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Basin-scale impacts of hydropower development on the Mompós Depression wetlands, Colombia

Héctor Angarita et al.

Correspondence to: Héctor Angarita (hangarita@javeriana.edu.co)

SI-1. SUPPLEMENTARY INFORMATION

ReservoirSimulator model description

The ReservoirSimulator allows simulation of the water balance of a group of reservoirs, based on individual or system-level dispatch rules for three main categories of use: downstream instream requirements, hydropower, and other supply (supply that bypasses turbines).

For a given reservoir, the model takes into account physical and technical constraints, such as the volume–elevation curve, tail-water elevation, operational levels (inactive, buffer, technical, and safety), turbine type, capacity, and efficiency. It allows modeling of the topology of reservoirs and tributary sub-basins.

ReservoirSimulator performs a lumped, discrete-time water balance of the components shown in Figure SI-1 with the model parameters and inputs shown in Table SI-1.

For each reservoir, calculations are done according to the sequence in Table SI-2:

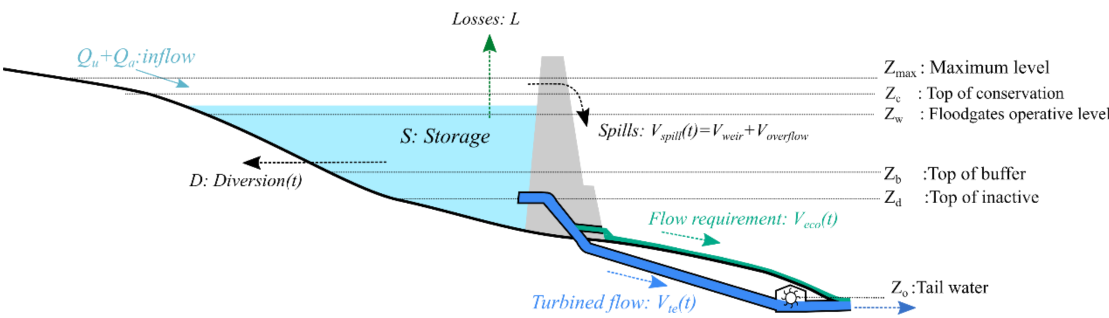

Figure SI-1. Schematic of reservoir inflow, outflow and storage components of the reservoir simulator model.

Table SI-1. Description of reservoir data requirements of the model

Symbol	Reservoir physical and technical data	Units
$Q_a(t)$	Specific runoff: Runoff from upstream sub-watershed during step *t* (excludes outflows from upstream infrastructure)	m^3/s
Δt	Time step	s
V_c	Reservoir storage capacity at top of conservation level (Z_c)	m^3
V_{buffer}	Reservoir storage capacity at buffer level (Z_b)	m^3
V_{min}	Reservoir storage capacity at top of inactive level (Z_d)	m^3
V_{w0}	Reservoir storage capacity at floodgates operative level (Z_w)	
H(V)	Volume-elevation curve of reservoir	masl
A(V)	Area-elevation curve of reservoir	masl
B_c	Buffer coefficient: fraction of buffer storage that can be allocated in a given time step *Note: Can be a user defined function of local (i.e. reservoir storage, etc.) or system-level state variables or context variables (i.e. downstream storage, etc.).*	%
B_w	Floodgates allocation factor: determines the fraction of storage above the floodgates operational level delivered downstream in a given time step. *Note: Can be a user defined function of local (i.e. reservoir storage, etc) or system-level state variables or context variables (i.e. downstream storage, etc.).*	
ET(t)	Evaporation rate in a time step *t*	mm
Z_0	Tail water elevation (water level at the point where turbine flow is discharged)	masl
D(t)	Water demand diverted from the reservoir, bypassing the turbines, with higher priority than hydropower	m^3
$V_{eco,1}(t)$	Average instream flow requirement at step *t*, for the reach between reservoir and turbines discharge	m^3
P	Installed generation capacity	Mw
f	Friction loss factor in hydropower load pipes.	m
N	Number of turbines	
E(H,Q)	Turbine efficiency curve, as a function of net head and flow (typically a function of turbine type i.e. Francis, Pelton, etc.)	%
e_{target}	Minimum efficiency threshold of turbines. Hydropower won't be generated if actual efficiency is lower than e_{target}	%
Q_w	Floodgates max hydraulic capacity	m^3/s
Reservoir topological data		
K_T	Identifier of the project downstream of turbine flow discharge	
K_E	Identifier of the project downstream of e-flow discharge	
K_s	Identifier of the project downstream of spills discharge	
R	Position of the reservoir in the simulation sequence (1^{st}, 2^{nd}, …)	

Table SI-2. Sequence of calculations performed by the reservoir simulator model at a given time-step

Value	Description	Calculation	Units
$Q_u(t)$	Sum of upstream outflows (turbine, e-flows and/or spills) directed to the reservoir		$[m^3/s]$
S_t	Reservoir storage at the beginning of step t		$[m^3]$
A_t	Area of reservoir at the beginning of step t, calculated from area volume curve	$A(S_t)$	$[m^2]$
L	Reservoir losses as evaporation	$A_t * ET$	$[m^3]$
Va_t	Total available water for allocation without restrictions at the reservoir, during step t	$\max\left(0, S_t + (Q_a(t) + Q_u(t)) * \Delta t - L(t) - V_{buffer}\right)$	$[m^3]$
Vr_t	Total available water for allocation, from the buffer zone, during step t	$(V_{buffer} - V_{min}) * B_c$: if $Va_t > 0$ $(S_t + Q_a(t) * \Delta t - L(t) - V_{min}) * B_c$: if $Va_t = 0$	
Vu_t	Total available water for allocation during step t	$Vr_t + Va_t$	
Z_t	Reservoir water level at the beginning of step t, calculated from volume elevation curve	$Z(S_t)$	masl
ΔZ_t	Working water head at step t.	$Z_t - Z_0$	[m]
H_f	Friction losses	$\Delta Z_t * f$	[m]
RPE	Expected generation at step t, expressed as a percentage of installed capacity.	User defined function of local (i.e. reservoir storage at previous timestep, instream flow requirement downstream of turbines, etc) or system-level state variables or context variables (i.e. system level demand, ENSO signal, etc.). See paper Figure 3	[%]
V_{pt}	Release requirement, to fulfill 100% of expected energy generation at step t, operating at target efficiency	$RPE * P * 1e6 / (9801 * (\Delta Z_t - H_f) * e_{target}) * \Delta t$	$[m^3]$
Vd_t	Total water available during step t, after the allocation of demands with higher priorities than hydropower	$\max(0, Vu_t - D_t - V_{eco,1})$	$[m^3]$
V_{te}	Effective turbined volume during step t	$\min(V_{pt}, Vd_t t)$	$[m^3]$
Q_{te}	Effective turbined flow during step t	$V_{te}/\Delta t$	$[m^3/s]$
Vs_t	Water available after hydropower is allocated.	$Vd_t - Vt_e$	$[m^3]$
V_w	Controlled spill volume (floodgates operation)	$V_w = \min\left(R_w^{1/B_w}, Q_w * \Delta t\right)$ with: $R_w = \max(0, Vs_t - V_{w0})$: Volume above the floodgates operational level	$[m^3]$
Vs_w	Water available after controlled spill is allocated.	$Vs_t - V_w$	$[m^3]$
V_{spill_t}	Total spill during step t	$\max(0, Vs_w - Vc)$	$[m^3]$

Value	Description	Calculation	Units
P_n	Net power output if available flow is turbined given $H_{n,t}$, using n turbines.	$\gamma * \frac{Q_{te}}{n} * H_{n,t} * e_{t,n}$	[Mw]
$e_{t,n}$	Actual Turbine/Generator efficiency given $(\Delta Z_t - H_f)$ and flow = $\frac{Q_{te}}{n}$. See example in Figure SI-2. If efficiency is lower than a target efficiency, is adopted as 0.	e_n $0 \quad \text{if } e_n < e_{target}$	%
P_t	Average power output during step t	$\max(P_1, 2 * P_2, \ldots N * P_N)$	[Mw]
S_{t+1}	Reservoir storage at the beginning of step t+1	$Vs_t - V_{spill_t}$	m^3

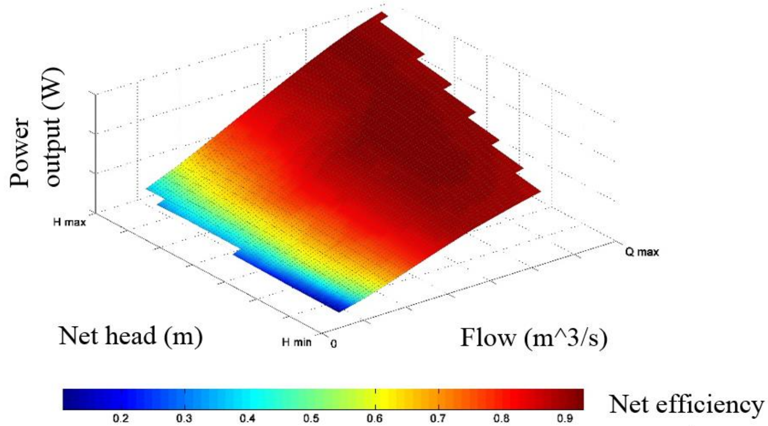

Figure SI-2. Example of a turbine power–efficiency function (Francis type)