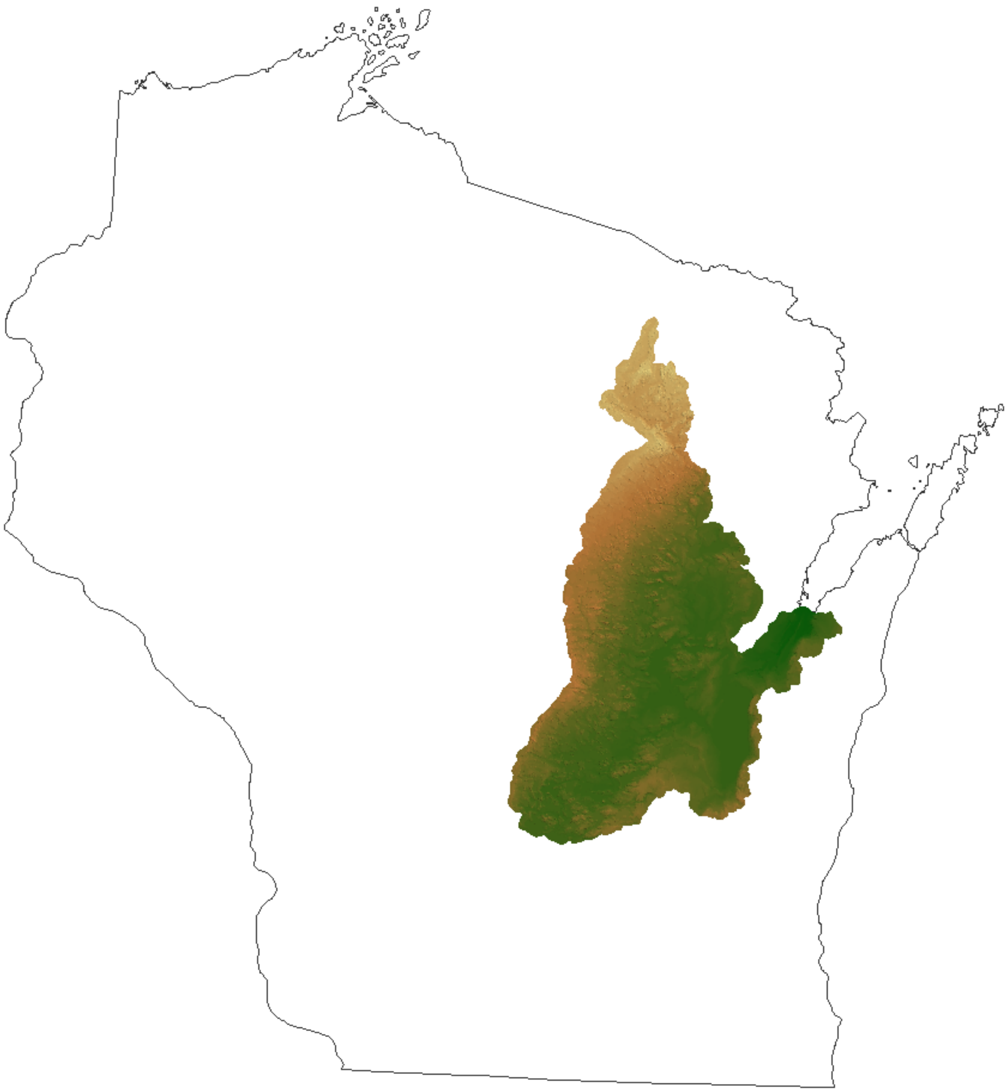
Effects of Historic and Current Land Covers on Water Budget and Water Quality in Agricultural Regions of Michigan and Wisconsin:

SWAT Model Report 040302 (Wolf/Fox Rivers)



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1.0 General Information

The Wolf and Fox Rivers lie in east-central Wisconsin. The basin (Wolf Basin) has a mild topography with the minimum elevation of 176m and maximum elevation reading 579m, with a mean of 378m. The catchment has a total area of 1.57 million hectares (or 3.89 million acres). The Fox River drains into Green Bay with an annual average flow rate of 130 cubic meters per second (cms), or 4609 cubic feet per second (cfs). A relief map is shown in figure 1.

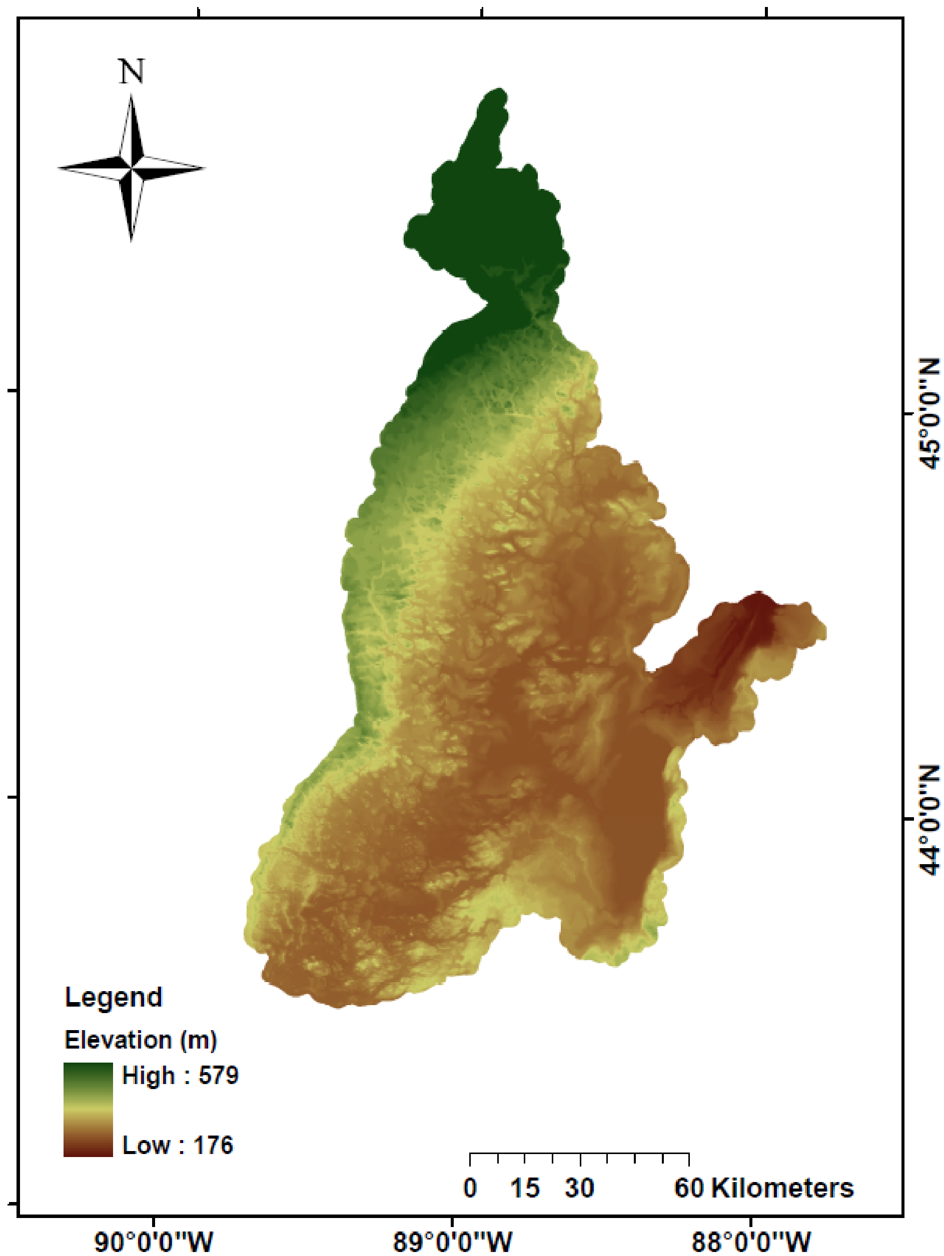


Figure 1. Relief map of the Wolf Basin

2.0 River Network

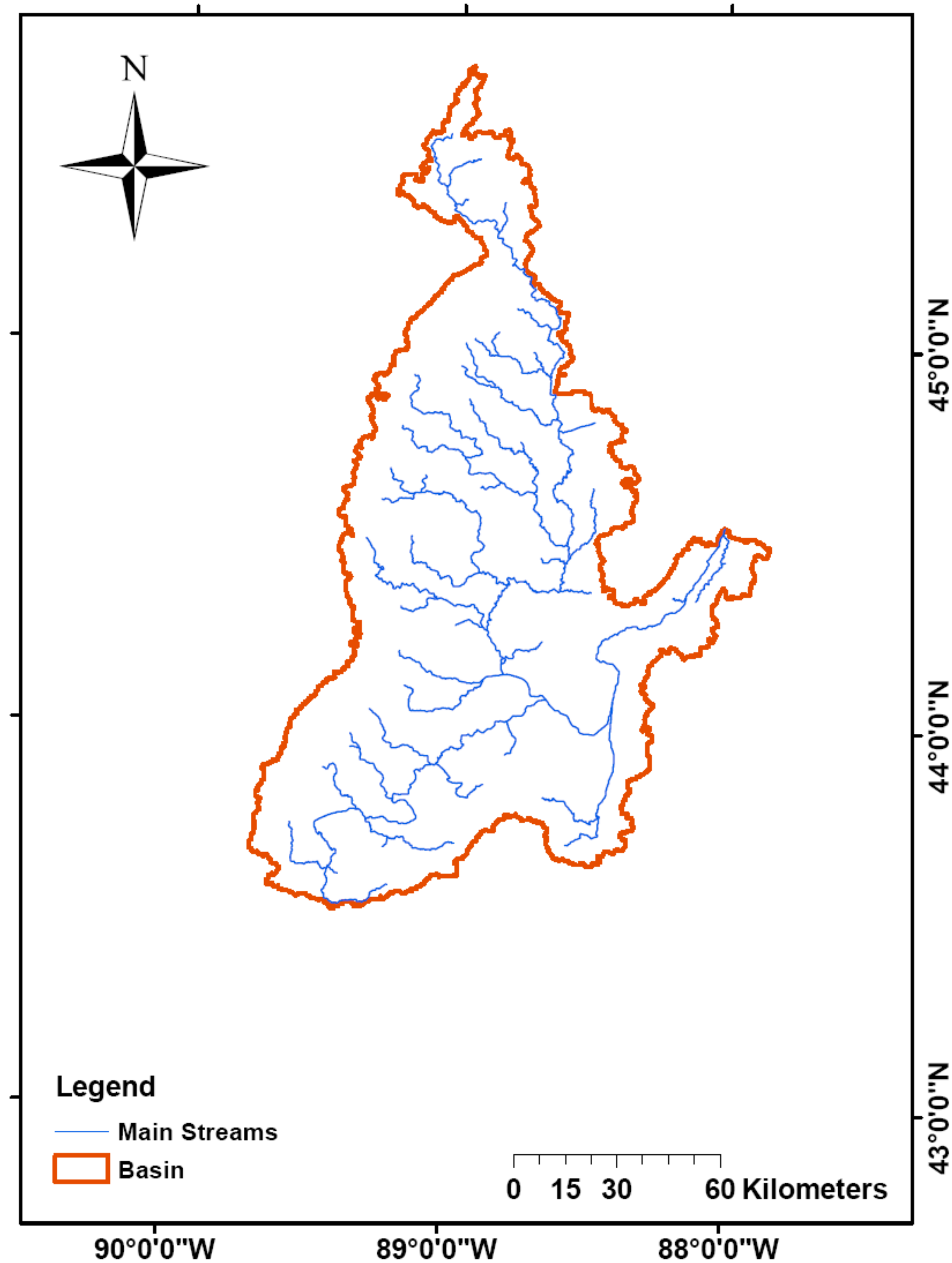


Figure 2. Major streams of the Wolf Basin

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 Wolf Basin Watershed is the predominant land usage covering 41 percent of land area. Forest covers 28 percent of the land area. Urban areas, wetlands, rangelands, and water constitute the remaining 31 percent of land cover (Tables 1a and 1b). In the Wolf Basin, forest and wetland dominates its north upland and agricultural land occupies a majority of the southern area (Figure 3). Large densities of urban development are found lower in the watershed along the Wolf River and Lake Winnebago.

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

LANDUSE:	AREA (ha)	PERCENTAGE
Agricultural Land-Row Crops	487058.1	31.0
Forest-Deciduous	357172.1	22.7
Wetlands-Forested	158987.4	10.1
Hay	154624.9	9.8
Water	100665.2	6.4
Wetlands-Non-Forested	76102.05	4.8
Residential-Low Density	61539.56	3.9
Forest-Mixed	42145.81	2.7
Residential-Medium Density	39196.51	2.5
Forest-Evergreen	36748.59	2.3
Range-Grasses	22420.13	1.4
Range-Brush	18414.58	1.2
Residential-High Density	12061.8	0.8
Industrial	4911.109	0.3
Range-Other	817.3607	0.1

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

Agriculture	40.8%
Forest	27.7%
Wetland	15.0%
Urban	7.5%
Water	6.4%
Range	2.7%

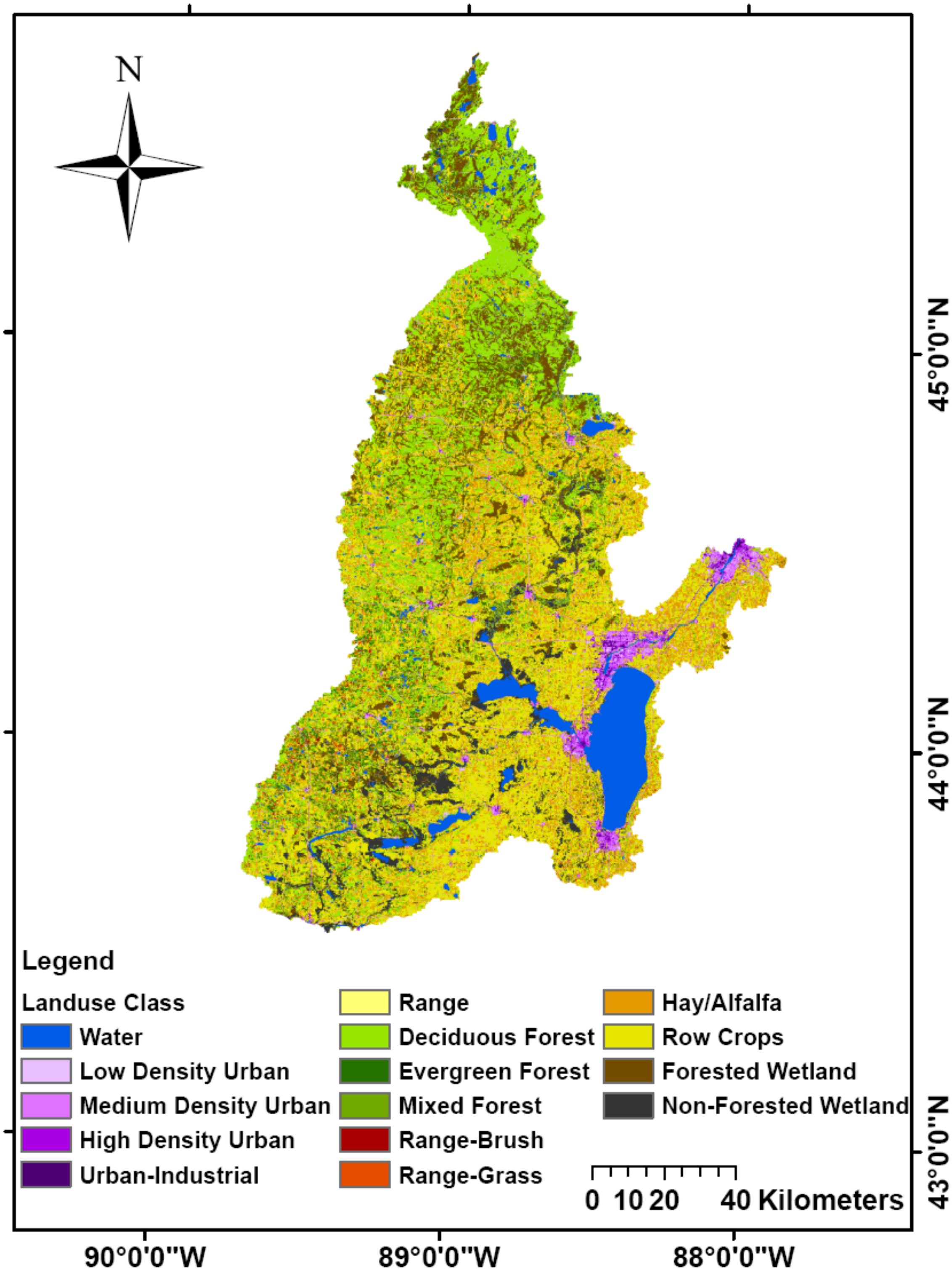


Figure 3. Current landuse map of the Wolf Basin

Based on the Landuse circa 1800 county base (LU1800), forest was the predominant land usage in the Wolf Basin covering 73 percent of land area. Wetlands covered 18 percent of the land area. Rangeland and water constitute the remaining 9.7 percent of land cover (Tables 2a and 2b). In the Wolf 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 Wolf Basin ranked by area (LU1800)

LANDUSE:	AREA (ha)	PERCENTAGE
Forest-Deciduous	753715.6	47.9
Forest-Mixed	363694.3	23.1
Wetlands-Forested	169059	10.8
Wetlands-Non-Forested	106866.6	6.8
Water	91883.29	5.8
Range-Grasses	43511.79	2.8
Forest-Evergreen	27024.99	1.7
Range-Brush	17109.71	1.1

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

Forest	72.8%
Wetland	17.5%
Rangeland	5.8%
Water	3.9%
Urban	0.0%
Agriculture	0.0%

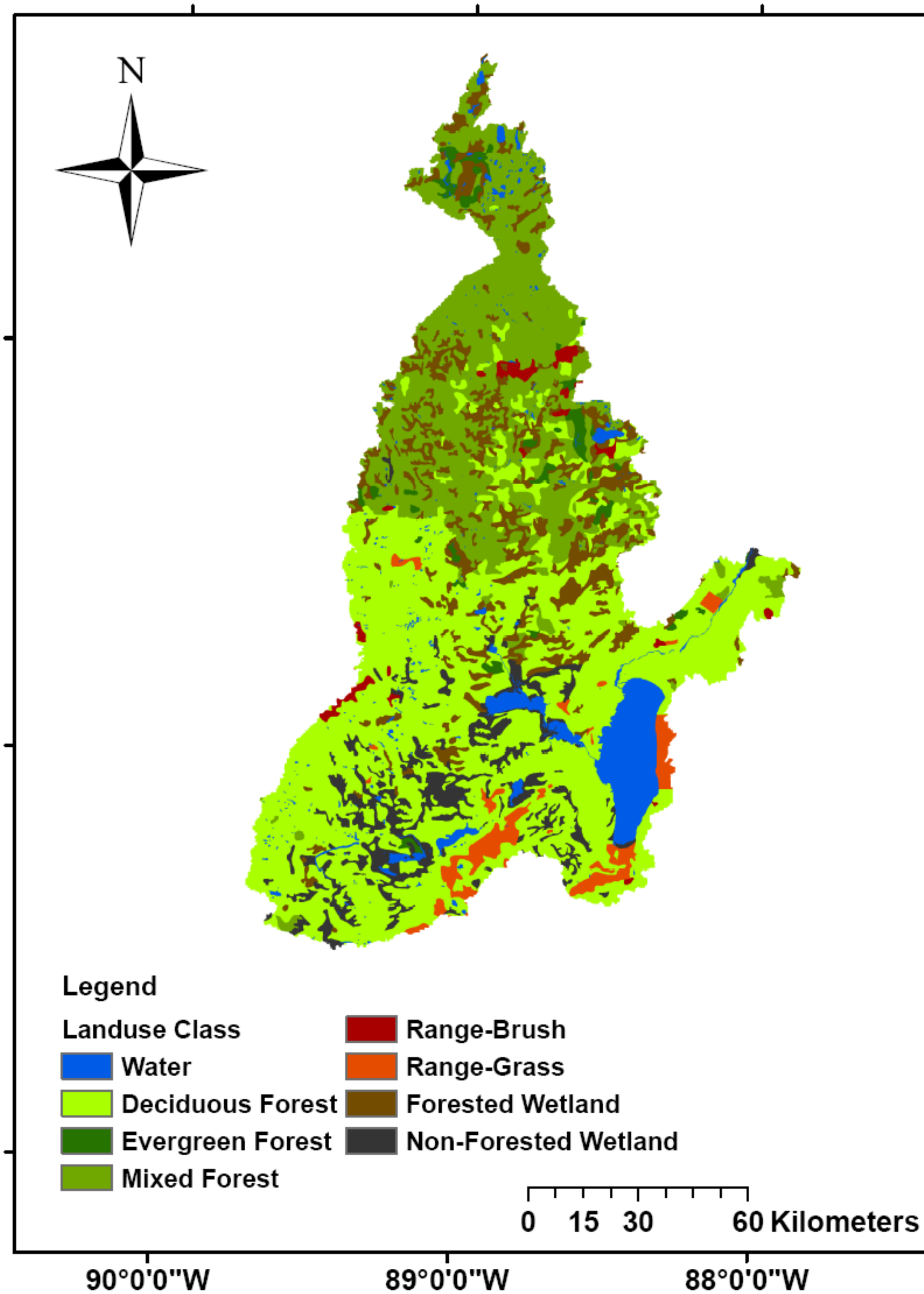


Figure 4. Pre-Settlement landuse map of the Wolf Basin

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 Wolf River Basin.

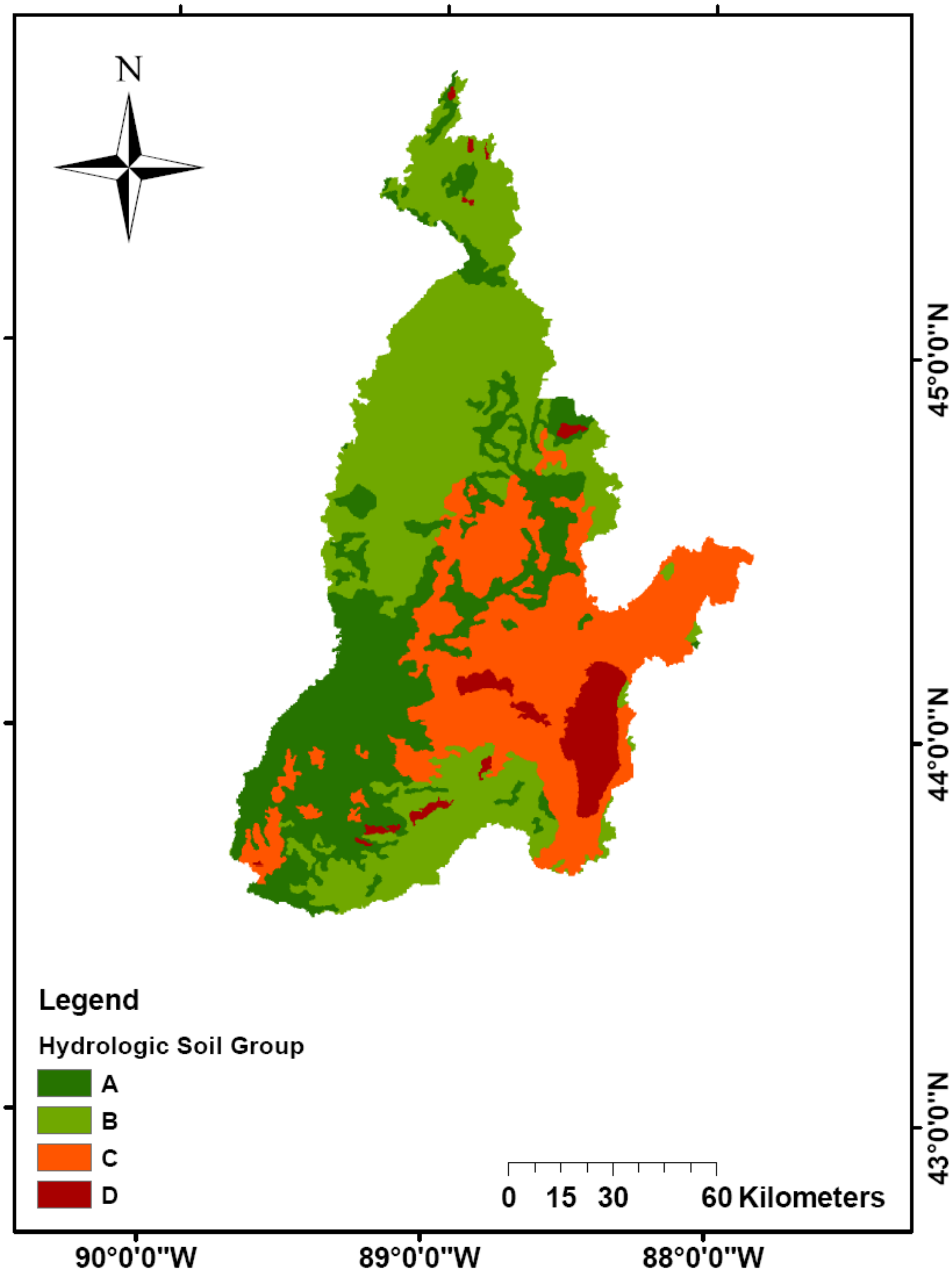


Figure 5. Hydrologic Soil Groups for the Wolf Basin

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.

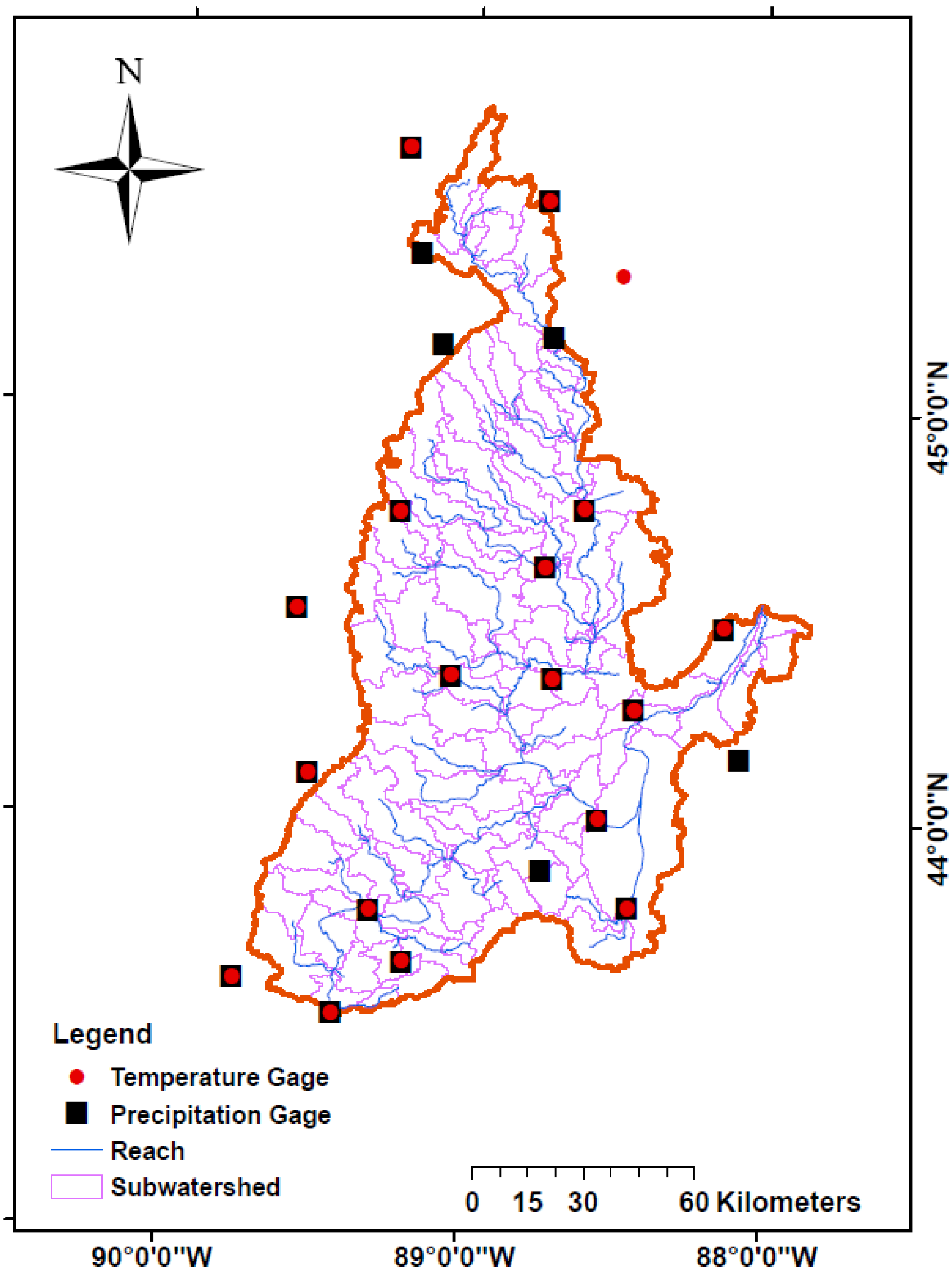


Figure 6. Temperature and precipitation gages in the Wolf Basin

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. The Better Assessment Science Integrating point & Non-point Sources (BASINS v. 4.0 released on 03/2009) was also used 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. The study area was divided to 117 subwatersheds. Figure 7 shows the boundary and the locations of subwatersheds in the Wolf basin.

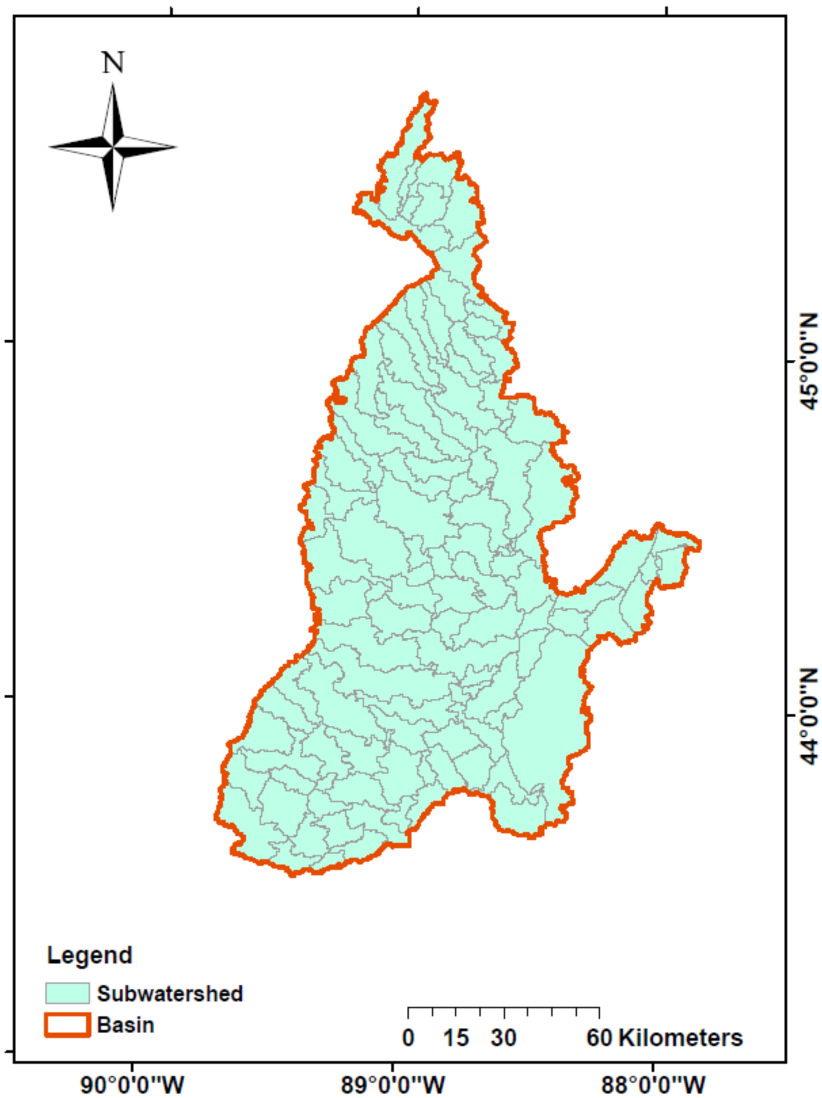
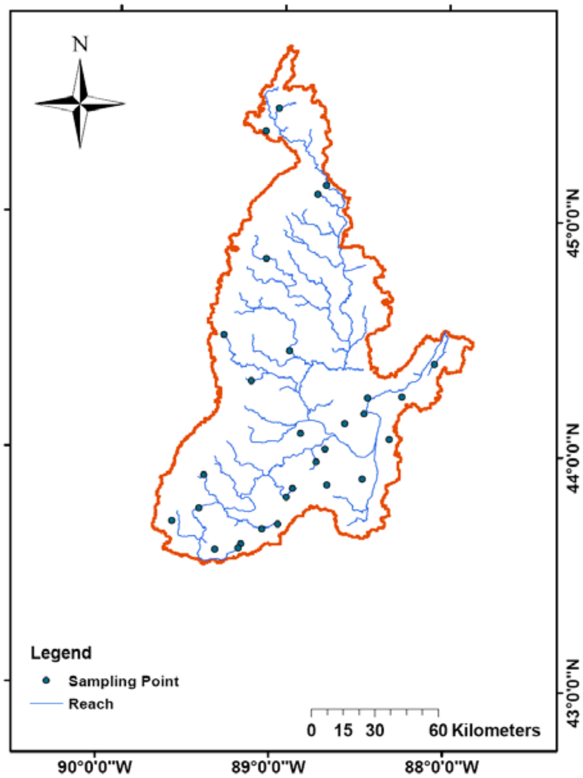


Figure 7. The delineated subwatersheds

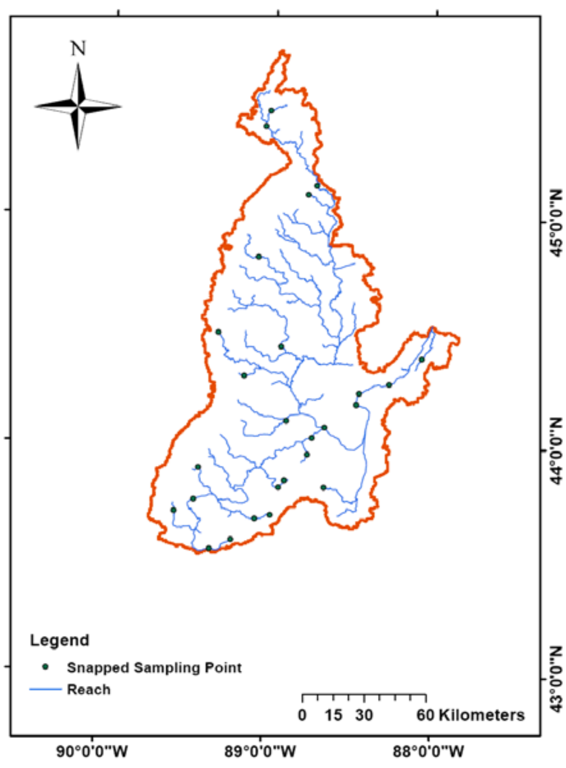
The SWAT model generates results on the outlets of subwatersheds. Since our goal is to obtain the model results on the locations of fish sampling points, these points were introduced to the model. In some cases, the fish sampling points lie on small creeks, which are too small for the model to recognize. In those cases, fish sampling points are snapped to the nearest stream network. Therefore, the location of the outlet is sometimes different 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	43.5870	-89.3389	1	43.5870	-89.3389
2	43.5953	-89.2031	2	43.6136	-89.1880
3	43.6136	-89.1880	3	43.6794	-89.0669
4	43.6794	-89.0669	4	43.7012	-88.9756
5	43.7012	-88.9756	5	43.7051	-89.5954
6	43.7051	-89.5954	6	43.7612	-89.4401
7	43.7612	-89.4401	7	43.8172	-88.9285
8	43.8172	-88.9285	8	43.8546	-88.8935
9	43.8546	-88.8935	9	43.8734	-88.6913
10	43.8734	-88.6913	10	43.9035	-89.4165
11	43.9001	-88.4848	11	43.9697	-88.7571
12	43.9035	-89.4165	12	44.0258	-88.7067
13	43.9697	-88.7571	13	44.0895	-88.8524
14	44.0258	-88.7067	14	44.1355	-88.5941
15	44.0703	-88.3292	15	44.1782	-88.4811
16	44.0895	-88.8524	16	44.2450	-88.4614
17	44.1355	-88.5941	17	44.2524	-88.2581
18	44.1782	-88.4811	18	44.3086	-89.1515
19	44.2450	-88.4614	19	44.3924	-88.0680
20	44.2524	-88.2581	20	44.4395	-88.9287
21	44.3086	-89.1515	21	44.5022	-89.3210
22	44.3924	-88.0680	22	44.8309	-89.0801
23	44.4395	-88.9287	23	45.1078	-88.7811
24	44.5022	-89.3210	24	45.1473	-88.7302
25	44.8309	-89.0801	25	45.3728	-89.1014
26	45.1078	-88.7811	26	45.4718	-89.0253
27	45.1473	-88.7301	27		
28	45.3728	-89.1014	28		
29	45.4718	-89.0253	29		



(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. Sufficient phosphorus data was not available for calibration. Four years of data were used for calibration.

The USGS gaging station located on the Fox River at New London (Station No. 004079000) was used to calibrate the model for flow (Figure 9) and the EPA STORET station 693035, located immediately downstream, was used to calibrate for water quality (Figure 10). Daily water quality data were input to the USGS Load Estimator model (LOADEST) in order to generate monthly average values based on daily flow.

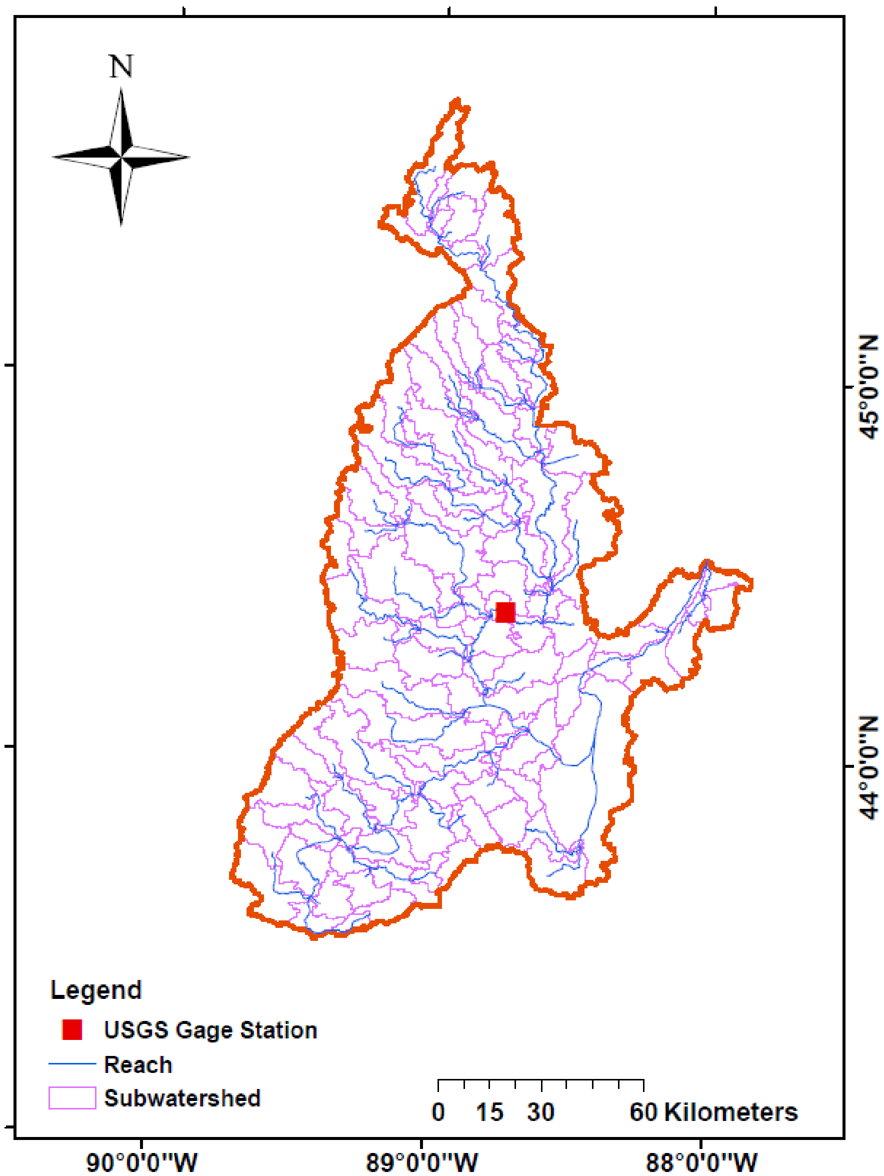


Figure 9. The delineated subwatersheds and USGS station.

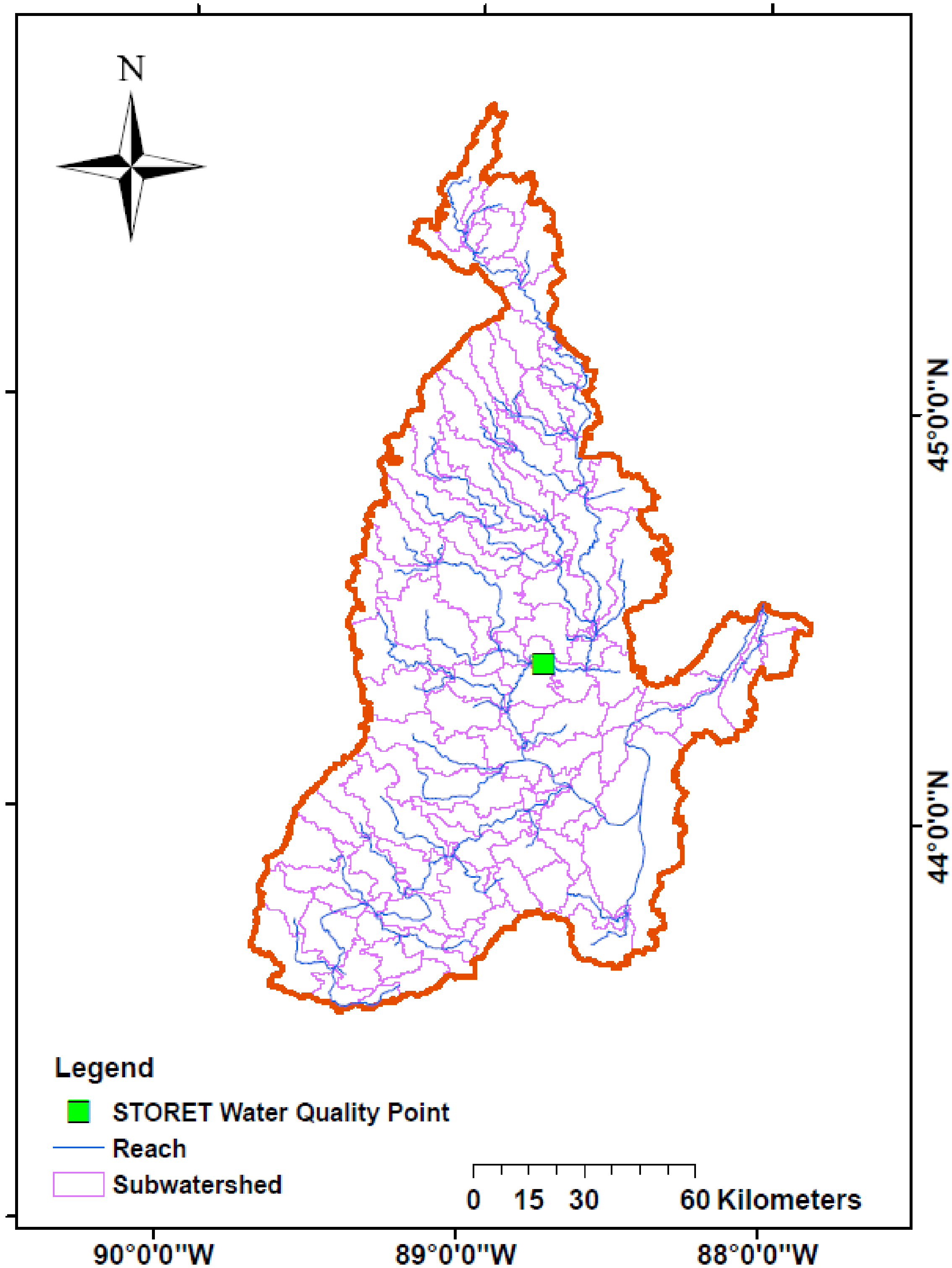


Figure 10. STORET sampling location used to calibrate water quality parameters

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 data (van Griensven, Meixner et al. 2006). Sensitivity analysis was performed for total phosphorus without observed data. The sensitivity ranking of 42 parameters for this watershed is given in Table 4.

Table 4: Rank-Based Sensitivity Analysis*

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

The calibrated model has achieved excellent comparisons with observed flow and total nitrogen. The comparisons of sediment were not as good because the observed data contained unexplained anomalies during the year 2004. However, the model is still able to give proper predictions on the same magnitude with the observed data for validation years 2005-2006.

Table 5. Statistics of model calibration

	Nash-Sutcliffe	RMSE	R^2
Flow	0.823	1.97	0.863
Total Suspended Solids (TSS; Overall Statistics)	-0.465	7.12	0.372
Total Suspended Solids (TSS; 2005-2006)	0.607	2.33	0.614
Total N	0.637	403.42	0.733

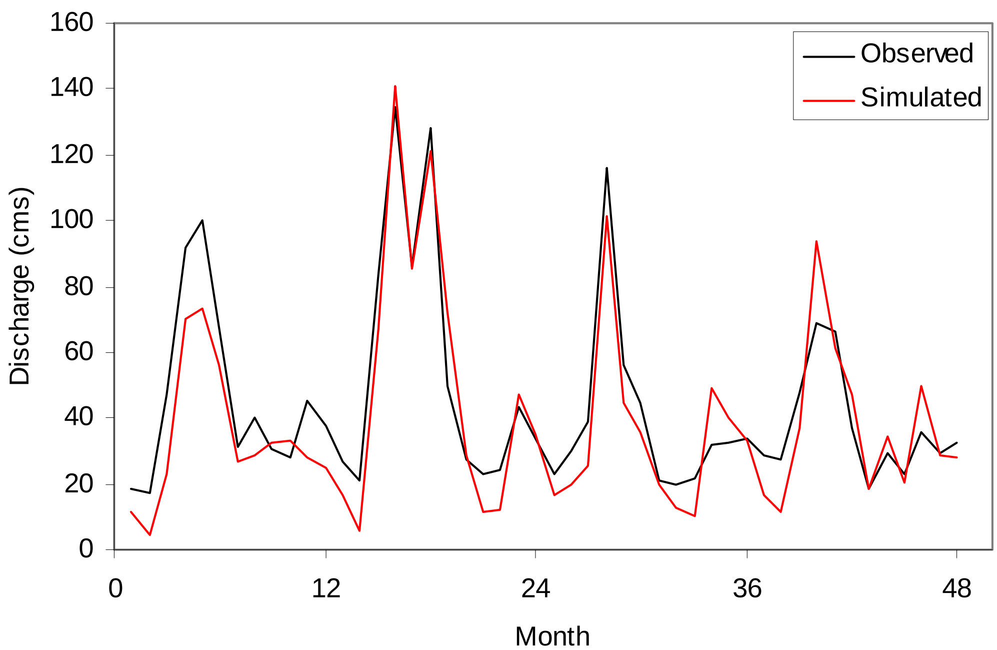


Figure 11. Model simulated results vs. USGS measurements at USGS 04079000 station

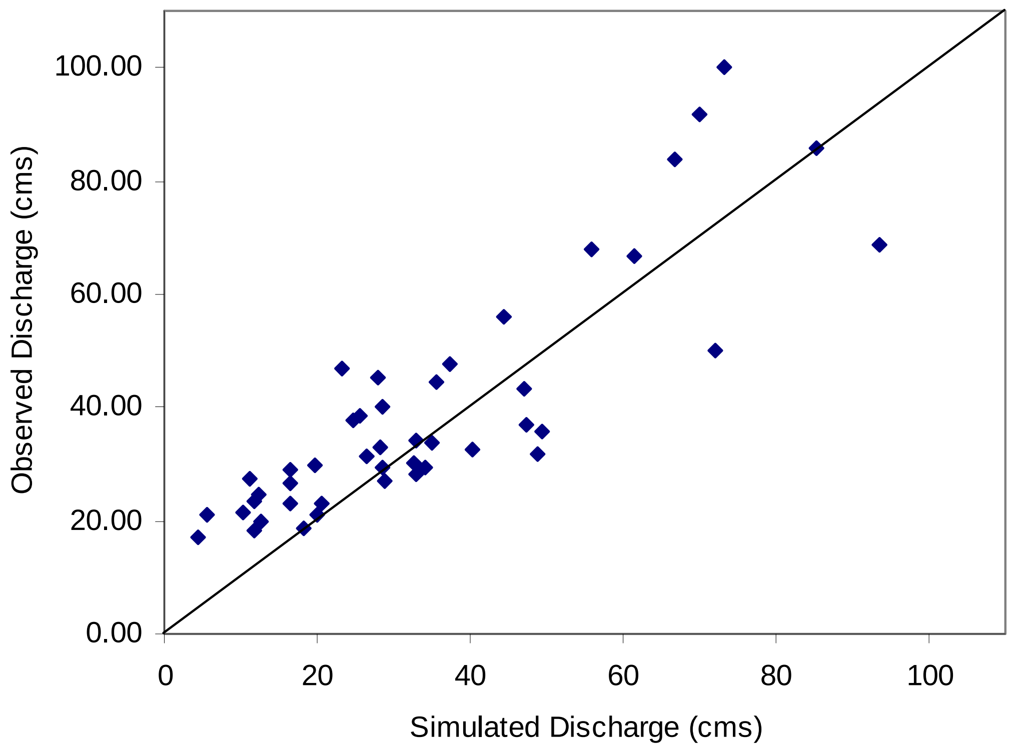


Figure 12. Simulated vs observed flow at USGS 04079000 station

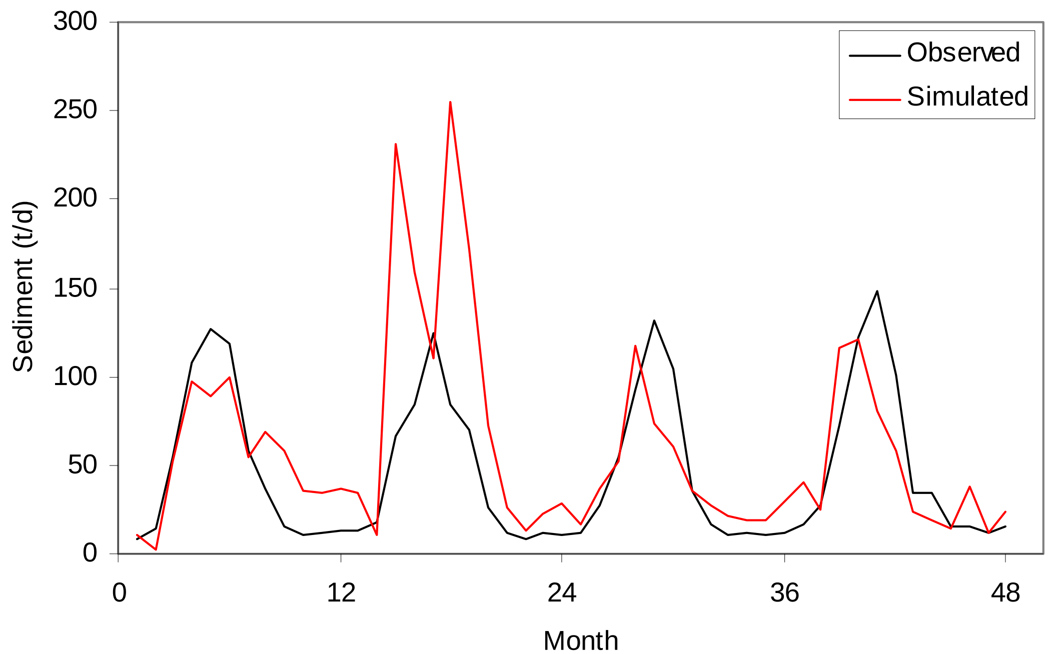


Figure 13. Time series of simulated vs observed TSS

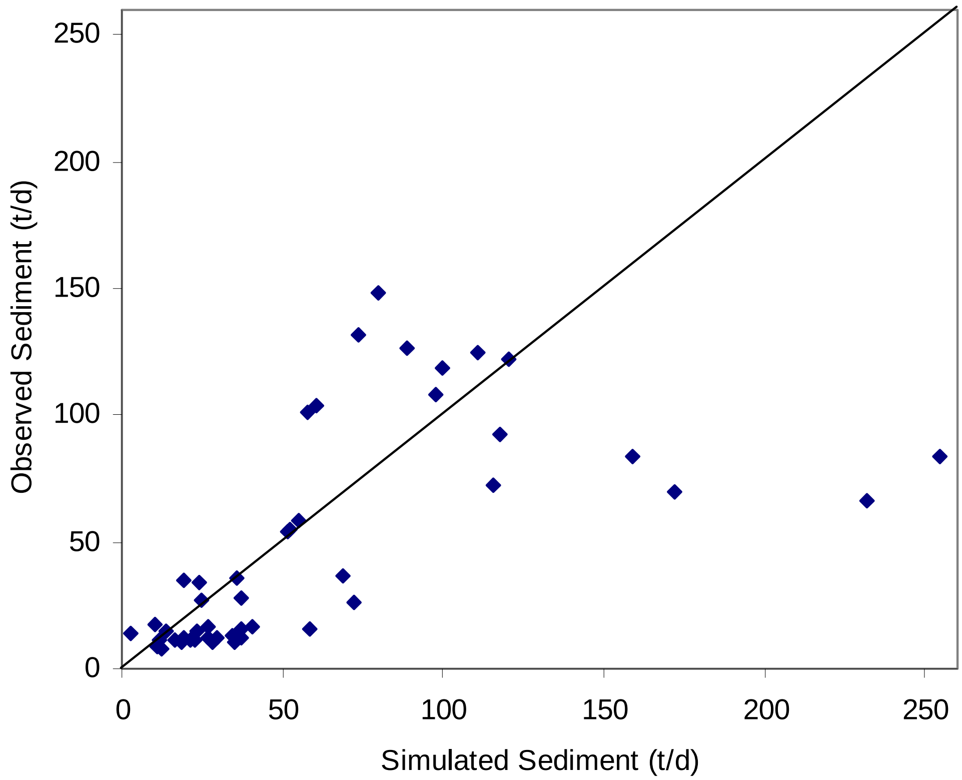


Figure 14. Simulated vs observed TSS

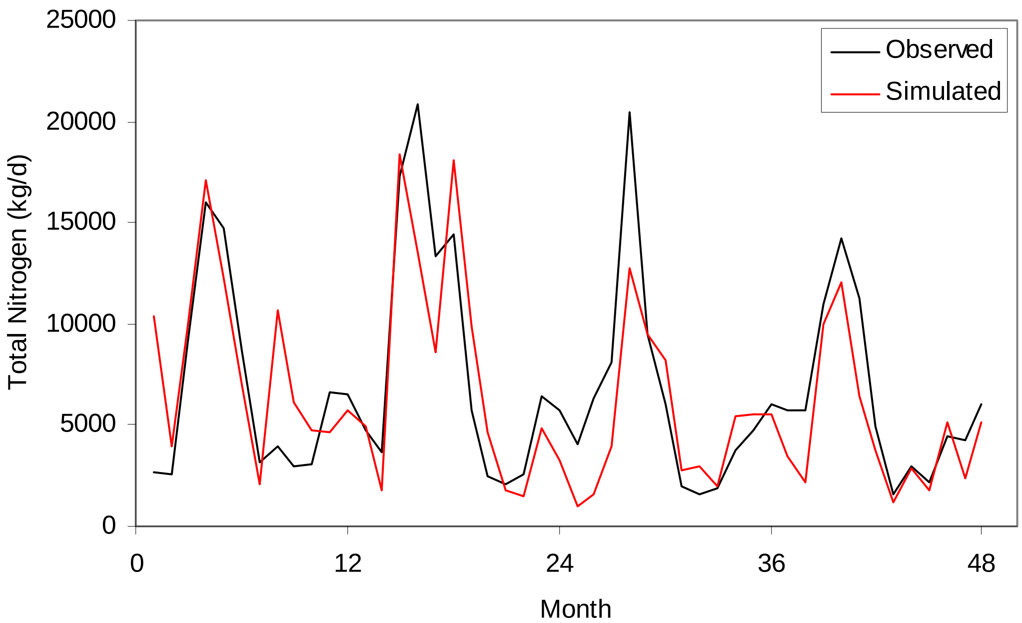


Figure 15. Time series of simulated vs observed Total Nitrogen

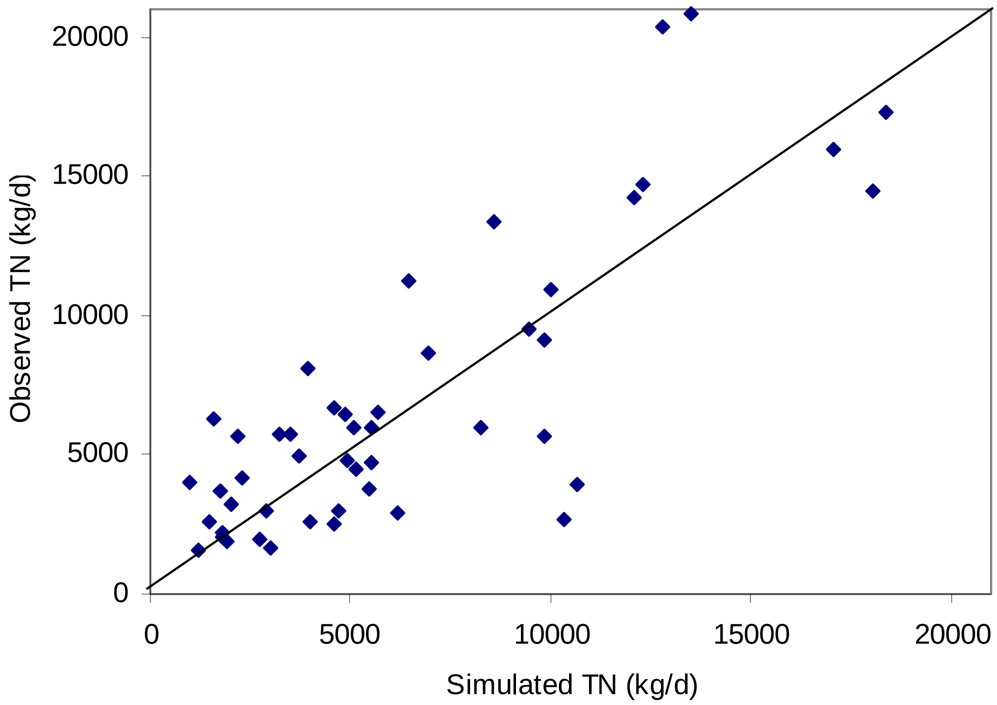


Figure 16. Simulated vs observed Total Nitrogen

Table 6. Monthly and annual hydrologic budget from the Wolf Basin

Month	Rain	Snowfall	Surface Runoff	Lateral Flow	Total Water Yield	ET	Sediment Yield	PET
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(ton/ha)	(mm)
1	28.38	23.06	5.28	0.01	7.38	8.18	0	13.74
2	29.22	24.81	5.52	0	6.24	8.12	0	15.33
3	49.58	19.25	17.31	0.52	18.6	29.18	0.01	45.3
4	53.16	4.92	17.77	0.95	29.16	61.29	0.01	111.08
5	129.59	0.37	11.64	1.63	24.81	76.48	0.01	125.76
6	92.31	0	14.37	1.17	29.52	98.3	0.02	167.55
7	76.75	0	8.49	0.68	17.53	98.77	0.01	180.97
8	77.92	0	6.77	0.84	11.97	74.38	0.01	148.65
9	76.42	0	5.26	0.81	8.72	45.35	0	109.65
10	64.04	0.99	5.17	0.72	10.96	36.99	0	63.41
11	67.14	13.85	4.65	0.76	11.25	24.55	0	38.69
12	42.32	21.03	7.18	0.14	12.49	11.29	0	17.36
Annual Average	786.83	108.28	109.41	8.23	188.63	572.88	0.07	1037.49

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 17 to 26 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 Wolf Basin

Calibrated	Current	Pre-Settlement	Percent Change	Percent Different
Recharge (mm)	103.98	207.74	-49.95%	-66.57%
Surface Runoff (mm)	115.47	50.39	129.13%	78.47%
Baseflow (mm)	81.49	158.15	-48.47%	-63.98%
Water Yield (mm)	205.81	217.02	-5.17%	-5.31%
Sediment Yield (t/ha)	0.12	0.00	6049.40%	193.60%
Total N Output (t/ha)	6.34	1.90	234.20%	107.88%
Total P Output (t/ha)	0.15	0.01	2143.69%	182.93%

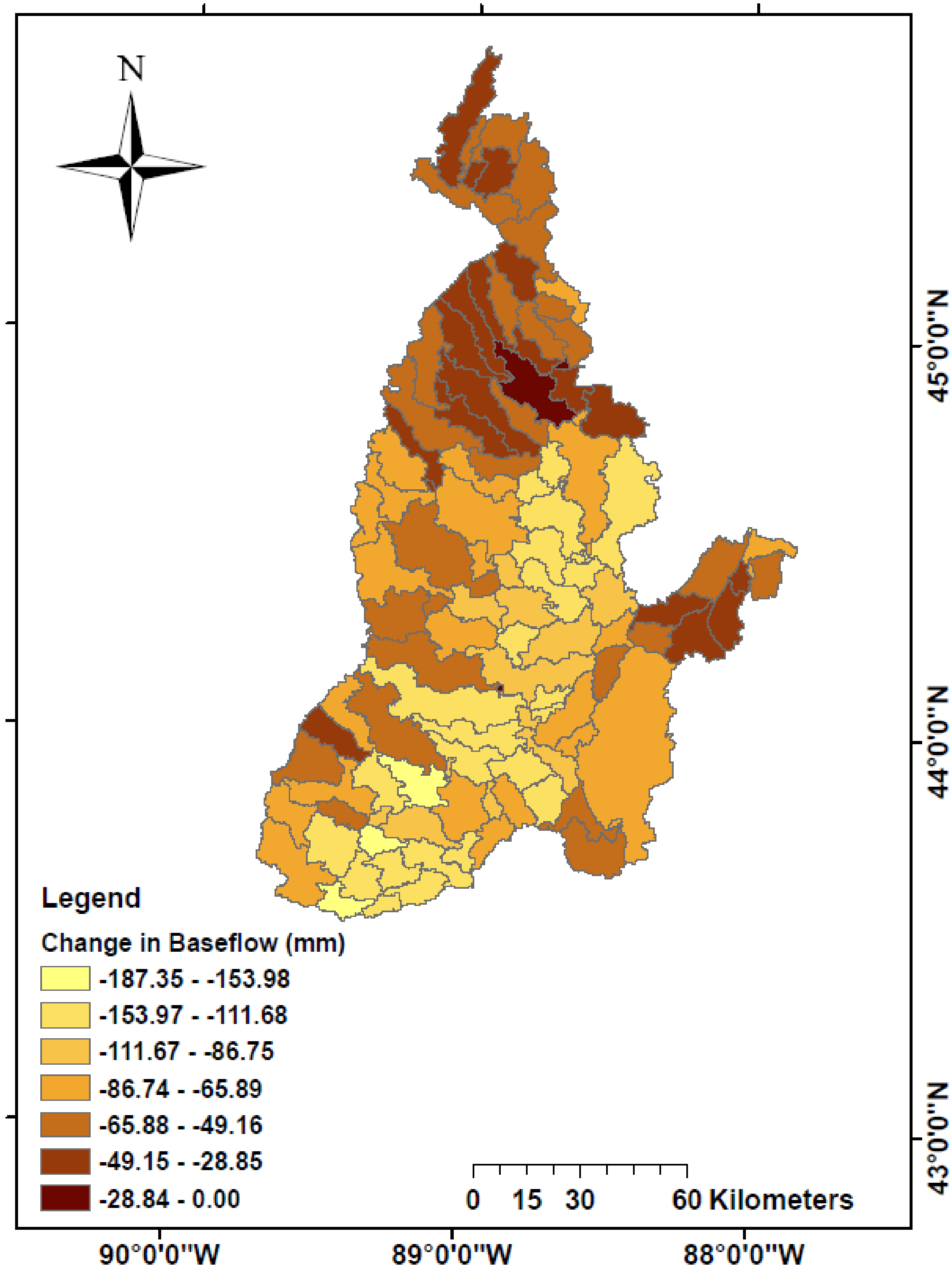


Figure 17. Change of baseflow values resulted from landuse changes (mm)

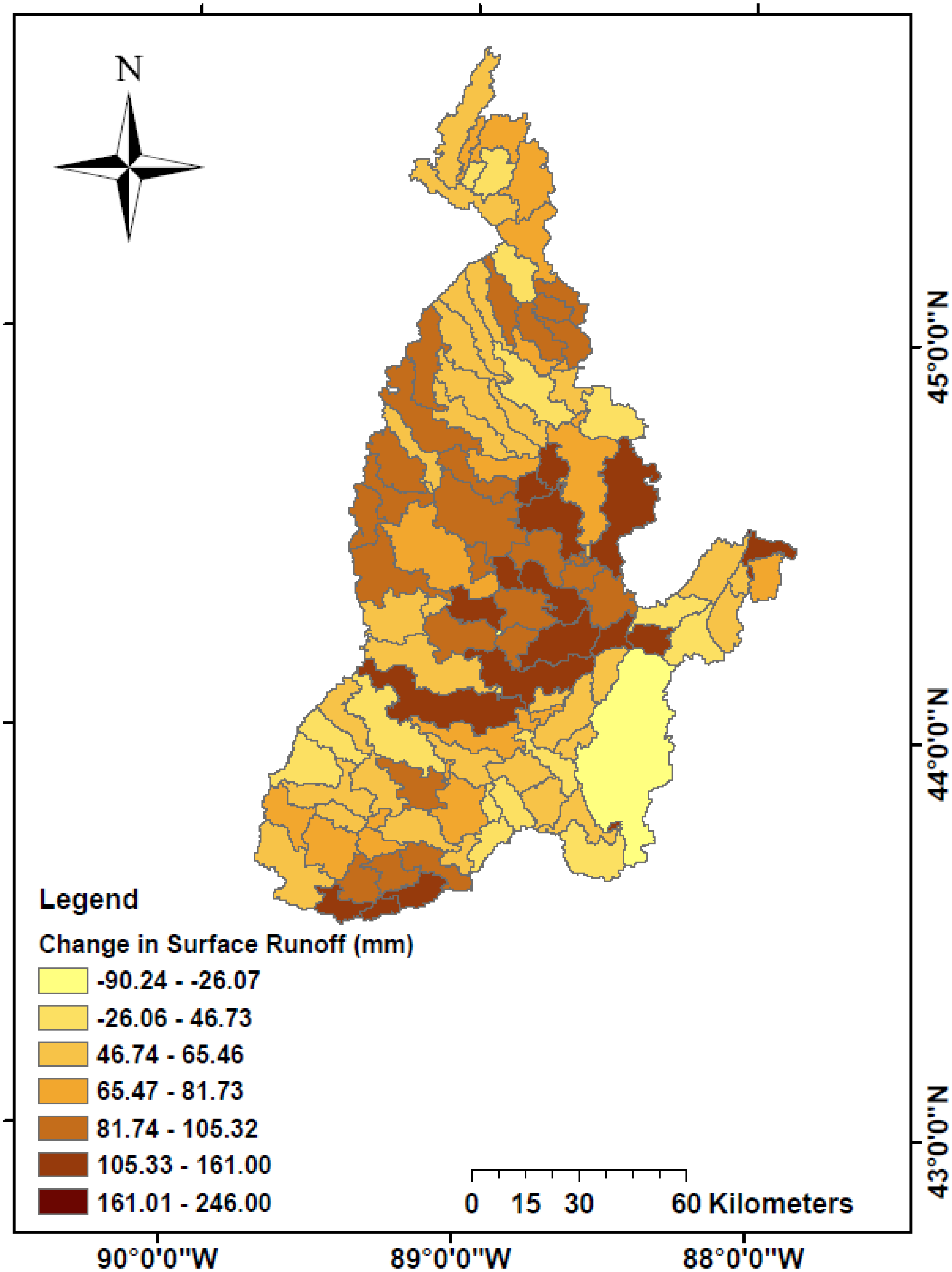


Figure 18. Change of surface runoff values resulted from landuse changes (mm)

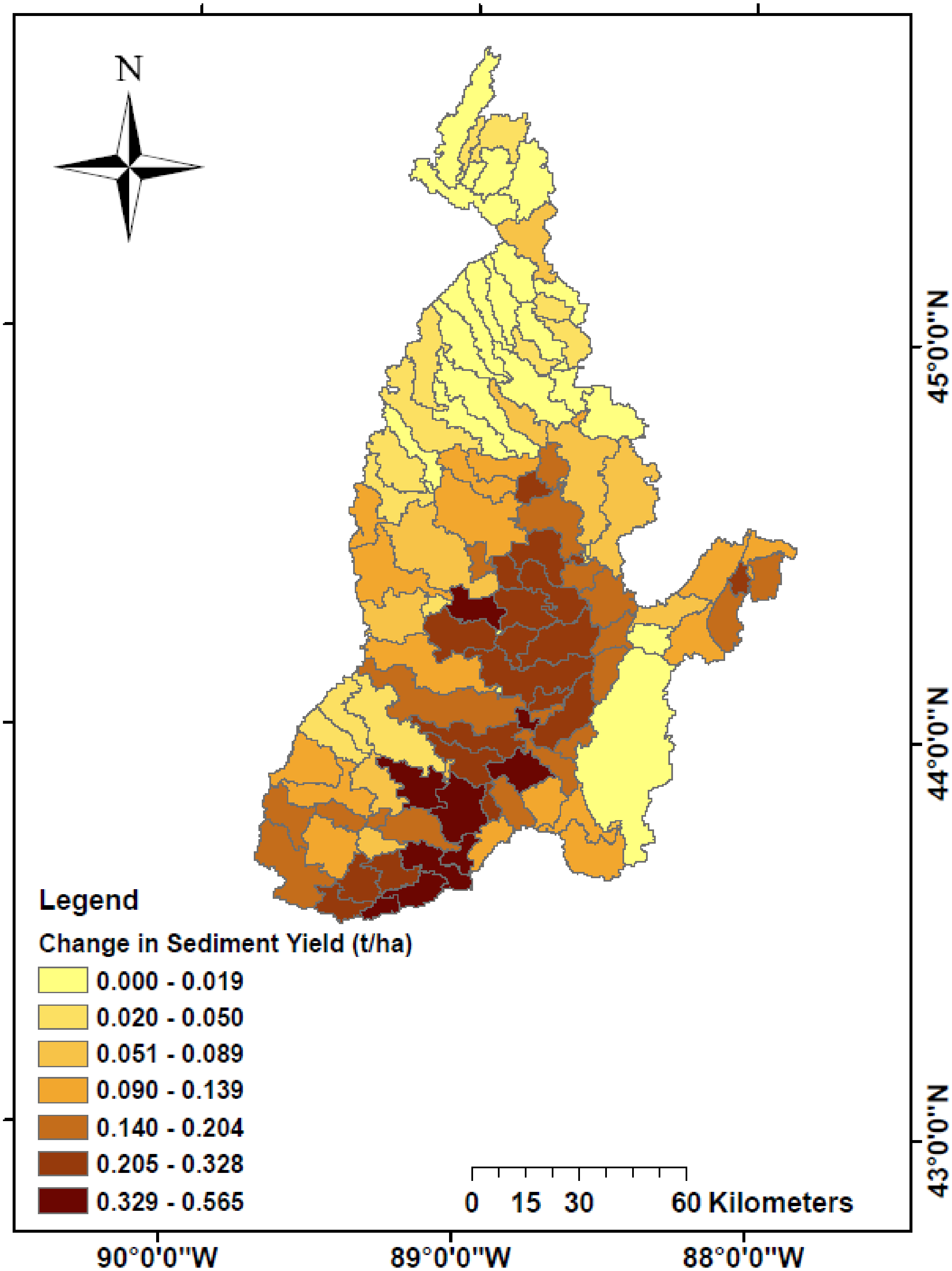


Figure 19. Change of sediment yields resulted from landuse changes (t/ha)

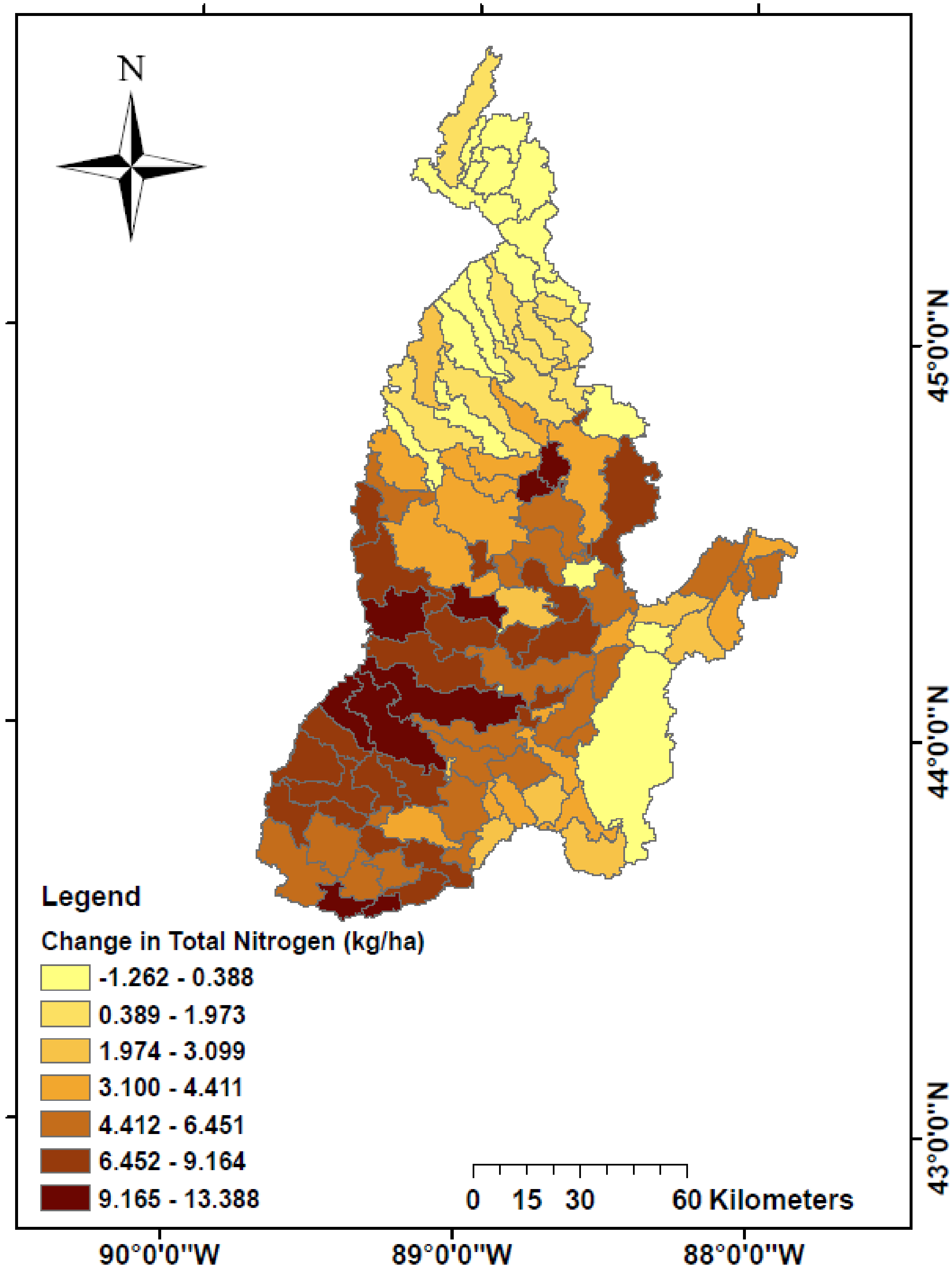


Figure 20. Change of total N output values resulted from landuse changes (kg/ha)

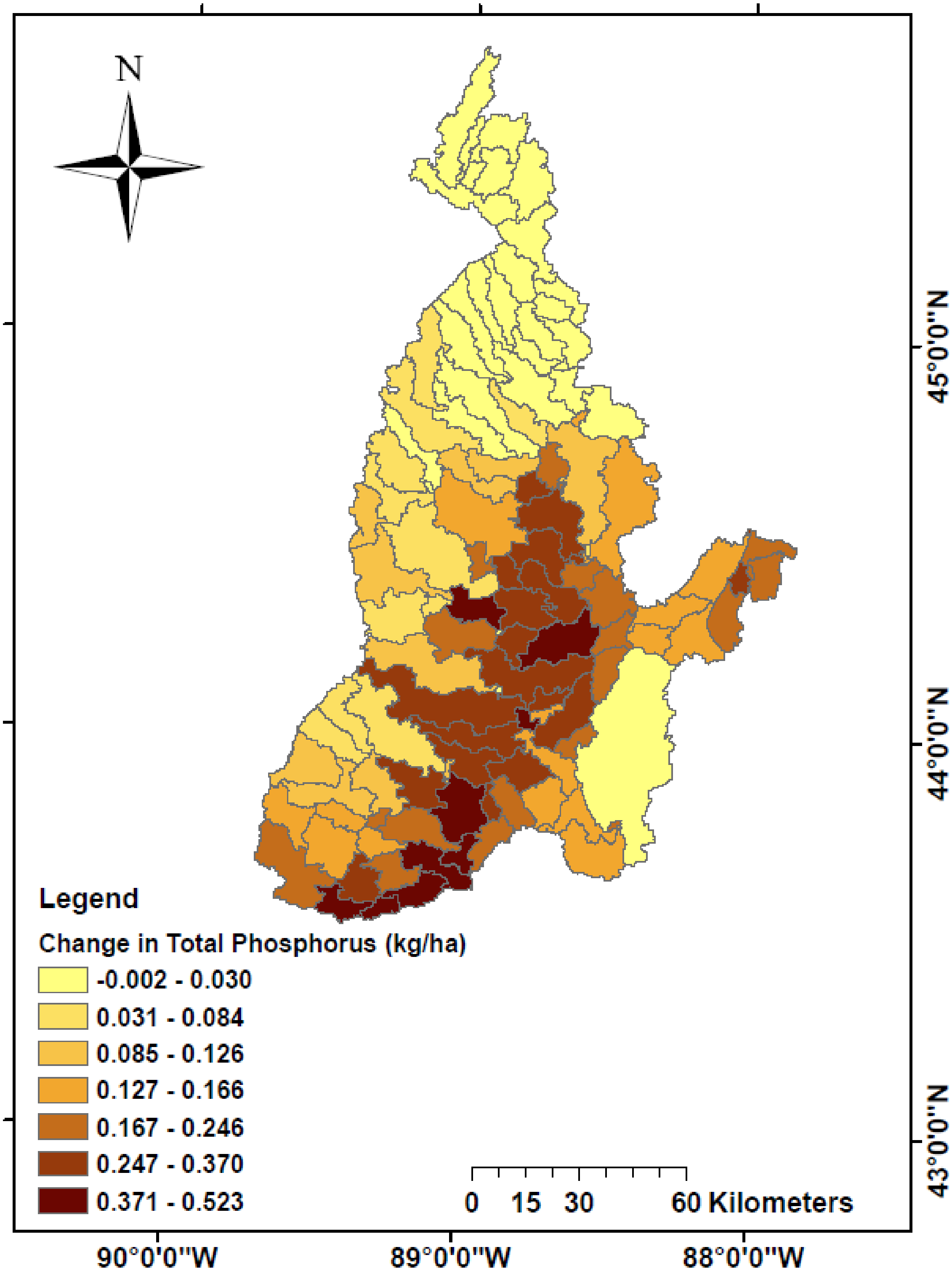


Figure 171. Change of total P output values resulted from landuse changes (kg/ha)

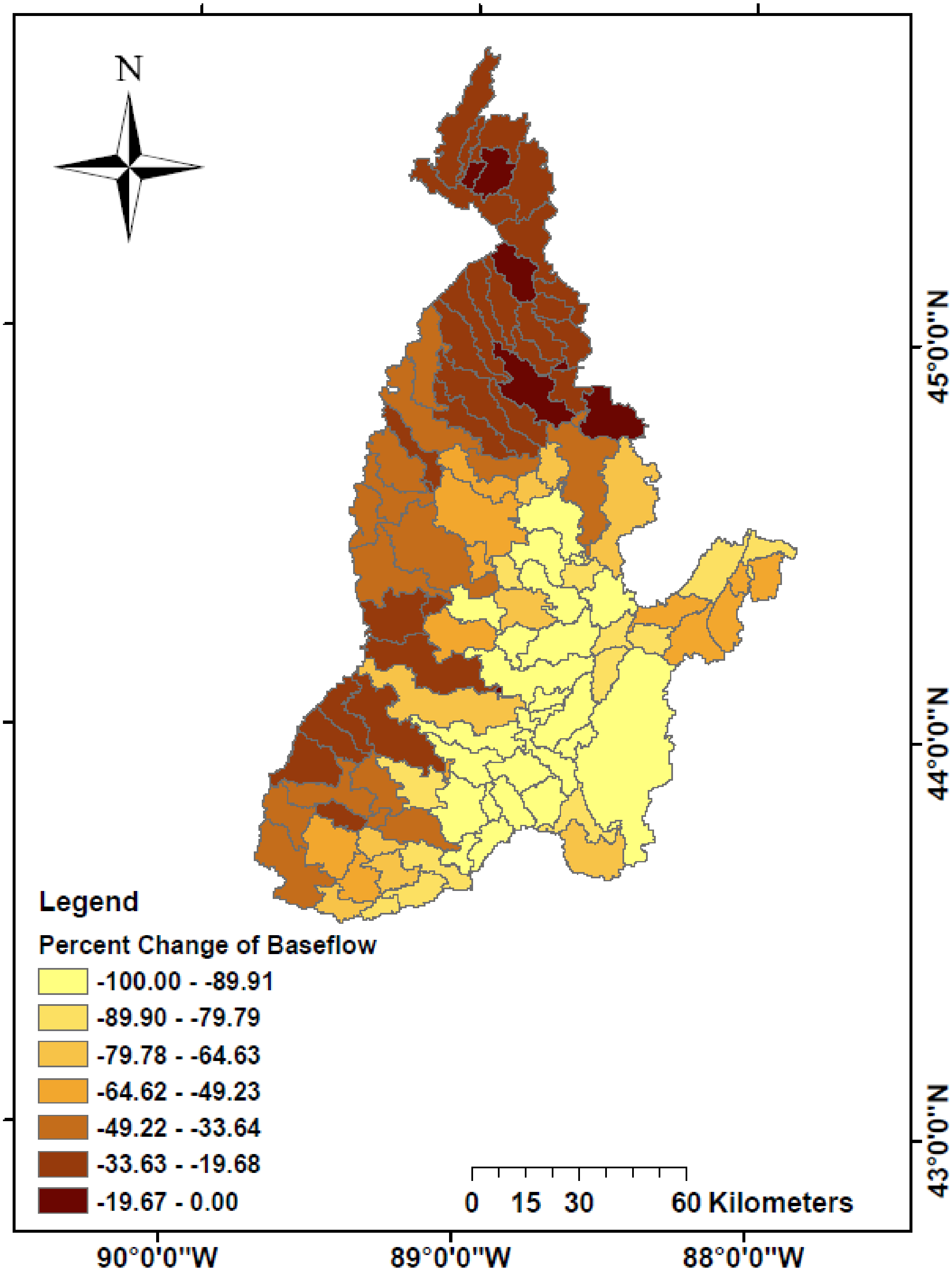


Figure 22. Percent change of baseflow values resulted from landuse changes

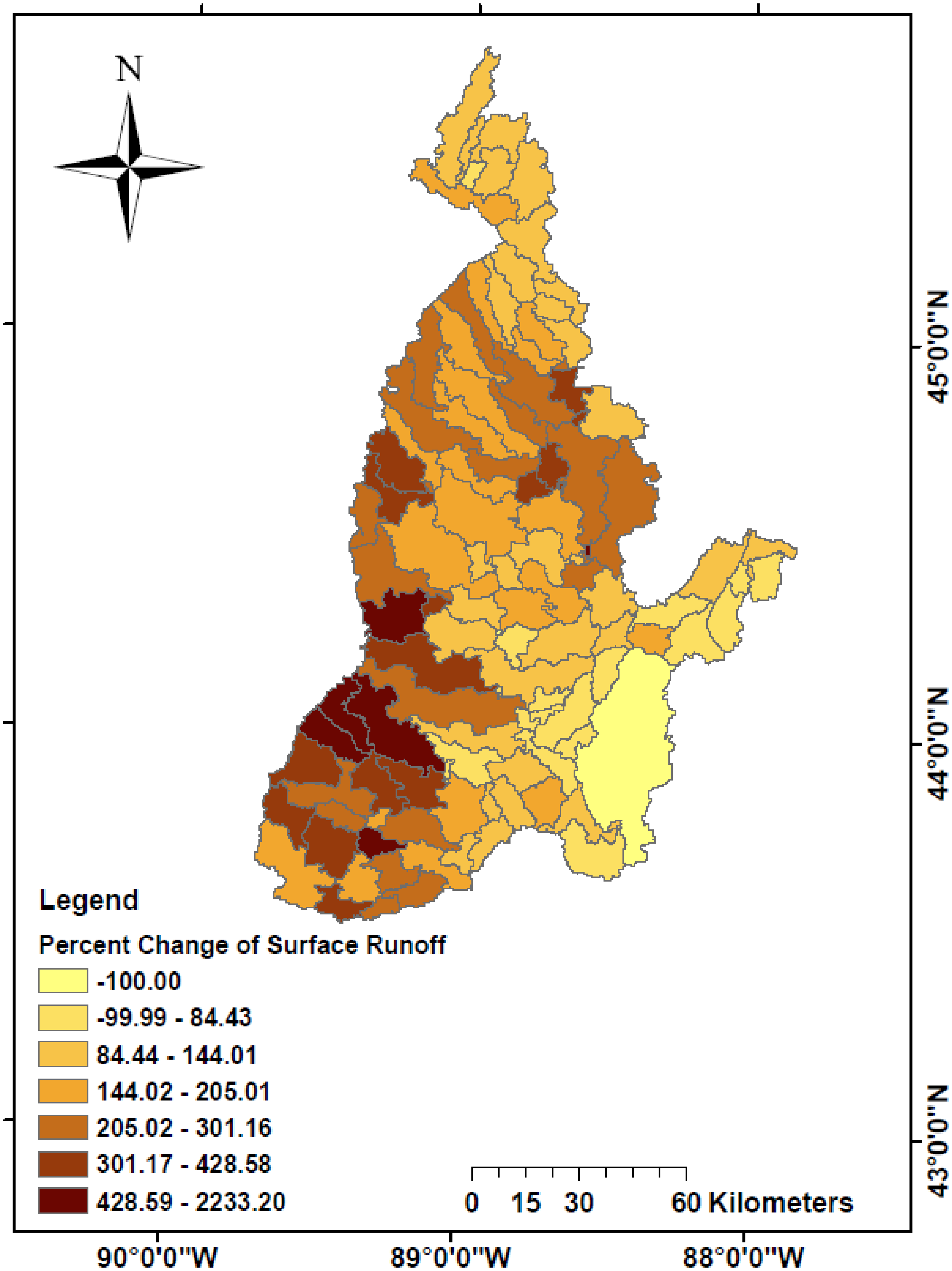


Figure 23. Percent change of surface runoff values resulted from landuse changes

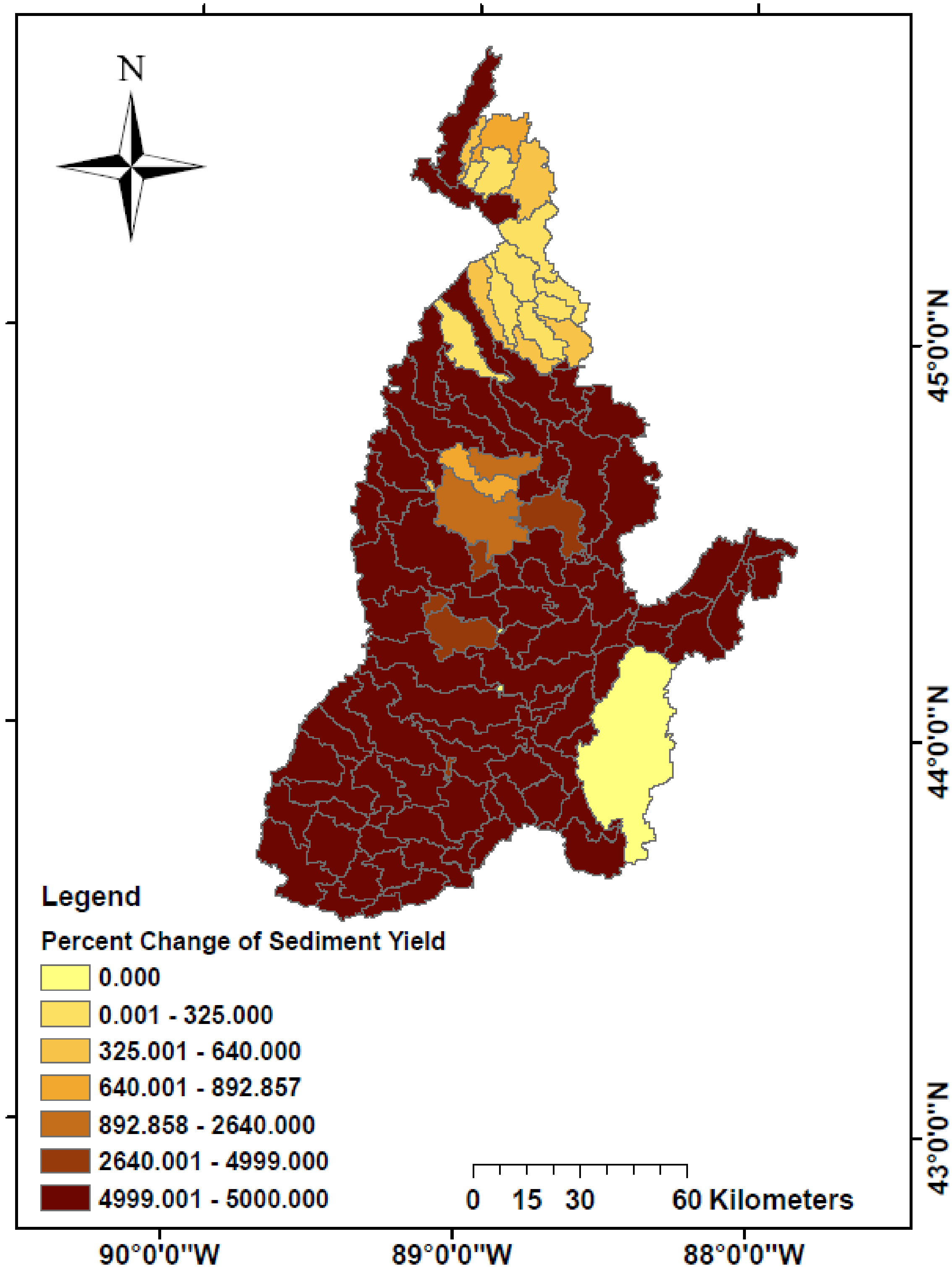


Figure 24. Percent change of sediment yield resulted from landuse changes

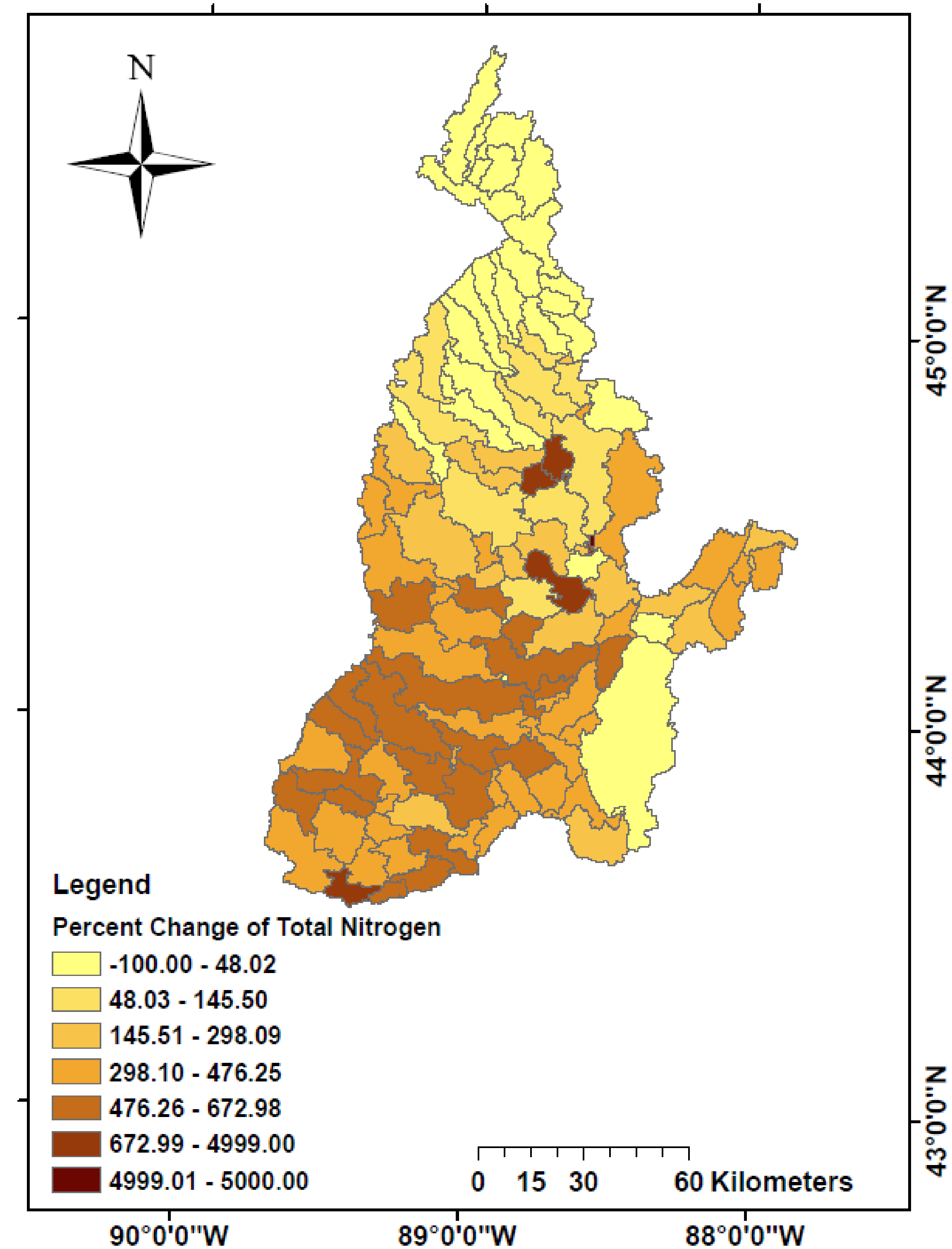


Figure 25. Percent change of total N output values resulted from landuse changes

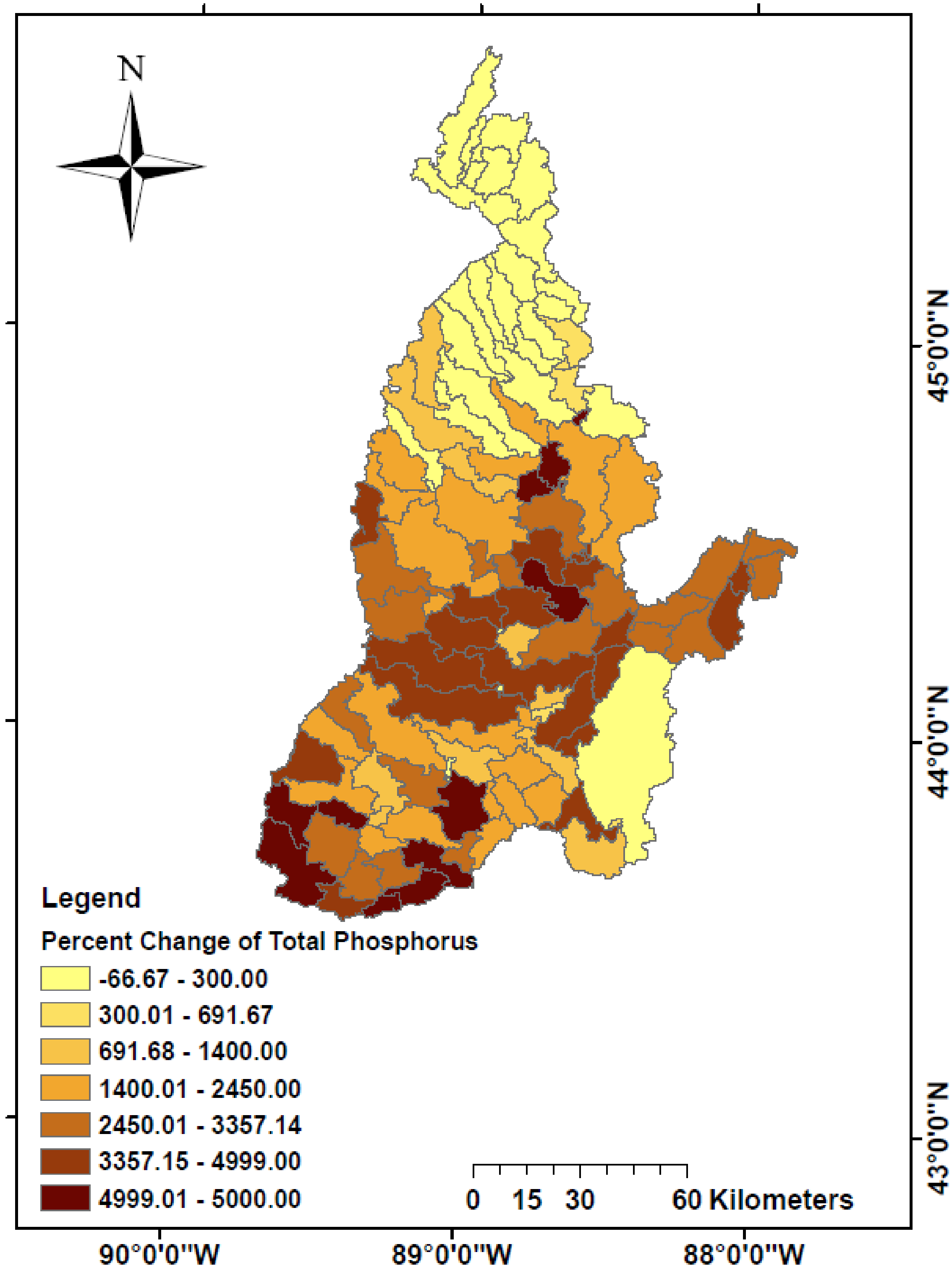


Figure 26. Percent change of total P output values resulted from landuse changes

7.0 Acknowledgment:

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8.0 References

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