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2D CNN-Based Parameter Estimation for Hydrologic and Water Quality Model

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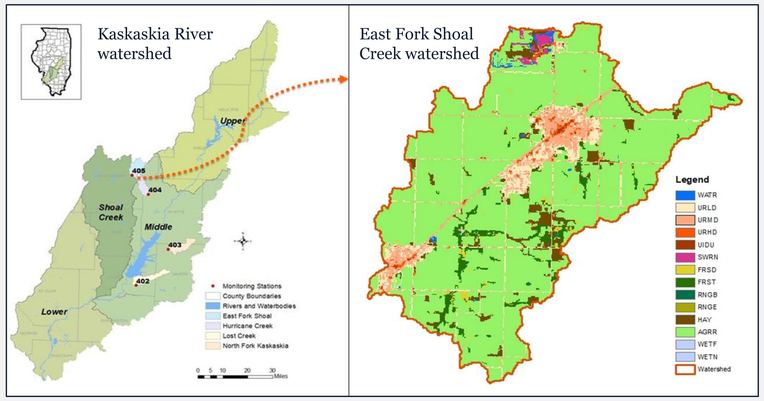
INTRODUCTION

Hydrologic and water quality models simulate essential geophysical processes within a watershed, including surface runoff, infiltration, groundwater flow, sediment transport, and nutrient cycling. These models are critical tools for understanding and managing water resources under varying land use and climate conditions. The Soil and Water Assessment Tool (SWAT) is a widely used, process-based, and scalable watershed model designed to assess the environmental impacts of land management practices and climate change. A key component of model development is parameter estimation, which ensures accurate simulation and reliable prediction of watershed responses. Methods for parameter estimation range from manual calibration and autocalibration using optimization algorithms to advanced deep learning techniques capable of handling high-dimensional parameter spaces.

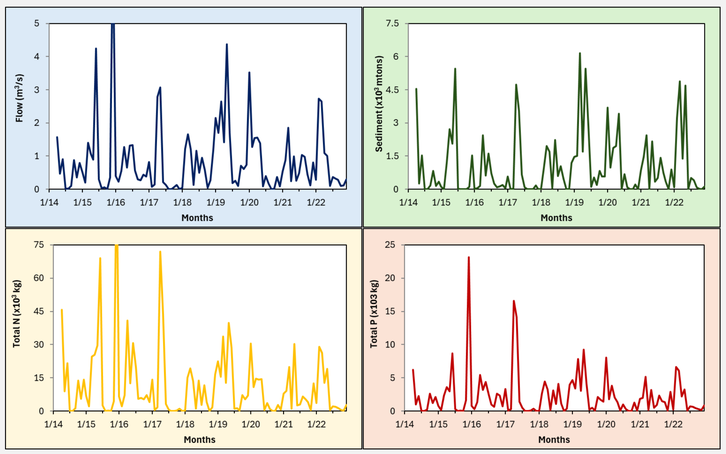
METHOD

Hydrologic and Water Quality Modeling

- **Study watersheds:** East Fork Shoal (EFS) and Lost (LST) Creeks, which are tributaries of the Kaskaskia River watershed, are being monitored as part of the Conservation Reserve Enhancement Program (CREP) in Illinois.
- **Watershed monitoring by ISWS**: Flow, sediment, and nutrient data collected at the outlets of the CREP study watersheds since 2014.

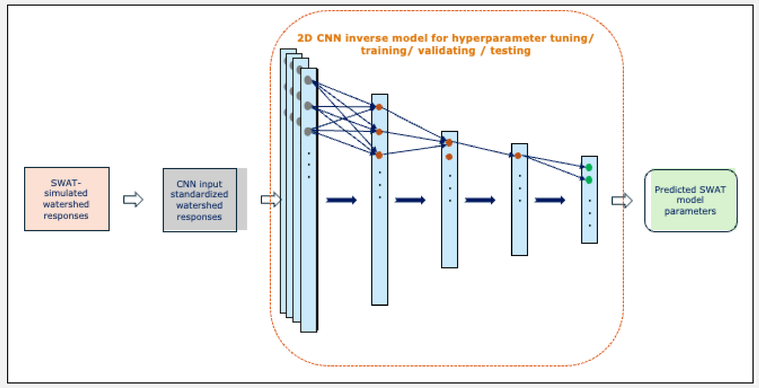


- **Observed data at EFS watershed outlet**: Flow, sediment, total N and P



Deep Learning for Parameter Estimation

- **Deep learning using 2D CNNs:** Workflow for SWAT parameter estimation

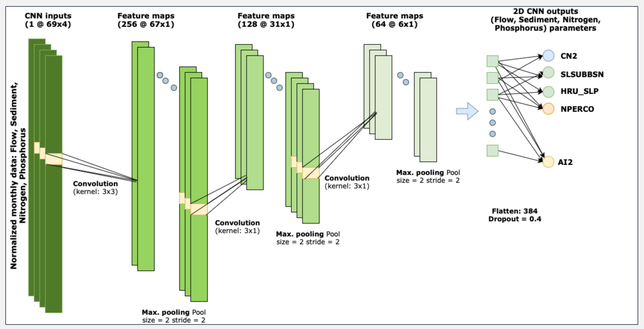


- **Hyperparameter tuning:** Identifying the best 2D CNN architecture by tuning hyperparameters including filter, kernel and pool sizes, learning and dropout rates, epochs and batch sizes

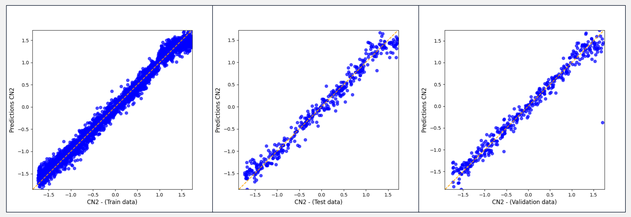
CNN hyperparameters explored using grid search

Hyperparameters	Solution space
2D convolutional layers	3
Filter / kernel sizes	256-128-64 / 3-3-3 128-64-32 / 3-3-3 64-32-16 / 3-3-3
Pool size	2-2-2
Dropout rate	0.0 / 0.1 / 0.2 / 0.3 / 0.4
Learning rate	1.e-6 / 1.e-5 / 1.e-4 / 1.e-3/ 1.e-2
Epochs	50 / 100 / 200 / 300 / 400 / 500
Batch size	4/ 8/ 16/ 32/ 64
Total CNNs explored	2250

- **Best 2D CNN architecture:** Obtained for estimating SWAT parameters



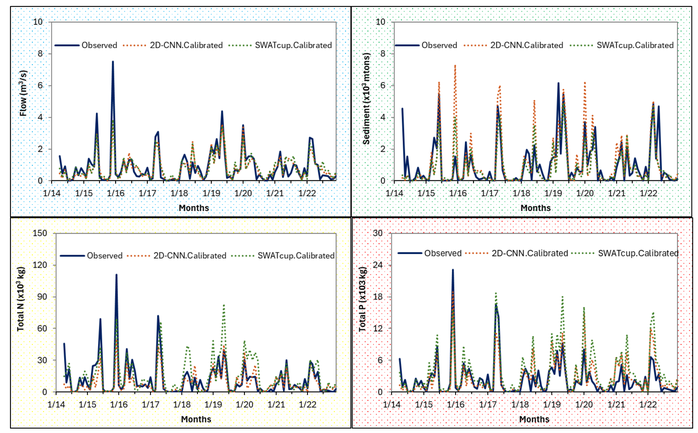
- **Estimated SWAT parameter**: e.g., Curve Number (CN2)



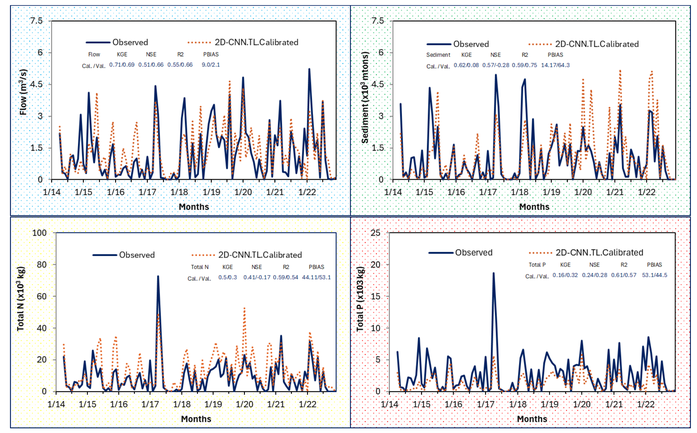
- **Performance metrics:** 2D CNN and SWATcup (SC) (SPE: Single/Multi)

Performance metrics	Flow			Sediment			Total N			Total P		
	2D - CNN	SC-multi	SC-single	**2D - CNN**	SC-multi	SC-single	**2D - CNN**	SC-multi	SC-single	**2D - CNN**	SC-multi	SC-single
Calibration (2014-2019)												
KGE	**0.69**	0.69	0.68	**0.66**	0.56	0.62	**0.44**	0.02	0.71	**0.81**	0.79	0.65
NSE	**0.78**	0.73	0.78	**0.34**	0.24	0.56	**0.61**	0.16	0.53	**0.79**	0.77	0.63
R2	**0.82**	0.75	0.82	**0.56**	0.50	0.58	**0.76**	0.68	0.58	**0.80**	0.78	0.73
PBias	**11.6**	-11.1	8.3	**6.6**	-26.7	20.7	**35.3**	63.2	-14.7	**9.3**	-14.9	-29.6
Vadlidation (2020-2022)												
KGE	**0.73**	0.53	0.68	**0.72**	0.69	0.69	**0.86**	0.23	0.16	**-0.06**	-0.21	-0.72
NSE	**0.73**	0.44	0.70	**0.42**	0.54	0.63	**0.75**	0.31	-0.28	**-0.36**	-0.60	-2.11
R2	**0.75**	0.57	0.73	**0.57**	0.57	0.65	**0.76**	0.59	0.56	**0.81**	0.75	0.77
PBias	**8.9**	-36.3	-16.1	**2.5**	-13.7	14.6	**0.7**	40.2	-67.6	**76.1**	-111.0	-134.5

- **Calibration (2014-2019) & validation (2020-2022):** Observed and simulated monthly watershed responses based on 2D CNN and SWAT-cup



- **Transfer learning:** Simulated watershed responses for LST based on best-trained 2D CNN model for EFS



CONCLUSIONS

This study shows that using 2D CNNs for parameter estimation significantly improves the accuracy and efficiency of hydrologic and water quality modeling. Integrating deep learning with SWAT produced robust predictions of sediment, nutrient, and flow in the EFS and LST watersheds. The results highlight the potential of artificial intelligence for advancing watershed management and monitoring, with future work directed toward expanding on transfer learning, model refinement, and broader watershed applications.