

**Effects of Historic and Current Land Covers on
Water Budget and Water Quality in Agricultural
Regions of Michigan and Wisconsin:
SWAT Model Report 040303 (Lake Michigan)**



Brad Wardynski and Pouyan Nejadhashemi ©

1.0 General Information

The Lake Michigan Basin lies on the East edge of Wisconsin. The basin has a mild topography with minimum elevation of 176m and the maximum elevation reading 381m, with a mean of 276m. The catchment has a total area of 861 thousand hectares (or 2.13 million acres). A relief map is shown in figure 1.

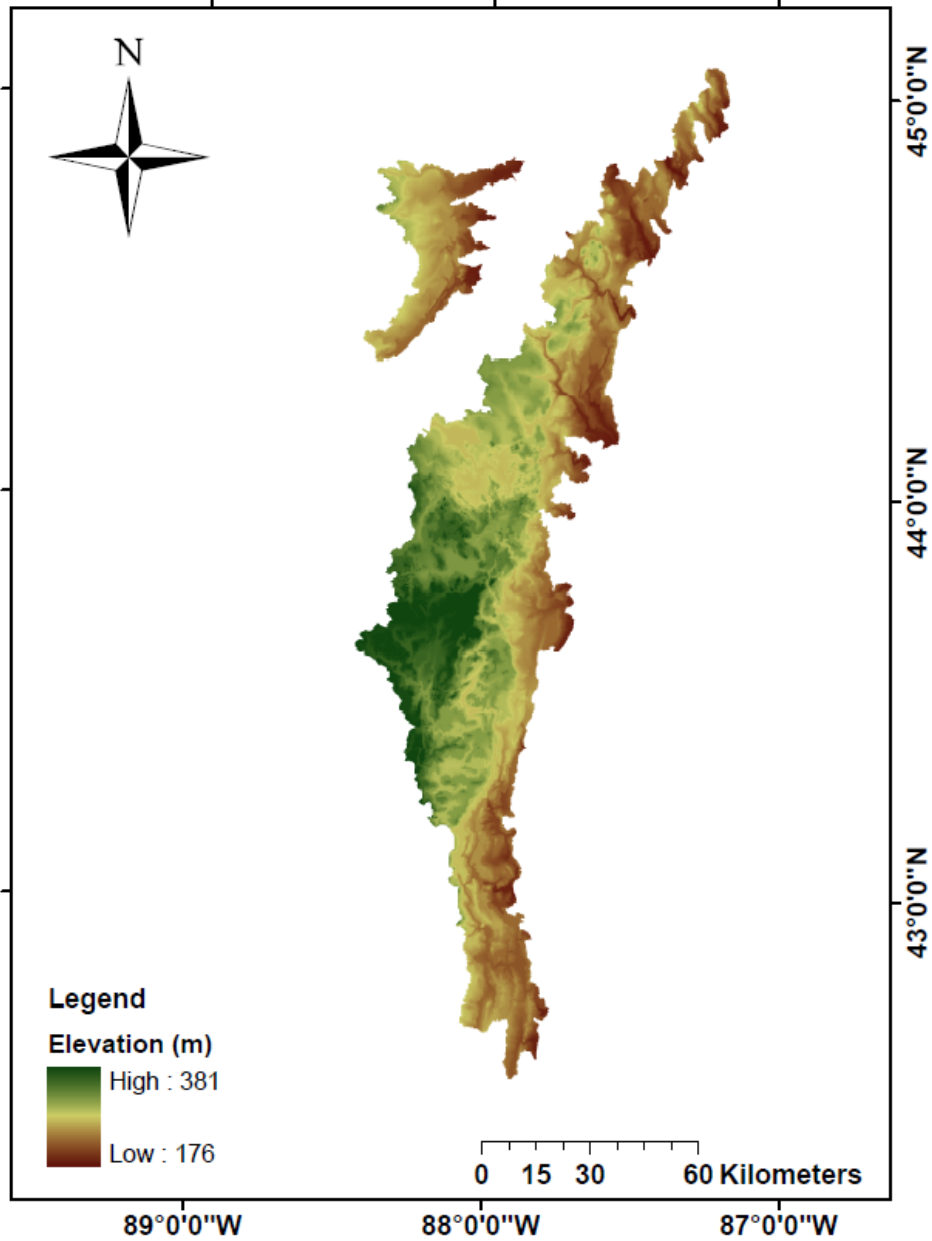


Figure 1. Relief map of the Lake Michigan Basin

2.0 River Network

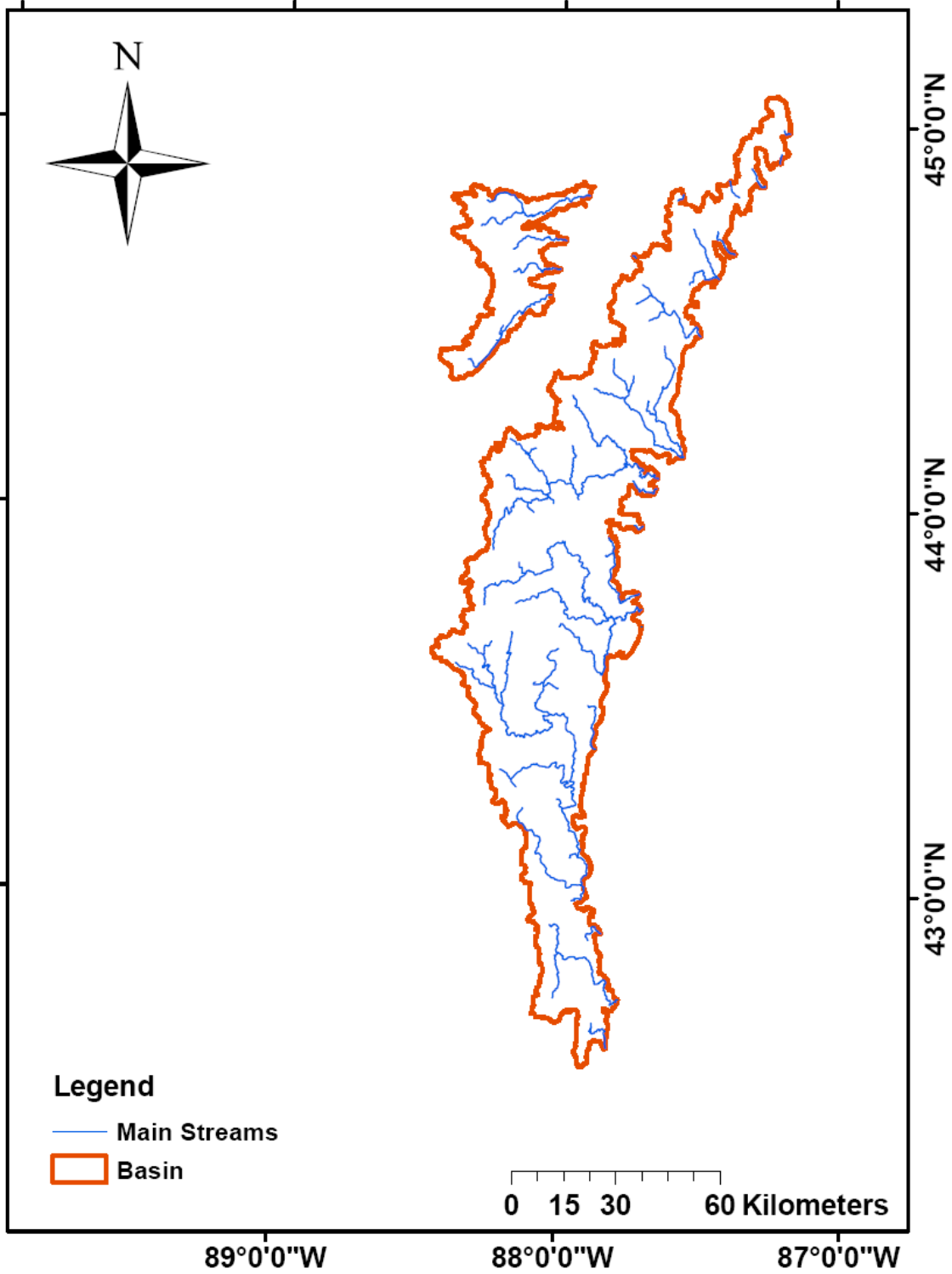


Figure 2. Major streams of the Wolf Basin

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 Michigan Basin Watershed is the predominant land usage covering 59 percent of land area. Urban land covers 15 percent of the watershed area. Forest, wetlands, rangelands, and water constitute the remaining 26 percent of land cover (Tables 1a and 1b). In the Lake Michigan Basin, large urban development is found along the coast, with agriculture and other landuses inland (Figure 3).

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

LANDUSE:	AREA (ha)	PERCENTAGE
Agricultural Land-Row Crops	295613.8	34.3
Hay	212825.6	24.7
Forest-Deciduous	94001.3	10.9
Wetlands-Forested	74788.2	8.7
Residential-Medium Density	55070.1	6.4
Residential-Low Density	39634.7	4.6
Residential-High Density	24638.9	2.9
Wetlands-Non-Forested	17989.6	2.1
Range-Grasses	15227.1	1.8
Industrial	9086.8	1.1
Range-Brush	8380.6	1.0
Water	5770.8	0.7
Forest-Evergreen	5102.8	0.6
Range-Other	1021.5	0.1
Forest-Mixed	1045.8	0.1

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

Agriculture	59.1%
Urban	14.9%
Forest	11.6%
Wetland	10.8%
Range	2.9%
Water	0.7%

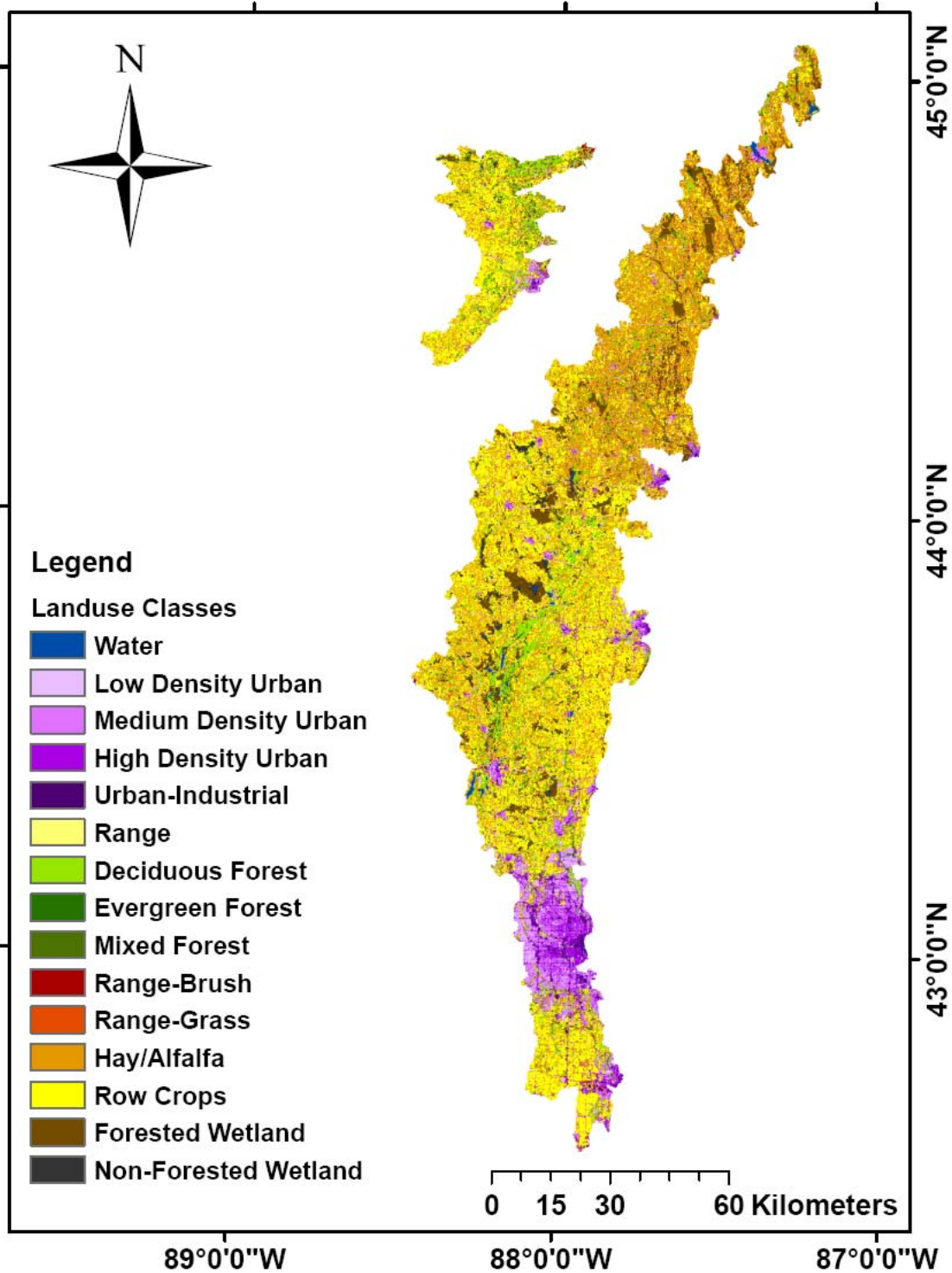


Figure 3. Current landuse map of the Lake Michigan Basin

Based on the Landuse circa 1800 county base (LU1800), forest was the predominant land usage in the Lake Michigan Basin covering 82 percent of land area. Wetlands covered 13 percent of the land area. Rangeland and water constitute the remaining 5 percent of land cover (Tables 2a and 2b). In the Lake Michigan Basin, mixed forest dominates its northern upland and deciduous forest dominates the southern area (Figure 4). Range and wetlands are scattered throughout the basin.

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

LANDUSE:	AREA (ha)	PERCENTAGE
Forest-Deciduous	563651.1	65.5
Forest-Mixed	140063.8	16.3
Wetlands-Forested	102377.0	11.9
Range-Grasses	32245.8	3.8
Wetlands-Non-Forested	8938.9	1.0
Range-Brush	6304.2	0.7
Water	5167.4	0.6
Forest-Evergreen	1366.0	0.2

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

Forest	81.9%
Wetlands	12.9%
Rangeland	4.5%
Water	0.6%
Urban	0.0%
Agriculture	0.0%

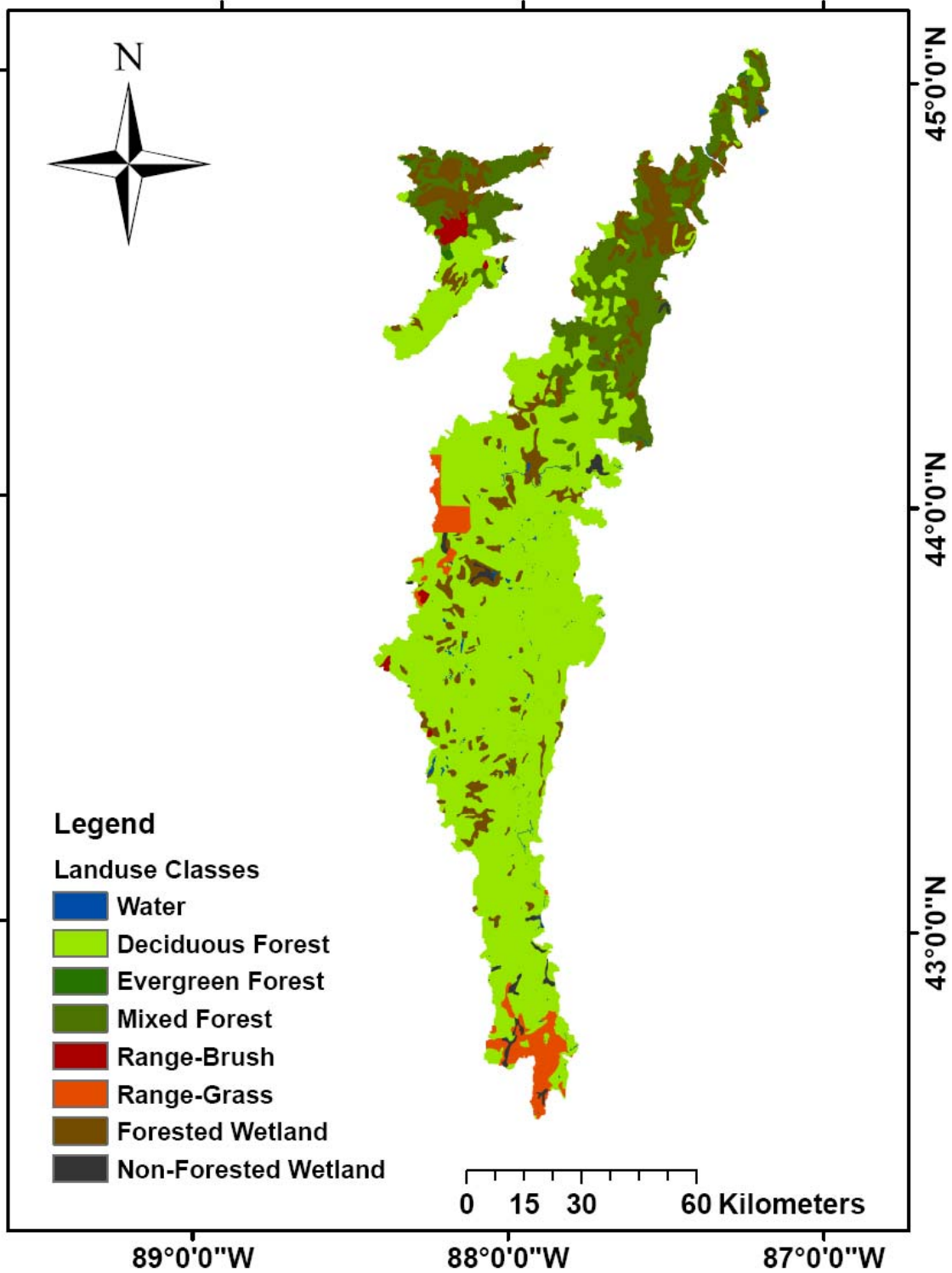


Figure 4. Pre-Settlement landuse map of the Lake Michigan Basin

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 Michigan Basin.

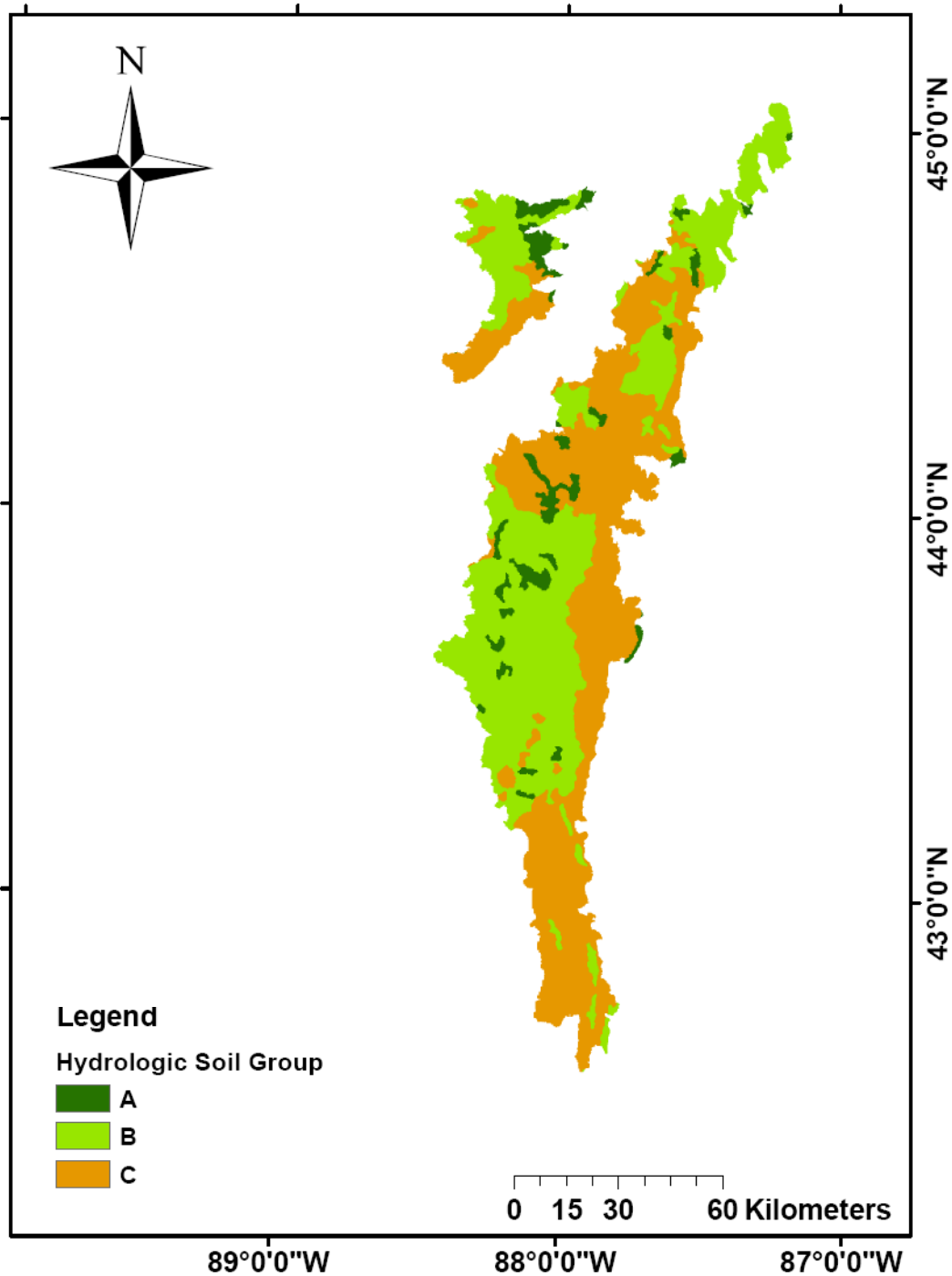


Figure 5. Hydrologic Soil Groups for the Lake Michigan Basin

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.

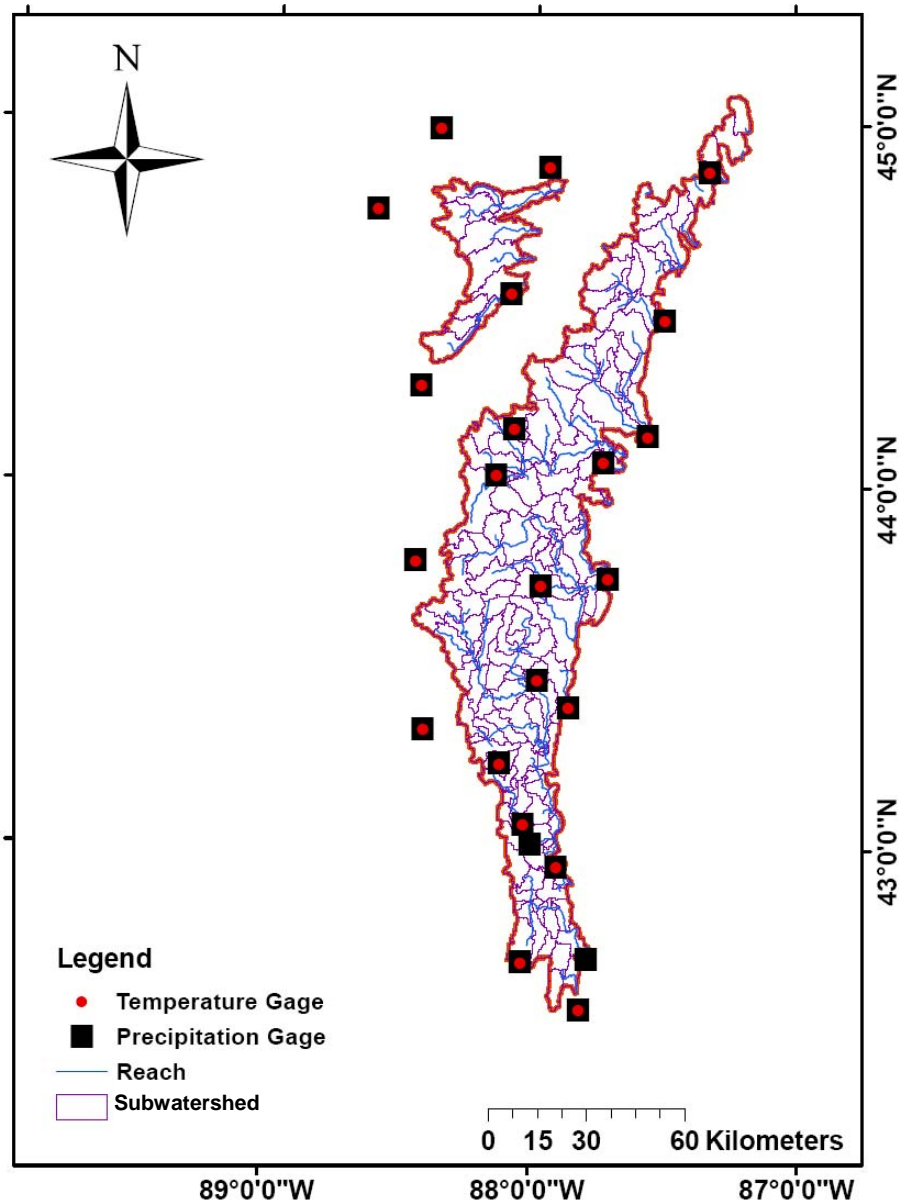


Figure 6. Temperature and precipitation gages in the Lake Michigan Basin

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 197 subwatersheds. Figure 7 shows the boundary and the locations of subwatersheds in the Lake Michigan Basin.

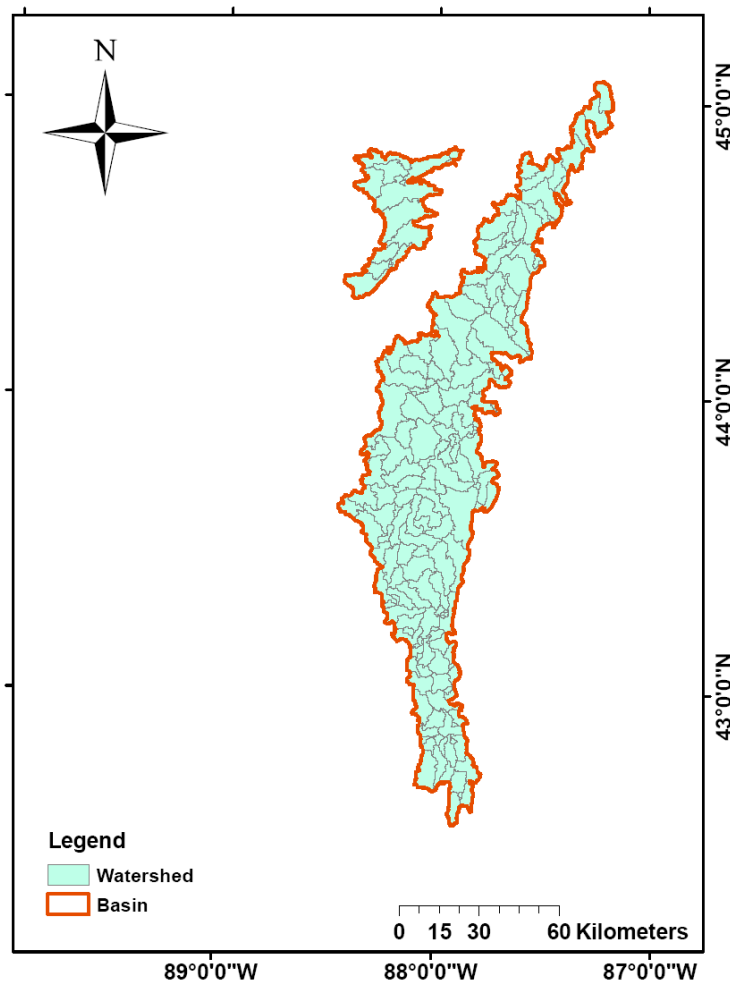


Figure 7. Delineated watersheds of the Lake Michigan Basin

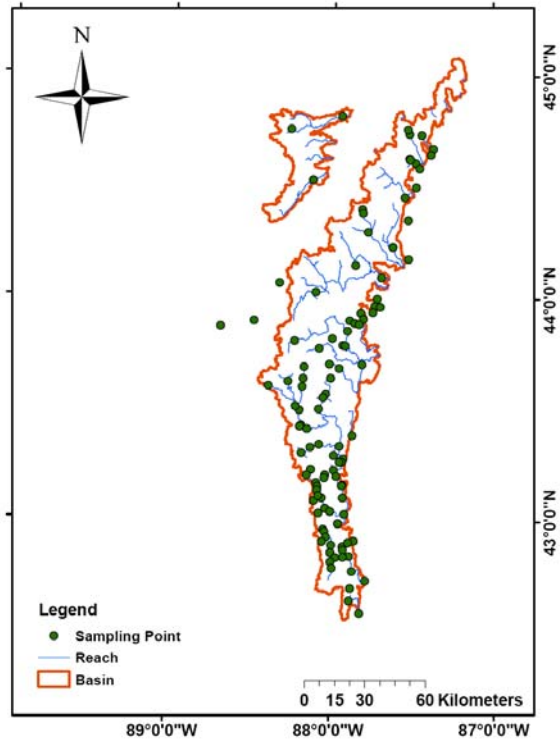
The SWAT model generates results on the outlets of subwatersheds. Since our goal is to obtain the model results on the locations of fish sampling points, these points were introduced to the model. In some cases, the fish sampling points lie on small creeks, which are too small for the model to recognize. In those cases, fish sampling points are snapped to the nearest stream network. Therefore, the location of the outlet sometimes is different from 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

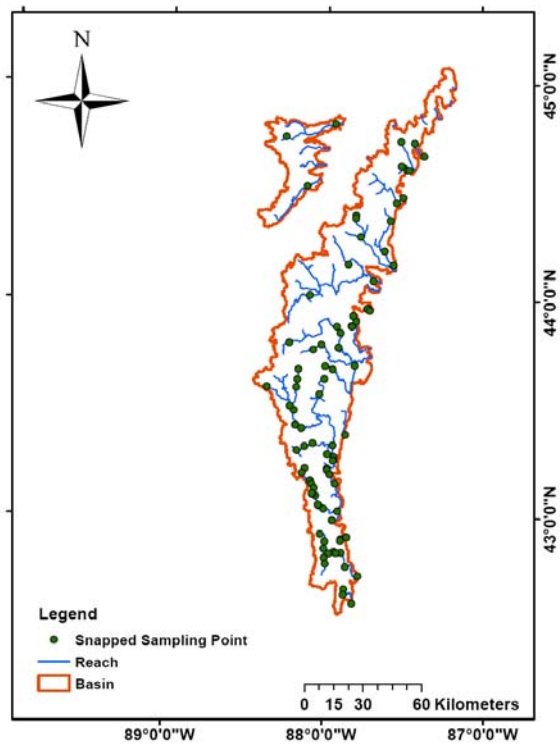
Original	LAT	LONG	Snapped	LAT	LONG
1	44.7407	-87.5262	1	44.5331	-88.0978
2	44.7364	-87.4506	2	44.4628	-87.5050
3	44.7616	-87.5358	3	44.2786	-88.4386
4	44.6734	-87.3769	4	44.1617	-88.0803
5	44.6471	-87.3907	5	44.1428	-87.5686
6	44.6301	-87.5251	6	44.0692	-87.7386
7	44.6085	-87.4863	7	44.0328	-88.1469
8	44.5854	-87.4627	8	43.7500	-87.7167
9	44.6265	-87.5225	9	43.7300	-87.9714
10	44.5010	-87.4837	10	43.7961	-88.4506
11	44.4556	-87.5529	11	43.4703	-87.9836
12	44.0703	-88.3292	12	43.3311	-88.4114
13	43.8734	-88.6913	13	43.3944	-87.8636
14	43.9001	-88.4848	14	43.2389	-88.1222
15	43.6938	-88.1709	15	43.0719	-88.0294
16	43.6437	-88.0054	16	43.0175	-88.0017
17	43.6416	-88.1765	17	42.9550	-87.9044
18	43.6290	-88.2701	18	42.7022	-87.7861
19	43.6084	-88.3903	19	42.6903	-88.0336
20	43.6045	-88.1823	20	42.5608	-87.8156
21	43.5733	-88.0362	21	44.8722	-87.3353
22	43.5561	-88.0527	22	44.8836	-87.9539
23	43.4996	-88.1974	23	44.9878	-88.3769
24	43.5042	-88.0793	24	44.7642	-88.6181
25	43.5175	-88.2229	25	44.5331	-88.0978
26	43.4326	-88.1861	26	44.4628	-87.5050
27	43.4266	-88.1934	27	44.2786	-88.4386
28	43.4266	-88.1934	28	44.1617	-88.0803
29	43.4163	-88.1490	29	44.1428	-87.5686
30	43.3467	-88.0745	30	44.0692	-87.7386
31	43.3375	-87.9485	31	44.0328	-88.1469
32	43.3328	-88.1275	32	43.7500	-87.7167
33	43.3080	-88.1824	33	43.7300	-87.9714

34	43.2962	-87.9830	34	43.7961	-88.4506
35	43.2820	-87.9237	35	43.4703	-87.9836
36	43.2662	-87.9322	36	43.3311	-88.4114
37	43.2665	-87.9473	37	43.3944	-87.8636
38	43.2331	-88.1219	38	43.2389	-88.1222
39	43.2330	-88.1221	39	43.0719	-88.0294
40	43.2299	-87.9825	40	42.9550	-87.9044
41	43.2101	-88.0356	41	42.6903	-88.0336
42	43.2094	-88.1476	42	42.5608	-87.8156
43	43.2031	-87.9660	43	44.8722	-87.3353
44	43.1970	-88.0403	44	44.8836	-87.9539
45	43.1745	-88.0892	45	44.9878	-88.3769
46	43.1645	-87.9276	46	44.7642	-88.6181
47	43.1610	-87.9329			
48	43.1587	-88.0813			
49	43.1414	-88.0831			
50	43.1056	-88.0548			
51	43.1059	-87.9259			
52	43.0946	-88.1024			
53	43.1157	-88.0765			
54	43.0593	-88.0334			
55	43.0448	-88.0025			
56	43.0379	-88.0731			
57	43.0593	-88.0334			
58	43.0327	-87.9149			
59	42.9905	-87.9530			
60	42.9905	-87.9530			
61	43.0448	-88.0025			
62	44.8212	-87.9500			
63	44.7608	-88.2687			
64	44.5343	-88.1280			
65	44.5343	-88.1280			
66	42.9647	-88.0439			
67	42.9548	-88.0358			
68	42.9299	-88.0266			
69	42.9106	-88.0501			
70	42.9051	-87.8913			
71	42.9134	-87.8556			
72	42.8936	-87.9930			
73	42.8864	-87.9246			
74	42.8864	-87.9246			
75	42.9051	-87.8913			
76	42.8726	-87.9219			

77	42.8609	-87.9985			
78	42.8609	-87.9985			
79	42.8436	-87.8840			
80	42.8383	-87.9669			
81	42.8397	-87.9217			
82	42.8177	-87.9965			
83	42.7903	-87.9887			
84	42.7760	-87.8659			
85	42.7336	-87.7840			
86	42.7002	-87.8753			
87	42.6439	-87.8819			
88	42.5877	-87.8183			
89	44.4027	-87.8178			
90	44.3856	-87.8138			
91	44.3534	-87.5322			
92	44.2998	-87.7820			
93	44.2335	-87.6267			
94	44.2335	-87.6267			
95	44.1788	-87.5289			
96	44.1507	-87.8588			
97	44.0954	-87.6974			
98	44.0301	-88.1040			
99	44.0011	-87.7223			
100	43.9683	-87.7373			
101	43.9647	-87.7037			
102	43.9392	-87.7496			
103	43.9353	-87.8234			
104	43.9087	-87.8064			
105	43.9019	-87.8915			
106	43.8909	-87.8607			
107	43.8852	-87.8323			
108	43.8558	-87.9052			
109	43.8218	-87.9976			
110	43.8104	-88.2317			
111	43.7910	-87.9336			
112	43.7884	-87.9177			
113	43.7774	-88.0785			
114	43.7066	-88.0152			
115	43.6872	-87.9539			
116	43.7050	-87.8139			
117	43.3866	-87.8698			



(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, total nitrogen, and total phosphorus. Five years of data were used for calibration, including 255 observations for sediment, 160 observations for total nitrogen, and 221 observations for total phosphorus.

The most downstream USGS gaging station on the Milwaukee River (Station No. 04087000) 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.

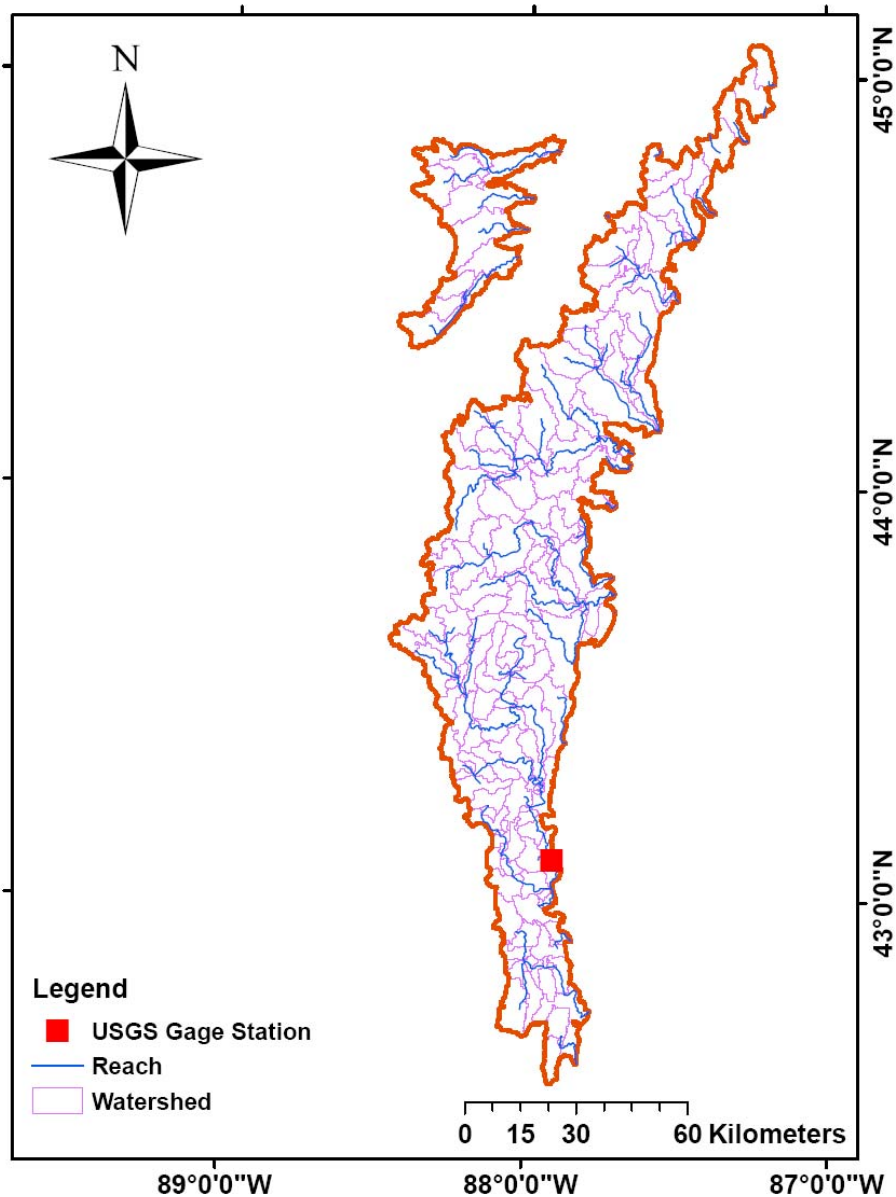


Figure 9. The delineated watersheds and selected USGS station.

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, total nitrogen, and total phosphorus data (van Griensven, Meixner et al. 2006). The sensitivity ranking of 42 parameters for this watershed is given in Table 4.

Table 4: Rank-Based Sensitivity Analysis*

	Flow	Sed	TotalN	TotalP
Cn2	1	1	1	1
Alpha_Bf	2	4	2	2
Sol_Z	3	5	3	6
Esco	4	6	4	4
Timp	5	11	8	8
Sol_Awc	6	12	7	10
Ch_K2	7	10	9	7
Rchrg_Dp	8	14	13	15
Canmx	9	16	10	9
Blai	10	13	6	5
Surlag	11	8	5	3
Ch_N2	12	3	17	16
Biomix	13	15	15	13
Epc0	14	22	22	21
Smtmp	15	19	14	14
Gw_Delay	16	21	21	24
Sol_K	17	23	16	12
Ssubbsn	18	20	19	17
Slope	19	17	20	18
Sol_Alb	20	25	18	19
Nperco	21	24	12	20
Spcon	42	2	42	42
Spexp	42	7	42	42
Usle_P	42	9	11	11
Usle_C	42	18	23	23
Phoskd	42	42	24	22
Pperco	42	42	25	25
Ch_Cov	42	42	42	42
Ch_Erod	42	42	42	42
Gw_Revap	42	42	42	42
Gwqmn	42	42	42	42
Revapmn	42	42	42	42
Sftmp	42	42	42	42
Shallst_N	42	42	42	42
Sfmfn	42	42	42	42
Sfmfx	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
Tlaps	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 17.

The calibrated model has achieved excellent comparisons with observed flow and sediment. The comparisons of sediment were not as good because the observed data did not provide enough information. 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	0.744	1.223	0.769
Total Suspended Solids (TSS)	0.793	5.562	0.833
Total N	0.452	367.767	0.562
Total P	0.463	38.551	0.631

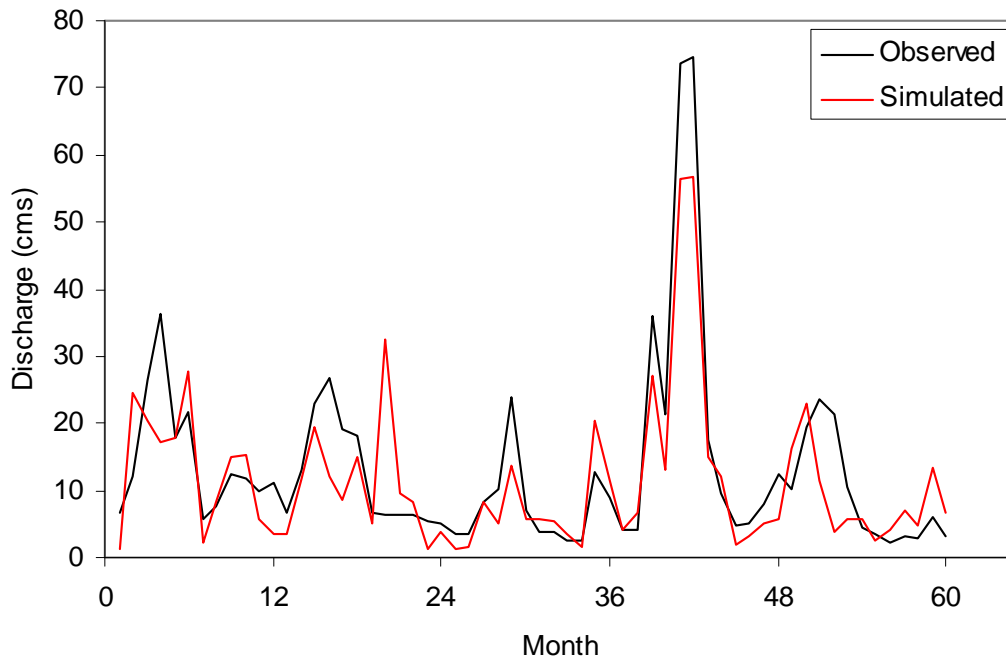


Figure 10. Model simulated results vs. USGS measurements at USGS 04087000 station

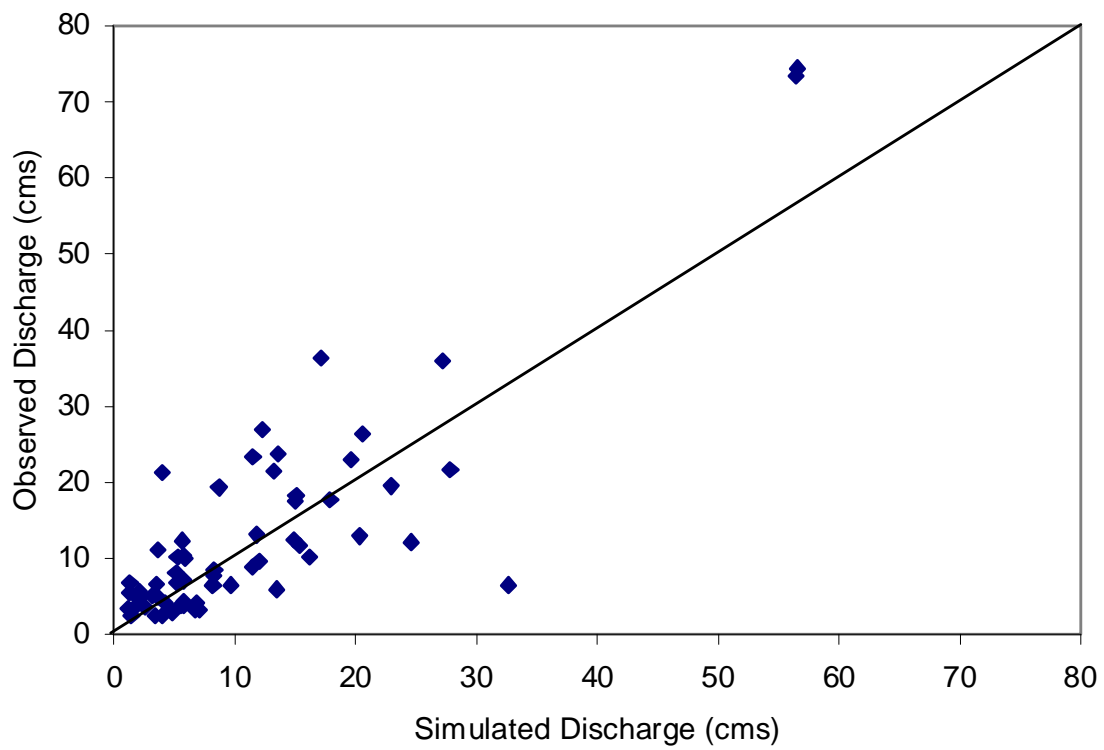


Figure 11. Simulated vs observed flow at USGS 04087000 station

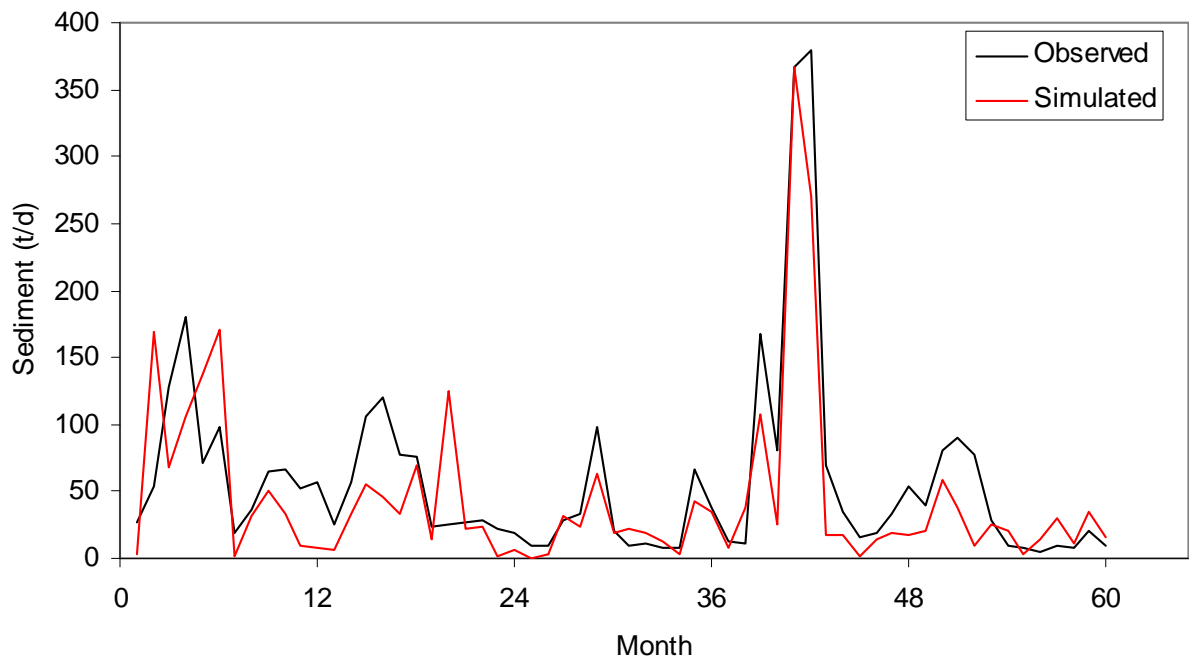


Figure 12. Time series of simulated vs observed TSS

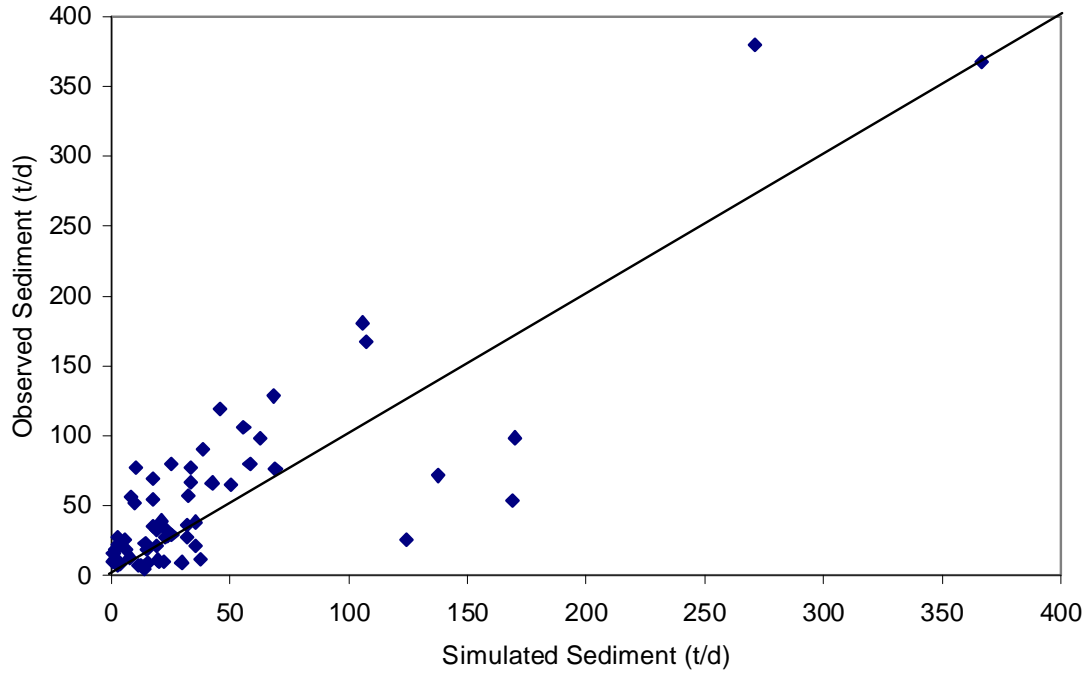


Figure 13. Simulated vs observed TSS

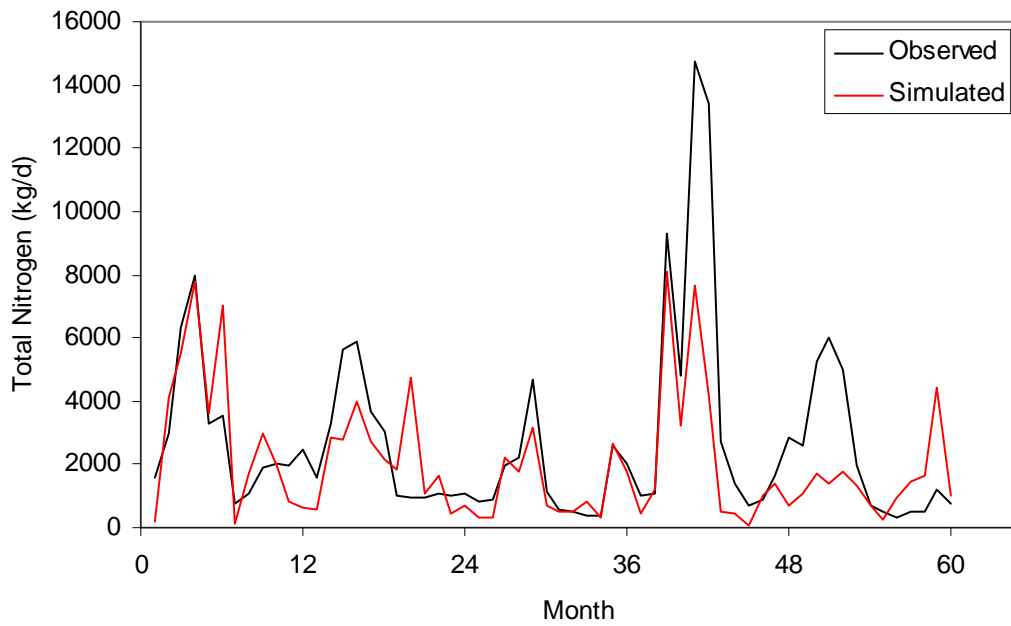


Figure 14. Time series of simulated vs observed Total Nitrogen

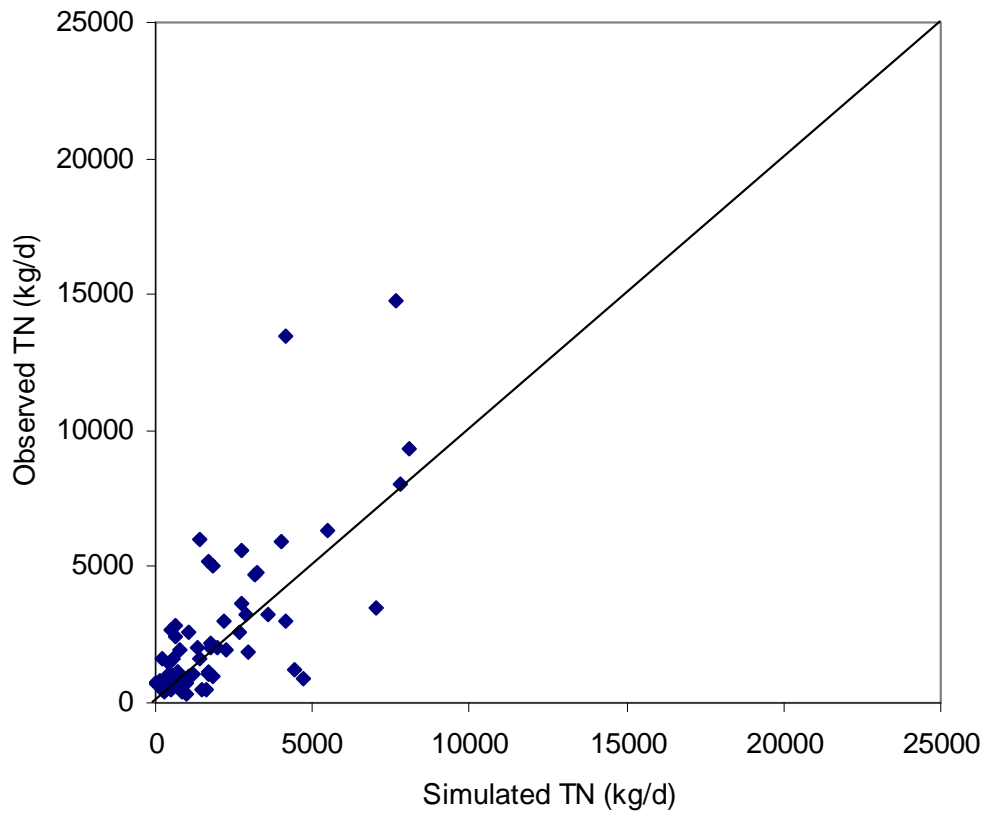


Figure 15. Simulated vs observed Total Nitrogen

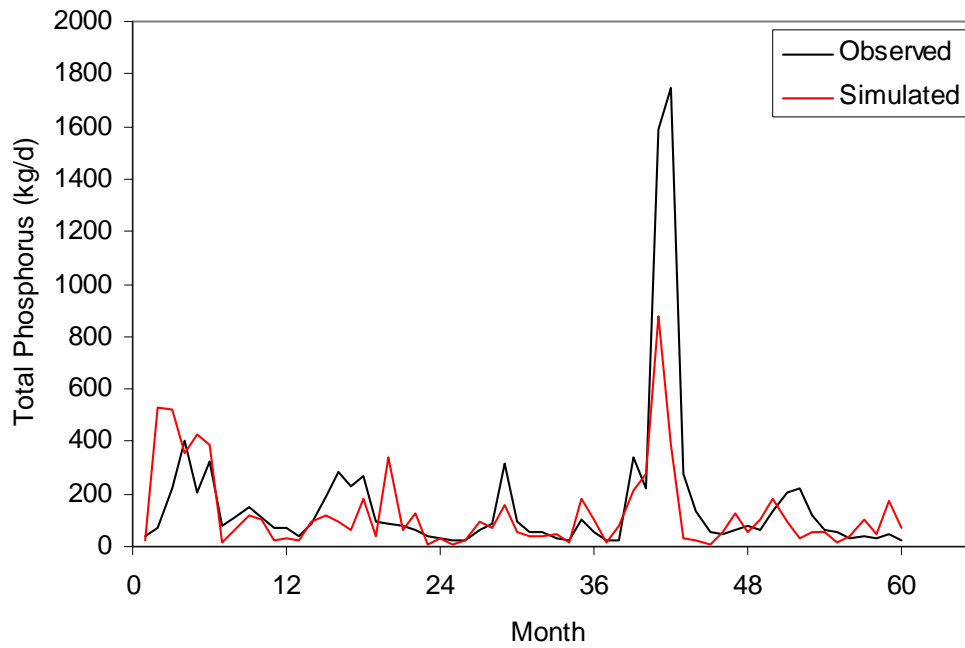


Figure 16. Time series of simulated vs. observed total phosphorus

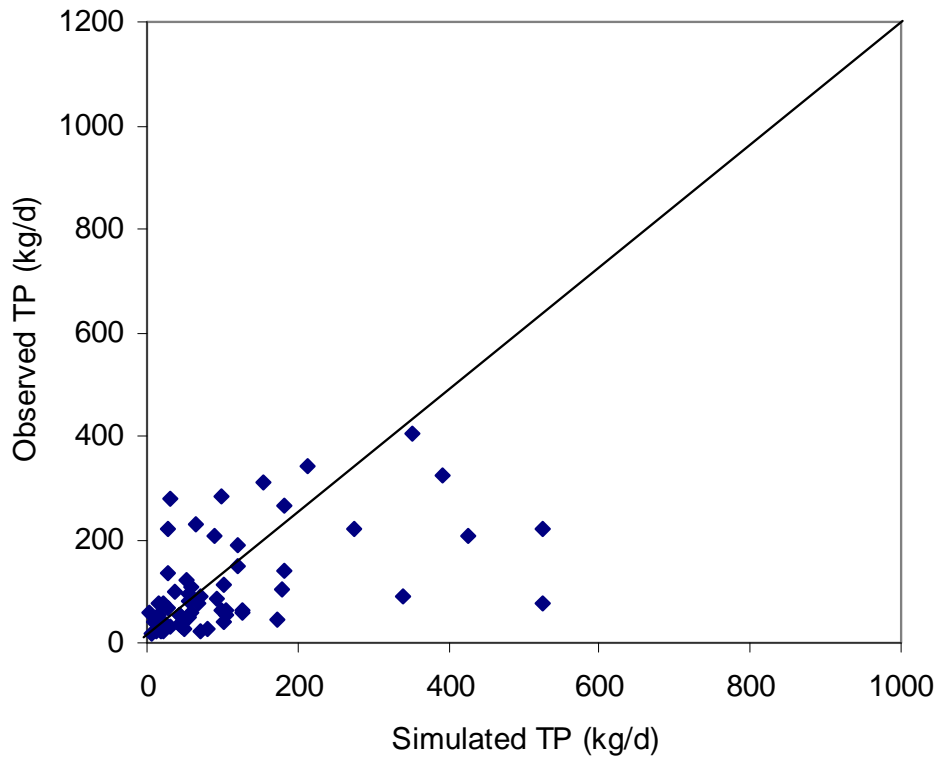


Figure 17. Simulated vs. observed total phosphorus

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

Month	Rain	Snowfall	Surface Runoff	Lateral Flow	Total Water Yield	ET	Sediment Yield	PET
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(t/ha)	(mm)
1	43.23	32.68	14.61	0.01	15.4	10.1	0.03	19.74
2	34.38	24.11	23.79	0.01	24.14	13.24	0.05	24.37
3	45.9	16.15	32.77	0.03	33.92	31.35	0.08	55.74
4	80.48	5.8	24.46	0.08	28.76	50.27	0.08	93.04
5	94.29	0	27.63	0.07	33.07	64.99	0.12	129.14
6	110.65	0	36.93	0.09	43.31	79.15	0.13	148.3
7	92.52	0	18.53	0.05	22.98	87.36	0.04	162.88
8	95.2	0	22.36	0.05	24.81	68.59	0.05	141.37
9	77.65	0	20.09	0.04	21.7	49.79	0.05	114.23
10	62.06	0.53	14.73	0.04	16.07	38.53	0.04	69.79
11	56.11	7.26	14.93	0.04	16.38	26.14	0.03	44.18
12	42.02	26.46	12.74	0.02	14.01	14.71	0.02	24.55
Annual Average	834.49	112.99	263.57	0.53	294.55	534.2	0.72	1027.3

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 18 to 27 and Table 7. In addition, 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) for the Wolf Basin

Calibrated	Current	Pre-Settlement	Percent Change	Percent Different
Recharge (mm)	33.09	23.93	38.24%	32.10%
Surface Runoff (mm)	259.82	217.77	19.31%	17.61%
Baseflow (mm)	33.79	25.40	33.02%	28.34%
Water Yield (mm)	294.15	243.69	20.71%	18.77%
Sediment Yield (t/ha)	0.72	0.07	903.09%	163.74%
Total N Output (t/ha)	9.07	1.56	481.22%	141.28%
Total P Output (t/ha)	0.63	0.06	990.46%	166.40%

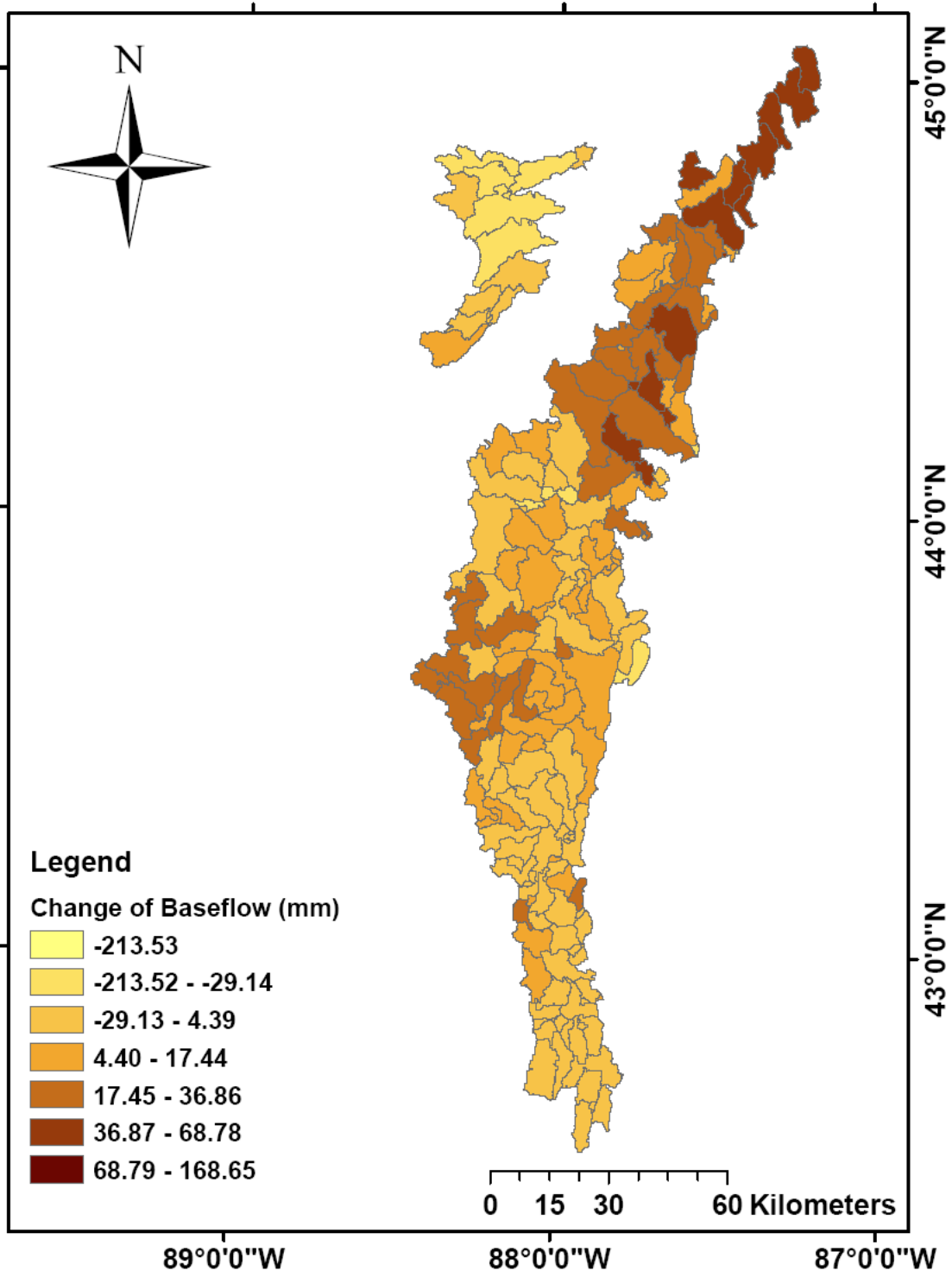


Figure 18. Change of baseflow values resulted from landuse changes (mm)

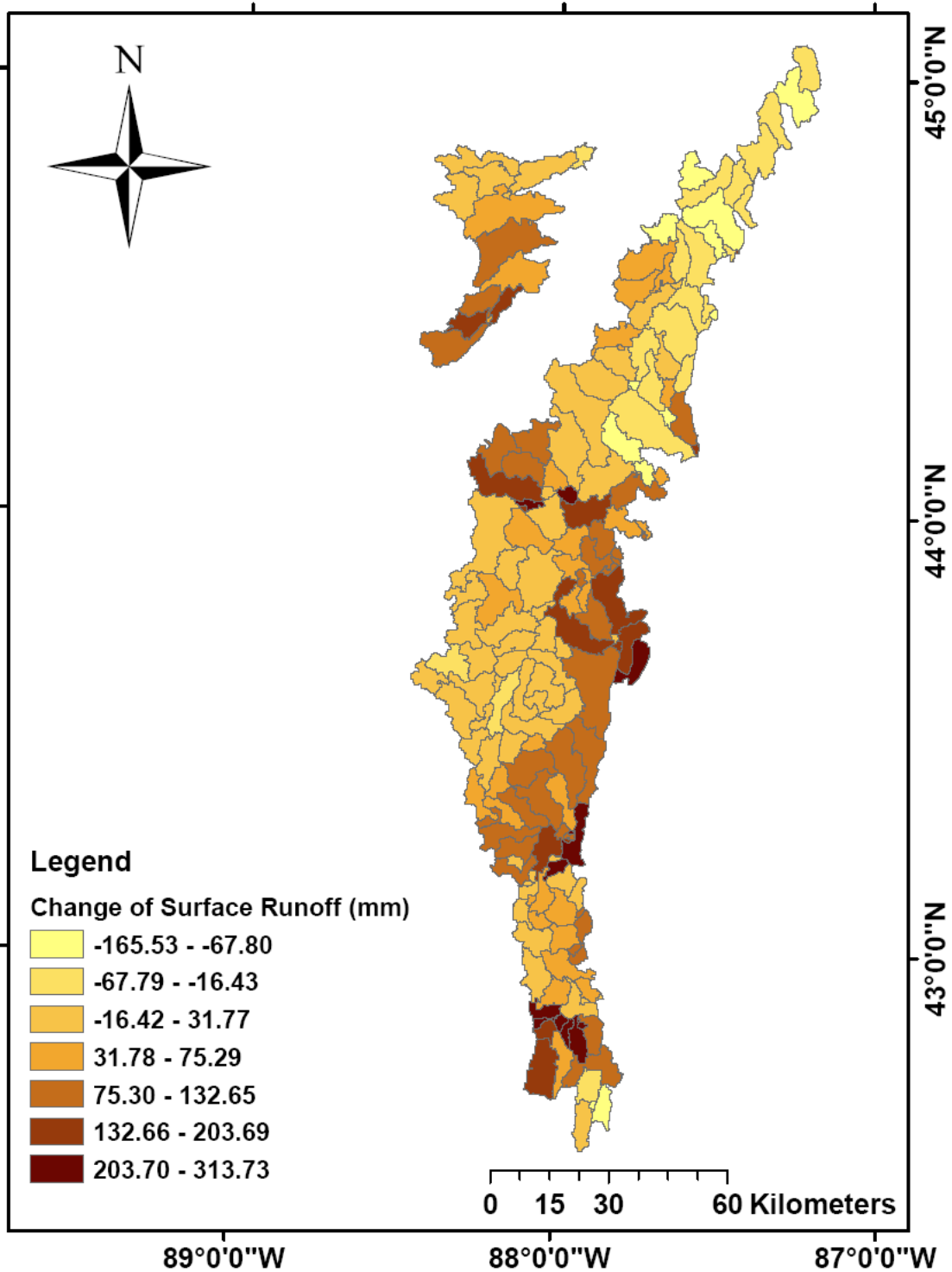


Figure 19. Change of surface runoff values resulted from landuse changes (mm)

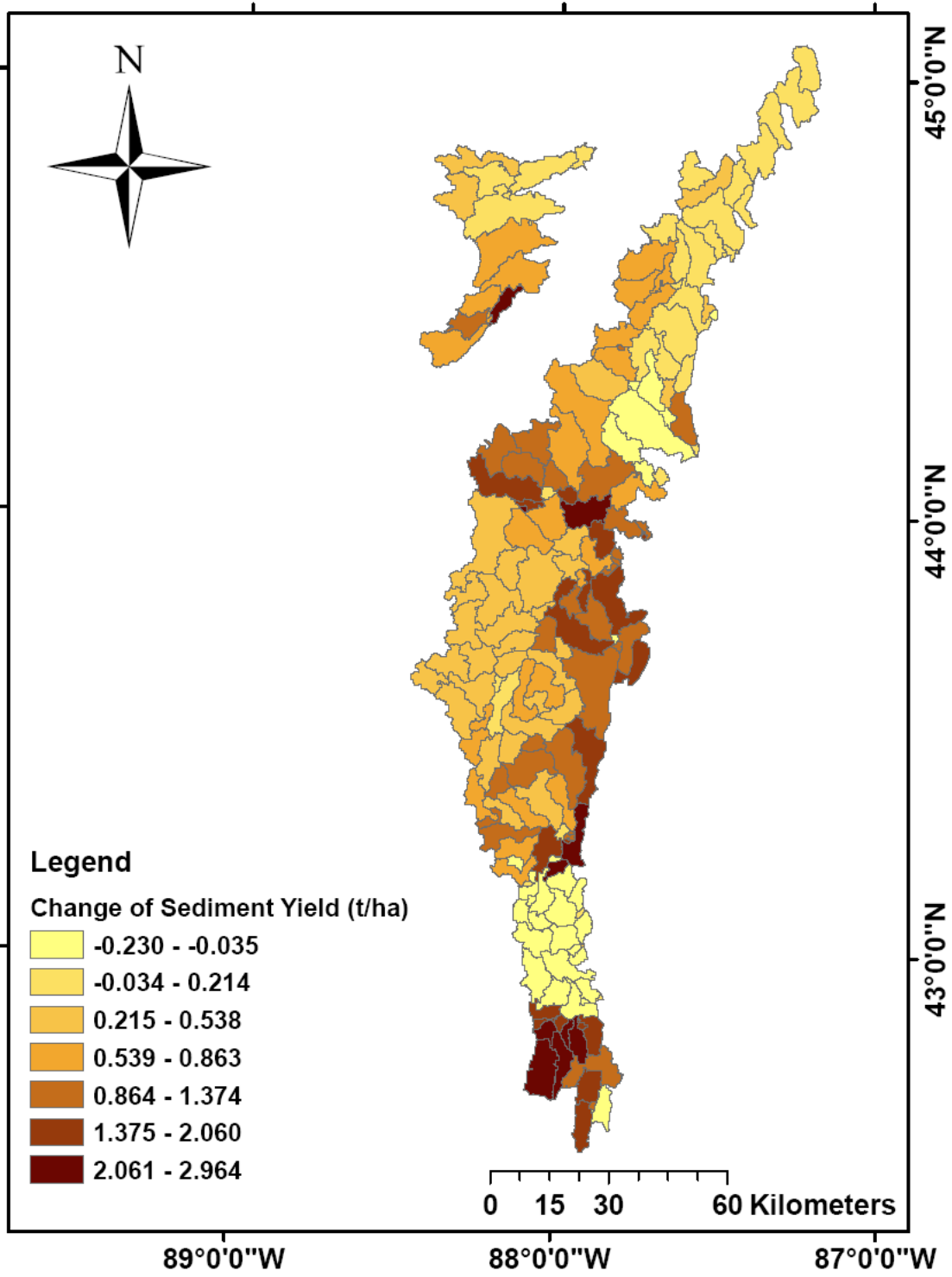


Figure 180. Change of sediment yields resulted from landuse changes (t/ha)

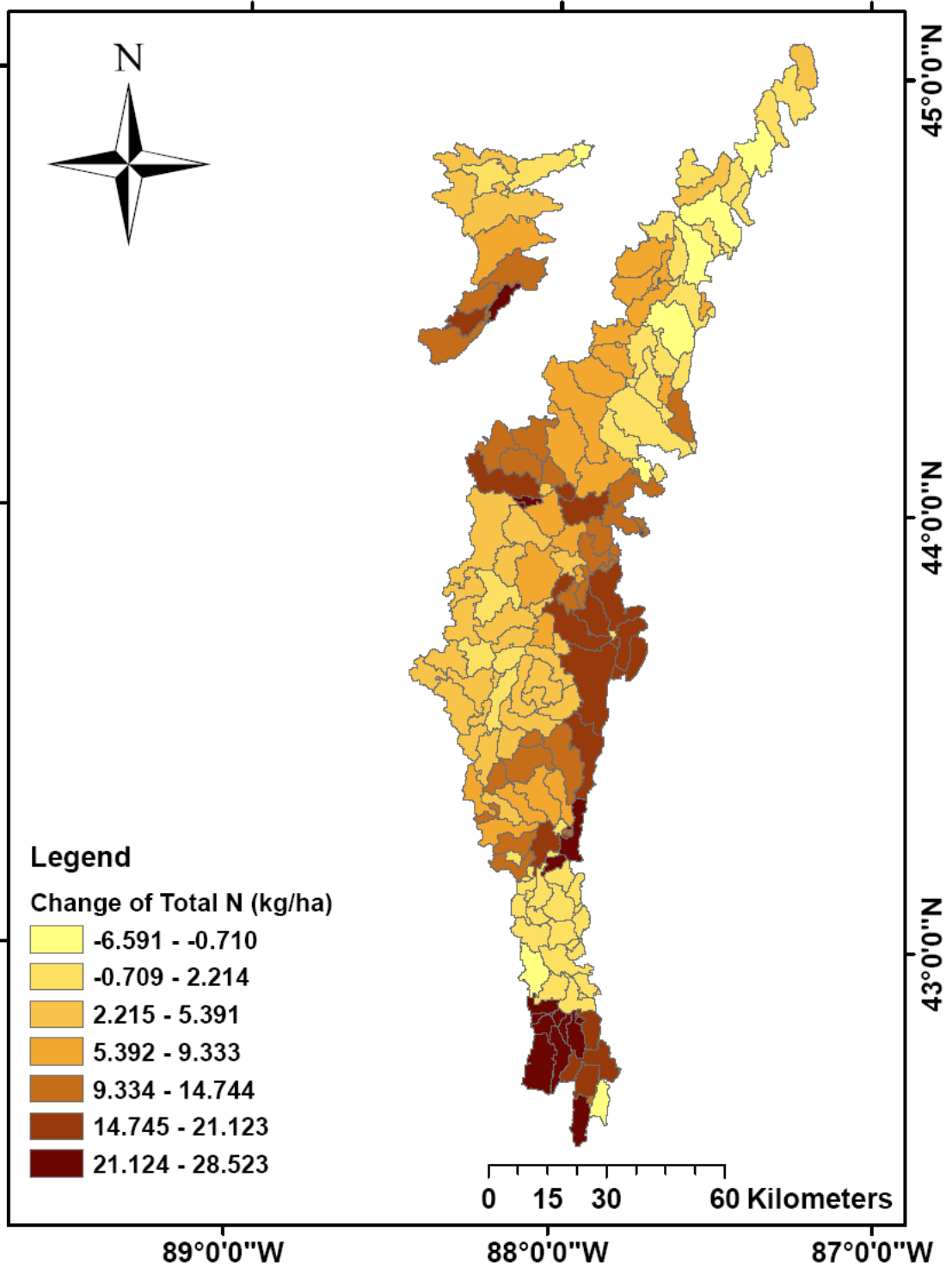


Figure 191. Change of total N output values resulted from landuse changes (kg/ha)

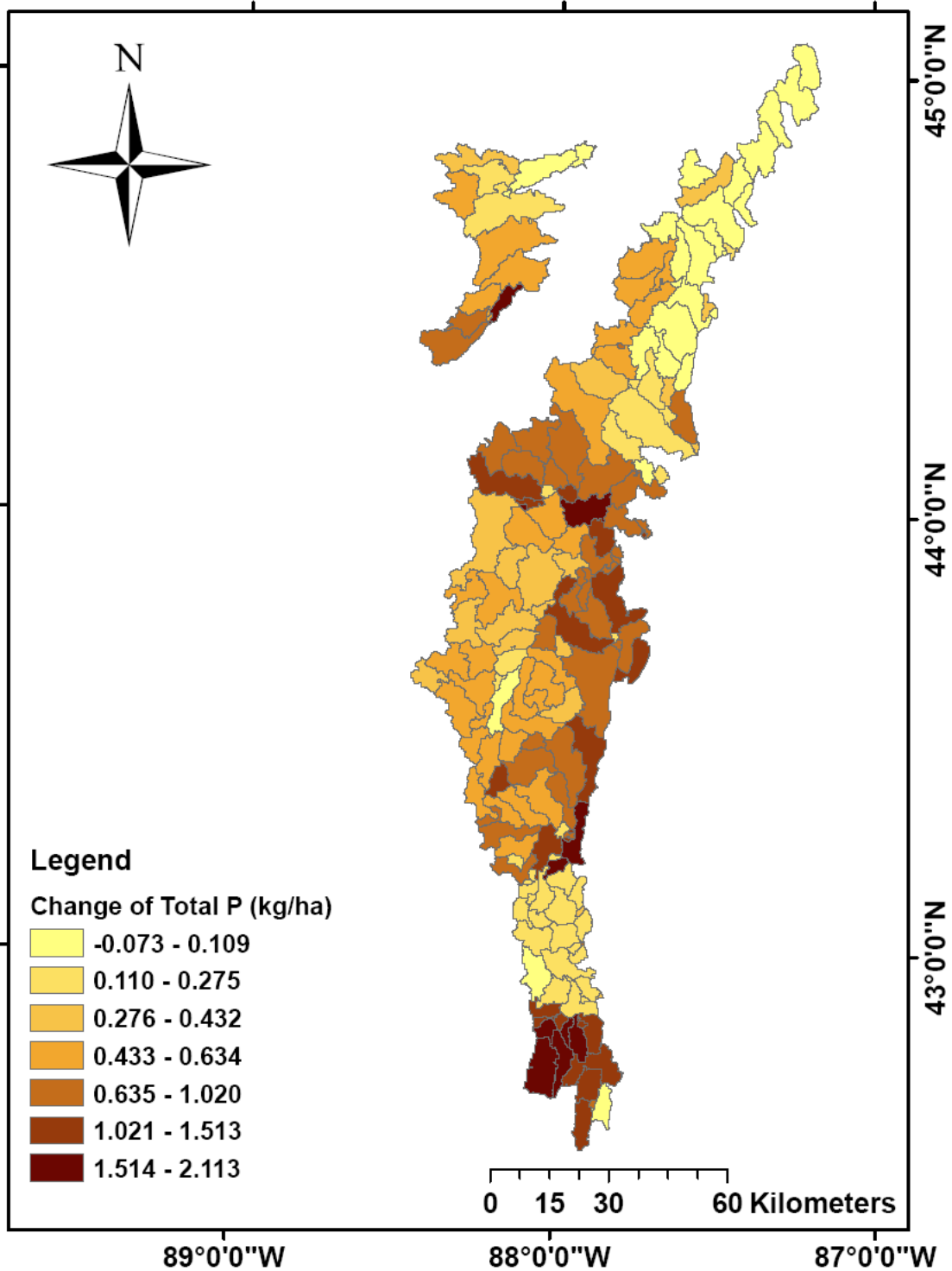


Figure 202. Change of total P output values resulted from landuse changes (kg/ha)

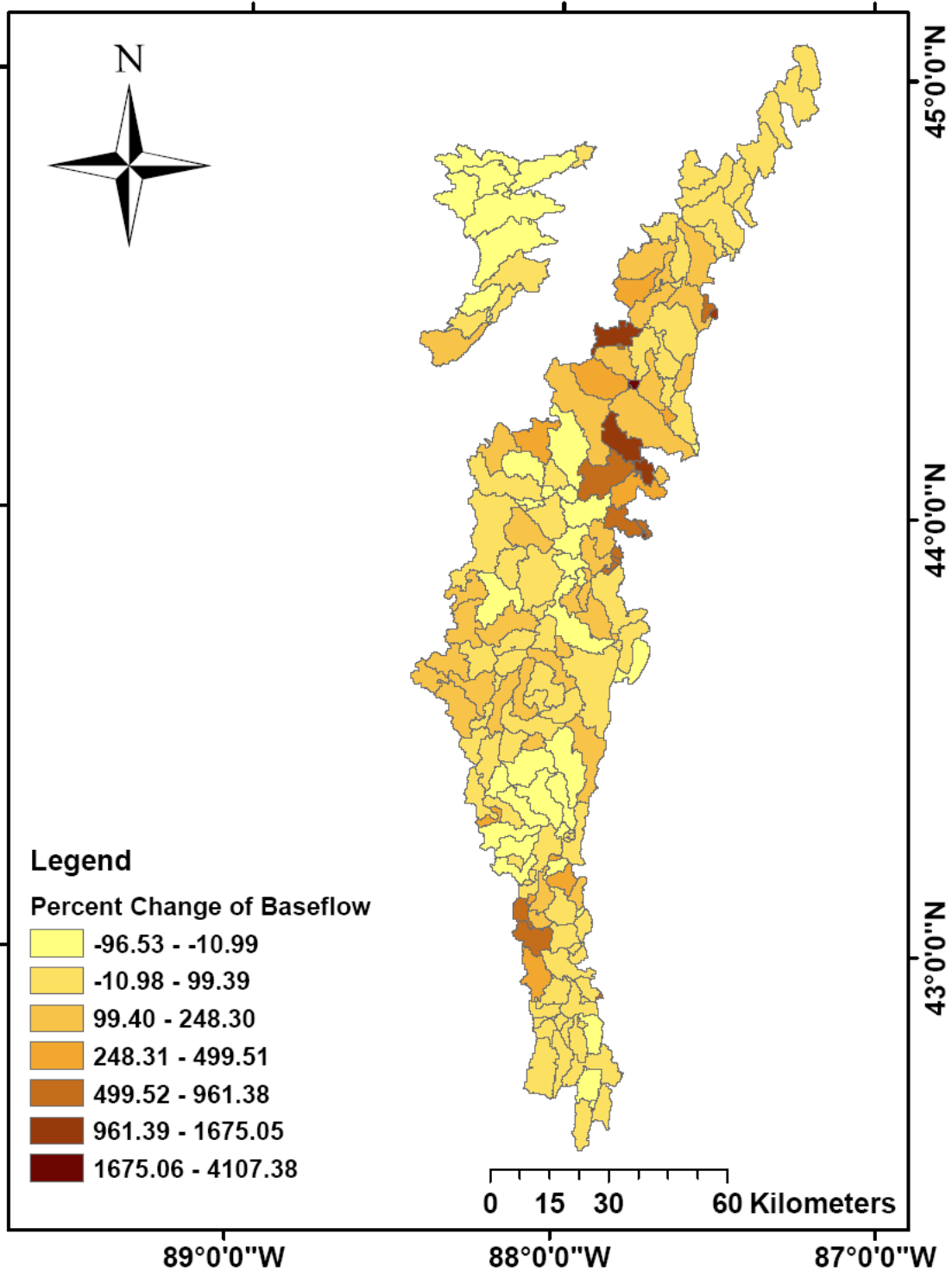


Figure 23. Percent change of baseflow values resulted from landuse changes

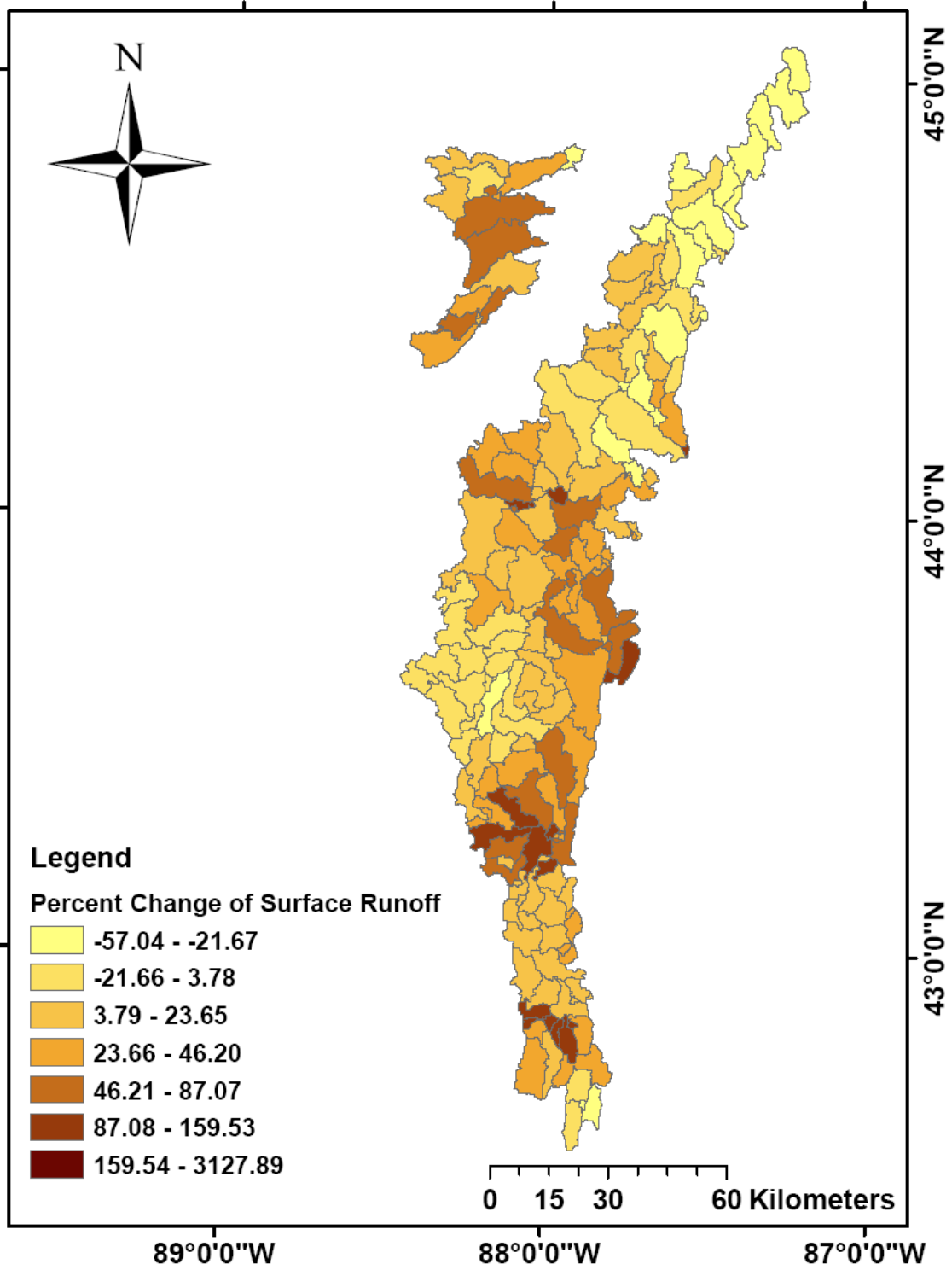


Figure24. Percent change of surface runoff values resulted from landuse changes

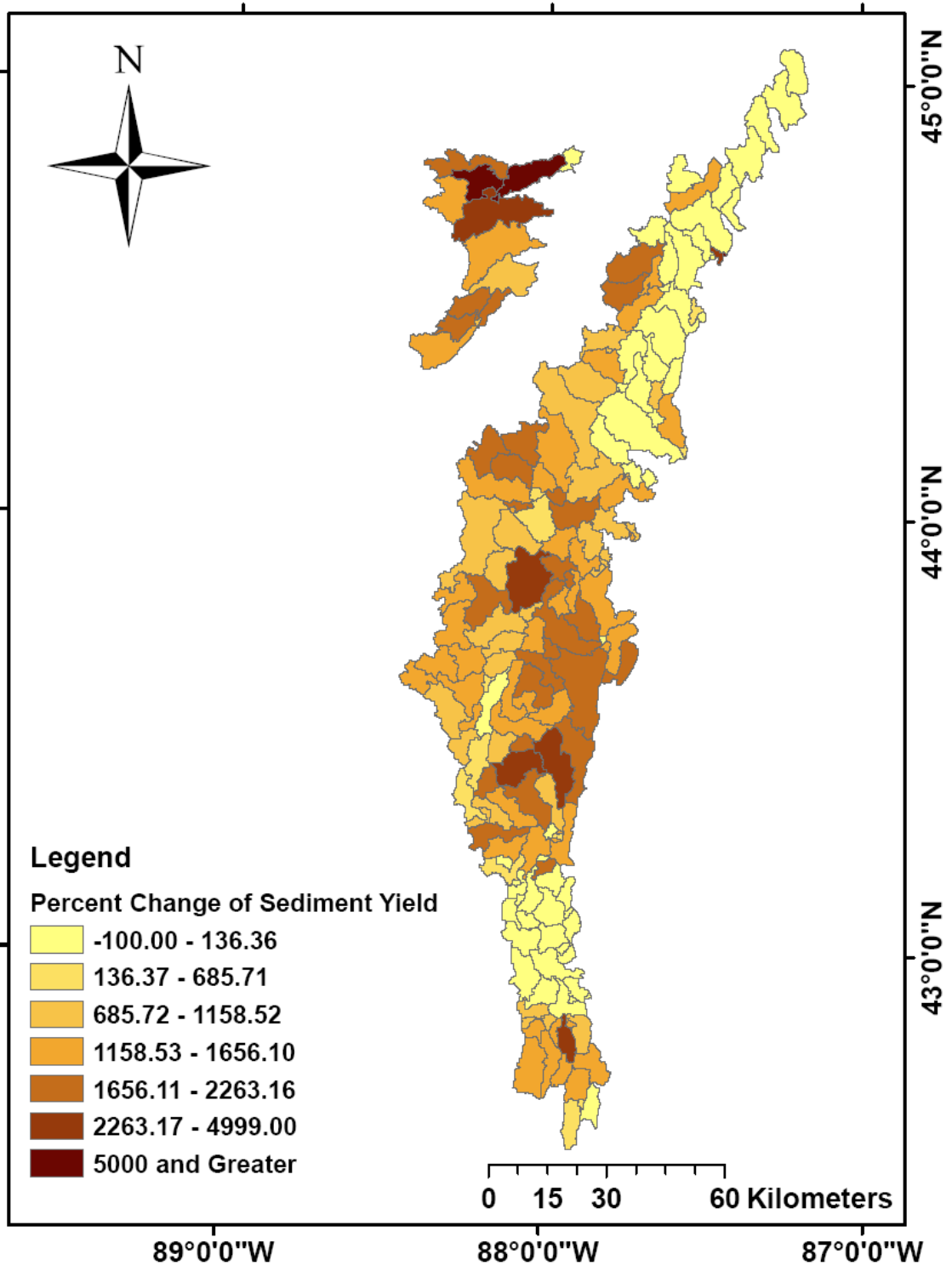


Figure25. Percent change of sediment yield resulted from landuse changes

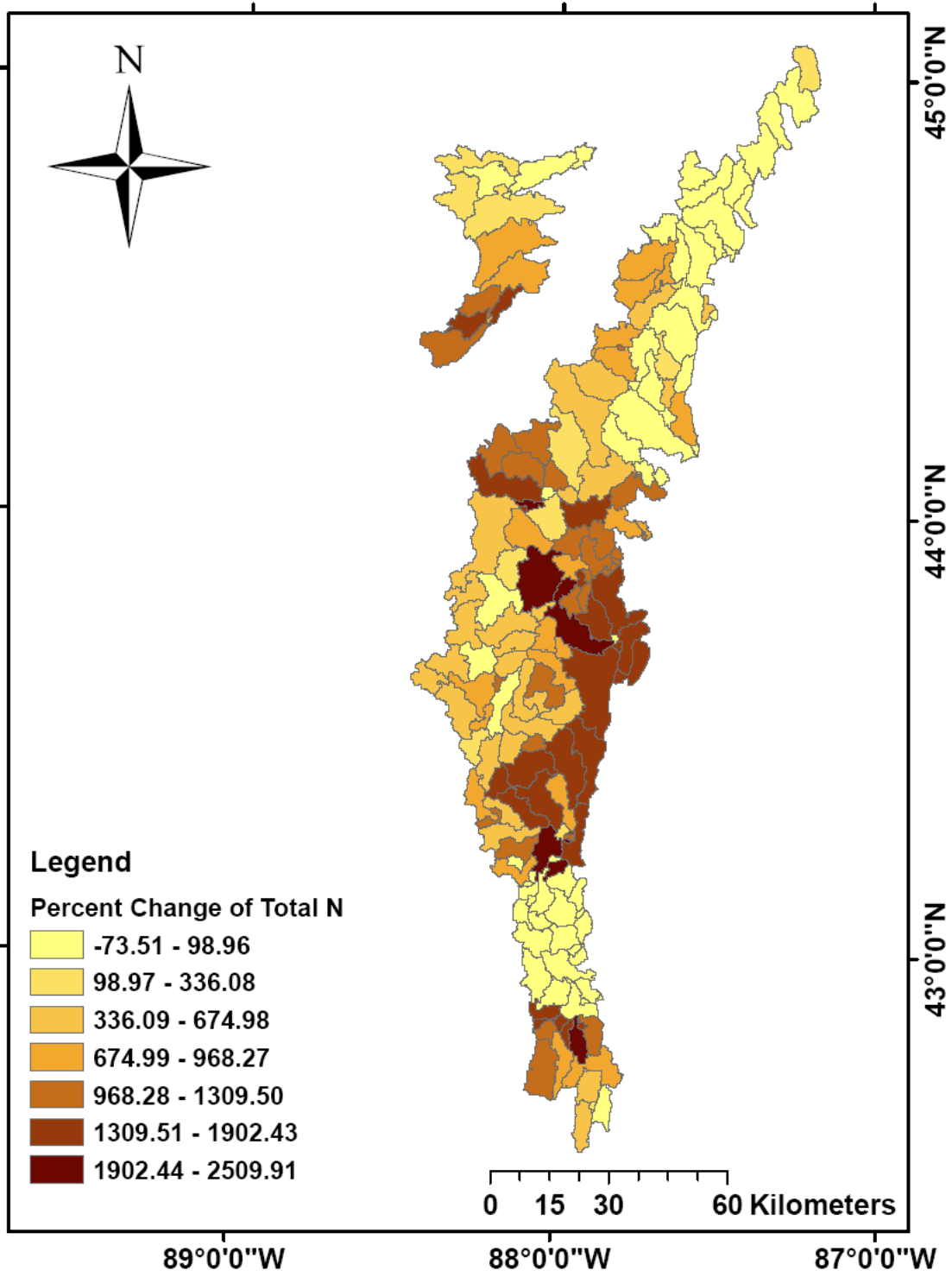


Figure 26. Percent change of total N output values resulted from landuse changes

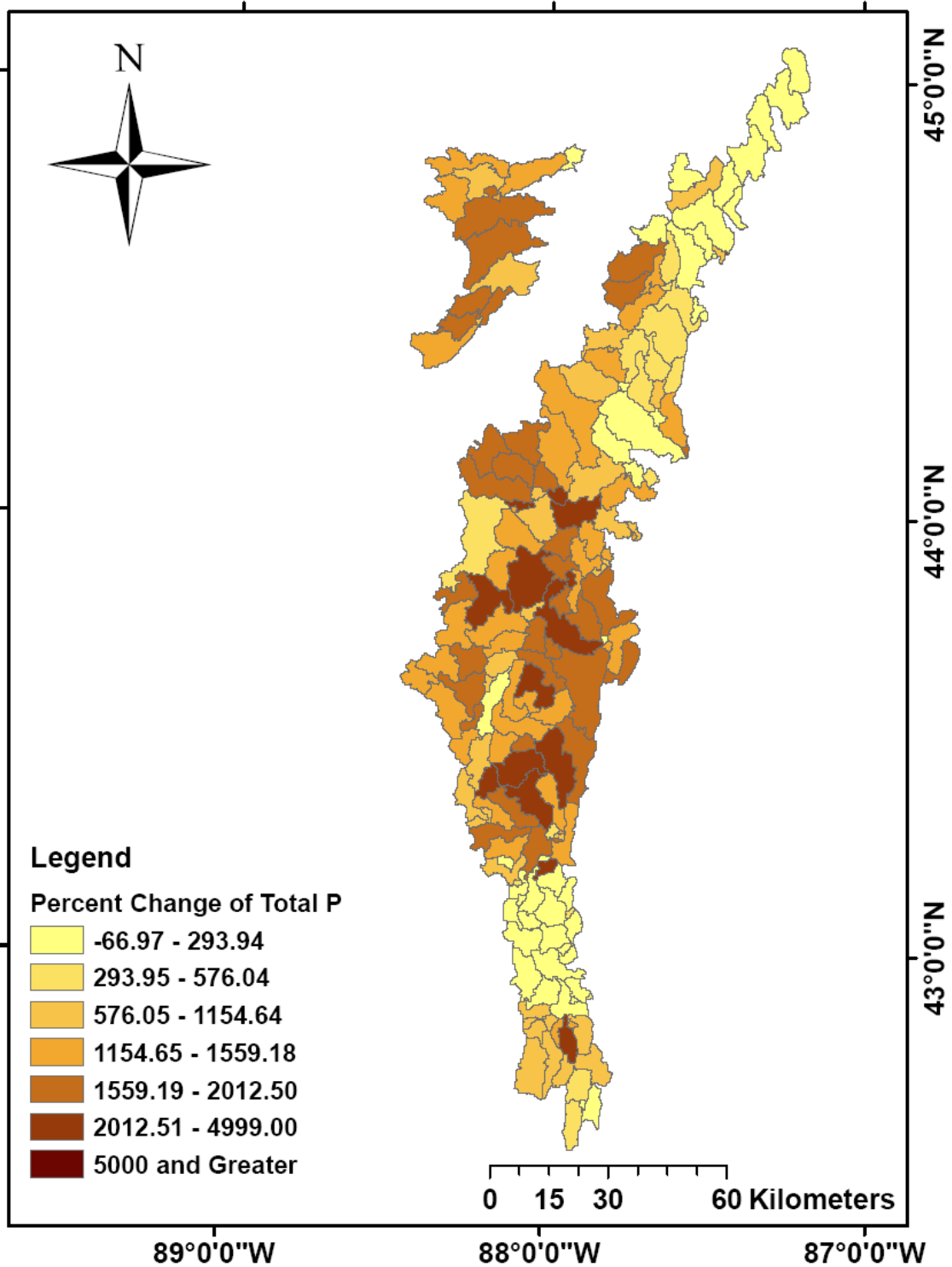


Figure 27. Percent change of total P output values resulted from landuse changes

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7.0 References

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