.out, spillway002.out…………..in the order of reservoirs as in the hydroplant.hpl file. This file contains water surface level (m.a.s.l.) in the 1st column and respective discharge capacity in m^3/s in the 2nd column (Figure 13).

The spillway outlet is used to spill the excess volume of water when the water level is higher than the active storage level of the reservoir. It is assumed that the spillway crest level is located at the top of the active storage level. Thus, this outlet does not allow for hydropower generation. Hence, this outlet is used to release excess flood storage water. However, even if the water surface level of the reservoir is higher that the active storage level, the spillway does not release any water until the rule curve for the reservoir dictates a release is required.

spillway001.out - Notepad

File Edit Format View Help

```
500.0   0.0
508.5   3700.0
```

Figure 13: An example file of spillway rating curve (.out)

4.7 Hydroplant pool curve (.out) file

Water discharge capacity of a hydropower intake with respect to water elevation is provided by this hydroplant pool curve. Discharge through the hydropower intake is solely used to generate hydropower energy and is discharged to immediate downstream channel of the basin after passing through turbines.

The file names for hydroplant pool curves should be as hydropool001.out, hydropool 002.out………….in the order of reservoirs as in the hydroplant.hpl file. This file contains water surface level (m.a.s.l.) in the 1st column and respective discharge capacity in m^3/s in the 2nd column (Figure 14). The water elevation at the first line should be minimum operating level (MOL) and water level at the last line should be full supply level (FSL) and their respective discharge capacities.

hydropool001.out - Notepad

File Edit Format View Help

```
470     0
476     65.3
482     92.3
488     113.1
494     130.6
500     146
```

Figure 14: An example of hydroplant pool curve (.out) file

4.8 Flushing gate rating curve (.out) file

Flushing gate or low level outlet gates are located at the bottom of the dam. This flushing gates are used to release water and sediment into the downstream channel for during simulation with flushing and sluicing management techniques and discharge through these gates do not result hydropower generation. It is assumed that these gates are only operable during flushing and sluicing and remain closed at normal condition operation.

The file names for flushing gate rating curves should be as flushoutlet001.out, flushoutlet 002.out…………..in the order of reservoirs as in the hydroplant.hpl file. This file contains water surface level (m.a.s.l.) in the 1st column and respective discharge capacity of gates in m^3/s in the 2nd column (Figure 15). The water elevation at the first line should be original river bed elevation (i.e. the first elevation of ".cur" file).

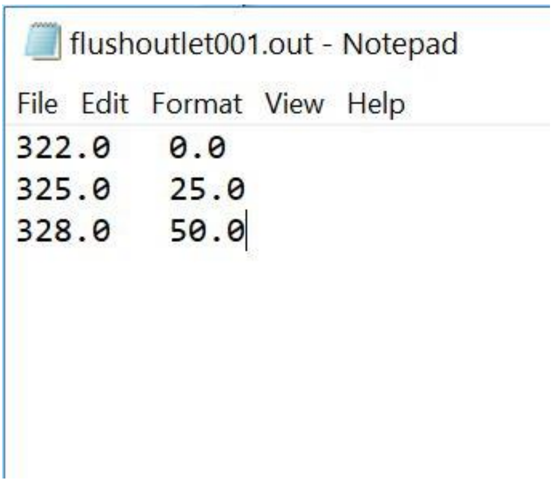


Figure 15: An example of flushing gate outlet rating curve (.out) file

4.9 Flushing specification data (.smn) file

This file is needed to simulate the reservoir with flushing sediment management technique. When the user has assigned 1 for "Simulate with flushing or not (integer)" in the ".hpl" file, this file must be provided for each of the reservoirs. The file names should be as flushingdata001.smn, flushingdata002.smn …………..in the order of reservoirs as in the hydroplant.hpl file. The first line of the file is specified for the header or comments and data begins from the 2nd line of the file. The data should be entered in the order as described below and columns should be delaminated by tabs.

```
flushingdata001.smn - Notepad
File  Edit  Format  View  Help
date      fdays     maxfl     minflq    W_f       SS_s      mxddr     minresfli           W_bot     SS_res    inver_evel
19800601            6.0       493.0     42.0      0.0       0.0       2.0       0.0       61.0      1.0       455.0
19810601            6.0       493.0     42.0      0.0       0.0       2.0       0.0       61.0      1.0       455.0
19820601            6.0       493.0     42.0      0.0       0.0       2.0       0.0       61.0      1.0       455.0
19830601            6.0       493.0     42.0      0.0       0.0       2.0       0.0       61.0      1.0       455.0
19840601            6.0       493.0     42.0      0.0       0.0       2.0       0.0       61.0      1.0       455.0
19850601            6.0       493.0     42.0      0.0       0.0       2.0       0.0       61.0      1.0       455.0
```

Figure 16: An example of flushing specification data (.smn) file

4.9.1 Drawdown start date (yyyymmdd)

The first column of this file is the drawdown start date in yyyymmdd format. Drawdown will be started at this date when the inflow rate criterion (defined in the 3rd column) is satisfied. If the flushing is simulated more than once during the overall SWAT simulation period, then the user must provide each data line with all required parameters for each drawdown start date (Figure 16).

4.9.2 Flushing duration (days)

The 2nd column is number of days required to remove deposit sediment due to flushing after flushing criteria have met. This duration does not include drawdown duration.

4.9.3 Maximum water level (m.a.s.l.)

The 3rd column of this file is maximum water level (m.a.s.l.) of the reservoir. When reservoir water level is higher than this level, the reservoir will not be able remove sediment due to flushing. To achieve successful flushing, this criterion should be met. The user must provide this information.

4.9.4 Minimum flushing discharge (m^3/s)

The 4th column in the flushing data file is the minimum flushing discharge through the flushing gates. When the water release through the flushing gates is greater than the required minimum flushing discharge, the deposit sediment will be removed successfully due to flushing process. After the complete drawdown of the reservoir, the outflow through the flushing gates equals about to the runoff of the river and it depends on hydrological condition of the catchment and time of operation of the flushing. Thus, the model user can define the required minimum flushing flow analyzing the historical hydrological data of the river flow.

4.9.5 Flushing channel bottom width (m)

The 5th column of this file is bottom width (m) of the flushing channel. The ResSMan assumes that trapezoidal flushing channel will be formed during the flushing process. The cross sectional area of flushing channel is used to estimate quantity of sediment removal by flushing process. If the user assigned this column with 0.0, then the model will estimate by itself as described in the section 2 (Atkinson 1996).

4.9.6 Flushing channel side slope (factor)

The user should enter side slope (m/m, vertical/horizontal) of the flushing channel in the 6th column of this file. The user can allow to determine the flushing channel side slope by entering 0.0 for this variable as described in the section 2.

4.9.7 Maximum drawdown rate (m)

The 7th column of this file is maximum drawdown rate (m). This criterion controls the rapid drawdown of water level and thus controls downstream flash floods.

4.9.8 Minimum flow to initiate drawdown (m^3/s)

The 8th column of the file is the minimum flow into the reservoir which controls the drawdown start date. The user must enter the drawdown start date at 1st column. The ResSMan checks inflow to the reservoir on and after specified drawdown start date, but drawdown will actually initiate after the reservoir inflow exceeds this value. If the user wants to initiate drawdown at exact specified date in the 1st column, then the user should enter this column with 0.

4.9.9 Representative reservoir bottom width (m)

In the 9th column of this file, the user should provide the representative reservoir bottom width. This value is used to compute the cross sectional area of the reservoir. This value can be assumed the bottom length of the dam. This value should be constant for the reservoir and so should enter same value for different dates of flushing.

4.9.10 Reservoir side slope (factor)

The user should enter side slope (m/m, vertical/horizontal) of the reservoir side banks in the 10th column of this file. This value is also constant for the reservoir and so should be entered the same value for different dates of flushing. This value is also used to estimate cross sectional area of the reservoir during flushing process.

4.9.11 Flush gate invert level (m.a.s.l.)

The 10th column of this input file is the invert level of the flush gate or low level outlet. The user must provide this elevation. This value must be equal to the first elevation value of the flushoutlet.out file.

4.10 Sluicing specification data (.smn) file

This file is needed to simulate the reservoir with sluicing sediment management technique. When the user has assigned 1 for "Simulate with sluicing or not (integer)" in the ".hpl" file, this file must be provided for each of the reservoirs. The file names should be as sluicingdata001.smn, sluicingdata 002.smn …………..in the order of reservoirs as in the hydroplant.hpl file. The first line of the file is specified for the header or comments and data begins from the 2nd line of the file. The data should be entered in the order as described below and columns should be delaminated by tabs (Figure 17).

```
sluicingdata001.smn - Notepad
File  Edit  Format  View  Help
start_date      duration        slminflq        slminfli        slmaxlvl        slmxddr mxrefil slpower
20200601        20      37.6    37.6    520     2       0.5     1
20210601        20      37.6    37.6    520     2       0.5     1
20220601        20      37.6    37.6    520     2       0.5     1
```

Figure 17: An example of sluicing specification data (.smn) file

4.10.1 Sluicing start date (yyyymmdd)

The 1st column of the sluicing specification data (.smn) file is the starting date of the sluicing for the specified year. This column can be filled with 0, if the user wish to start sluicing after meeting the criteria of 3rd column.

4.10.2 Sluicing duration (days)

The 2nd column is the duration of sluicing in days. The sluicing will continue for this duration period after the starting date of the sluicing and then simulation will continue according to the defined rule curve. This value can be assigned with 0, if the user wishes to stop the sluicing after meeting the 4th column criterion.

4.10.3 Minimum flow into reservoir to start sluicing (m^3/s)

The 3rd column of this file is an optional and can be filled with 0.0. If sluicing starting date is not specified, the ResSMan will start sluicing when the reservoir inflow is greater than this value and sluicing will be delayed until this criterion is fulfil.

4.10.4 Minimum flow into reservoir to stop sluicing (m^3/s)

The value on the 4th column is also an option if the user has assigned the sluicing start date and duration. If 1st and 2nd column values are 0, then this column must be enter with proper value. The sluicing will be stopped when the reservoir inflow is lower than this value. The sluicing will be continue until this criterion has met.

4.10.5 Drawdown water surface elevation limit (m.a.s.l.)

In this column, the user must provide the water surface elevation of the reservoir. The ResMan attempts to maintain the water level at this limit by releasing the water and sediment through flushing gates. The value of this limit could be assign nearly equal to MOL.

4.10.6 Maximum drawdown rate (m)

The 6th column of this file is the maximum drawdown rate of the reservoir. This value controls the abrupt drop in water surface level.

4.10.7 Maximum refill rate (m)

In this column, the user should specify the maximum rate of refilling per day the reservoir after the sluicing process.

4.10.8 Hydropower production during sluicing (integer)

In this column, the user should specify with value 1, if hydropower generation is allowed during sluicing or specify with value 0, if hydropower generation is not allowed during sluicing.

4.11 Summary of input files

Table 1: Input files and variables required for simulation with the ROSMan routine

File/variable	HydROR	ResSMan	Remarks
IRESCO (.res file)	6	7	Must provide
hydroplant.hpl	Applicable columns (1-10)	All columns applicable	Not applicable columns can be assigned with 0.
vea.cur	Applicable	Applicable	Must provide
rulecurve.rul	Applicable	Applicable	Must provide
spillway.out	Applicable	Applicable	Must provide
hydropool.out	Applicable	Applicable	Must provide
flushoutlet.out	Not applicable	Applicable	Must provide
flushingdata.smn	Not applicable	Applicable	Optional
sluicingdata.smn	Not applicable	Applicable	Optional

4.12 Output file

In addition to all other output files of the SWAT, there is a one separate output file for ROSMan routine, called output_rosman.rsv. This file contains the reservoir ID number (not the subbasin number), Julian day of simulation period, reservoir volume in m^3, water elevation (m.a.s.l.), reservoir inflow (m^3/s), outflow (m^3/s), precipitation (m^3), evaporation (m^3), seepage (m^3), power (MW), energy generation (GWh), sediment inflow (ton), sediment outflow (ton), sediment concentration (ppm), trapping efficiency (factor), accumulated sediment (ton) (N/A for the HydROR) and simulation year.

output_rosman.rsv - Notepad

File Edit Format View Help

	RES	MON	VOLUMEm3	Elev_masl	FLOW_INcms	FLOW_OUTcms	PRECIPm3	EVAPm3	SEEPAGEm3	Power_MW	Energy_GWh	SED_INtons	SED_OUTtons	SED_CONCppm	TrapEff	SedMass_to	
RES	1	1	0.6066E+09	0.4218E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.4696E+05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.4000E+04	0.0000E+00	0.0000E+00	1
RES	2	1	0.0000E+00	0.7000E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	3	1	0.0000E+00	0.8750E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	4	1	0.0000E+00	0.2790E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	5	1	0.0000E+00	0.7780E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	6	1	0.0000E+00	0.7600E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	7	1	0.0000E+00	0.7920E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	9	1	0.0000E+00	0.8770E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	10	1	0.0000E+00	0.8000E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	11	1	0.0000E+00	0.7180E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	12	1	0.0000E+00	0.5100E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	13	1	0.0000E+00	0.1140E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	14	1	0.0000E+00	0.1118E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	15	1	0.0000E+00	0.4880E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	16	1	0.0000E+00	0.2350E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	17	1	0.0000E+00	0.4400E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	18	1	0.0000E+00	0.2600E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	21	1	0.0000E+00	0.5260E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	22	1	0.0000E+00	0.4260E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	23	1	0.0000E+00	0.7500E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	24	1	0.0000E+00	0.2690E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	25	1	0.0000E+00	0.1200E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	26	1	0.0000E+00	0.1073E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1
RES	27	1	0.0000E+00	0.1350E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1

Figure 18: The output file for the ROSMan

5. QUICK START GUIDE

This guide briefly explains the steps that are obligatory to run the ROSMan. Regarding the preparation of input data to the routine, the user must strictly follow the previous sections.

5.1 SWAT model setup

Before simulation with the ROSMan, a SWAT model for the study area needs to be set up. The detailed process and theory on the SWAT are explained in SWAT I/O manual (Arnold et al. 2013) and SWAT Theoretical Documentation (Neitsch et al. 2011).

5.2 Simulation with the ROSMan

The user must load all the required input files for the ROSMan, as described above, in the SWAT "TxtInOut" folder. Furthermore, an executable file of the ROSMan (ROSMan.exe) also must be placed in the "TxtInOut" folder. Finally, the simulation can be run by clicking the ROSMan.exe file.

5.3 Post-processing of the outputs

After completion of the simulation, the outputs of the ROSMan will be printed in the "output_rosman.rsv" file as explained in the previous section. The user can export the output file into the MS-Excel to plot graphs and to further analyse the results or can use any other data processing tools. The user must evaluate the outputs of the ROSMan whether the outputs are reasonable or not. The performance of the ROSMan solely depend on user defined physical properties of hydropower plants, outlet capacities, reservoir geometry and operation policies such as rule curves. Thus, the user must provide accurate and realistic input data to obtain reasonable results.

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