Effects of Historic and Current Land Covers on Water Budget and Water Quality in Agricultural Regions of Michigan and Wisconsin:

SWAT Model Report 040801 (Lake Huron)

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1.0 General Information

The Lake Huron Watershed lies on the East edge of Michigan's Lower Peninsula. The basin, as the rest of the Peninsula, has a mild topography. The minimum elevation is 176m and the maximum elevation reads 472m with a mean of 324m. The catchment has a total area of 664 thousand hectares (or 1.64 million acres). A relief map is shown in figure 1.

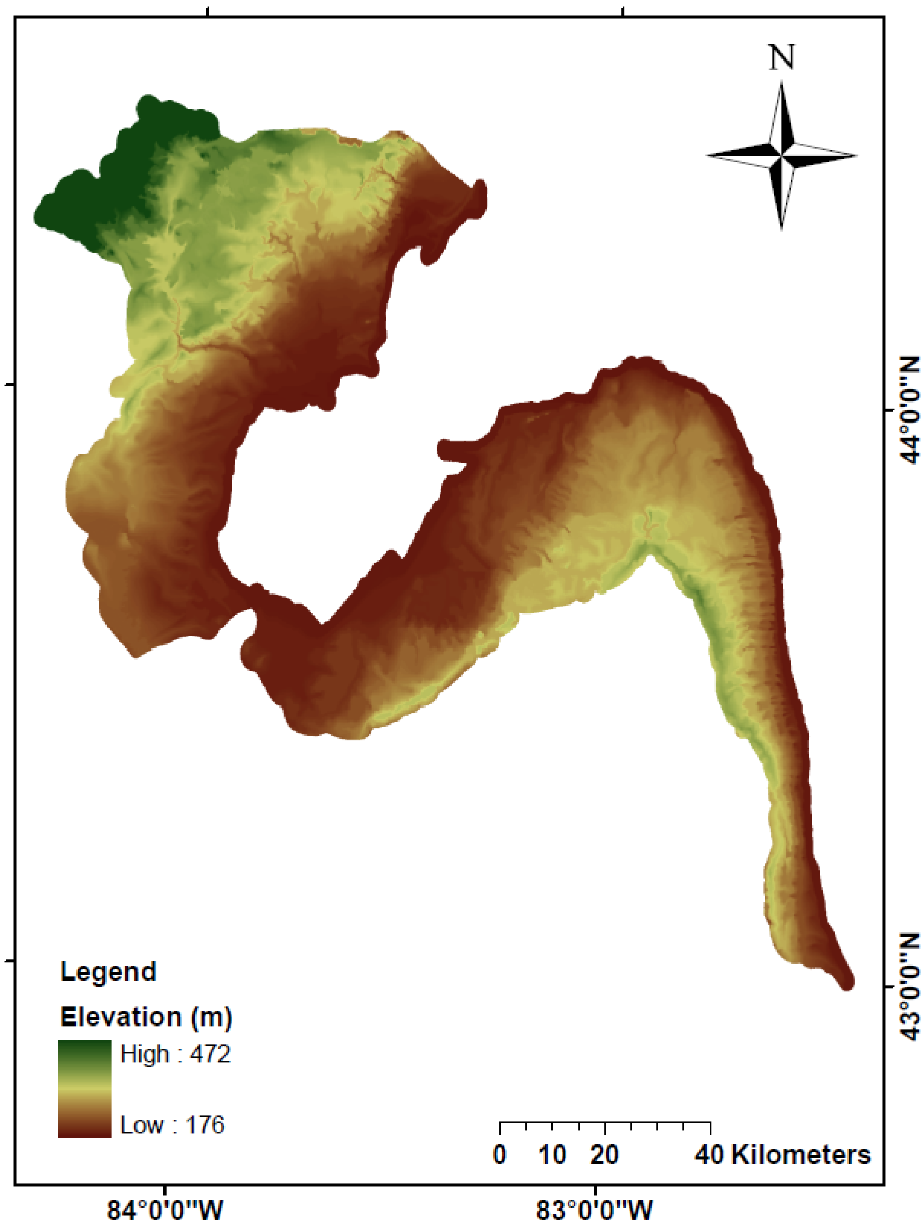


Figure 1. Relief map of the Lake Huron Basin

2.0 River Network

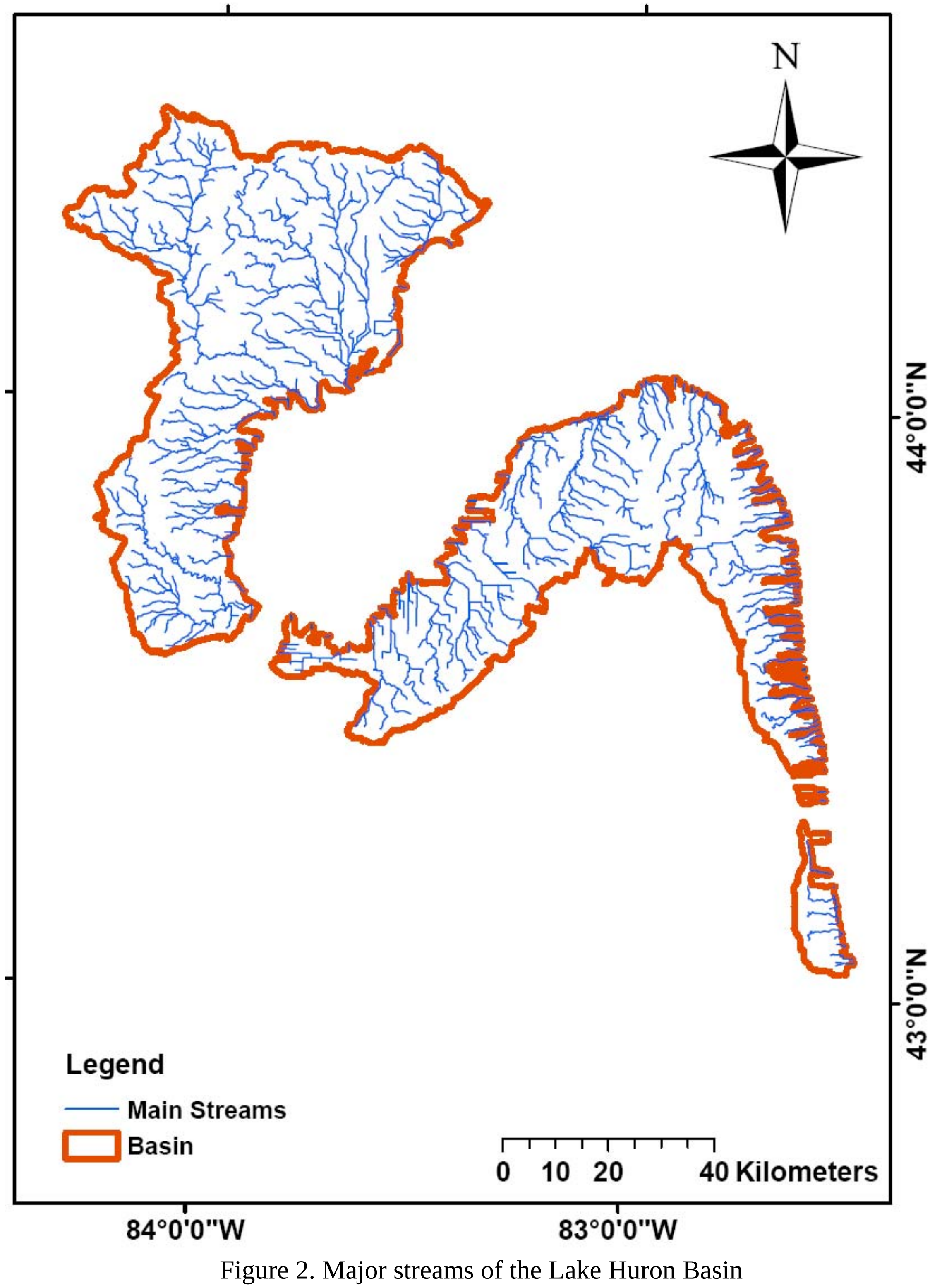


Figure 2. Major streams of the Lake Huron Basin

3.0 Landuse/Land Cover map

Two set of maps were used in this study.
1) 2001 National Land Cover Dataset (NLCD 2001)
2) Landuse Circa 1800 County Base (LU1800) Edition: 1.

Based on the 2001 National Land Cover Dataset, cropland in the Lake Huron Basin Watershed is the predominant land usage covering 52 percent of land area. Forest covers 20 percent of the land area. Urban areas, wetlands, rangelands, and water constitute the remaining 28 percent of land cover (Tables 1a and 1b). In the Lake Huron Basin, forest, wetland, and agriculture are dispersed throughout the northern area and agricultural land occupies a majority of the southern area (Figure 3).

Table 1a. Landuse of the Lake Huron Basin ranked by area (NLCD 2001)

LANDUSE:	AREA (ha)	PERCENTAGE
Agricultural Land-Row Crops	306905.4	42.8
Forest-Deciduous	95995.1	13.4
Wetlands-Forested	86052.0	12.0
Hay	66643.0	9.3
Forest-Evergreen	35956.2	5.0
Range-Grasses	34025.0	4.8
Residential-Low Density	26925.7	3.8
Residential-Medium Density	25929.8	3.6
Forest-Mixed	12612.5	1.8
Wetlands-Non-Forested	7892.4	1.1
Water	5415.3	0.8
Range-Brush	4245.8	0.6
Range-Other	3754.2	0.5
Residential-High Density	3463.2	0.5
Industrial	693.1	0.1

Table 1b. Landuse of the Lake Huron Basin given by coarse classification (NLCD 2001)

Agriculture	52.1%
Forest	20.2%
Wetland	13.1%
Urban	8.0%
Rangeland	5.9%
Water	0.8%

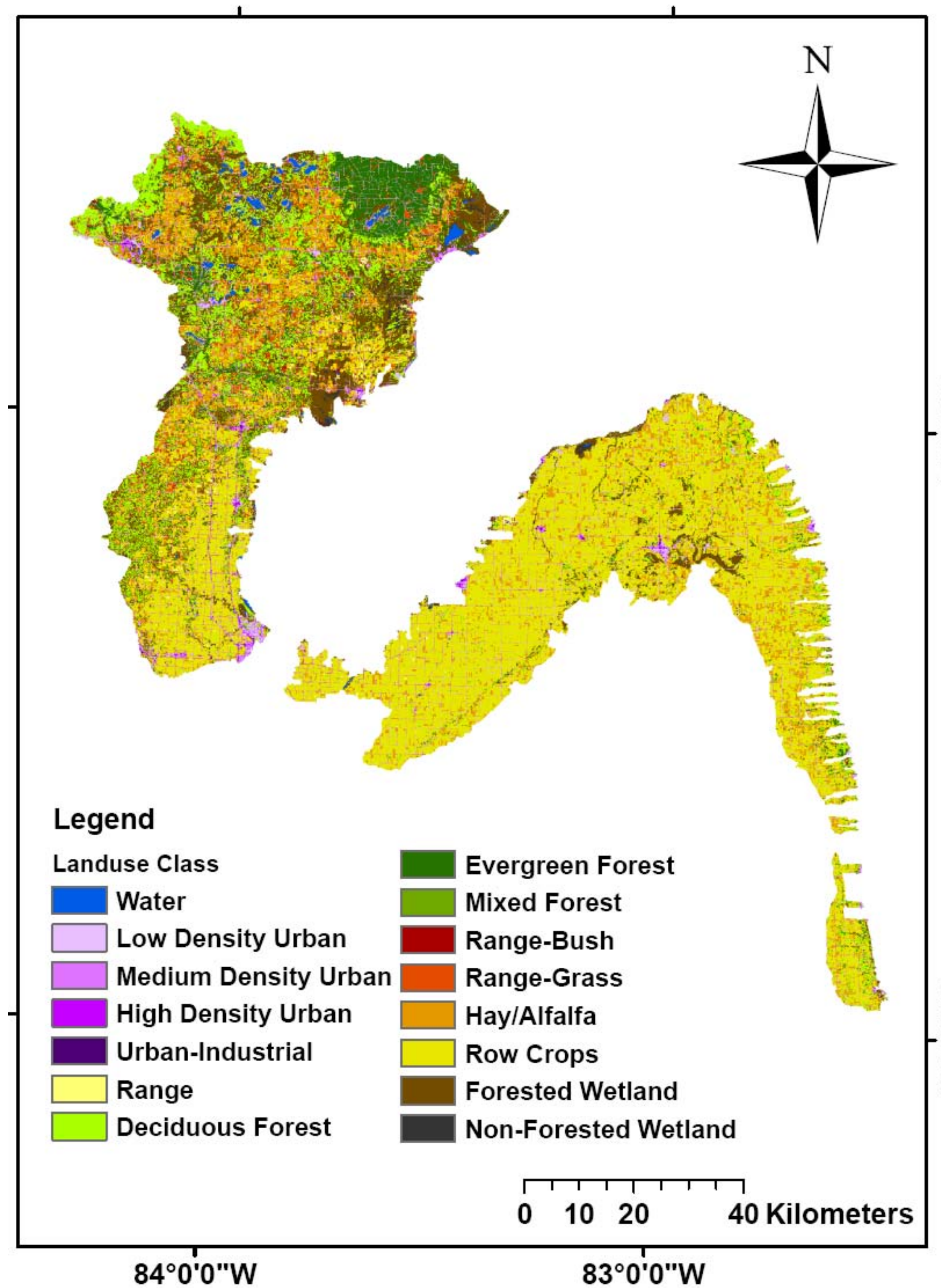


Figure 3. Current landuse map of the Lake Huron Basin

Based on the Landuse circa 1800 county base (LU1800), forest was the predominant land usage in the Lake Huron Basin covering 74 percent of land area. Wetlands covered 25 percent of the land area. Rangeland and water constitute the remaining one percent of land cover (Tables 2a and 2b). In the Lake Huron Basin, extensive wetlands were found along the shore of Saginaw Bay and scattered throughout the basin. (Figure 4).

Table 2a. Landuse of the Lake Huron Basin ranked by area (LU1800)

LANDUSE:	AREA (ha)	PERCENTAGE
Forest-Evergreen	283679.7	39.6
Forest-Mixed	240279.1	33.5
Wetlands-Forested	158177.7	22.1
Wetlands-Non-Forested	18436.8	2.6
Forest-Deciduous	8144.4	1.1
Water	4586.8	0.6
Rye	1674.3	0.2
Range-Brush	812.5	0.1
Range-Grasses	234.7	0.0
Range-Other	12.5	0.0

Table 2b. Landuse of the Lake Huron Basin given by coarse classification (LU1800)

Forest	74.2%
Wetland	24.6%
Water	0.6%
Rangeland	0.4%
Urban	0%
Agriculture	0%

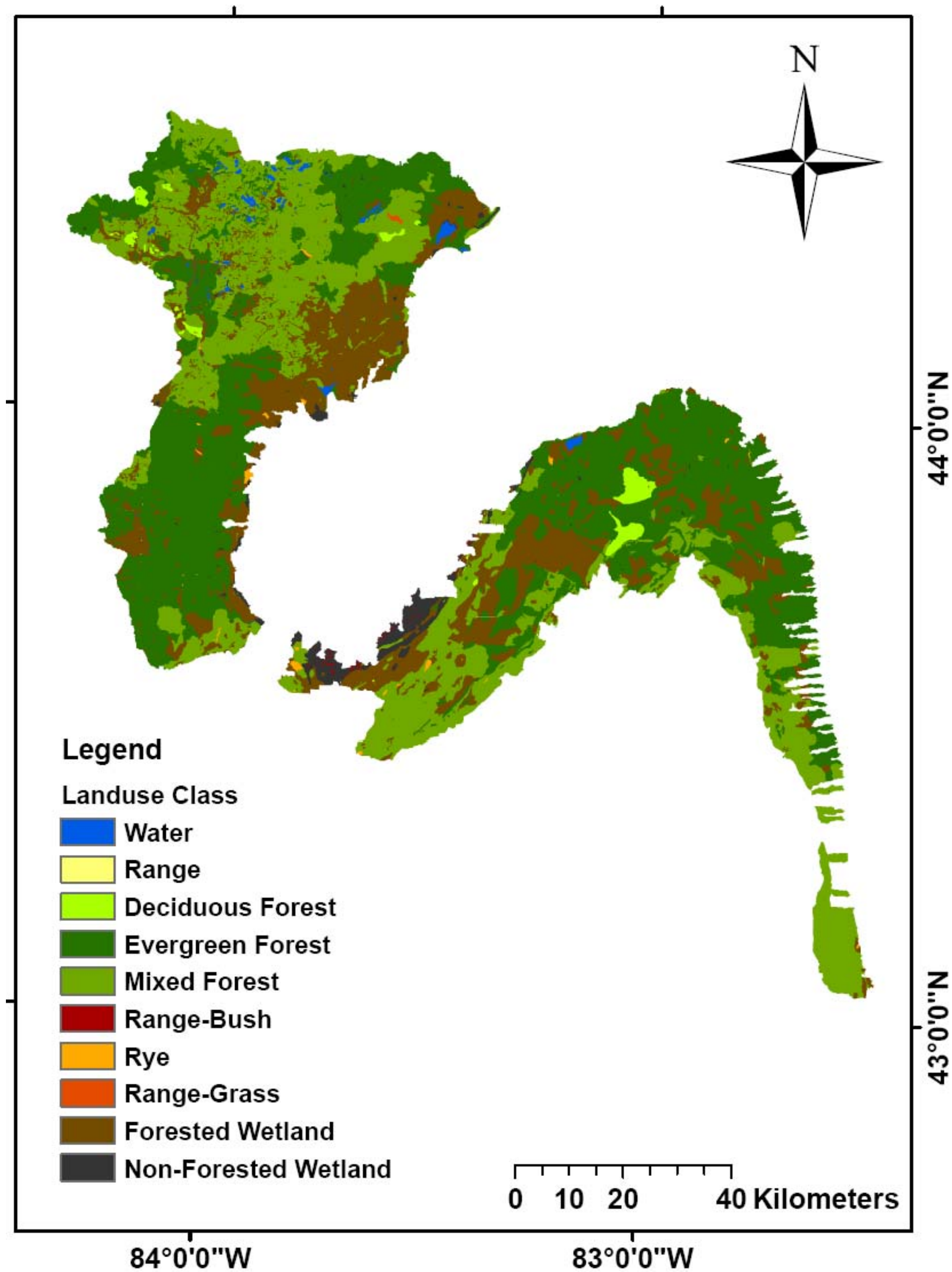


Figure 4. Pre-Settlement landuse map of the Lake Huron Basin

4.0 Hydrologic Soil Groups

The Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center (NCGC) developed the State Soil Geographic (STATSGO) Database. Figure 5 shows the hydrologic soil group for the Lake Huron Basin.

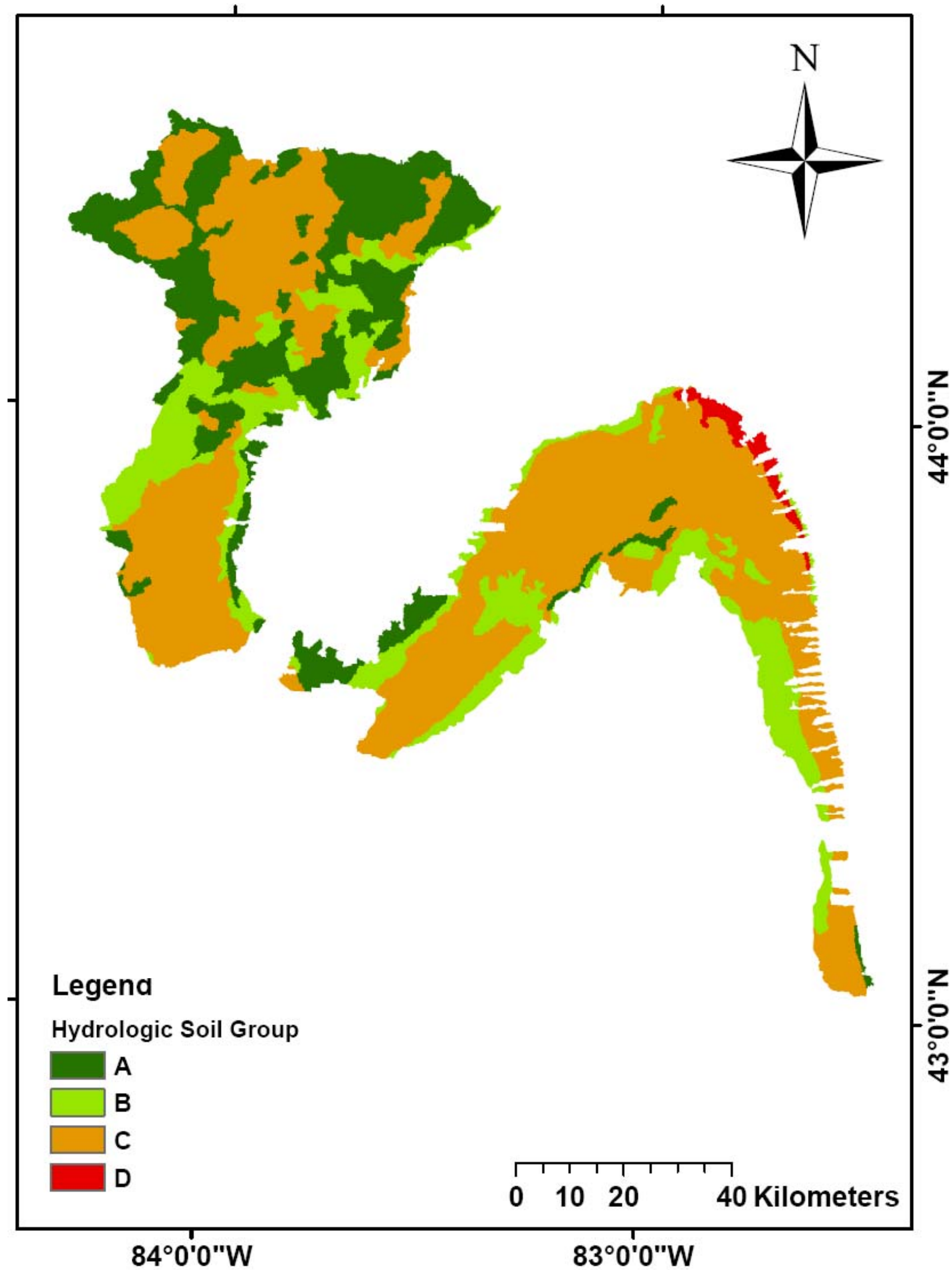


Figure 5. Hydrologic Soil Groups for the Lake Huron Basin

5.0 Climate data

Daily records of precipitation along with minimum and maximum temperatures are obtained from National Climatic Data Center (NCDC). However, relative humidity, wind speed and solar radiation were estimated by the weather generator in the SWAT model. Figure 6 shows the locations of precipitation and temperature gages used for this watershed. As a default approach, the climatic data of a watershed is assigned from the nearest climatic station.

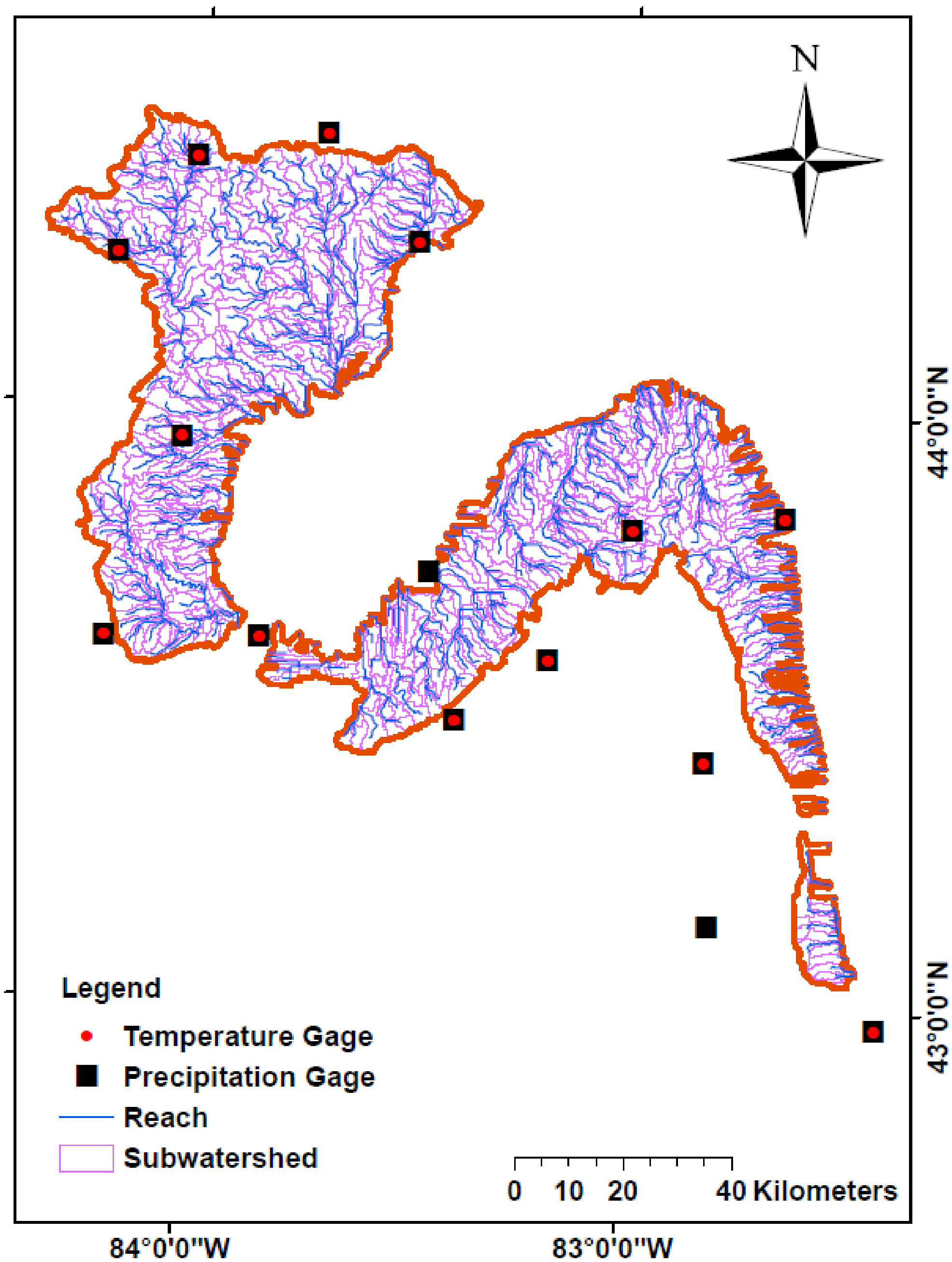


Figure 6. Temperature and precipitation gages in the Lake Huron Basin

6.0 SWAT Model

In this project ArcSWAT 2.1.5a for ArcGIS 9.2 SP6 was used. This version of the SWAT model was released on 7/20/2009. We also used Better Assessment Science Integrating point & Non-point Sources (BASINS v. 4.0 released on 03/2009) to obtain model inputs. Nineteen years of daily precipitation and temperature data (1990 to 2008) were used to setup the model.

6.1 Watershed Delineation

The Digital Elevation Model (DEM 90 m) and USGS National Hydrography Dataset (NHD) were used to delineate the study area. In the case of observing cuts in the stream networks, finer resolution elevation data set (National Elevation Dataset-NED) was employed to correct the inconsistencies within the stream networks. The study area was divided to 805 subwatersheds. Figure 7 shows the boundary and the locations of subwatersheds in the Lake Huron Basin.

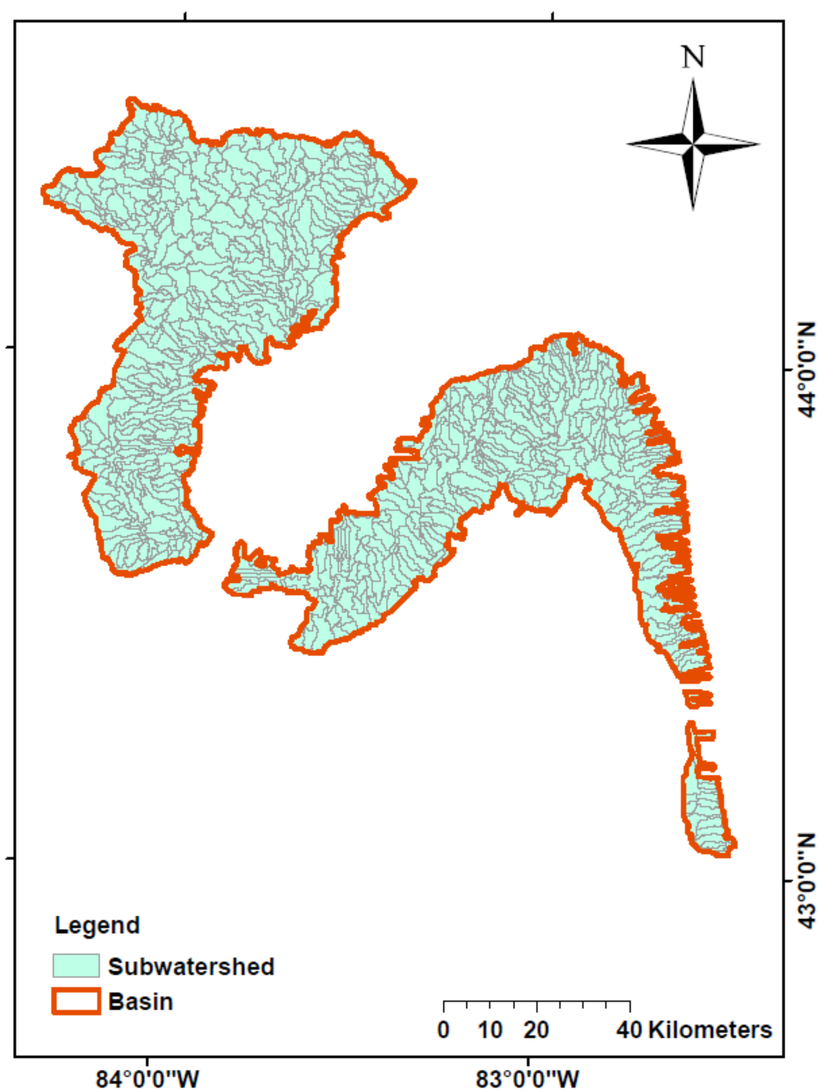
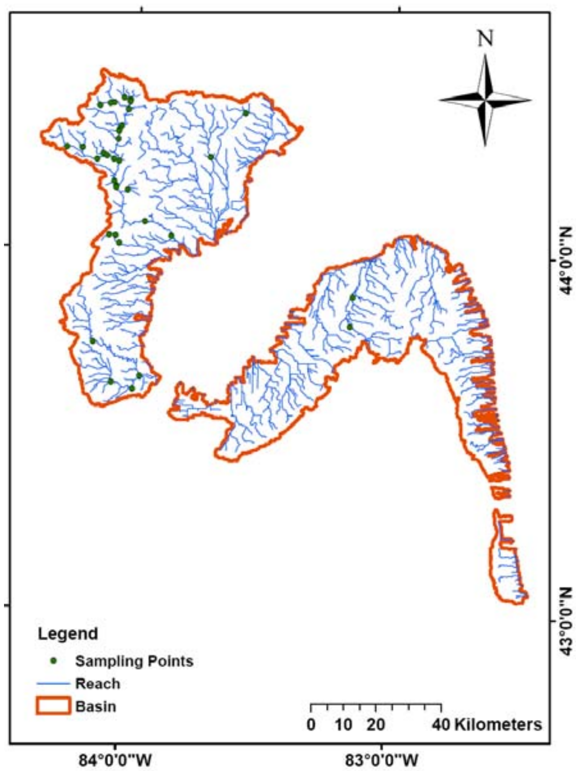


Figure 7. The delineated watersheds

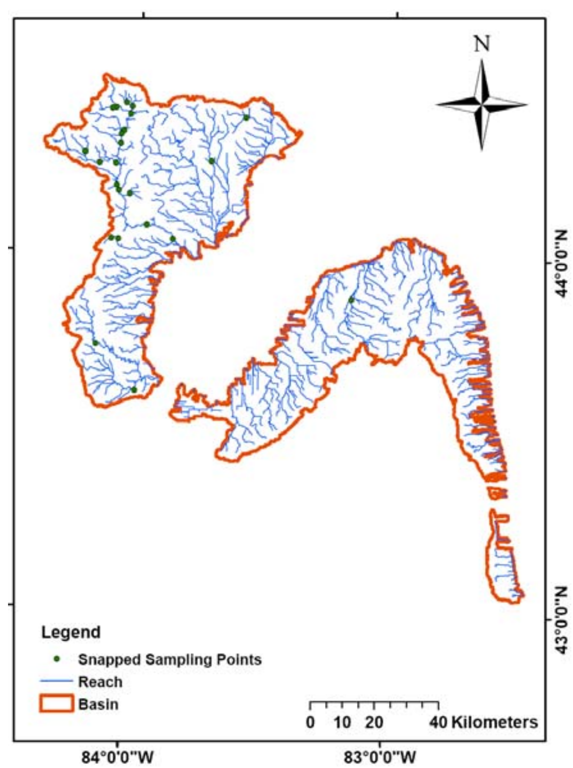
The SWAT model generates results on the outlets of subwatersheds. Since our goal is to obtain the model results on the locations of fish sampling points, these points were introduced to the model. In some cases, the fish sampling points lie on small creeks, which are too small for the model to recognize. In those cases, fish sampling points are snapped to the nearest stream network. Therefore, the location of the outlet is sometimes different form the original location of the fish sampling point (Table 3). Figures 8a and 8b show the locations of the original fish sampling points and the model.

Table 3. Coordinates of the original and snapped fish sampling points

Original	LAT	LONG	Snapped	LAT	LONG
1	44.0375	-84.0684	1	44.2783	-84.2088
2	44.0182	-84.0537	2	44.2788	-84.2076
3	44.0394	-84.0940	3	44.2481	-84.1500
4	43.7424	-84.1406	4	43.7424	-84.1406
5	43.6510	-83.9585	5	44.4035	-84.1062
6	43.6320	-84.0658	6	44.0394	-84.0940
7	43.6149	-83.9843	7	44.4062	-84.0915
8	43.8848	-83.1522	8	44.2497	-84.0854
9	43.8041	-83.1604	9	44.1883	-84.0811
10	44.4201	-84.0533	10	44.1751	-84.0722
11	44.4150	-84.0286	11	44.3056	-84.0704
12	44.4150	-84.0286	12	44.0375	-84.0684
13	44.4097	-84.0298	13	44.3324	-84.0678
14	44.4062	-84.0915	14	44.3417	-84.0599
15	44.3973	-84.1458	15	44.4201	-84.0533
16	44.4035	-84.1062	16	44.3892	-84.0351
17	44.3892	-84.0351	17	44.4097	-84.0298
18	44.3892	-84.0351	18	44.1653	-84.0282
19	44.3882	-83.5827	19	43.6149	-83.9843
20	44.3417	-84.0599	20	44.0797	-83.9576
21	44.3324	-84.0678	21	44.0426	-83.8546
22	44.3258	-84.0696	22	44.2639	-83.7128
23	44.3056	-84.0704	23	44.3882	-83.5827
24	44.2798	-84.2673	24	43.8848	-83.1522
25	44.2788	-84.2076	25		
26	44.2783	-84.2088	26		
27	44.2639	-83.7128	27		
28	44.2645	-84.1265	28		
29	44.2590	-84.1117	29		
30	44.2497	-84.0854	30		
31	44.2450	-84.0647	31		
32	44.2481	-84.1500	32		
33	44.1883	-84.0811	33		
34	44.1751	-84.0722	34		
35	44.1716	-84.0729	35		
36	44.1653	-84.0282	36		
37	44.0797	-83.9576	37		
38	44.0426	-83.8546	38		



(a)



(b)

Figure 8. Maps of the original fish sampling points (a) and the model's outlets (b).

6.2 Monitoring Stations

The model was calibrated on a monthly basis for flow, sediment, and total nitrogen. Calibration for phosphorus could not be completed because the required number of observed samples were not available. Five years of data were used for calibration, including 20 observations for sediment and 16 observations for total nitrogen.

The most downstream USGS gaging station on the Rifle River (Station No. 04142000) was used to calibrate the model for flow and water quality (Figure 9). Daily water quality data were input to the USGS Load Estimator model (LOADEST) in order to generate monthly average values based on daily flow.

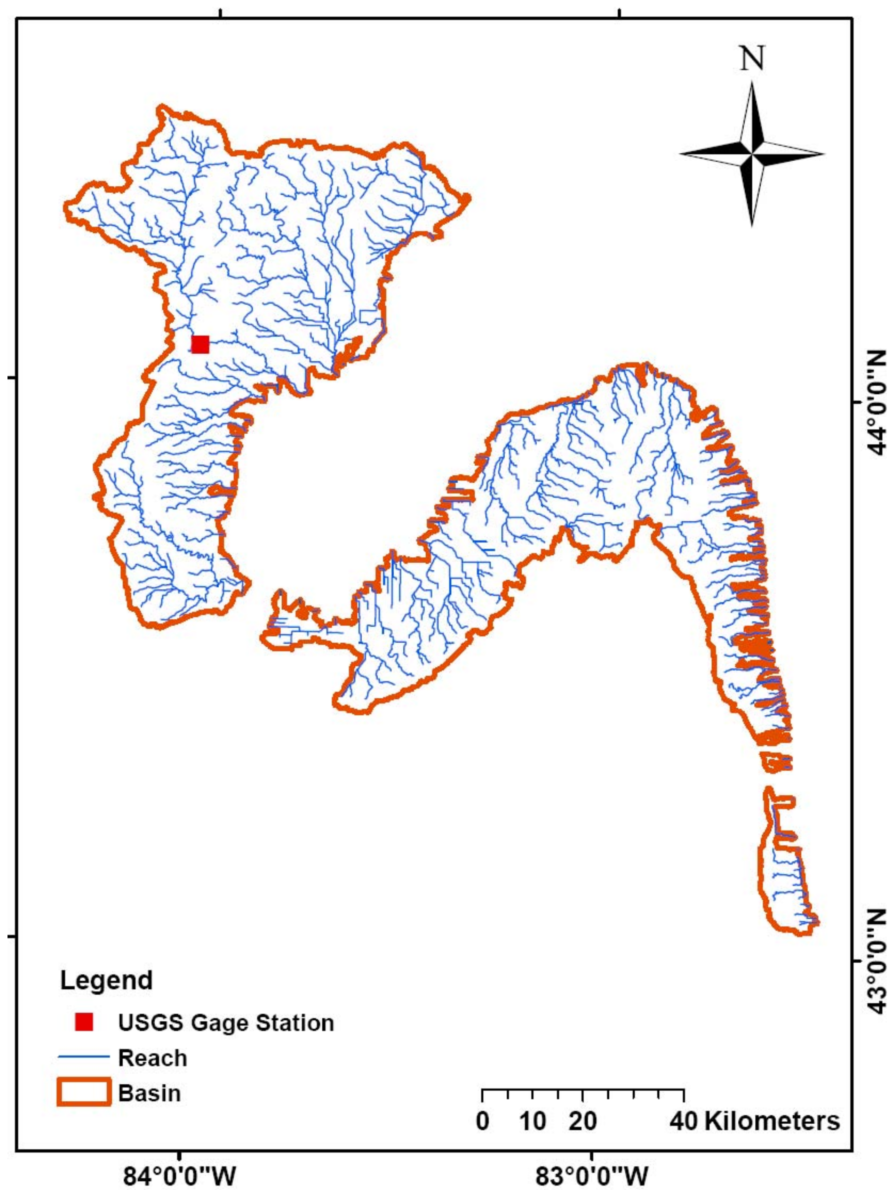


Figure 9. The delineated watersheds and selected USGS station.

6.3 Model Calibration

In the next step, the sensitivity analysis was performed. The Latin- Hypercube One-At-a-Time (LH-OAT) method was employed using observed flow, sediment, and total nitrogen (van Griensven, Meixner et al. 2006). Sensitivity analysis was performed for total phosphorus without using observed data. The sensitivity ranking of 42 parameters for this watershed is given in Table 4.

Table 4: Rank-Based Sensitivity Analysis*

	Flow	Sed	TotalN	TotalP
Alpha_Bf	1	3	1	2
Rchrg_Dp	2	8	5	13
Cn2	3	2	4	3
Gwqmn	4	15	9	20
Esco	5	12	14	9
Ch_K2	6	9	2	1
Timp	7	6	3	4
Canmx	8	14	10	7
Sol_Z	9	16	12	10
Sol_Awc	10	17	7	6
Blai	11	7	13	11
Slope	12	18	20	19
Gw_Revap	13	22	25	23
Surlag	14	13	6	5
Sol_K	15	25	18	14
Ch_N2	16	4	11	12
Biomix	17	10	15	16
Smtmp	18	19	8	8
Revapmn	19	28	23	27
Gw_Delay	20	23	19	15
Epco	21	21	21	18
Slsubbsn	22	24	16	17
Nperco	23	27	17	25
Sol_Alb	24	26	22	21
Usle_C	25	20	26	26
Spcon	42	1	42	42
Usle_P	42	5	24	22
Spexp	42	11	42	42
Pperco	42	29	28	28
Phoskd	42	30	27	24
Ch_Cov	42	42	42	42
Ch_Erod	42	42	42	42
Sftmp	42	42	42	42
Shallst_N	42	42	42	42
Smfmn	42	42	42	42
Smfmx	42	42	42	42
Sol_Labp	42	42	42	42
Sol_No3	42	42	42	42
Sol_Orgn	42	42	42	42
Sol_Orgp	42	42	42	42

* Each number represents the relative important of each parameter for a given objective, with 1 being most important and 42 being virtually no impact.

In the next step, the model was calibrated based on the results obtained from the sensitivity analysis and observed values from the monitoring stations. The Nash and Sutcliffe coefficient of efficiency, along with the root mean square error (RMSE), and the coefficient of determination (R^2) were used for the model evaluation. The results of this section are presented in Table 5, 6 and figures 10 to 15.

The calibrated model has achieved good comparisons with observed flow and acceptable comparisons with sediment. The comparisons of total nitrogen were not as good because the 16 observed data points did not provide enough information for detailed extrapolation. However, the model is still able to give proper predictions on the same magnitude with the observed data.

Table 5. Statistics of model calibration

	Nash-Sutcliffe	RMSE	R^2
Flow	0.528	0.744	0.579
Total Suspended Solids (TSS)	0.291	13.820	0.367
Total N	0.055	71.536	0.258

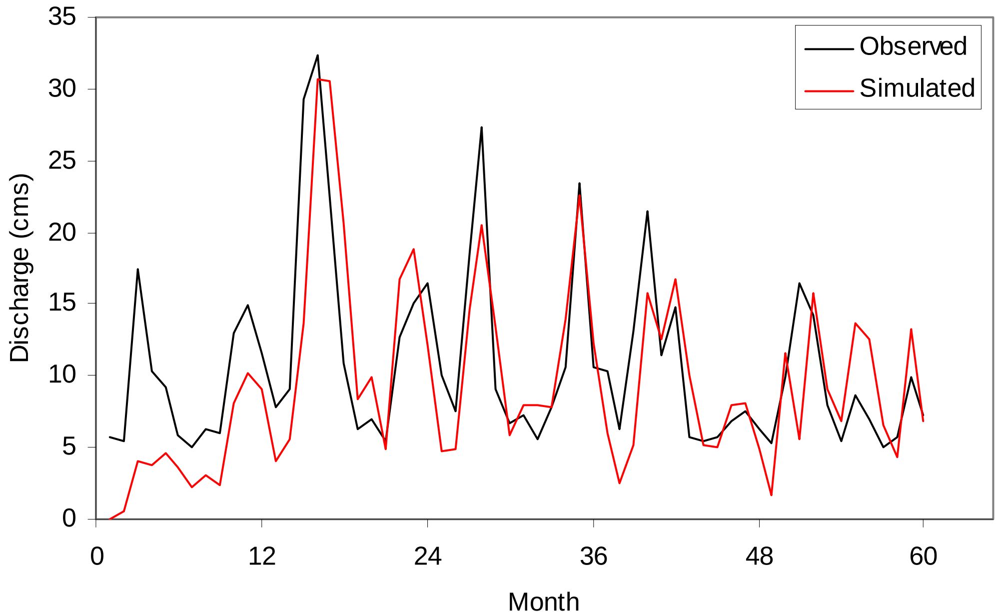


Figure 10. Model simulated results vs. USGS measurements at USGS 04142000 station

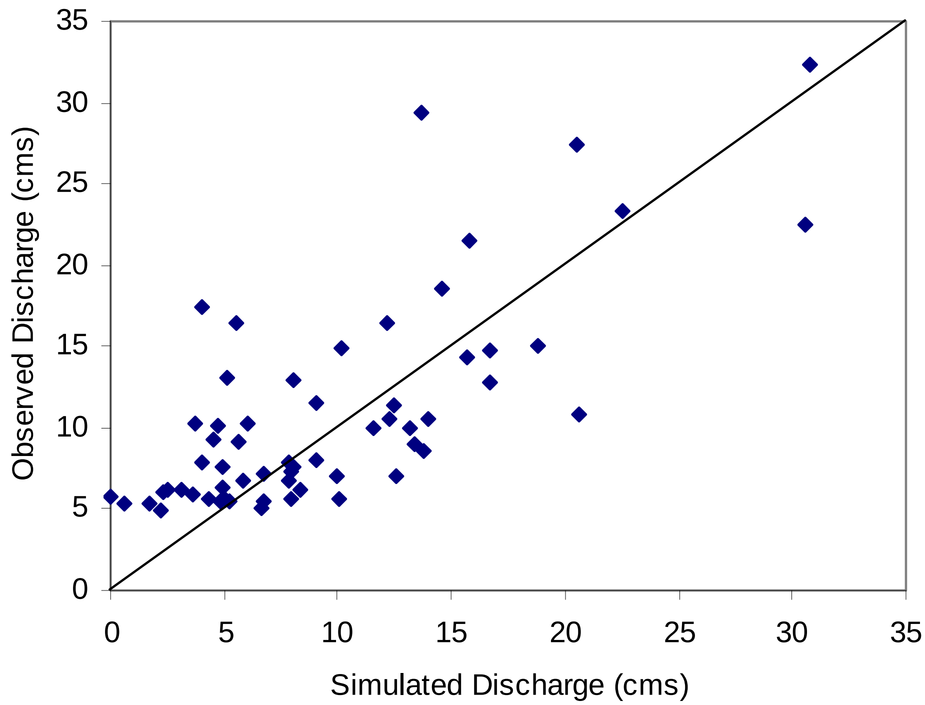


Figure 11. Simulated vs observed flow at USGS 04142000 station

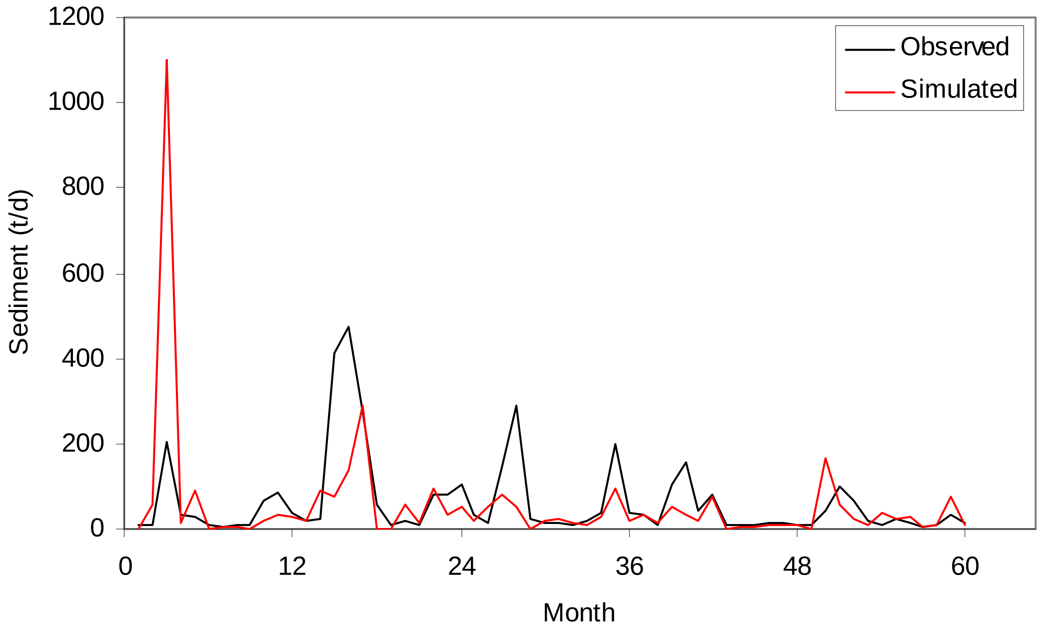


Figure 12. Time series of simulated vs observed TSS

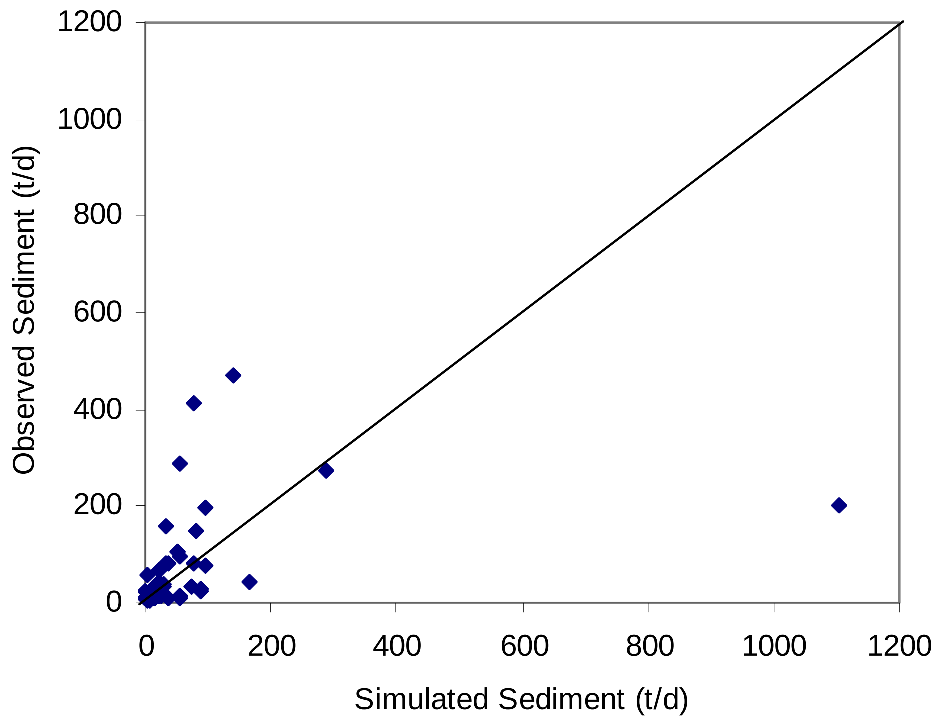


Figure 13. Simulated vs observed TSS

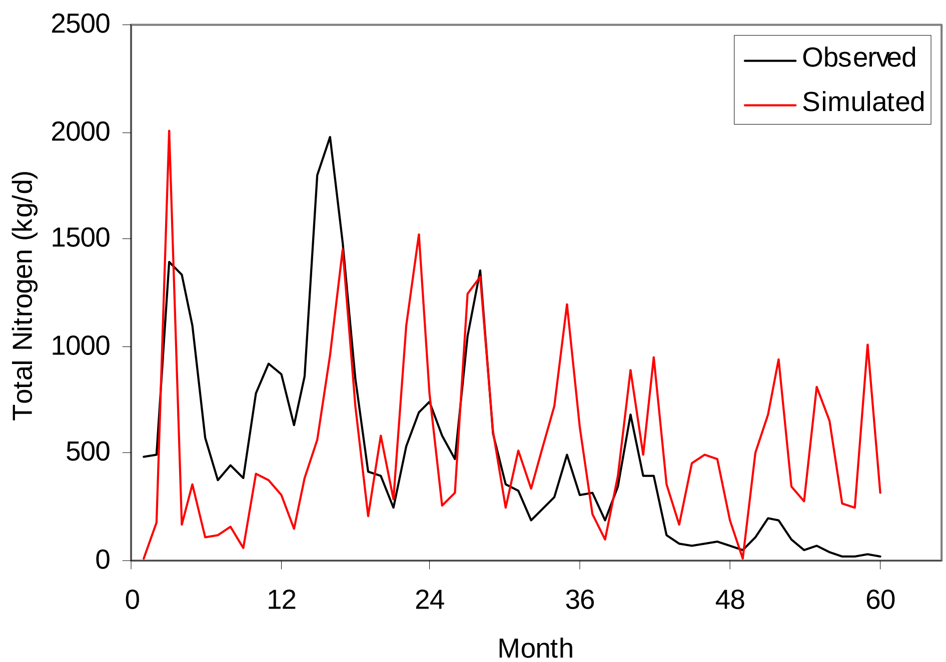


Figure 14. Time series of simulated vs observed Total Nitrogen

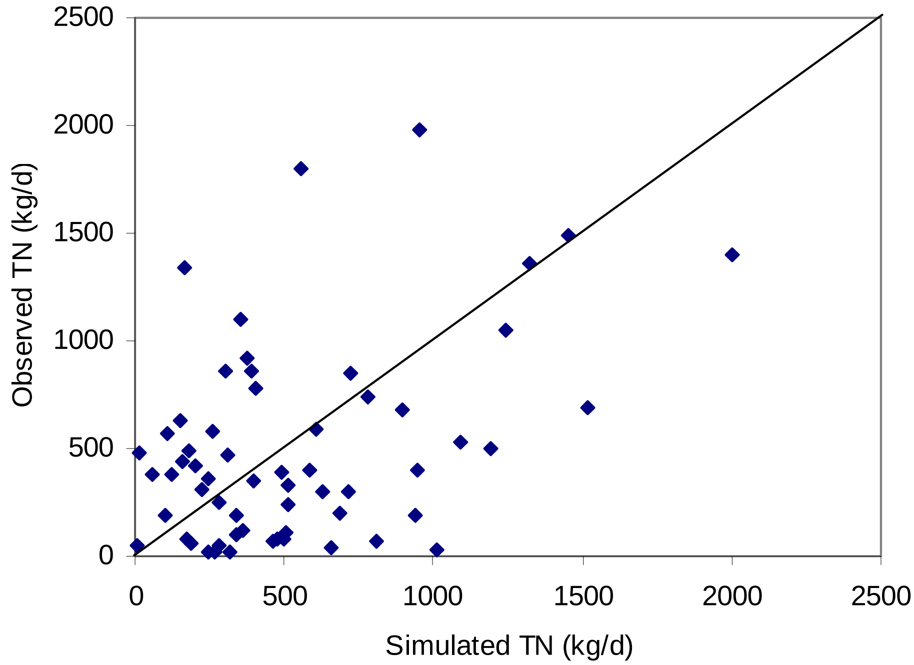


Figure 15. Simulated vs observed Total Nitrogen

Table 6. Monthly and annual hydrologic budget from the Lake Huron Basin

Month	Rain (mm)	Snowfall (mm)	Surface Runoff (mm)	Lateral Flow (mm)	Total Water Yield (mm)	ET (mm)	Sediment Yield (t/ha)	PET (mm)
1	52.54	35.42	16.7	0.04	24.48	6.94	0.18	11.3
2	42.4	30.89	19.56	0.03	23.45	9.62	0.21	15.95
3	44.76	18.69	31.12	0.43	40.43	28.32	0.32	47.48
4	73.45	7.51	11.35	0.6	35.27	43.64	0.12	85.99
5	84.51	0.01	10.73	0.46	31.77	58.86	0.15	128.64
6	82.85	0	10.26	0.41	26.46	86.59	0.12	159.07
7	80.7	0	5.08	0.33	16.4	110.95	0.04	167.55
8	82.38	0	4.08	0.38	12.59	58.22	0.03	140.9
9	78.24	0	6.82	0.36	14.3	39.26	0.06	105.34
10	67.8	0.49	4.84	0.42	15.35	32.59	0.04	64.25
11	68.79	8.56	7.64	0.42	21.94	20.82	0.06	34.37
12	51.37	29.82	11.6	0.11	25.22	11.64	0.1	18.43
Annual Average	809.79	131.39	139.78	3.99	287.66	507.45	1.43	979.27

6.4 Impacts of Landuse Changes (Pre-Settlement vs. Current) on Water Budget and Water Quality

In this stage of study, the landuse circa 1800 county base (LU1800) was used to setup the SWAT model for the pre-settlement (PS) scenario. Then the model was run for the period of 1990-2008 and the results were compared with the model results obtained based on the current landuse map (NLCD 2001). Results are presented in figures 16 to 25 and Table 7. Also, in order to compare the results from two different scenarios, percent change and percent difference were calculated. Percent change is the numerical interpretation of comparing one value with another (Equation 1). The equation for determining the percent difference is used to compare the change to the average of the two values (Equation 2).

$$\text{Percent change} = \frac{(x_1 - x_2)}{x_2} \times 100 \quad (1)$$

$$\text{Percent difference} = \frac{(x_1 - x_2)}{(x_1 + x_2)/2} \times 100 \quad (2)$$

The results are presented based on the average annual simulated values for the period of study (1990-2008).

Table 7. Annual average percent changes (1800 vs. current land covers) for the Saginaw Basin

Calibrated	Current	Pre-Settlement	Percent Change	Percent Difference
Recharge (mm)	148.06	234.79	-36.94%	-45.31%
Surface Runoff (mm)	137.95	88.27	56.28%	43.92%
Baseflow (mm)	146.02	230.58	-36.67%	-44.90%
Water Yield (mm)	287.98	322.57	-10.72%	-11.33%
Sediment Yield (t/ha)	1.43	0.02	8916.45%	195.61%
Total N Output (t/ha)	5.87	1.44	309.21%	121.45%
Total P Output (t/ha)	1.07	0.02	6543.60%	194.07%

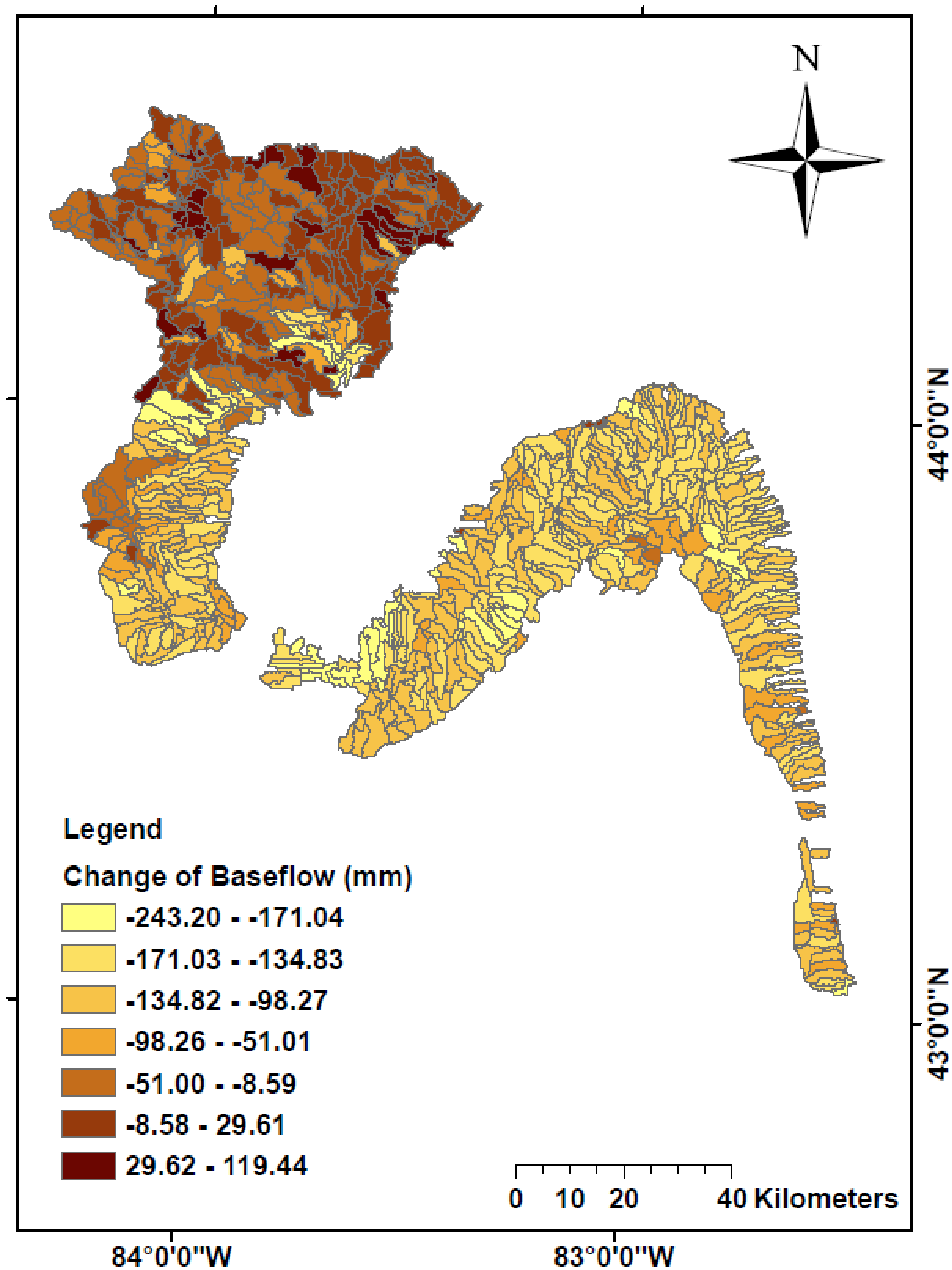


Figure 16. Change of baseflow values resulted from landuse changes (mm)

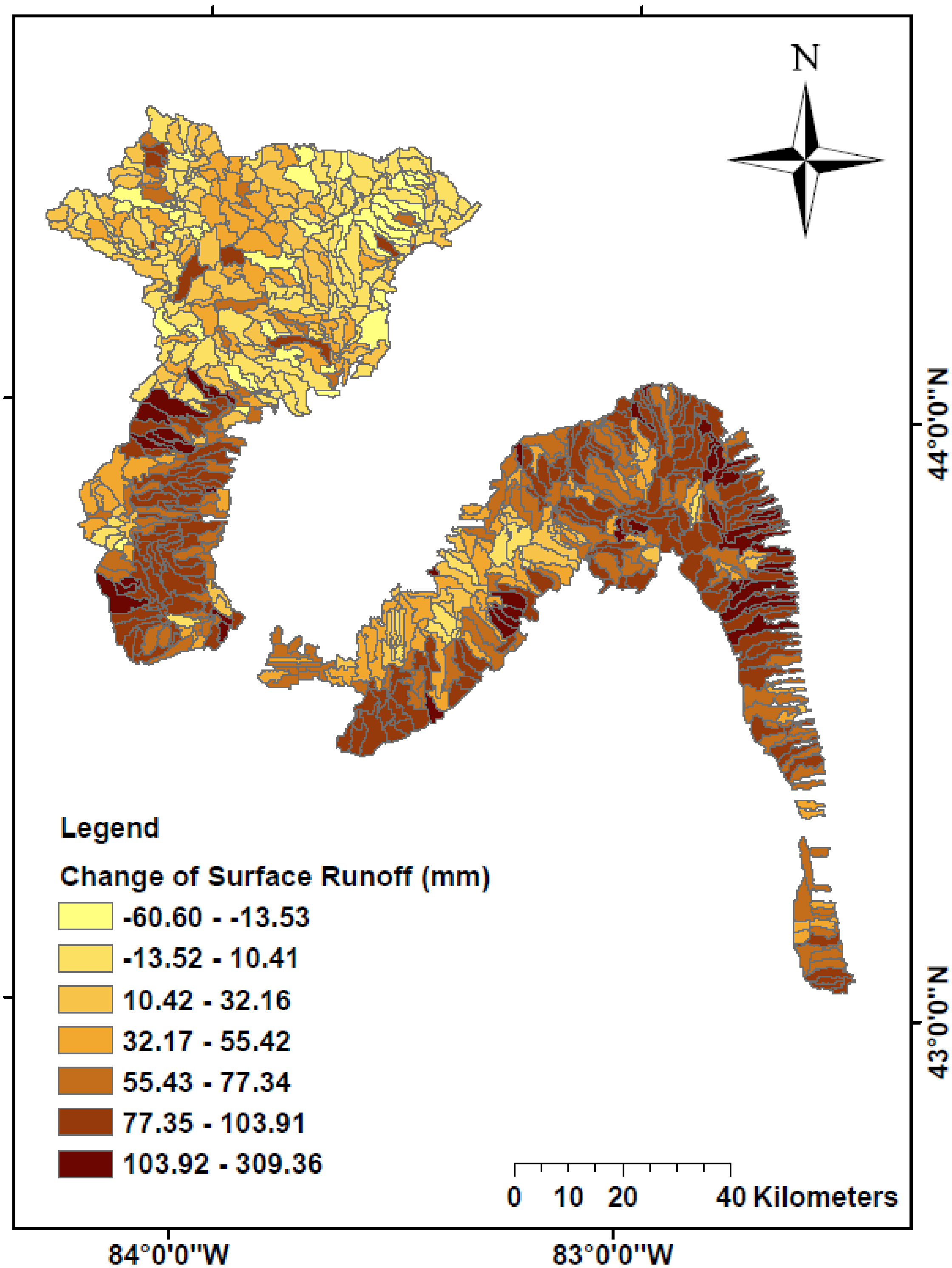


Figure 17. Change of surface runoff values resulted from landuse changes (mm)

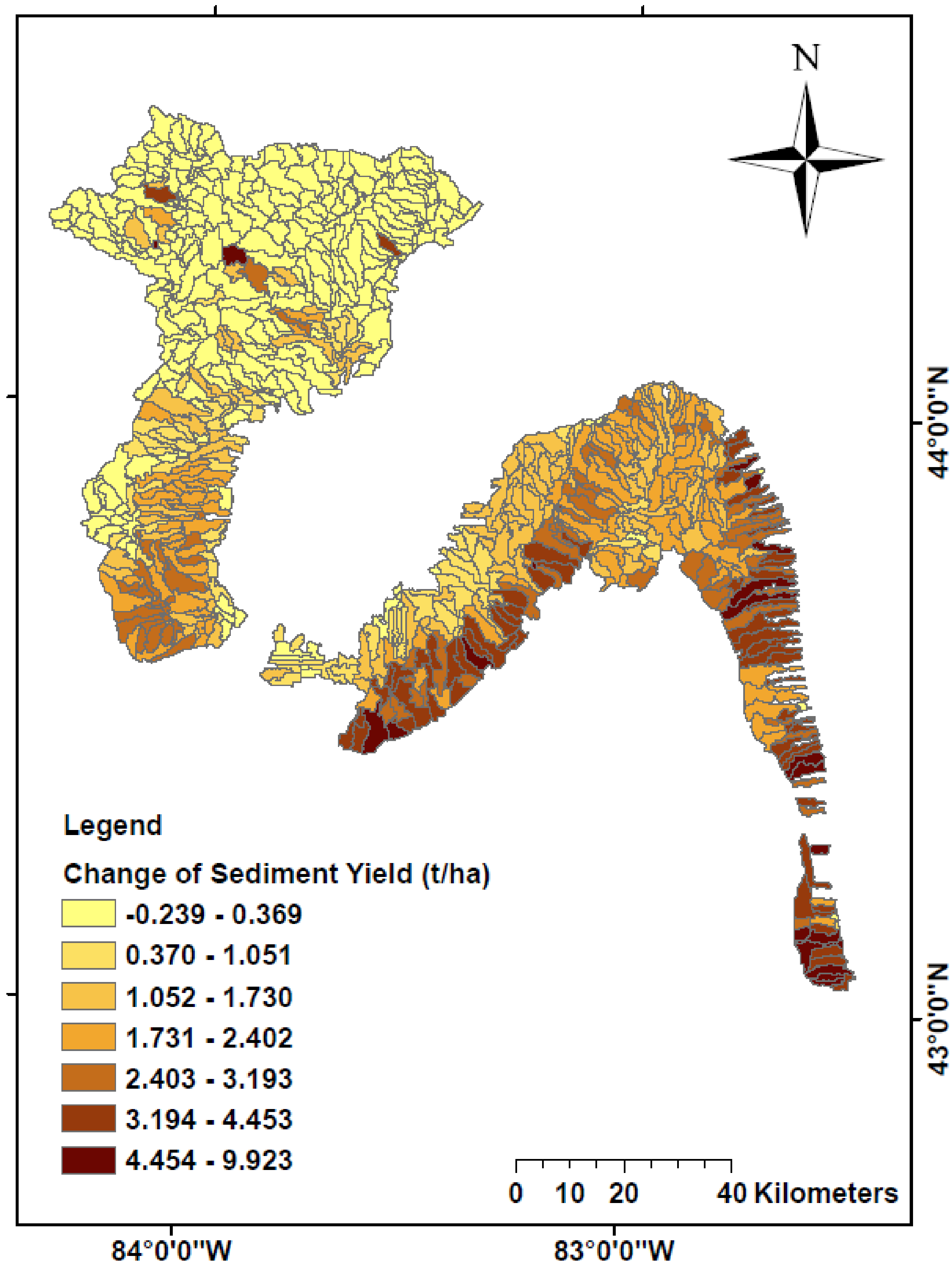


Figure 18. Change of sediment yields resulted from landuse changes (t/ha)

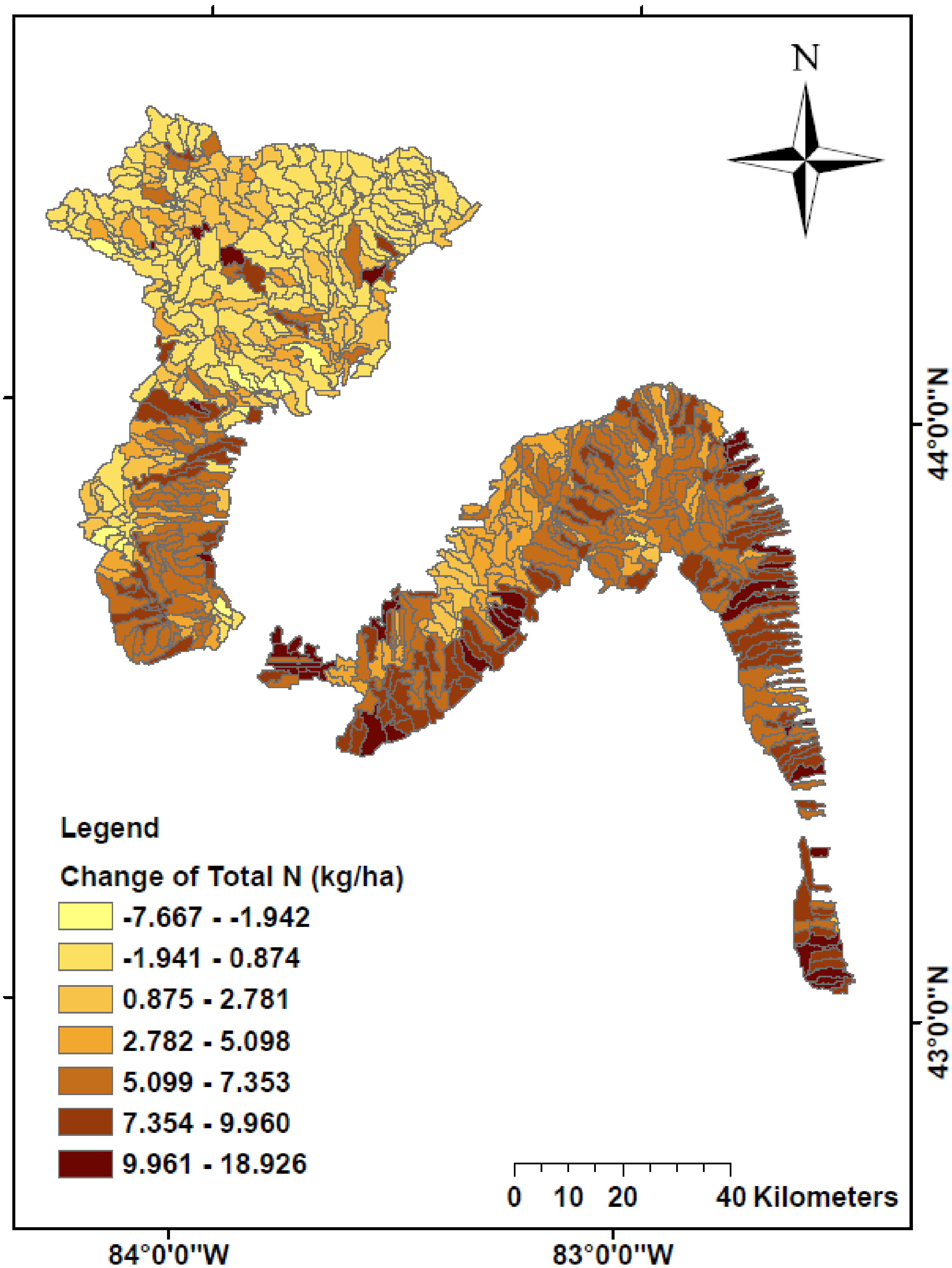


Figure 19. Change of total N output values resulted from landuse changes (kg/ha)

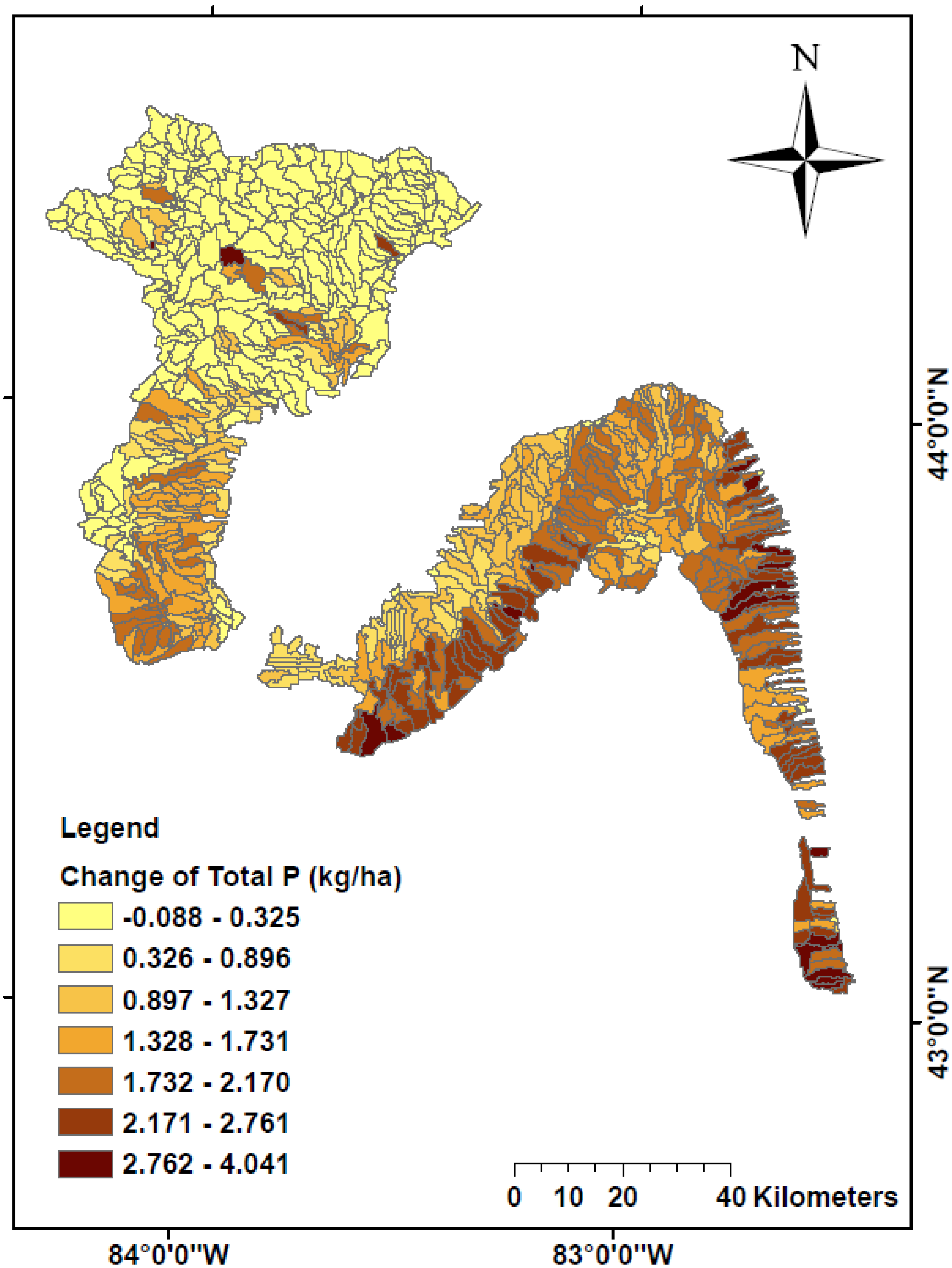


Figure 16. Change of total P output values resulted from landuse changes (kg/ha)

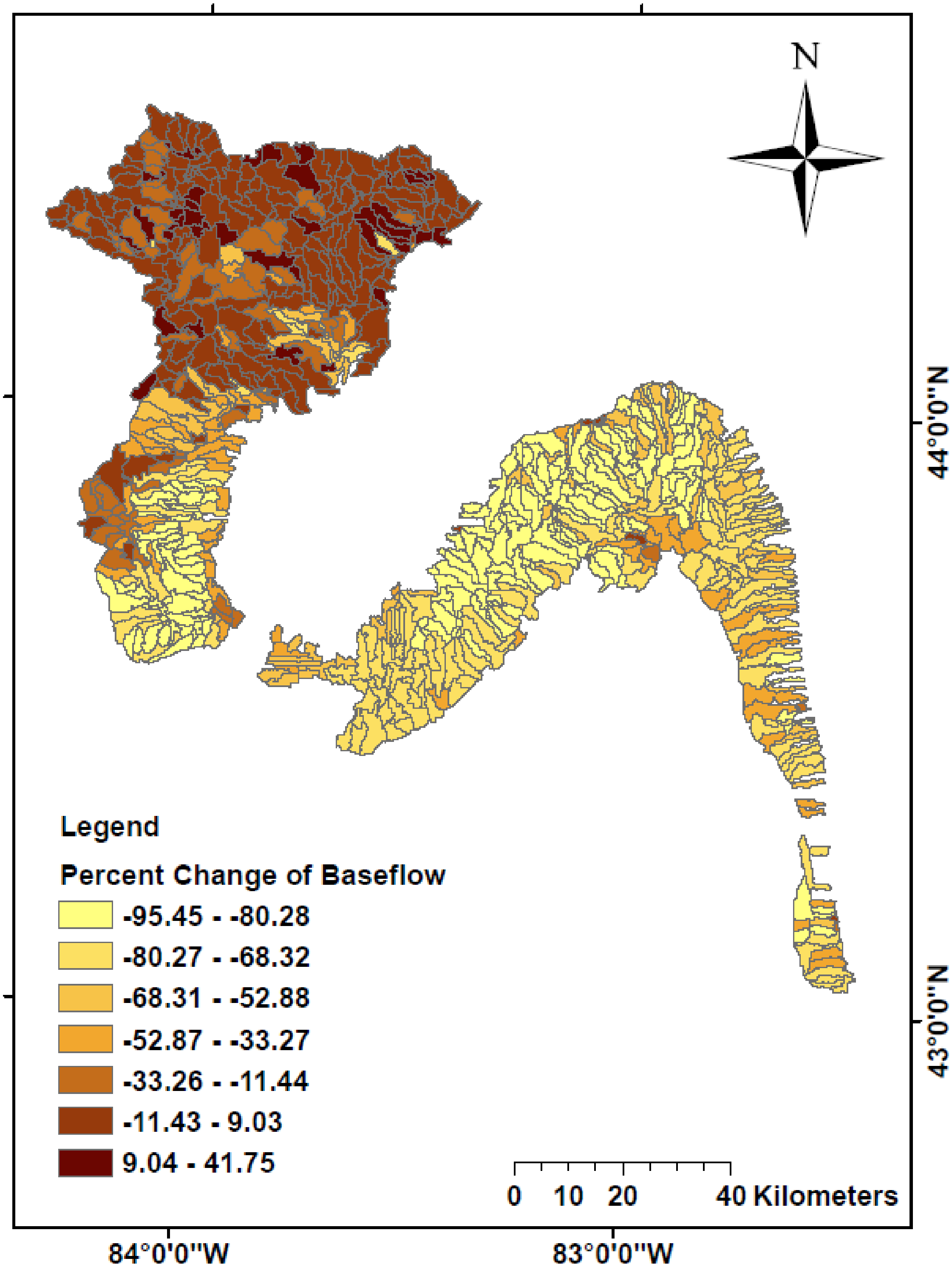


Figure 21. Percent change of baseflow values resulted from landuse changes

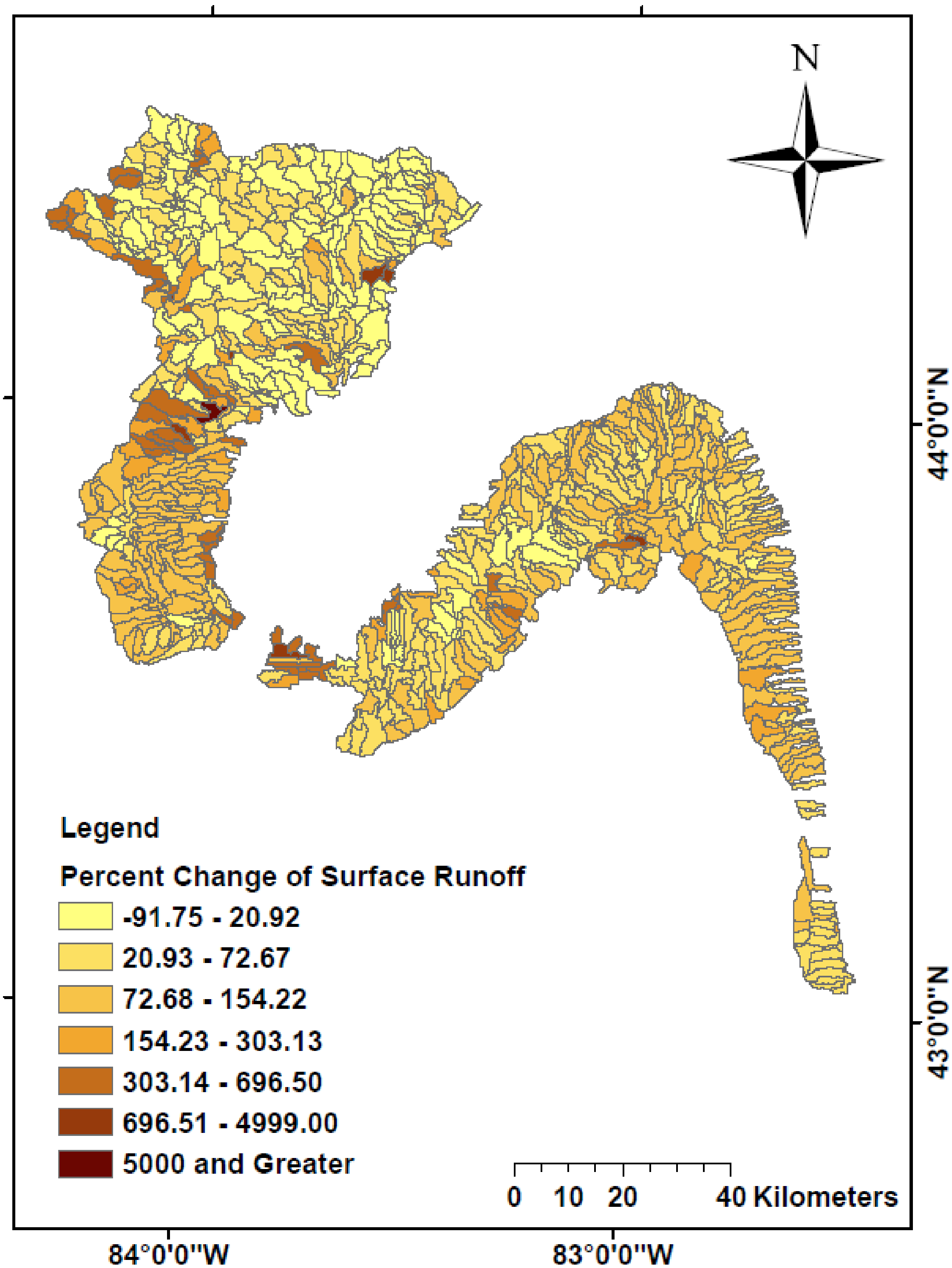


Figure 22. Percent change of surface runoff values resulted from landuse changes

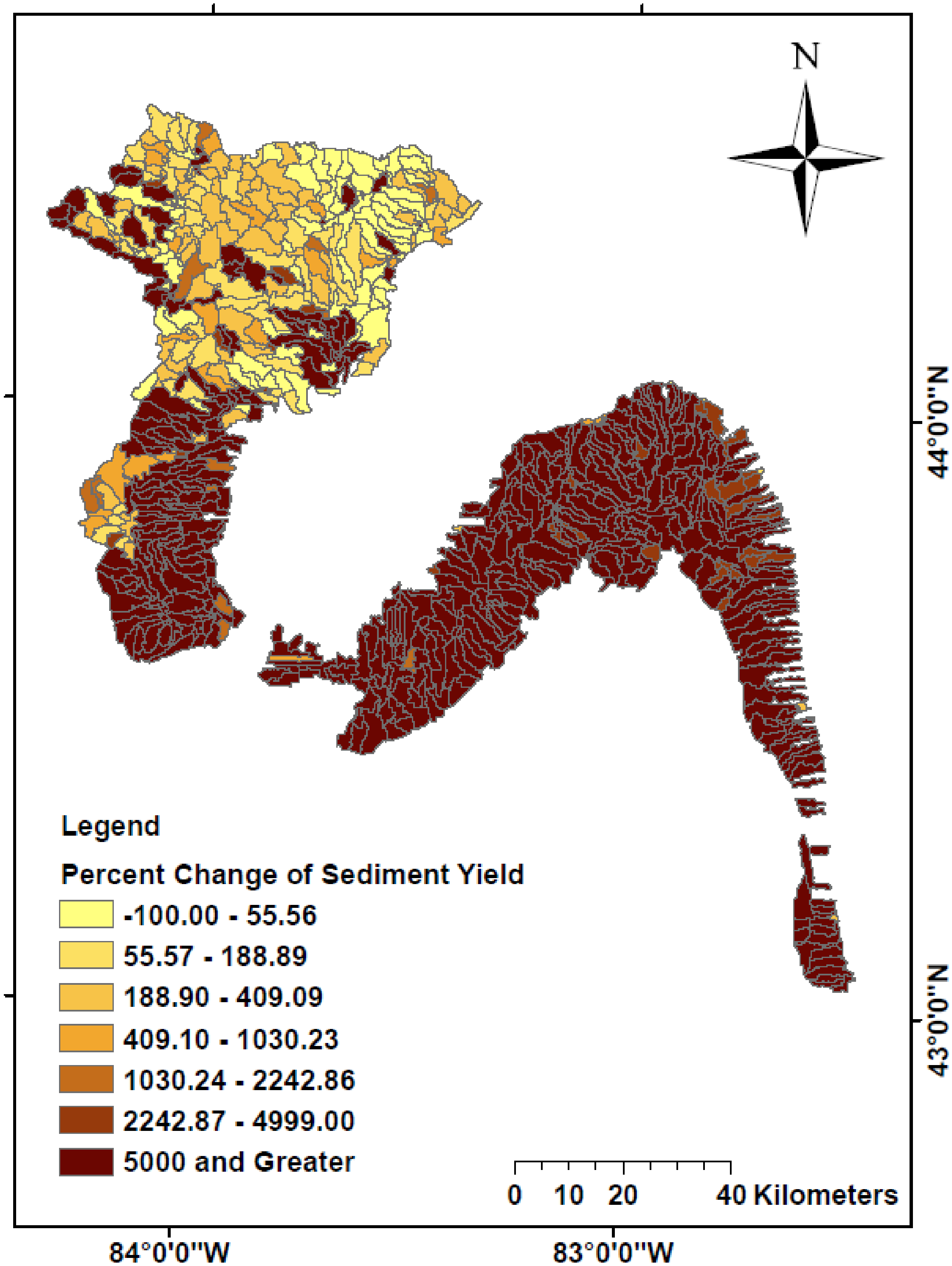


Figure 23. Percent change of sediment yield resulted from landuse changes

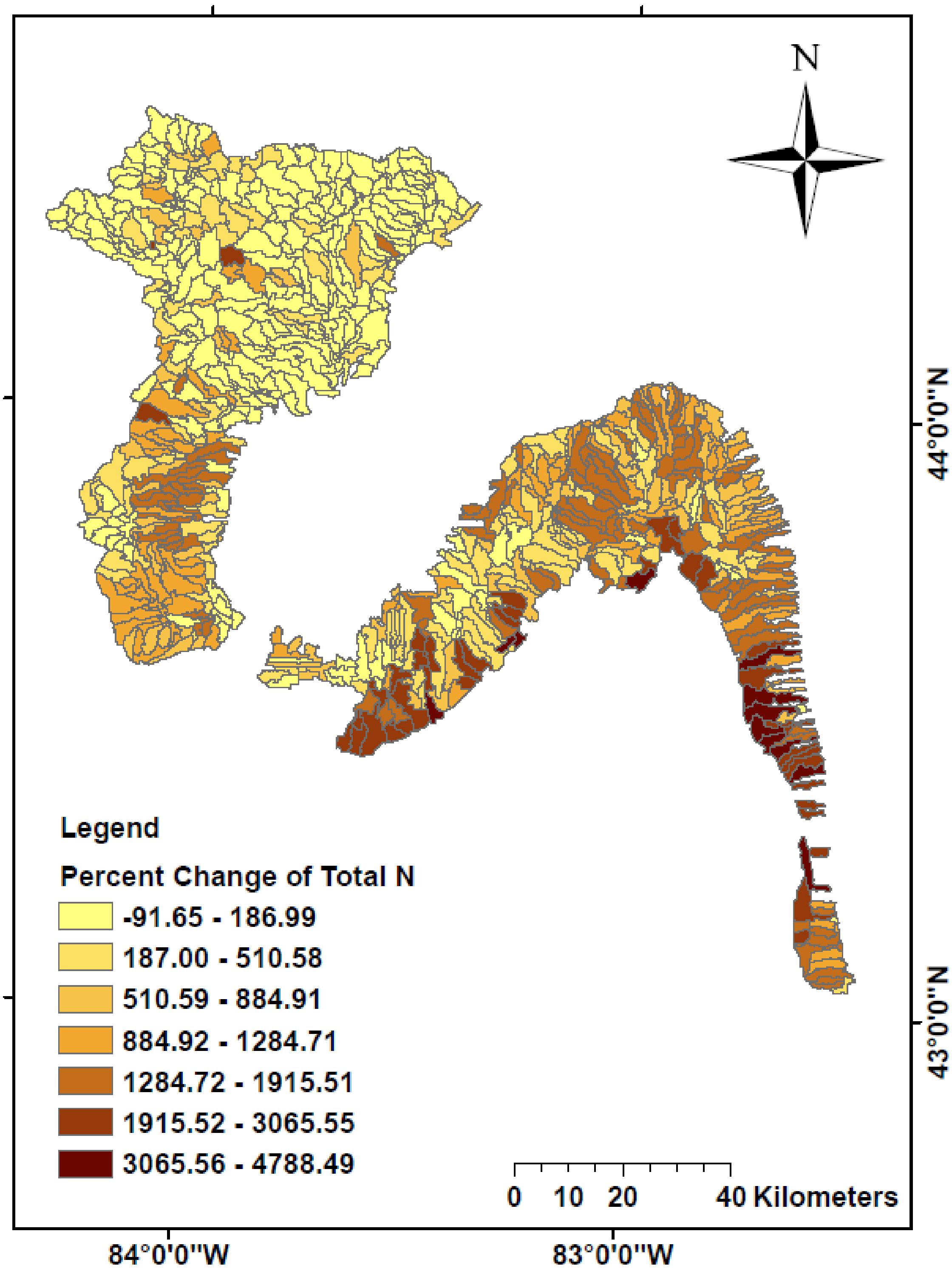


Figure 24. Percent change of total N output values resulted from landuse changes

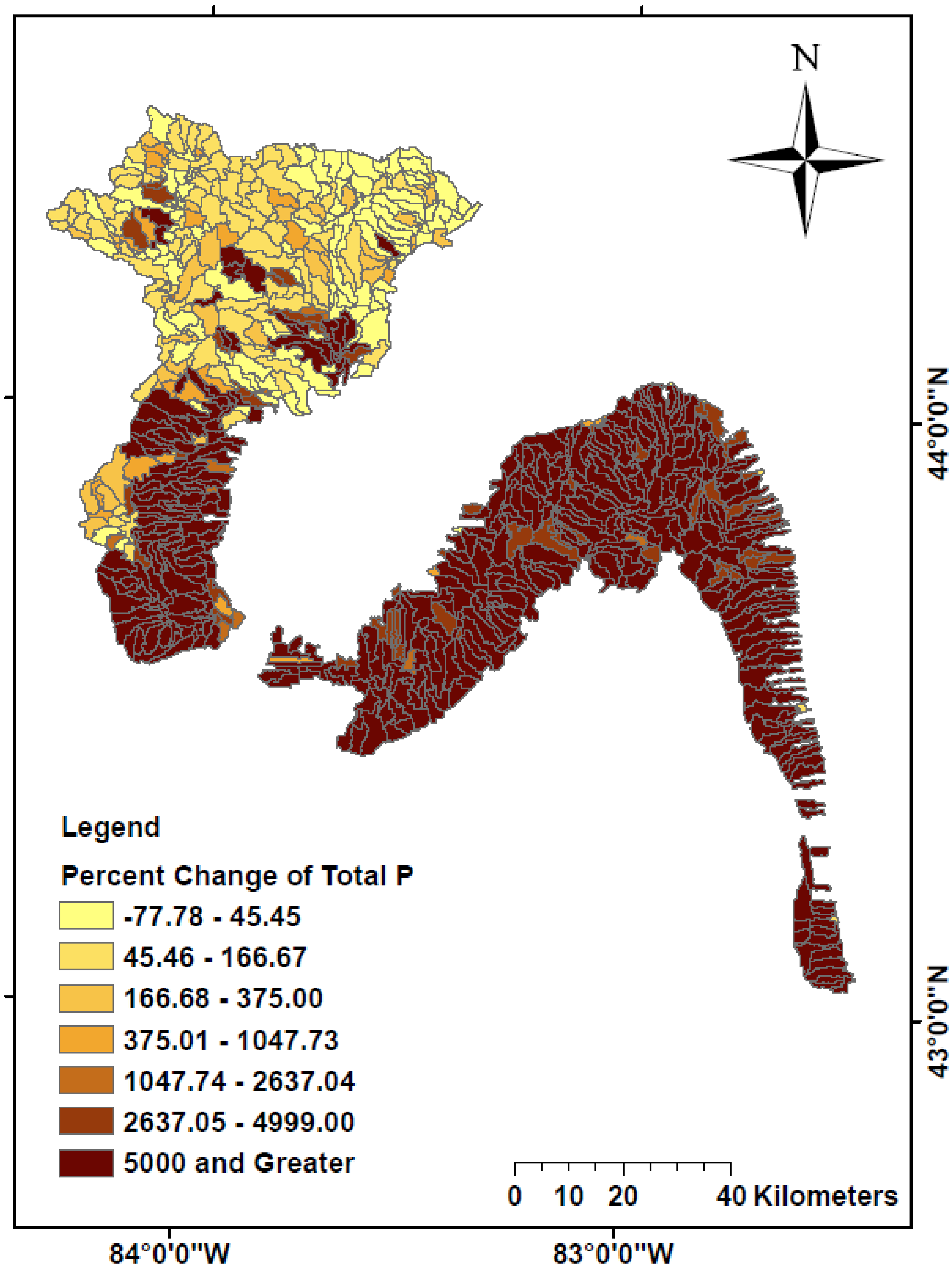


Figure 25. Percent change of total P output values resulted from landuse changes

7.0 Acknowledgment:

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8.0 References

Van Griensven, A., T. Meixner, et al. (2006). "A global sensitivity analysis tool for the parameters of multi-variable catchment models." Journal of Hydrology 324: 10-23.