





# wmpy-power: A Python package for process-based regional hydropower simulation

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## Summary

Hydropower is an important source of renewable energy in many parts of the world. The generation potential for a hydropower facility can vary greatly due to fluctuations in precipitation and snowmelt patterns impacting streamflow and reservoir storage. Human activities such as irrigation, manufacturing, and hydration can also influence water availability at nearby and downstream facilities. wmpy-power, the hydropower model described in this work, is process-based, leveraging explicit reservoir storage and release data to address impacts on hydropower from climate change and human adaptive behaviors to inform long-term planning and resource-adequacy considerations.

## Statement of need

wmpy-power (Water Management Python - Hydropower) is a Python implementation of the WMP algorithm ([Zhou et al., 2018](#)) for hydropower simulation developed to support long-term electricity grid infrastructure planning and climate impacts studies. The model simulates hydropower production at the facility scale using a minimal set of physical characteristics for each facility, timeseries of daily streamflow and reservoir storage, and historical observations of monthly hydropower production. With this data, the model performs a two-step calibration process using the Shuffled Complex Evolution algorithm ([Duan et al., 1993](#)) to optimize a set of facility and regional efficiency and bias-correction factors. Once calibrated, the model can then be used to simulate regional and facility-scale hydropower production for arbitrary timeseries of streamflow and reservoir storage. See [Figure 1](#) for an example of wmpy-power modeled generation compared to observed generation at the facility and regional scale.



**Figure 1:** Example model output of simulated hydropower at the regional and facility scales compared with example observations. The regional signal exhibits high fidelity despite the noise and missing data points in the certain facility signals. In this example, the calibration period was 1995–2006 and the simulation period was 2007–2010.

As a process-based model, wmpy-power utilizes time series of channel flow and reservoir storage to account for the non-stationarity of hydropower generation arising from uncertainties in hydrology and the non-linear effect of climate change on water management (Zhou et al., 2018). The model is designed to simulate an entire region of hydropower facilities in bulk where the details required to accurately simulate each facility are potentially incomplete, and accounts for biases in the input timeseries by calibrating against hydropower observations. Although it was designed for regional scale prediction with a focus on long-term infrastructure planning, it also demonstrates commendable accuracy at the facility scale despite a tradeoff in precision when compared to facility-specific models.

Turner & Voisin (2022) provide a review of the landscape of hydropower models used at large spatial scales. Physics-based models such as Hydrogenerate (Mitra et al., 2021) require more specific details on turbine characteristics and plant design to achieve high accuracy, which are not always widely available. Statistical models such as WRES (Kao, S.-C. et al., 2016) directly correlate runoff with hydropower generation but may overlook the complex interactions arising from human adaptive management of water availability and and hydropower production. wmpy-power fills this gap between the physics-based and statistical paradigms.

## Ongoing research

Active research is underway utilizing wmpy-power as part of a one-way coupled modeling chain from hydrology to river routing to reservoir operations to hydropower. The mosartwmpy model (Thurber et al., 2021; Voisin et al., 2013) routes runoff through a river network with detailed water management rules (Turner et al., 2021), providing flow and storage information to wmpy-power. Zhou et al. (2023) investigate the compounding effects of climate and model uncertainty in multi-model assessments of hydropower. Kao et al. (2022) provide monthly hydropower projections for hydropower facilities in the United States under climate and model uncertainties as part of the United States Department of Energy (US DOE) Secure Water Act. Broman et al. (2024) examine regional changes in projected hydropower availability across the United States for a high-population, high-warming socio-economic climate scenario.

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## References

- Broman, D., Voisin, N., Kao, S.-C., Fernandez, A., & Ghimire, G. (2024). Multi-scale impacts of climate change on hydropower for long-term water-energy planning in the contiguous United States. *Environmental Research Letters*, 19(9). <https://doi.org/10.1088/1748-9326/ad6ceb>
- Duan, Q. Y., Gupta, V. K., & Sorooshian, S. (1993). Shuffled complex evolution approach for effective and efficient global minimization. *Journal of Optimization Theory and Applications*, 76, 501–521. <https://doi.org/10.1007/BF00939380>
- Kao, S.-C., Ashfaq, M., Naz, B. S., Martínez, U. R., Rastogi, D., Mei, R., Jager, Y., Samu, N. M., & Sale, M. J. (2016). The second assessment of the effects of climate change on federal hydropower. ORNL/SR2015/357, Oak Ridge National Laboratory, Oak Ridge, TN. <https://doi.org/10.2172/1340431>
- Kao, S.-C., Ashfaq, M., Rastogi, D., Gangrade, S., Uria Martinez, R., Fernandez, A., Konapala, G., Voisin, N., Zhou, T., Xu, W., Gao, H., Zhao, B., & Zhao, G. (2022). *The third assessment of the effects of climate change on federal hydropower*. <https://doi.org/10.2172/1887712>
- Mitra, B., Gallego-Calderon, J. F., Elliott, S. N., Mosier, T. M., & Bastidas Pacheco, C. J. (2021). *Hydrogenerate: Open source python tool to estimate hydropower generation time-series*. [Computer Software] <https://doi.org/10.11578/dc.20211112.1>. <https://doi.org/10.11578/dc.20211112.1>
- Thurber, T., Vernon, C. R., Sun, N., Turner, S. W. d., Yoon, J., & Voisin, N. (2021). Mosartwmpy: A python implementation of the MOSART-WM coupled hydrologic routing and water management model. *Journal of Open Source Software*, 6(62), 3221. <https://doi.org/10.21105/joss.03221>
- Turner, S. W. D., Steyaert, J. C., Condon, L., & Voisin, N. (2021). Water storage and release policies for all large reservoirs of conterminous United States. *Journal of Hydrology*, 603, 126843. <https://doi.org/10.1016/j.jhydrol.2021.126843>
- Turner, S. W. D., & Voisin, N. (2022). Simulation of hydropower at subcontinental to global scales: a state-of-the-art review. *Environmental Research Letters*, 17(2). <https://doi.org/10.1088/1748-9326/ac9000>

[//doi.org/10.1088/1748-9326/ac4e38](https://doi.org/10.1088/1748-9326/ac4e38)

Voisin, N., Li, H., Ward, D., Huang, M., Wigmosta, M., & Leung, L. (2013). On an improved sub-regional water resources management representation for integration into Earth System Models. *Hydrology & Earth System Sciences*, 17(9). <https://doi.org/10.5194/hess-17-3605-2013>

Zhou, T., Kao, S.-C., Xu, W., Gangrade, S., & Voisin, N. (2023). Impacts of climate change on subannual hydropower generation: a multi-model assessment of the United States federal hydropower plant. *Environmental Research Letters*, 18(3). <https://doi.org/10.1088/1748-9326/acb58d>

Zhou, T., Voisin, N., & Fu, T. (2018). Non-stationary hydropower generation projections constrained by environmental and electricity grid operations over the western United States. *Environmental Research Letters*, 13(7). <https://doi.org/10.1088/1748-9326/aad19f>