SEA GRANT PROJECT FINAL REPORT

INSTITUTION: Indiana State University **ICODE:**
Terre Haute, IN 47809

TITLE: Modeling the effects of land use/land cover change on surface water quality within the Chicago MSA.

TYPE: Graduate Student Grant.

PROJECT NUMBER: 548582 (POT985) **REVISION DATE:**

PROJECT STATUS: Completed **INITIATION DATE:** 6/5/10

COMPLETION DATE: 5/31/11

SUB PROGRAM:

PRINCIPAL INVESTIGATOR: Wilson, Cyril O. **EFFORT:** 6.6 months
AFFILIATION: Indiana State University, Earth and Environmental Systems.
AFFILIATION CODE:

ASSOCIATE INVESTIGATOR: Weng, Qihao **EFFORT:** 0.01 months
AFFILIATION: Indiana State University, Earth and Environmental Systems.
AFFILIATION CODE:

SEA GRANT FUNDS: $ 6000.00

KEYWORDS: Surface water quality, Chicago MSA, land use/ land cover change.

OVERALL PROJECT SUMMARY

This project explores three important issues namely the relationship between land use structural complexity and surface water quality, the role of seasonal differentials on surface water quality, and the implications of future land use and climate changes on surface water quality. The study was conducted within Lake Calumet watershed and that portion of the Des Plaines River watershed that lies within the Chicago Metropolitan Statistical Area (MSA). Using multi-temporal remotely sensed images; historical, contemporary and future climate data, including an array of watershed data, the study employed a spatially distributed loosely coupled hydrologic and water quality modeling approach within a Geographic Information System (GIS) to investigate the impacts of land use changes on surface water quality between 1990 and 2010, and also make projections up to 2030. Water quality projection made beyond 2010 was condition by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenario (SRES) B1 and A1B groups. Furthermore, the projection was also based on three future land use/planning scenarios influenced by low density residential growth, normal urban growth, and commercial growth scenarios, respectively.

Results of the study revealed that surface water quality within the Chicago MSA is not influenced by the structural complexity of an urban landscape when total suspended solids (TSS), fats, oil and grease (FOG), total phosphorus (TP), and total kjeldahl nitrogen (TKN) are taken into consideration. Spatial hydrologic and water quality modeling demonstrated that seasonal differentials mostly alter pollutant concentrations compared to pollutant loads in surface water. The study also unearths that contemporarily, phosphorus and suspended sediments significantly affects surface water quality in the Chicago MSA. Results of the study predict that future land use and climate changes will greatly alter the concentration of TSS by 2030 in the Chicago MSA compared to other pollutants. The study recommends the development of medium and high density residential areas among other land use configurations for sustainable water quality within the Chicago MSA.

1.1 Significant Research findings

A. The study revealed that although land use structural complexity within the Lake Calumet watershed to some extent increased between 1990 and 2010, there is very weak relationship between the concentration levels of pollutants in Lake Calumet watershed and the level of structural complexity of land uses within the watershed. Bivariate regression analysis demonstrated that the spatial distribution of total suspended solids (TSS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), and fats, oil and grease (FOG) in the watershed have extremely weak association ($R^2 < 0.06$) with the structural complexity of the landscape. As such, surface water quality within Lake Calumet watershed is not influenced by the structural complexity of land use.

B. The study demonstrated that most of the pollutants modeled within the Des Plaines River watershed between 1990 and 2010 exhibited higher concentration levels during the winter months as opposed to the summer period analyzed. Total suspended solids (TSS), total Kjeldahl nitrogen (TKN), and nitrate-nitrite (NN) displayed higher concentration during the winter period compared to the summer, while total phosphorus (TP) to a greater extent veered away from this trend. Moreover, the study revealed that most of the pollutants concentration levels within the Des Plaines River watershed reduced between 1990 and 2010, while the loading of TSS within residential areas increased. Water quality modeling and bivariate correlation analysis suggest that there is similar pollutant loads irrespective of seasons ($r^2 > 0.8$) but concentration levels tend to vary according to winter and summer seasons ($r^2 < 0.3$). The study concluded that pollutant loads are similar irrespective of winter and summer seasons, while concentration varies according to seasons.

C. The response of pollutant concentration to future land use and climate changes is mostly non-linear and of a complex nature. The general watershed response of TSS to future land use and climate changes revealed an increase in concentration levels during the late winter and early spring period of 2020 and 2030 compared to the same season in 2010, while concentration wanes during the summer season. The higher the precipitation level coupled with relatively low temperature, the larger the concentration of TSS in a watershed. Sub-basin scale analysis further suggests that TSS will be a major problem in most areas of the watershed during the late winter and early spring periods of 2030. Portions of a watershed that has middle and high density residential development are better for mitigating high levels of TSS loading and concentration during the late winter and early spring periods.
On average, summer periods in 2020 and 2030 exhibited lower TP concentration levels compared to the baseline period of 2010, while the winter period displayed a reverse with the exception of the A1B climate scenario for 2030. This study predicted that TP especially in the late winter and early spring period will be problematic within populated areas compared to other sections of the watershed. Nitrate-nitrite evinced higher capacity for dilution under high precipitation and runoff scenarios during the late winter and early spring period compared to TKN and TP.

Future climate change has the potential to exert larger impact on the concentration of pollutants vis-à-vis the potential impact of land use change. The three land use/planning scenarios analyzed in the study demonstrated slight differences between nonpoint source pollutant concentrations under constant climate emission scenario; this trend significantly veered when inter-seasonal and inter-climate emission types are examined. The response of future water quality to climate and land use heavily depends on the type of climate emission scenario being evaluated. Land use mitigation strategies to preclude potential water quality impairment have to be dynamic in order to respond to the seasonal variations displayed by future climate.

1.2 Publications

Wilson, C.O. and Weng, Q. (2011). Simulating the impacts of future land use and climate changes on surface water quality in the Des Plaines River Watershed, Chicago Metropolitan Statistical Area, Illinois. Revised and resubmitted to Science of the Total Environment.

Wilson, C.O. and Weng, Q. Does structural complexity of an urban landscape influence surface water quality? A landscape metric and water quality modeling approach. (In preparation).

1.3 Presentations at conferences and workshops

Simulating the future impacts of urban land use/land cover change on surface water quality within the Chicago Metropolitan Statistical Area, Illinois. Paper presented at the American Society for Photogrammetry and Remote Sensing (ASPRS) annual conference, Milwaukee, Wisconsin. May 1- 5, 2011.

Modeling the future impacts of urban land use change on surface water quality within Des Plaines River watershed, Chicago MSA, Illinois. Paper presented at the annual meeting of the Association of American Geographers, Seattle, WA. April 12-16, 2011.

Simulating the future impacts of urban land cover change on surface water quality within the Chicago Metropolitan Statistical Area, Illinois. Paper presented at the 2010 Illinois Water Conference, Champaign, IL. October 5-7, 2010.

1.4 General impacts of the research

This research has unearthed a number of significant findings relating to land use change and surface water quality within a major metropolitan area in North America. The dissertation research has also made possible the discovery of additional areas for further exploration in the near future. For instance, it is presently unknown whether structural complexity of an urban watershed has relationship with ground water quality. The modeling approach developed in this study can be applied to watersheds in other metropolitan settings provided the data and expertise are available. It would be interesting to assess other nonpoint source pollutant response to other climate emission scenarios and watersheds that have more abrupt changes in elevation compared to those evaluated in this study. Finally, a longer term analysis of future land and climate changes is recommended to compare possible changes in water quality beyond 2030.

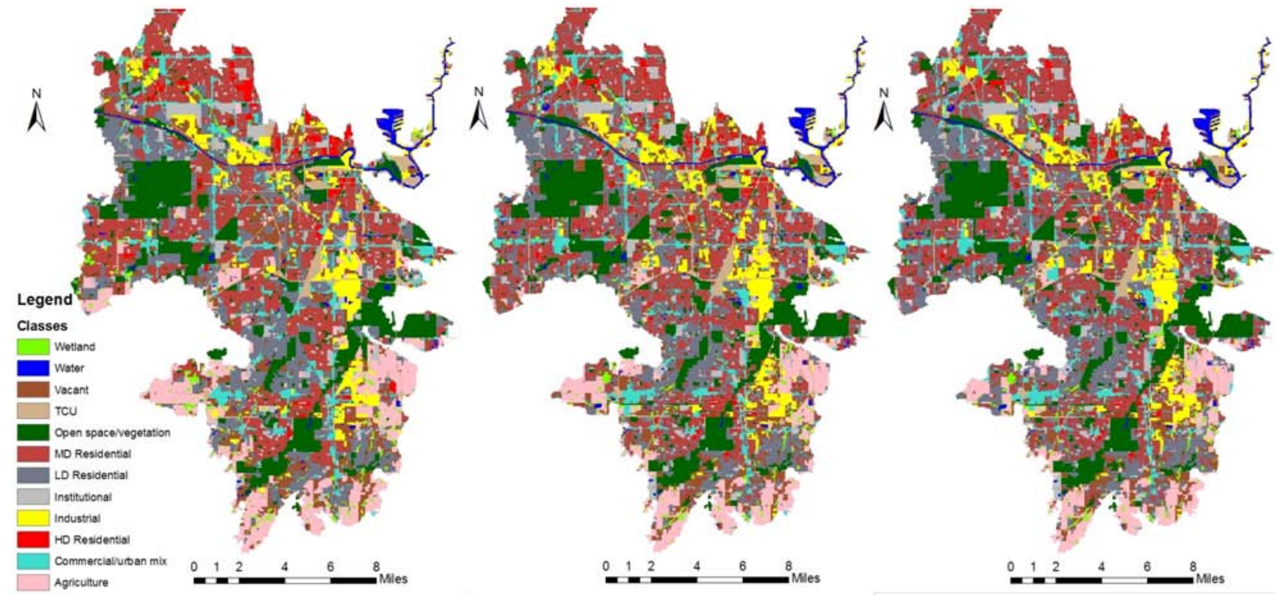
1.5 The role of IL-IN Sea Grant fund on the dissertation project

Funds from the Illinois-Indiana Sea Grant proved salutary to the successful and timely completion of the dissertation project. Money from the grant made possible the acquisition of a high-speed computer that was able to run the very complex simulation models used in this research. This would have been impossible under the old existing computers in the spatial analysis laboratory. In addition, the grant money facilitated the acquisition of a robust hydrologic model calibration software which allowed the fitting of model simulation results to observed data. Simulation results obtained from the employment of this calibration software had higher efficacy compared to those obtained without the utilization of the software. This engineered the production of more reliable result for the scientific community in the dissertation. Moreover, the purchase of daily surface climate data through funds from the grant provided data with finer temporal resolution that produced close to real world simulated stream discharge results. This made model calibration and validation of results less challenging and more efficient compared to the use of coarse temporal climate data. Finally, the project funds facilitated the collection of training samples through field work for the classification of remotely sensed data. Also field work allowed the morphology of the rivers and some of their tributaries to be studied which also

aided in improving the dissertation project. The research project resulted to the successful completion of my PhD degree.

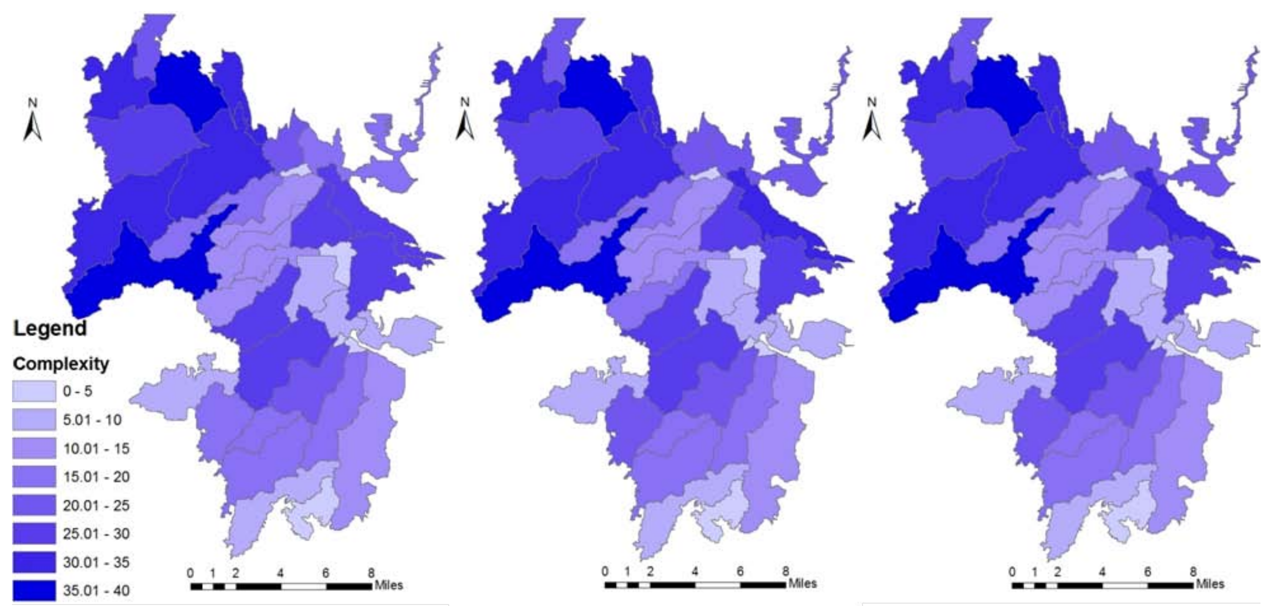
APPENDIX

Maps and charts



1990 2000 2010

Figure 1: Classified land use maps of Lake Calumet watershed (1990-2010)



1990 2000 2010

Figure 2: Land use structural complexity map of Lake Calumet watershed (1990-2010).

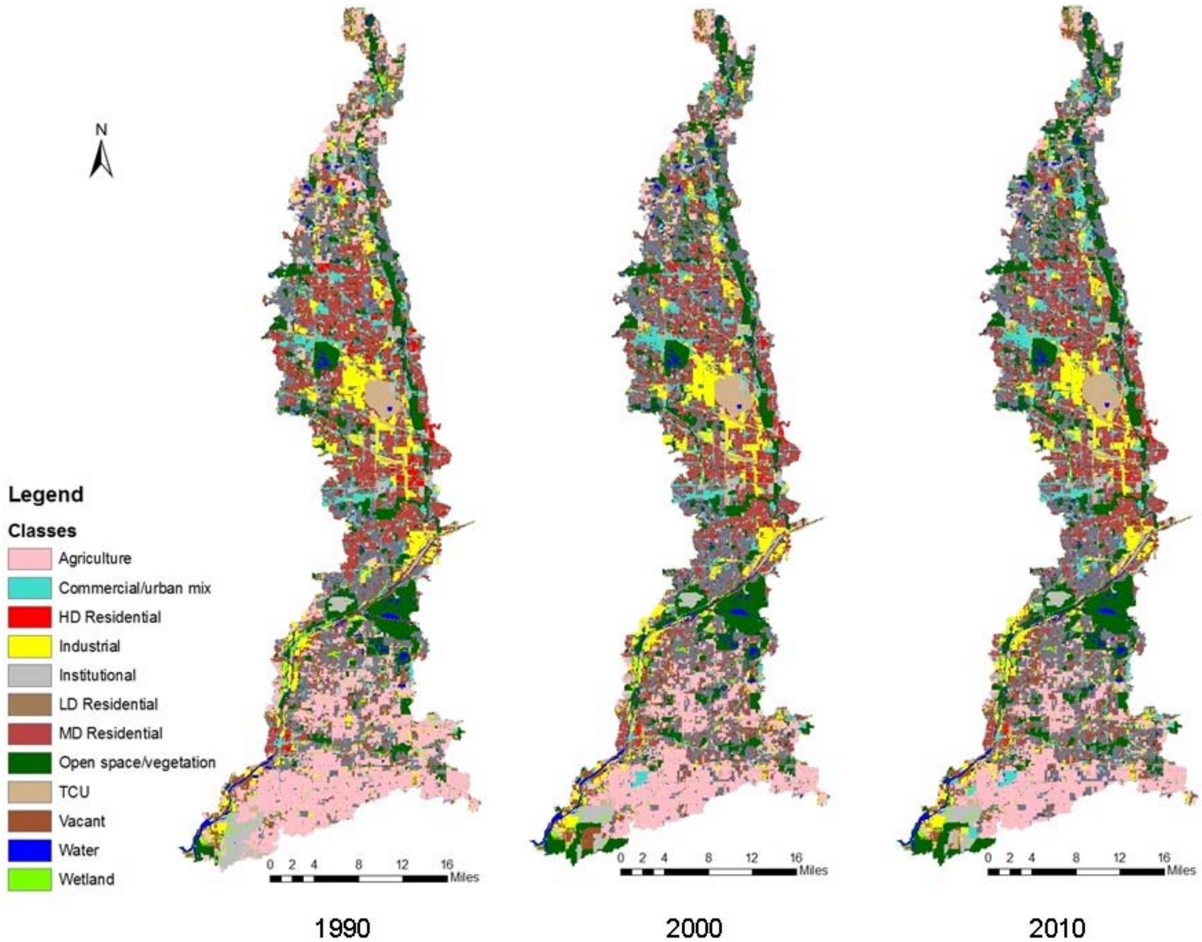


Figure 3: Classified land use maps of Des Plaines River watershed (1990-2010).

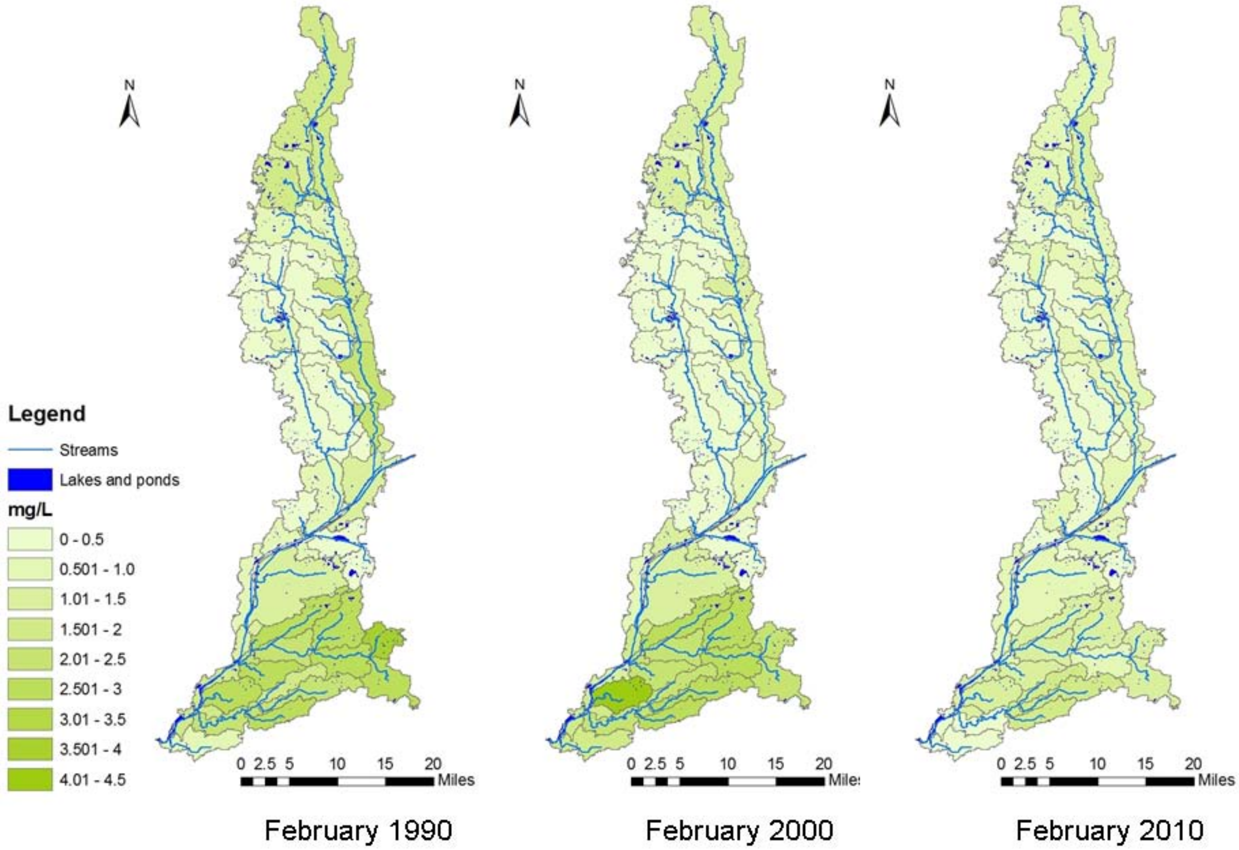


Figure 4: Trend of total phosphorus concentration for February within Des Plaines River watershed.

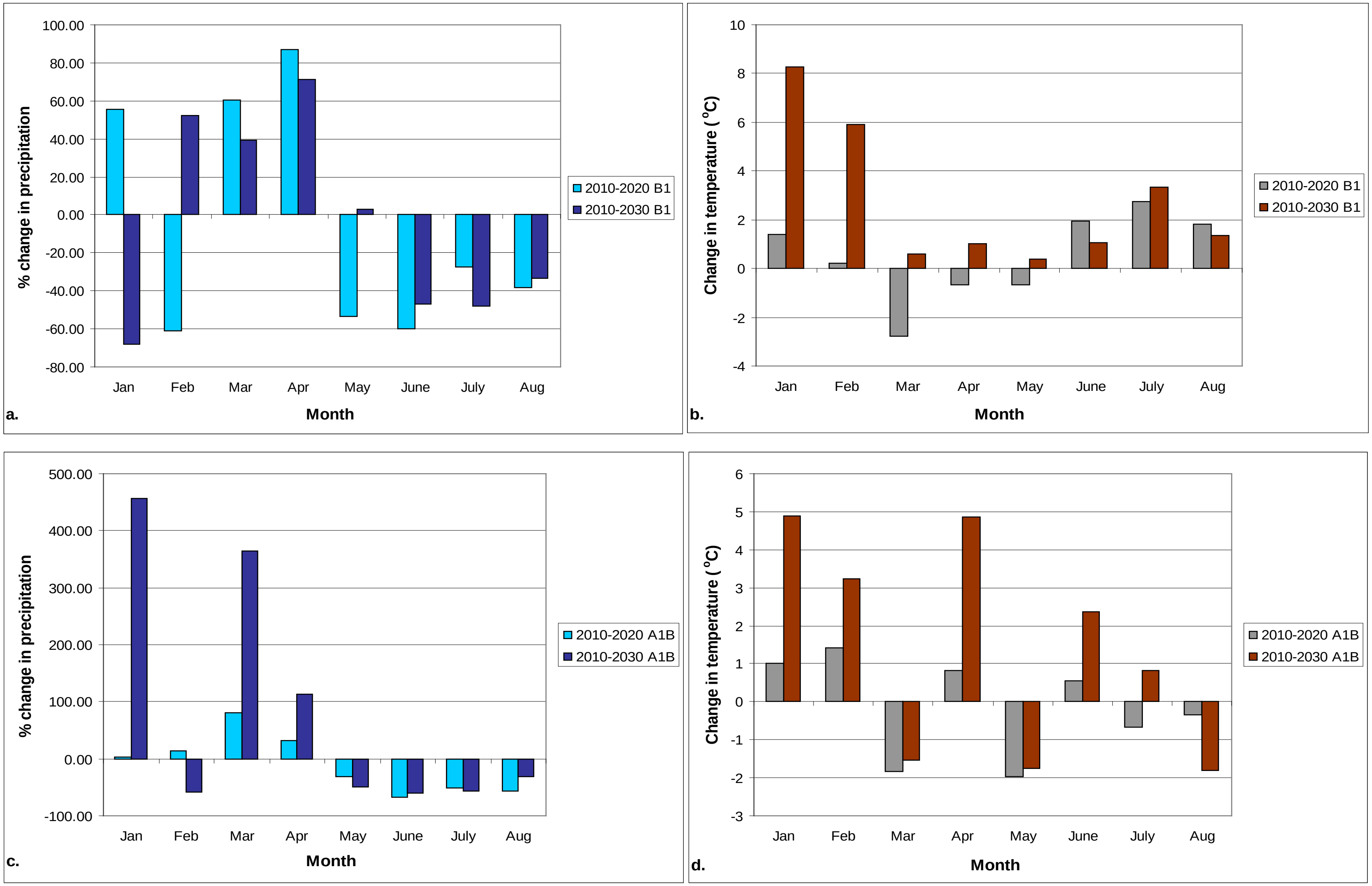


Figure 5: Change in precipitation (a,c) and temperature (b,d) between 2010-2020 and 2010-2030.

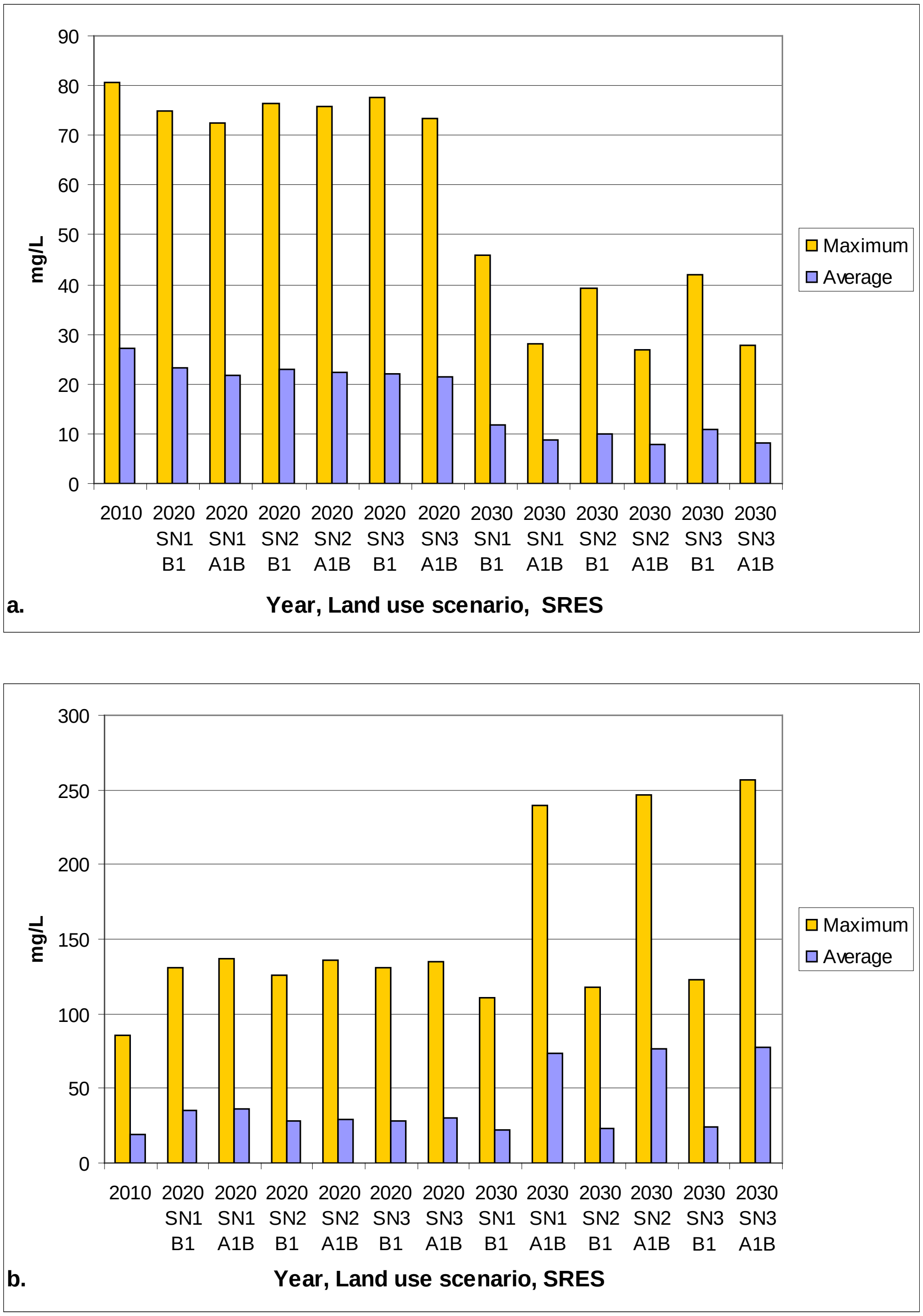


Figure 6: Maximum and average TSS concentration in Des Plaines River watershed. (A) July and (B) March. Note: TSS = total suspended solids; SRES = special report on emission scenarios; SN= land use/planning scenario.

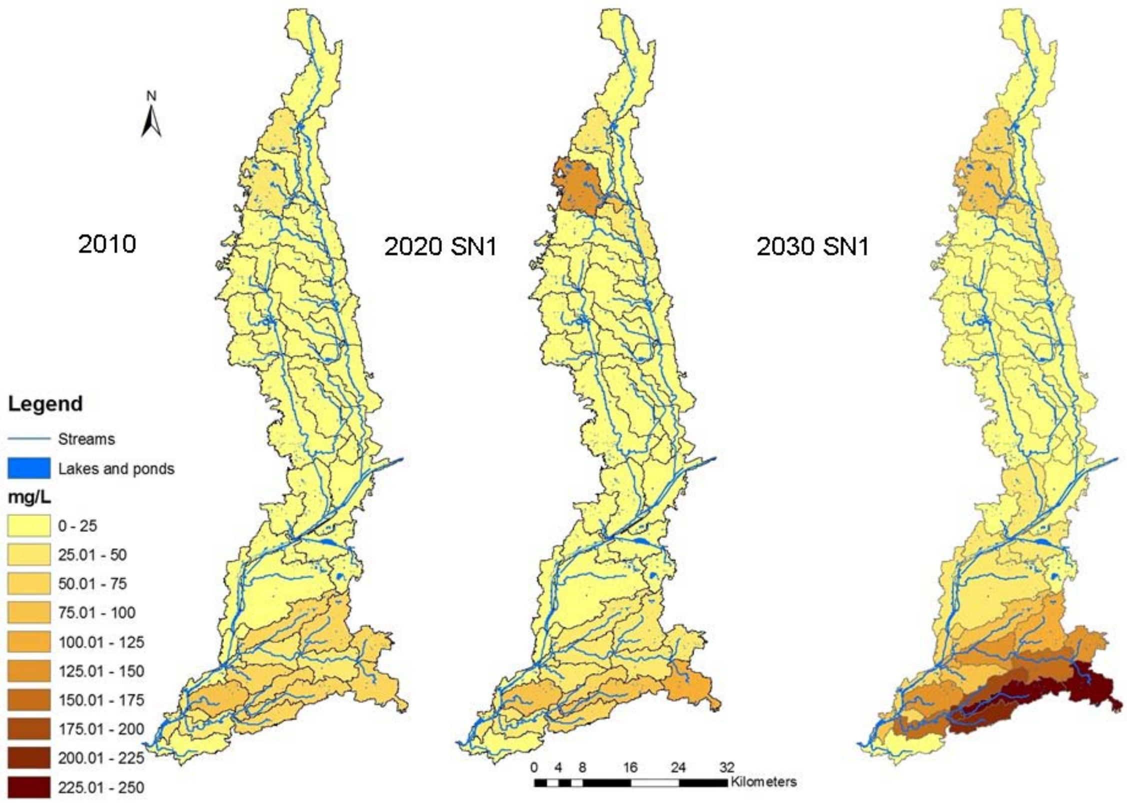


Figure 7: Projected total suspended solids concentration in Des Plaines River watershed for March under SRES A1B climate scenario. Note: SN1 = land use/planning scenario 1.