HEC ResSim Model of Lancang Cascade Dams

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Objective: The objective of this task is to develop flow model to the Lancang cascade of dams (existing, under construction and definitely planned), assuming operations are to maximize hydropower production. Calibrate the model to match the output (flows in the reaches) from the next guage downstream from lowest dam in cascade for the most recent year available. Perform sensitivity analyses on reservoir operation. Prepare a user's manual for the model and powerpoint presentations. Use model to help identify most impactful reservoirs and hot spots.

Task VII.A: Build HEC Res-Sim model to produce reservoir outflow time series data from simulation of reservoir operating policies to be used for assessing downstream hydrologic and ecologic impacts.

1. Gather and input information. Compile data on reservoir geometry, flows and sediment loads.

2. Model design. Develop HEC ResSim layout of selected projects in the basin, including inflow points on tributaries, flow network and routing, reservoir characteristics and operations.

3. Model calibration .Adjust flow network parameters, reservoir parameters and reservoir operations to achieve best fit between model simulated outputs and historical basin flows.

4. Model validation. Compare model simulated flows with separate set of historical flows for validation.

6. Model sensitivity analysis. Perform sensitivity analysis to determine model sensitivity and to determine parameters for which additional data collection may be needed.

7. Model documentation. Prepare model documentation.

Task VIII: Train Basin Counterparts: Cambodian MOWRAM, Lao WREA, Thai DWR, Vietnamese IMHEN in operation of models through training workshops. Provide training on use of models to local partners.

Model Development

Introduction

A simulation model is being developed for the operation of the Lancang Basin cascade of reservoirs in China. The intended use of the model is to promote understanding and aid in the development of efficient and sustainable water management options for the operations of the Lancang cascade. The goal is to have a simulation tool that can be used to easily and quickly identify good alternatives for reservoir operation leading to best practices for sediment management that can then be further refined or used in design and operational decision making.

The model is intended to be an integral part of the Climate Resilient Mekong sediment modeling tools being created for stakeholders in the basin. The tools are being designed to aid decision makers in solving the relatively large, unstructured water resource management problems faced by Mekong basin stakeholders.

HEC ResSim Model

The simulation software used in modeling the Lancang cascade is HEC-ResSim which was created by the U.S. Army Corp of Engineers – Hydrologic Engineering Center (version 3.0, USACE, 2007). Res-Sim has a graphical user interface (GUI) and utilizes the HEC Data Storage System (HEC-DSS) for storage and retrieval of input and output time-series data. ResSim is used to simulate reservoir operations including all characteristics of a reservoir and channel routing downstream. The model allows the user to define alternatives and run their simulations simultaneously to compare results. Network elements include reservoirs, routing reaches, diversions, and junctions. In ResSim, watersheds include streams, projects (i.e., reservoir, levees), gage locations, impact areas, time-series locations and hydrologic and hydraulic data for that specific area. Schematic elements in ResSim allow you to represent watershed, reservoir network and simulation data visually in a geo-referenced context that interacts with associated data.

ResSim ***reservoirs*** are complex elements that are made up of the pool, the dam, and one or more outlets. The criteria for reservoir release decisions, an operation set, are drawn from a set of discrete zones and rules. The zones divide the reservoir by elevation and contain a set of rules that describe the goals and constraints that should be followed when the reservoir's pool elevation is within the zone.

ResSim ***alternatives*** are developed to compare results using different model schematics (physical properties), operation sets, inflows, and/or initial conditions. ResSim deals with power generation as a characteristic of a reservoir, but it does not consider water quality, environmental in-stream flows, recreation, etc.

More information about HEC-ResSim can be found in the website http://www.hec.usace.army.mil/software/hec-ressim/.

Lancang Basin, China

Human activities have readily become a major concern for sustainable development, especially in the Lancang-Mekong basin. Dams (or reservoirs) are just one of the many human activities that have significant influence on the world's water resources. Researchers are collectively turning their attentions to the Mekong River Basin (Fig. 1) because of the rapid development of hydropower projects that is currently taking place. The Mekong River is the tenth largest river in the world. It is approximately 4,800 km in length, has about 4,000 m of elevation drop, about 450 to 475 billion m^3/yr of annual runoff, and 796,000 km^2 of drainage area—all of which contribute to the great potential for hydropower development. There are 64 hydropower stations in operation, 33 currently under construction, and 200 planned or under feasibility study (Fig. 1).

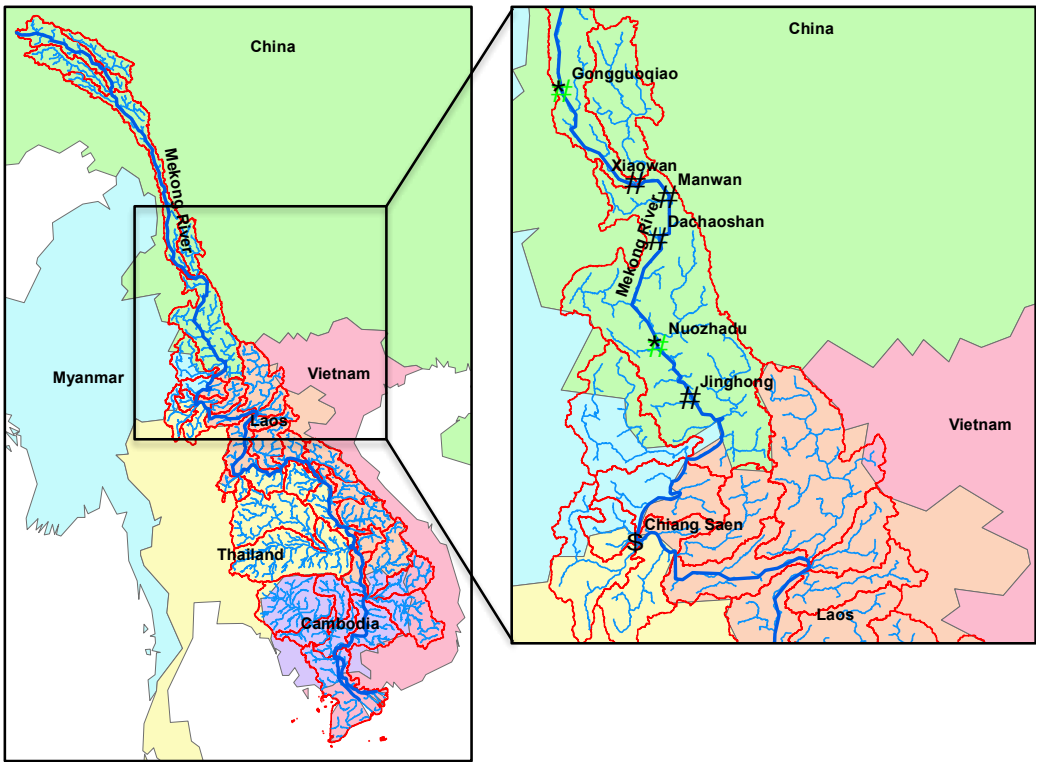


Figure 1. The Lancang-Mekong River Basin and detail of the Chinese Lancang cascade. Black triangles indicated the dams already existing and the green triangles indicate the dams under construction.

Modeling Network and Flows in the Basin

There are about eight hydropower stations existing or under construction in the upper basin, but information about these dams is very limited (Table 1). The flow data available comes from the Chiang Saen gauge, which is monitored by the Mekong River Commission (MRC), and was used as the inflow values for the upstream Gongguoqaio Dam. The locations of the Gongguoqaio Dam and Chiang Saen gauge are shown in Figure 1. The data from Chiang Saen gauge is shown in Figure 2.

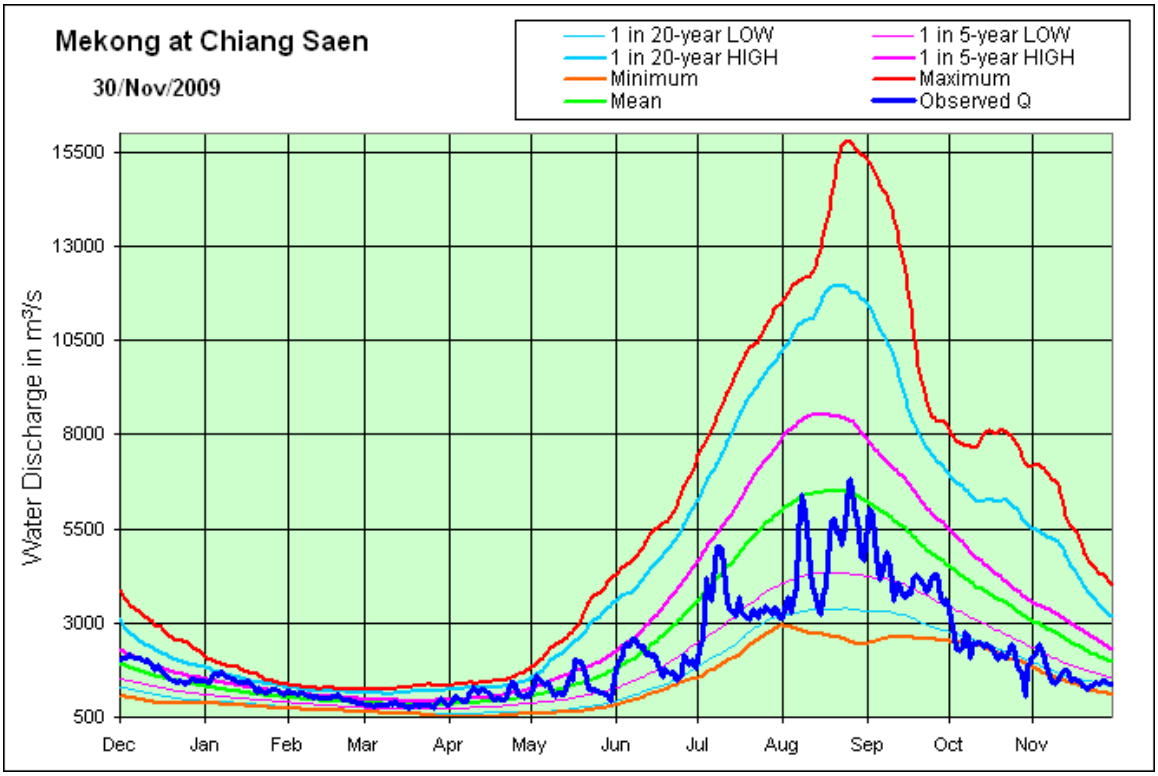


Figure 2. Observed discharge in comparison with historical data for the Mekong River at Chiang Saen gauge (Source: Mekong River Commission, www.mrcmekong.org).

Lancang Basin Reservoirs

The Lancang basin has almost 41,161 million m^3 of reservoir storage planned and 17,913 million m3 already built. The major dams are intended mainly for hydropower production (see Table 2).

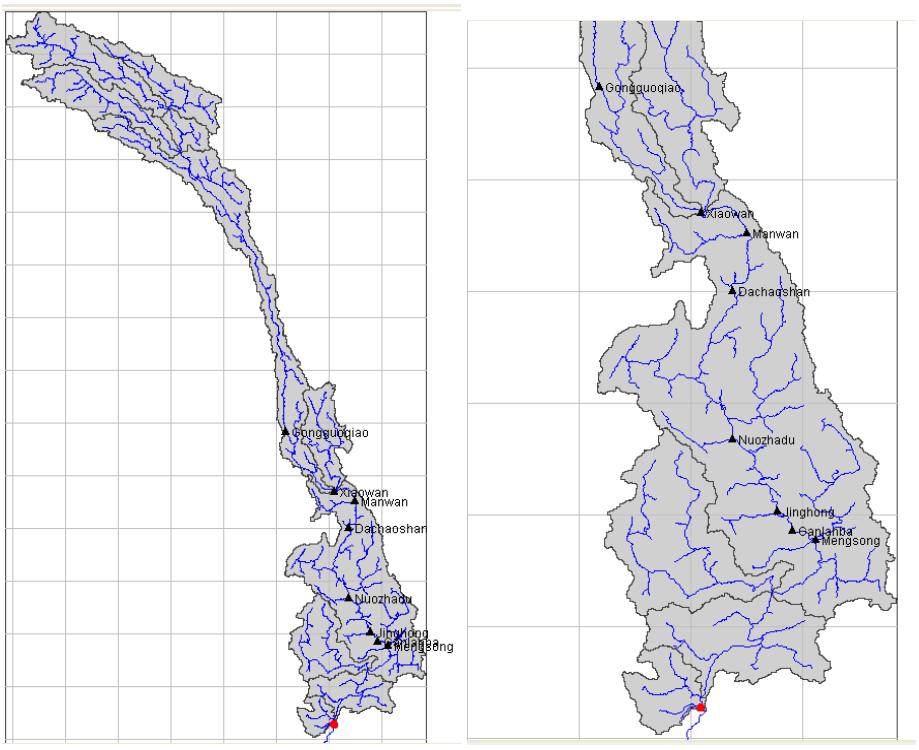
Watershed Setup - The watershed setup module provides a base framework among the different reservoir scenarios and layouts that could be used in modeling a reservoir system. Figure 3 shows the base framework used to model the Lancang Cascade.

Stream segments, computation points, and the Lancang Cascade dams have been added and roughly follow the actual Mekong stream alignment (which is the underlying stream shown in blue).

Table 1. Stations along the Lancang River

Station	Distance from Headwater	Catchment area	Extreme Discharge		Mean Annual Discharge	Mean Annual Flow
			Max	Min		
	km	km^2	m^3/s	m^3/s	m^3/s	Mm^3
Changdu	565	53800	3890	60	487	15400
Changdu to Liutongliang	423	22890				9900
Liutongliang	989	76690	4600	161	802	25300
Liutongliang to Jiuzhou	390	10515				4200
Jiuzhou	1379	87205	6360	206	935	29500
Jiuzhou to Gajiu	270	20476				8920
Gajiu	1649	107681	8840	275	1220	38420
Gajiu to Jinghong	411	33252				20480
Jinghong	2060	140933	12800	395	1870	58900
Jinghong to Border	101	26554				14730
Border	2161	167487				73630

Source: Plinston and Daming (2000).

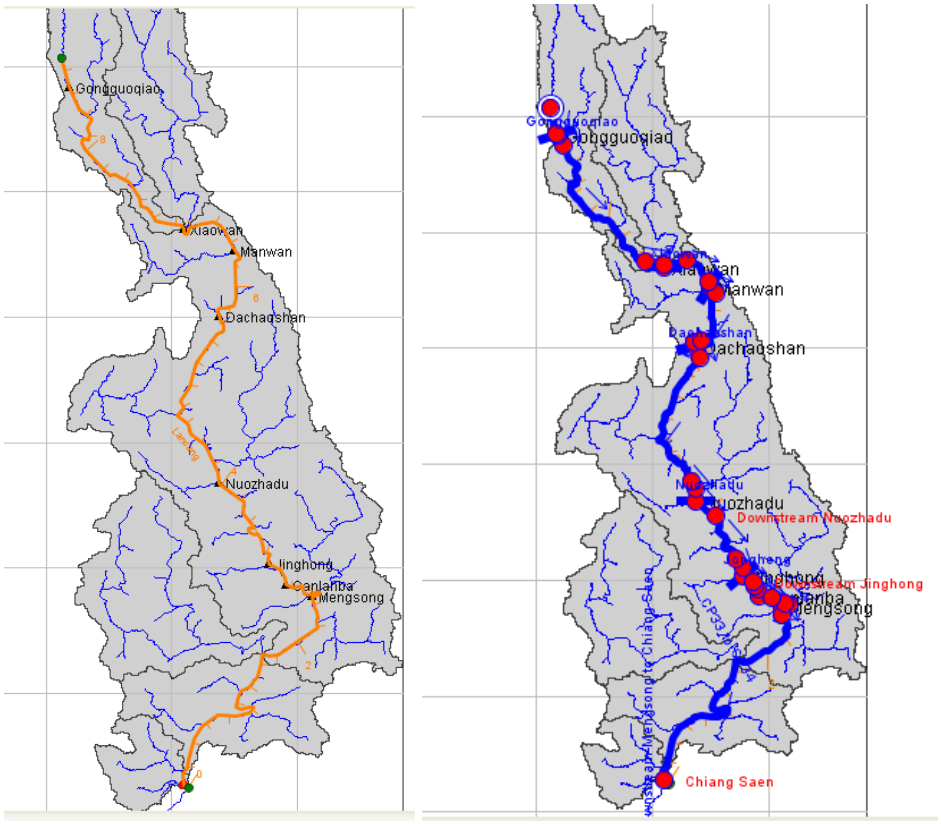


(a) **(b)**

Figure 3. Lancang basin showing the (a) full basin layout with the 8 dams – left; and (b) a detailed view of the reservoir area.

Reservoir Simulation Model

Reservoir Network - The reservoir network isolates the development of the reservoir model from the watershed setup and the simulation. Figure 4 shows the reservoir network for the Lancang Cascade down to the Jinghong Dam (since we do not have enough information about the last two dams in the cascade).



(a) **(b)**

Figure 4. Lancang basin showing the (a) ResSim "stream Alignment" for the reservoir area with 8 dams – left; and (b) a detailed view of the reservoir area.

Physical Characteristics of the Reservoirs - The physical characteristics of the reservoirs are entered into the model: elevation-area-volume relationship, elevation-discharge capacity relationship, power plant data, etc.

Operations - The operations of the reservoirs are entered into the model. The conservation and dead storage zones of each reservoir are defined. A 1m flood zone is assumed at the top of each reservoir due to lack of any other information. A hydropower schedule rule is applied to the operation of each reservoir. The hydropower schedule rule means that the model will operate the reservoirs will attempt to assuming that the objective of operation is to meet the hydropower

demand derived from the total energy listed in Table 2 for each year of simulation where a monthly energy demand has been specified to meet the annual total.

Simulation - The simulation output is shown in Figure 5. Given the preliminary nature of the model due to limited data for dam and reservoir physical and operating characteristics, very limited results are shown here.

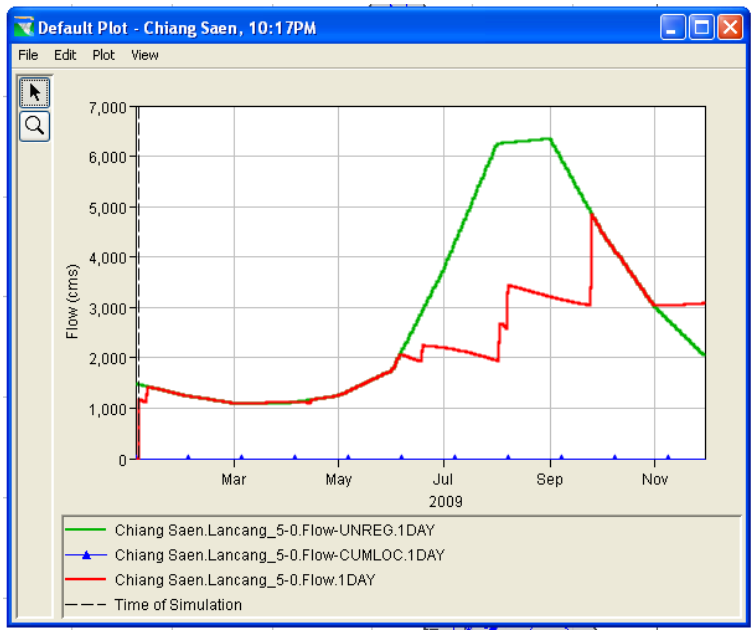


Figure 5. Results of running the Lancang Cascade ResSim model with the 6 upstream reservoirs: Flow at Chaing Saen gage with (red) and without dams (green).

Conclusion and Next Steps

The HEC-ResSim model that is being developed for the Lancang Cascade, once fully developed, can be used to determine the effect of the cascade on the Lower Mekong River. HEC-ResSim is a modeling program that has a steep learning curve, but it can be utilized to develop a powerful model.

The current version of the model is a very simplified model using preliminary data for the Chinese dams. HEC-ResSim has the ability to model dams in series and set up different objectives to satisfy for each dam. Therefore, it can be a very powerful modeling tool if the information is available to develop it. The amount of information on the Mekong River is very limited. Some of the future work that will be done on the model development will be incorporating more complete information on flows and dam characteristics. The current model version represents the start to modeling the Lancang Cascade of dams.

Table 2. Dams of the Lancang Cascade (Kummu and Varis, 2006; Dore and Wu, 2004; Plinston and Daming, 2000).

Name	Basin area	Average inflow		Dam Height	Full Supply Level	Minimum Operation level	Active Storage	Dead Storage	Total Storage	Design Head	Installed Capacity	Total Energy	Utilization
	km2	m3/s	mill m^3	m	m	m	mill m^3	mill m^3	mill m^3	m	MW	GWh	Hours
Gongguoqiao	97200	985	31060	130	1319	1311	120	390	510	77	750	4063	5420
Xiaowan	113300	1220	38470	300	1236	1162	9,900	4750	14,560	248	4200	18207	4850
Manwan	114500	1230	38790	126	994	982	257	662	920	89	1500	7884	5260
Dachaoshan	121000	1340	42260	118	895	860	367		890	80	1350	6500	5200
Nuozhadu	144700	1750	55190	254	807	756	12,300		22,400	205	5500	23107	5130
Jinghong	149100	1840	58030	118	602	595	249		1233	67	1500	7686	5690
Ganlanba	151800	1880	59290	NA	533	532	NA	NA	NA	10	250	777	5180
Mengsong	160000	2020	63700	NA	519	518	NA	NA	NA	28	600	3383	5640

References

Cochrane, T.A., M.E. Arias, R.L. Teasley, T. Killeen (2010). Simulated changes in water flows of the Mekong River from potential dam development and operations on the Se San and Sre Pok tributaries.

Kite, G. (2001) Modelling the Mekong: hydrological simulation for environmental impact studies. *Journal of Hydrology*, 253(1-4): 1-13.

Lei, S.， Liu, J.， Gu, Y.， Geng, L. (2010) Analysis the effect of the hydropower station building of Lancang-Jiang main stream on the change of runoff at leave country section. *Journal of Yunnan University* (*Natural Science Edition*), 32(1): 58-62. (in Chinese with English Abstract)

Mekong River Commission. (2005) Overview of the Hydrology of the Mekong Basin, Mekong River Commission, Vientiane, Lao PDR.

Mekong River Commission. (2009). http://www.mrcmekong.org/.

Plinston, D. and H. Daming, Water Resources and Hydropower in the Lancang River Basin, Landcare Research New Zealand Ltd. ADB TA 3139: PRC, Policies and Strategies for Sustainable Development of the Lancang River Basin, Chapter 4: Water Resources and Hydropower. May 2000.

Ringler, C. 2001. *Optimal Allocation and Use of Water Resources in the Mekong River Basin: Multi-country and intersectoral analyses*. Development Economics and Policy Series, Vol. 20, Frankfurt: Peter Lang.

USACE-U.S. Army Corps of Engineers, Klipsch, J.D. and Hurst, M.B. (2007a) HEC-*ResSim, Reservoir System Simulation – User's Manual, Version 3.0*, Institute for Water Resources, Hydrologic Engineering Center, Davis, CA, USA.

USACE-U.S. Army Corps of Engineers, Klipsch, J.D. and Hurst, M.B. (2007b) *HEC-ResSim, Reservoir System Simulation – Quick Start Guide, Version 3.0*, U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, Davis, CA, USA.

Xue, Z., Liu, J. P. and Ge, Q. (2011) Changes in hydrology and sediment delivery of the Mekong River in the last 50 years. *Earth Surf. Process. Landforms* 36: 296–308.