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Receiving Water Quality Models for Estimation of Total Maximum Daily Pollutant Loads: Case Study of the Küçük Menderes River Basin (Turkey)

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Objectives of Study

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To set up an Aquatox water quality model supported by field data to determine the impact of wastewater discharges and diffuse source pollution on river water quality

To simulate time-variable nitrogen and phosphorus, organic matter, PCB-138 and heavy metal concentrations in river water

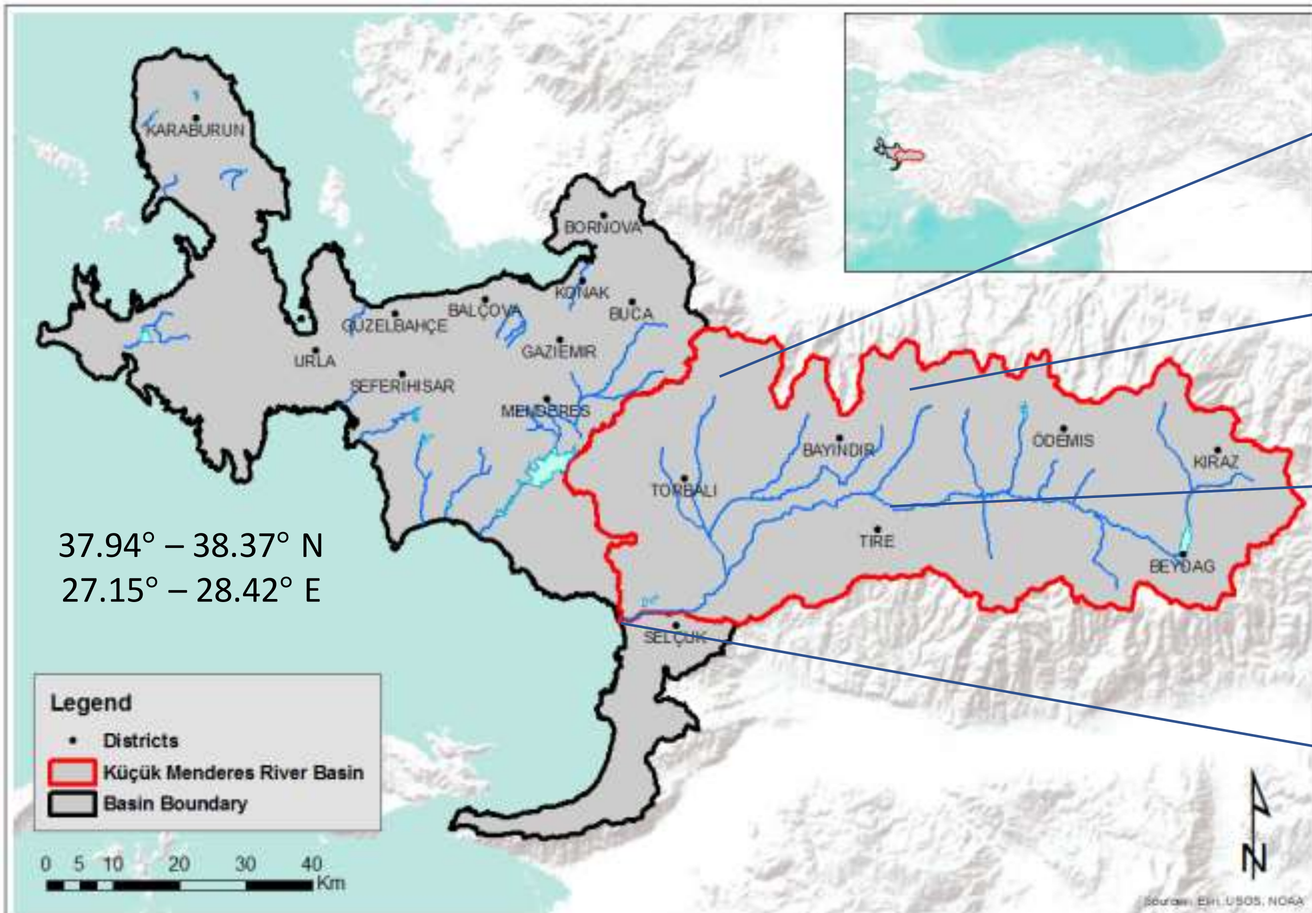
To estimate total maximum daily loads (capacity) of the receiving water body

Motivation

- According to the EU Water Framework Directive (WFD), the concentration of conventional, priority and specific pollutants should be lower than the mandated Environmental Quality Standards (EQS) to protect the aquatic environment and human health.
- In order to maintain these EQS for the entire river basin, pollutant loads coming from point sources (industrial and domestic wastewater discharge) and non-point sources (e.g. from agricultural activities) must be controlled.
- Mathematical water quality models that simulate transport and reaction processes in the receiving water body in response to contaminant loads are important tools to estimate the capacity of a watershed to sustain environmental quality standards (EQS).

Study Area: Küçük Menderes River Basin (KMRB)

- The KMRB is located in Aegean Region, Western Turkey
- River water quality in the basin is under significant environmental stress due to agriculture, animal husbandry and wastewater discharges.
- An intermittent flowing river that can become dominated by wastewater effluents during dry periods.
- About 77% of the wastewater is discharged from treatment plants while the remainder is being released directly from the sewerage systems.



Mean annual precipitation = 661 mm/a

Drainage area = 3490 km^2

Length of main river reach = 129 km

Annual average flow (1952-2012) = 9.05 m^3/s

AQUATOX Model Setup

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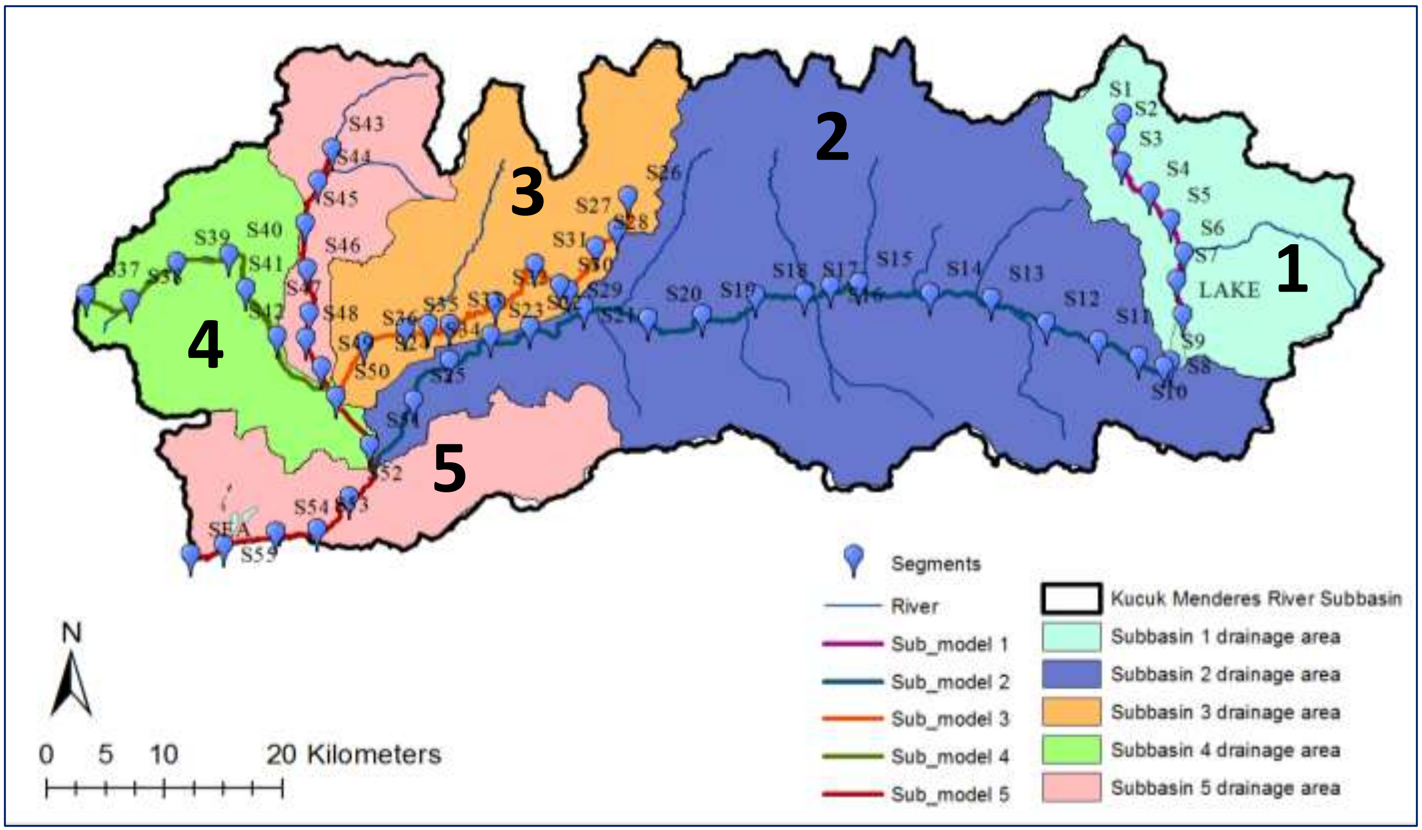
Water Quality Simulation Model: AQUATOX

- AQUATOX is a receiving water quality model developed by the U.S. EPA.
- It can simulate processes related with the fate and transport of conventional water pollutants, nutrients, sediments, and toxic chemicals.

- Large size of watershed and the number of points sources complicate the use of a single model, therefore the study area is divided into five sub-models.



- Submodel 1 ➔ 7 model segments
- Submodel 2 ➔ 18 model segments
- Submodel 3 ➔ 6 model segments
- Submodel 4 ➔ 11 model segments
- Submodel 5 ➔ 13 model segments

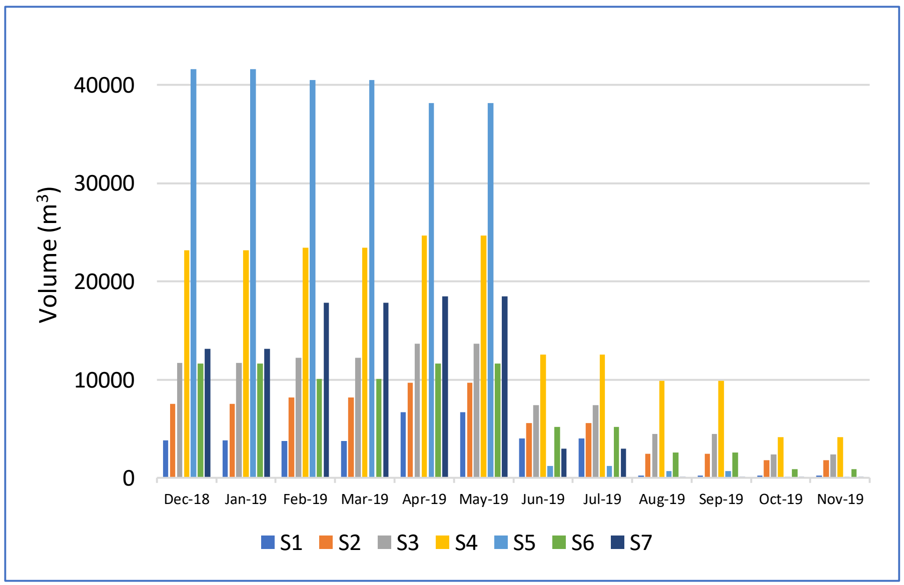
FLOW CALCULATION → POLLUTANT LOADS → SETUP of AQUATOX MODEL → SENSITIVITY ANALYSIS → CALIBRATION → TMDL

Calculation of Flow Between Model Segments

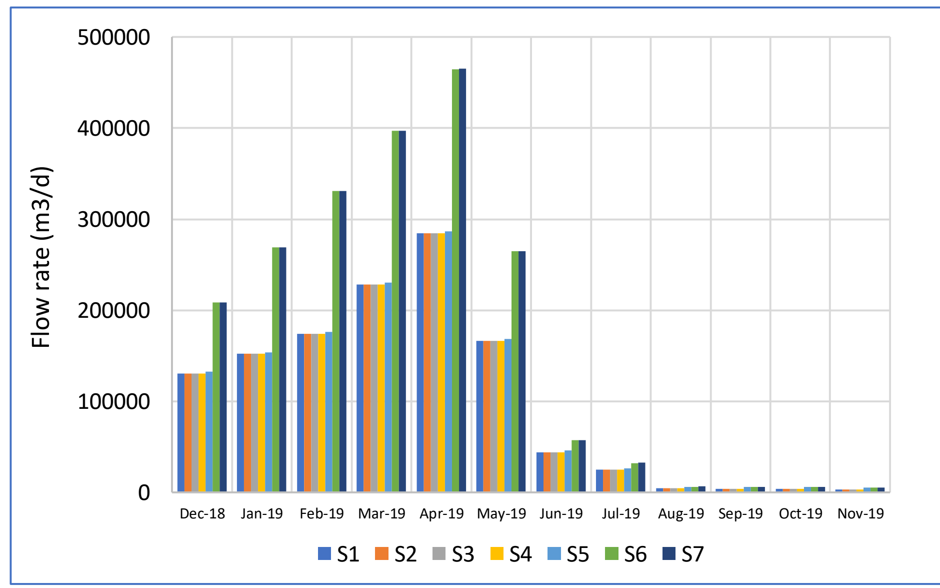
- Based on solving mass-balance equations for each model segment
- Transient segment volumes, V_i, were obtained using measured water depths and stream widths. Field flow measurements were used as boundary conditions.

$$Q_i = \frac{dV_i}{dt} - Q_{i-1} - Q_{trib} - Q_{PS} \qquad (i\text{: model segment index})$$

Segment Volumes of Submodel 1



Segment Flowrates of Submodel 1



FLOW CALCULATION → POLLUTANT LOADS → SETUP of AQUATOX MODEL → SENSITIVITY ANALYSIS → CALIBRATION → TMDL

POINT AND NON-POINT SOURCES

- 9 municipal wastewater treatment plants and 1 direct discharge
  - 20 industrial ww discharge
- Non-point source loads (TN,TP and COD) determined in the Küçük Menderes River Basin Management Plan were used as input in the model.

SIMULATED WATER QUALITY VARIABLES

- Nitrogen species
  - ammonium-N, nitrate-N
  - organic N
  - Phosphate
  - Dissolved Oxygen
  - Total Organic Carbon
  - PCB-138
  - Heavy metals:
    - aluminum, cobalt, copper

Some Properties of the AQUATOX MODEL:

- Simulation Period 1 year (12/2018-12/2019)
- Daily time step to calculate concentrations
- Time steps are variable to maintain numerical stability

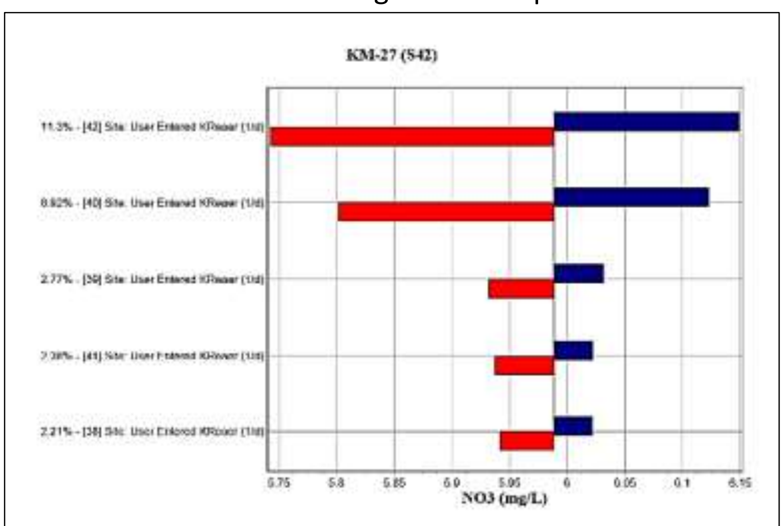
AQUATOX model parameters tested in sensitivity analysis and applied change ratios:

Parameter Name	Function	Ratio
Kreaer (1/d)	Depth-averaged reaeration coefficient	30%
KD, P to CaCO3 (L/kg)	Partition coefficient for phosphorus to calcite	30%
Phyto, Max. Photosynthesis Rate	Maximum photosynthetic rate of phytoplankton	30%
Peri, Max. Photosynthesis Rate	Maximum photosynthetic rate of periphyton	30%
Phyto, Resp Rate (g/g. d)	Respiration rate of phytoplankton	30%
Peri, Resp Rate (g/g. d)	Respiration rate of periphyton	30%
Phyto, Exponential Mort Coeff (g/g.	Exponential factor for suboptimal conditions of	50%
Peri, Exponential Mort Coeff (g/g.	Exponential factor for suboptimal conditions of	50%
Phyto, N Half-Sat (gN/m3)	half-saturation constant for intracellular nitrogen of	50%
Peri, N Half-Sat (gN/m3)	half-saturation constant for intracellular nitrogen of	50%
Phyto, P Half-Sat (gP/m3)	half-saturation constant for intracellular phosphorus of	50%
Peri, P Half-Sat (gP/m3)	half-saturation constant for intracellular phosphorus of	50%
Max. Refr. Degrad. Rate (g/g. d)	The maximum degradation rate of refractory	50%
Max. Labile. Degrad. Rate (g/g. d)	The maximum degradation rate of labile	50%
Detrital Sed. Rate (Ksed) (m/d)	Organic matter sedimentation rate	50%

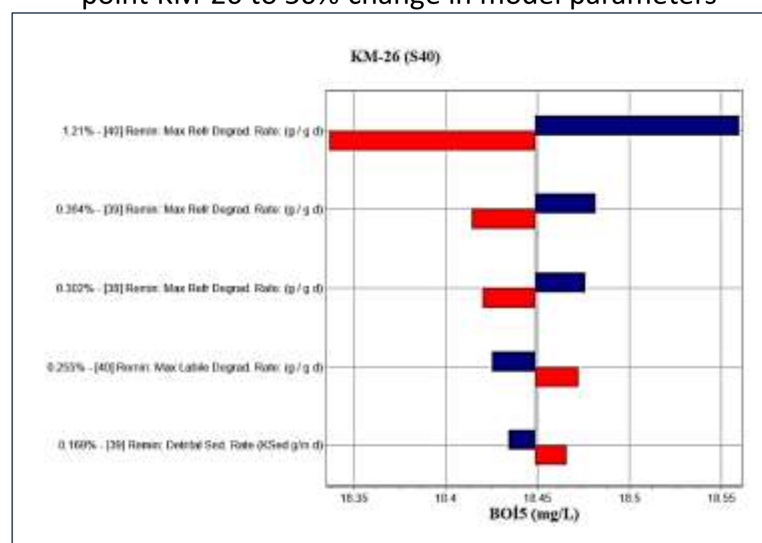
Most effective model parameters:

- Reaeration Constant (Krear)
- Nitrification Rate (Nitrif)
- Max. labile detritus degradation rate
- Max. refractory detritus degradation rate
- Detrital sedimentation rate (Ksed)

Sensitivity of NO_3-N concentration at observation point KM-27 to 30% change in model parameters



Sensitivity of Organic Matter concentration at observation point KM-26 to 50% change in model parameters



Determine of river hydrolics → POLLUTANT LOADS → SETUP of AQUATOX MODEL → SENSIVITY ANALYSIS → **CALIBRATION** → TMDL

Calibrated model parameters:

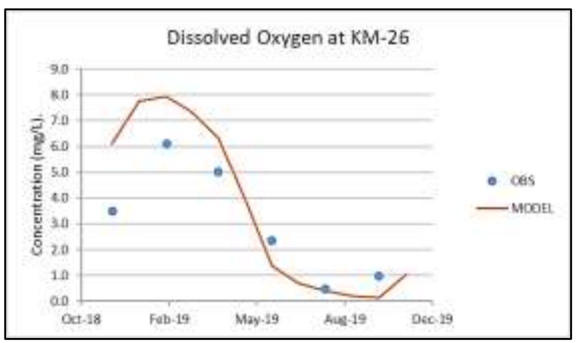
Parameter Name	Units	Range value	Reference
Kreaer	1/d	0.4 – 10	(Schnoor, 1996)
Phyto, Max. Photosynthesis Rate	1/d	0 – 3	(Bui et al., 2019)
Peri, Max. Photosynthesis Rate			
Phyto, Resp Rate	g/g. d	0.05 – 0.5	(R. Zhang et al., 2012)
Peri, Resp Rate	g/g. d		
Max. Labile. Degrad. Rate	g/g. d	0.003 – 0.5	(EPA,2019)
Max. Ref. Degrad. Rate	g/g. d	0.0005 – 0.015	(EPA,2019)
Detrital Sed. Rate (Ksed)	m/d	0.03 – 0.24	(Burns & Rosa, 1980)
KDenitri	1/d	0 – 2	(Bui et al., 2019)
KNitri	1/d	0 – 10	(Bui et al., 2019)

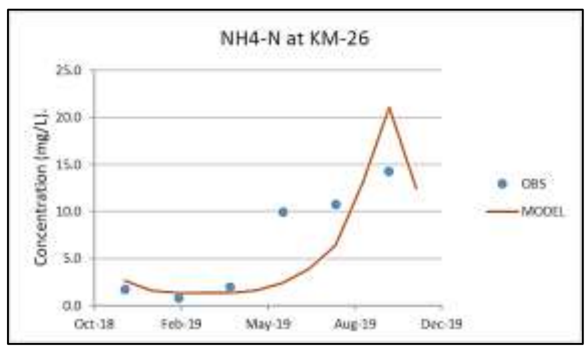
- The model was calibrated against water quality measurements obtained bi-monthly for one year.
- 24 monitoring stations

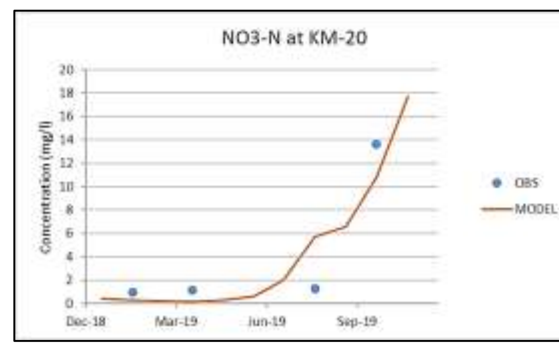
Model performance statistics:

- Root Mean Square error (RMSE),
- nRMSE statistics normalized with the observation standard deviation of the RMSE,
- PBIAS were monitored.

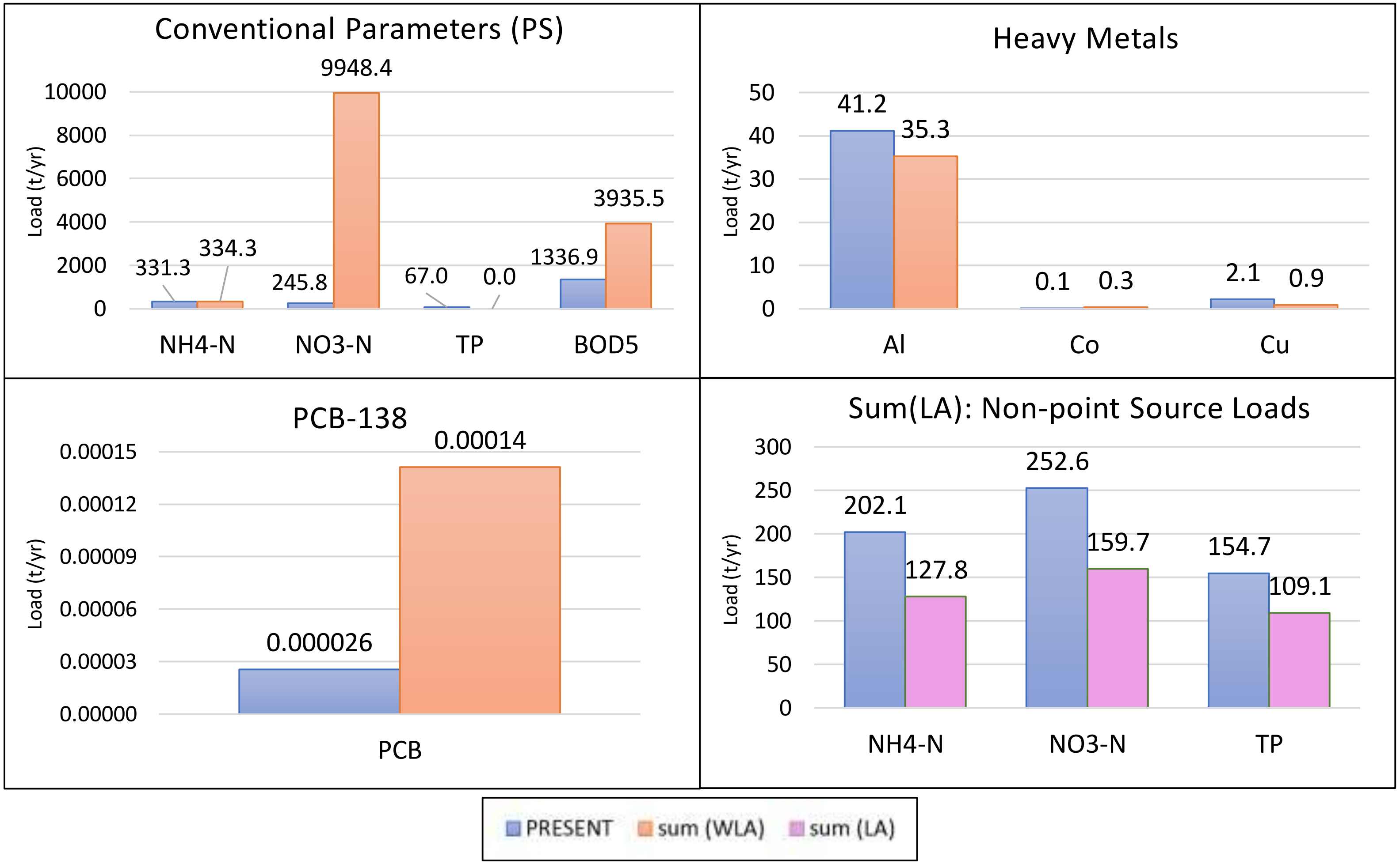
Simulated monthly average concentration time series:







$$TMDL = \text{sum (WLA)} + \text{sum (LA)} + \text{MOS}$$



Total Maximum Daily Load (TMDL) for KMRB using MOS = 5%:

t/yr	NH4-N	NO3-N	TP	BOD5	PCB	Al	Co	Cu
PRESENT	506.71	473.50	210.67	1270.07	0.00002	39.11	0.11	2.03
TMDL	474.91	9647.57	103.63	3738.74	0.00013	33.52	0.29	0.81
DIFFERENCE (Present-TMDL)	31.80	-9174.07	107.05	-2468.67	-0.00011	5.59	-0.19	1.21

Conclusion & Suggestions

- Modeling results suggest that even drastic reductions in TN and TP loads are not sufficient to achieve water quality goals for downstream reaches of the river.
- Concentrations in the receiving river are influenced by the influx of nutrients from diffuse sources during wet periods and by point sources during intermittent periods.
- It is evident that strict measures are required to control discharges and prevent further impairment.
- Water quality modeling is essential to assess and mitigate the effects of human activities on the water cycle.
- Our study demonstrates also how to predict the effectiveness of controlling these activities and identifying solutions specific to the watershed.
- Water quality models should be periodically updated with new data.

THANK YOU !

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