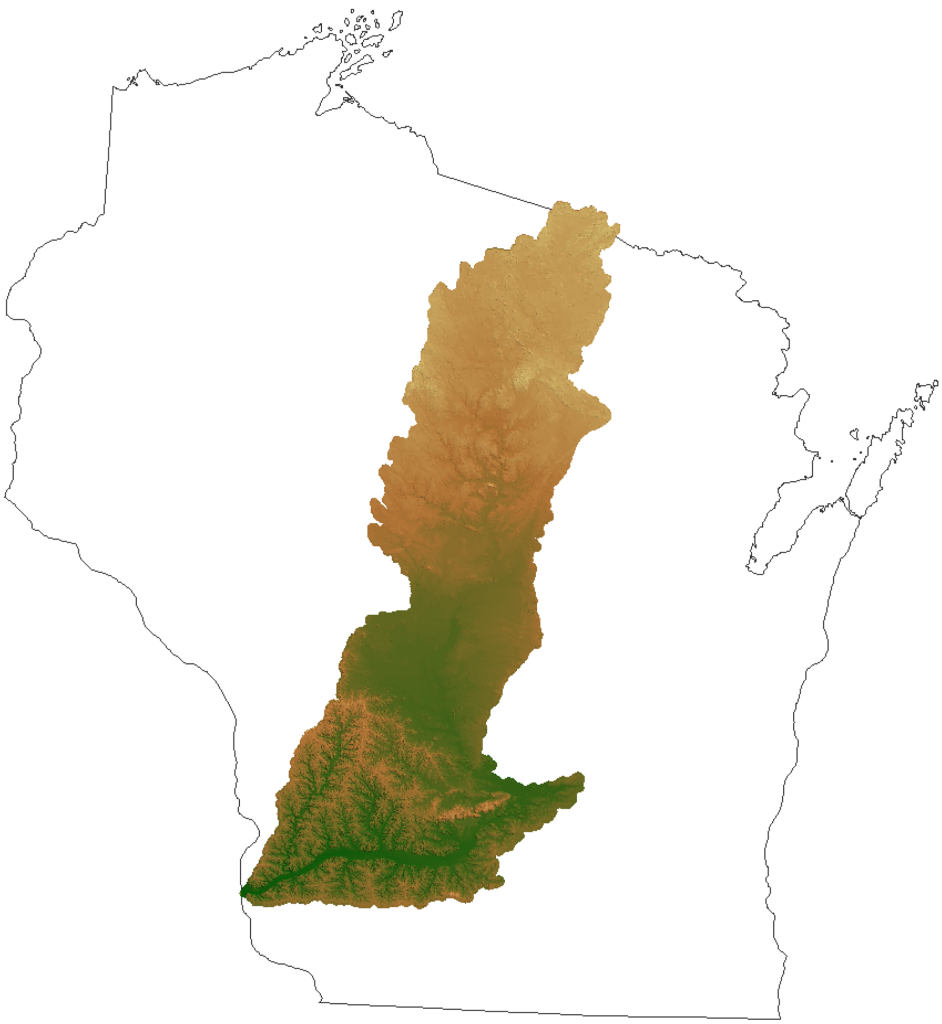
Effects of Historic and Current Land Covers on Water Budget and Water Quality in Agricultural Regions of Michigan and Wisconsin:

SWAT model Report 070700 (Wisconsin River)



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1.0 General Information

The Wisconsin River Basin extends from central to southern Wisconsin. The basin has a mild topography with a minimum elevation of 185m and maximum elevation of 588m, with a mean of 385m. The catchment has a total area of 3.01 million hectares (or 7.43 million acres). A relief map is shown in figure 1.

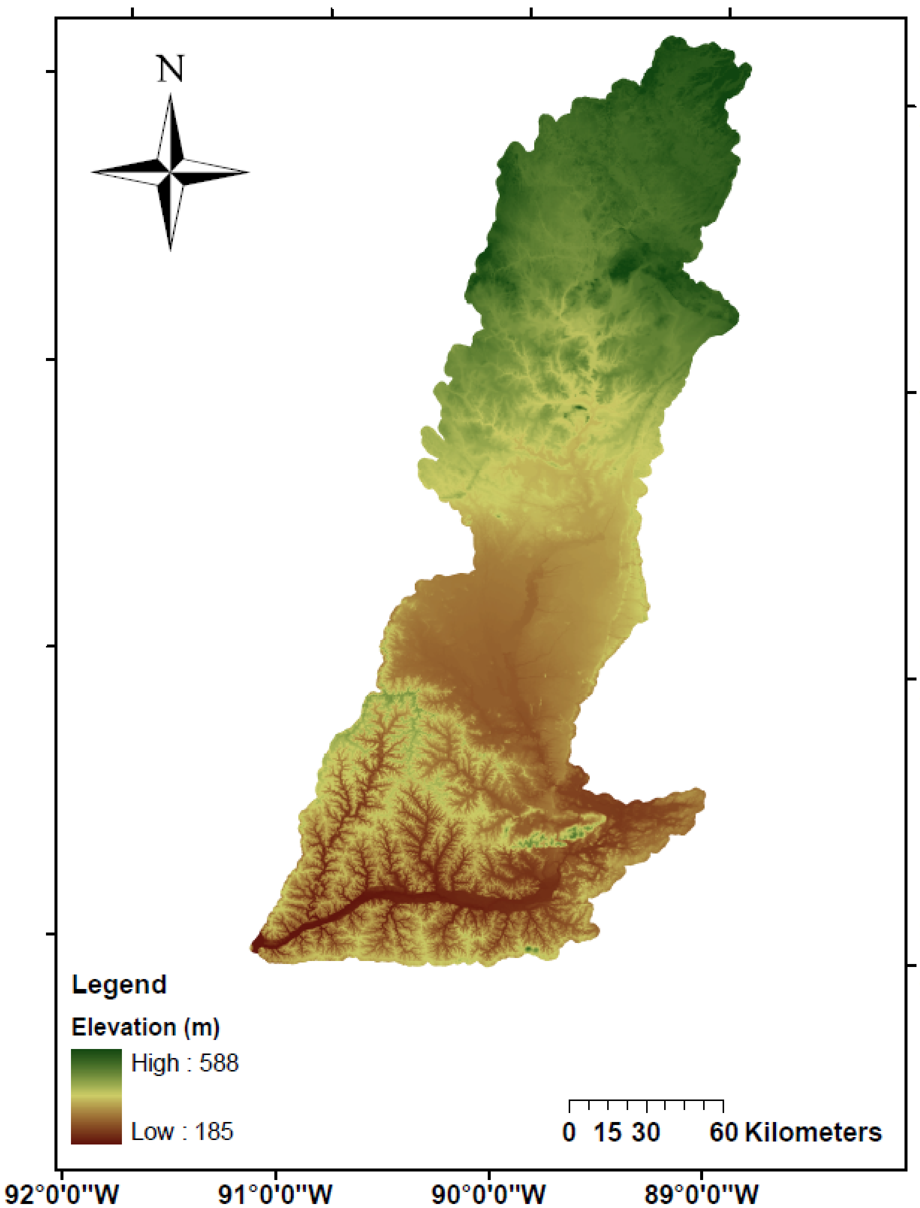


Figure 1. Relief map of the Wisconsin River Basin

2.0 River Network

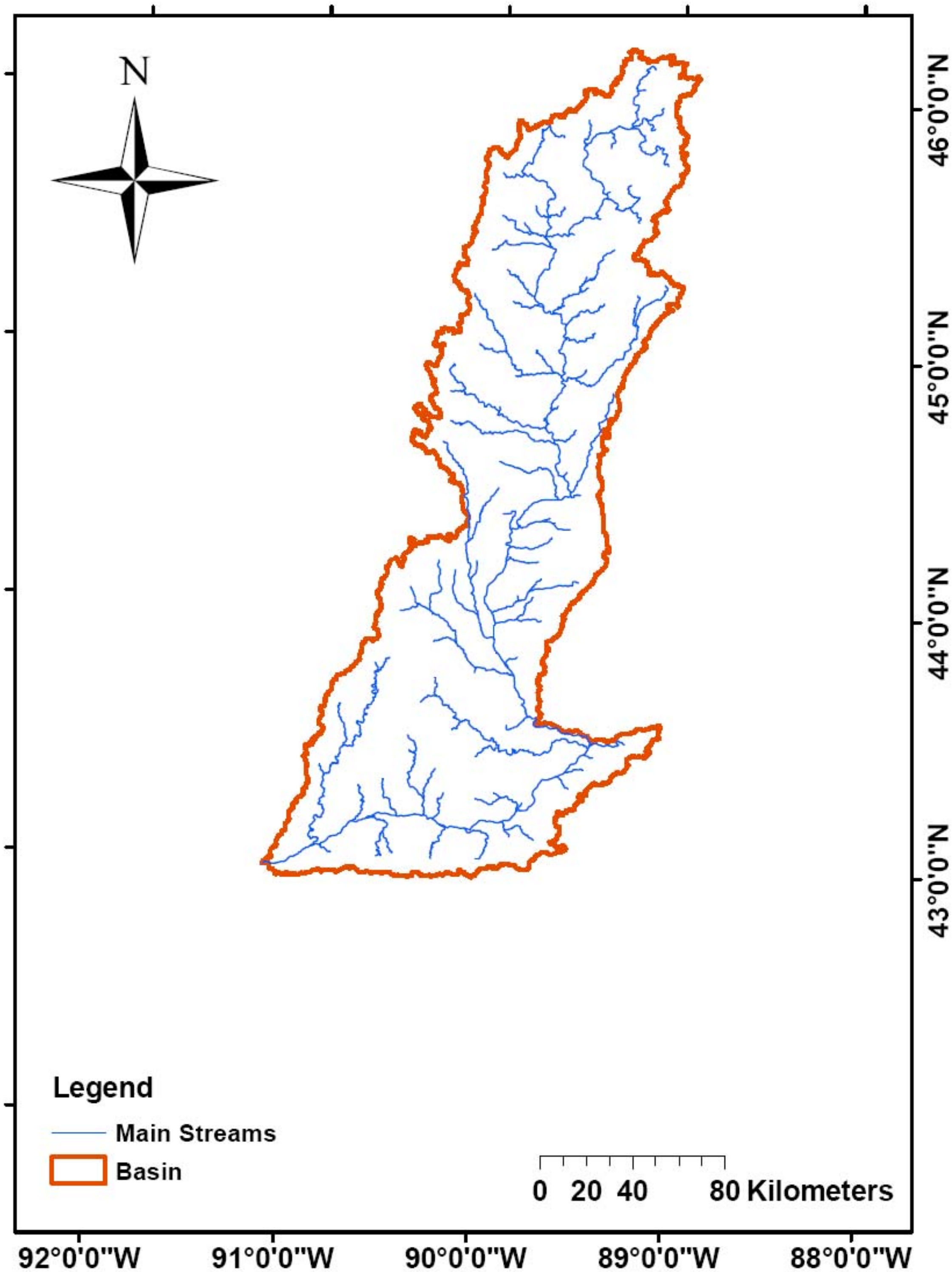


Figure 2. Major streams of the Wisconsin River Basin

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, forest land in the Wisconsin Basin Watershed is the predominant land usage, covering 41 percent of land area. Agriculture covers 34 percent of the land area. Wetlands, urban, range, and water constitute the remaining 25 percent of land cover (Tables 1a and 1b). In the Wisconsin River Basin, forest and wetlands dominate the north uplands and mixed agriculture/forest occupies a majority of the south area (Figure 3).

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

Landuse	Area (ha)	Percentage
Forest-Deciduous	998273.2	33.2
Agricultural Land-Row Crops	806094.8	26.8
Wetlands-Forested	289908.9	9.6
Hay	213884.6	7.1
Forest-Mixed	146694.4	4.9
Residential-Low Density	126895.1	4.2
Water	107038.8	3.6
Forest-Evergreen	95918.7	3.2
Wetlands-Non-Forested	88935.4	3.0
Range-Grasses	54178.4	1.8
Residential-Medium Density	38543.0	1.3
Range-Brush	30214.6	1.0
Residential-High Density	6891.0	0.2
Industrial	2858.3	0.1
Range-Other	553.5	0.0

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

Forest	41.3%
Agricultural	33.9%
Wetlands	12.6%
Urban	5.8%
Water	3.6%
Rangeland	2.8%

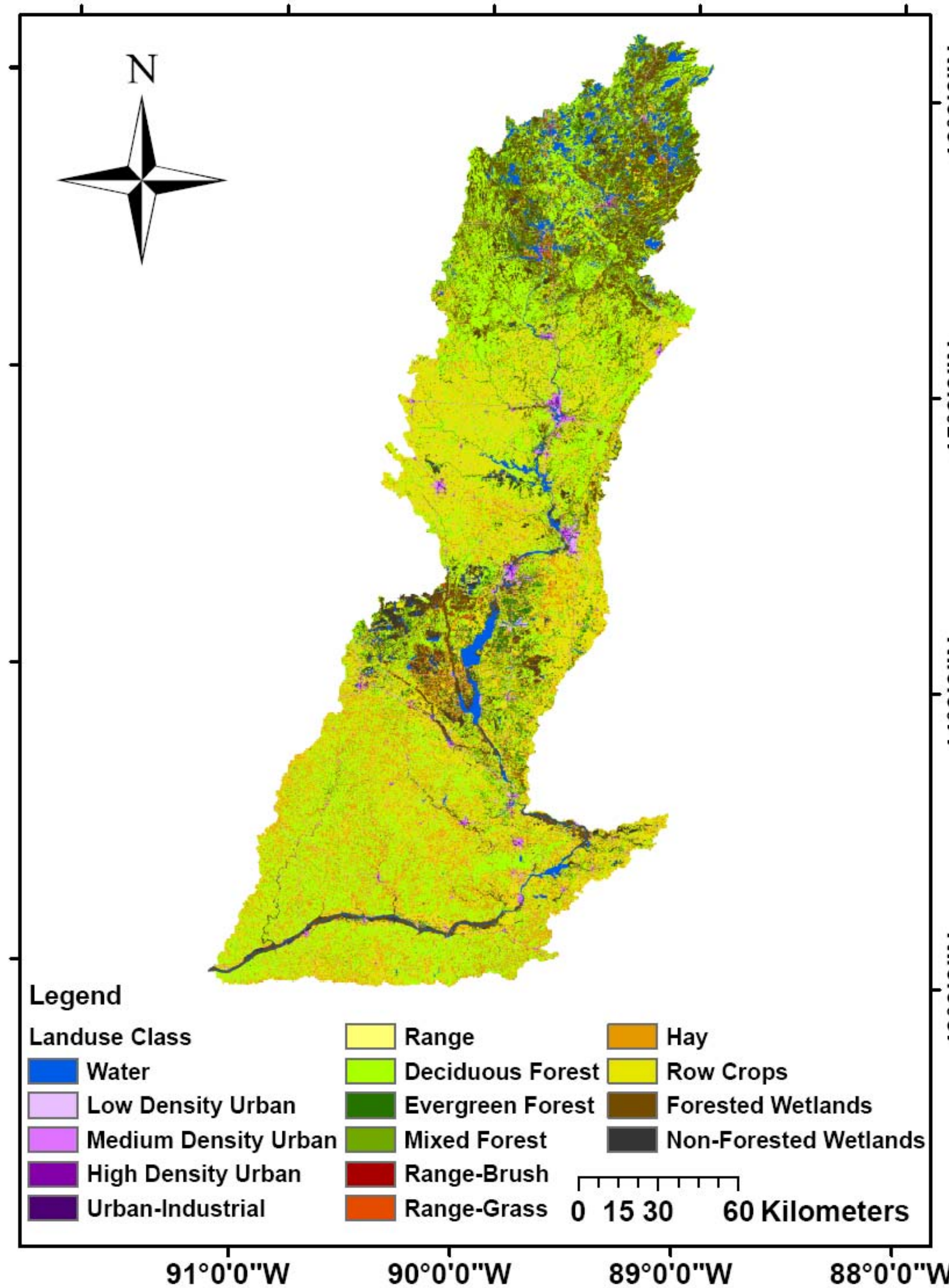


Figure 3. Current landuse map of the Wisconsin River Basin

Based on the Landuse circa 1800 county base (LU1800), forest was the predominant land usage in the Wisconsin River Basin covering 80 percent of land area. Wetlands covered 14 percent of the land area. Rangeland and water constituted the remaining 6 percent of land cover (Tables 2a and 2b). In the Wisconsin River Basin, mixed forest dominates its north upland and deciduous forest dominates the southern area (Figure 4).

Table 2a. Landuse of the Wisconsin River Basin ranked by area (LU1800)

Landuse	Area (ha)	Percentage
Forest-Deciduous	1102681.4	36.7
Forest-Mixed	1092889.1	36.4
Wetlands-Forested	312991.5	10.4
Forest-Evergreen	198606.2	6.6
Wetlands-Non-Forested	106943.7	3.6
Water	90636.1	3.0
Range-Grasses	62294.4	2.1
Range-Brush	30650.7	1.0

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

Forest	80%
Wetlands	14%
Rangeland	3%
Water	3%
Agriculture	0%
Urban	0%

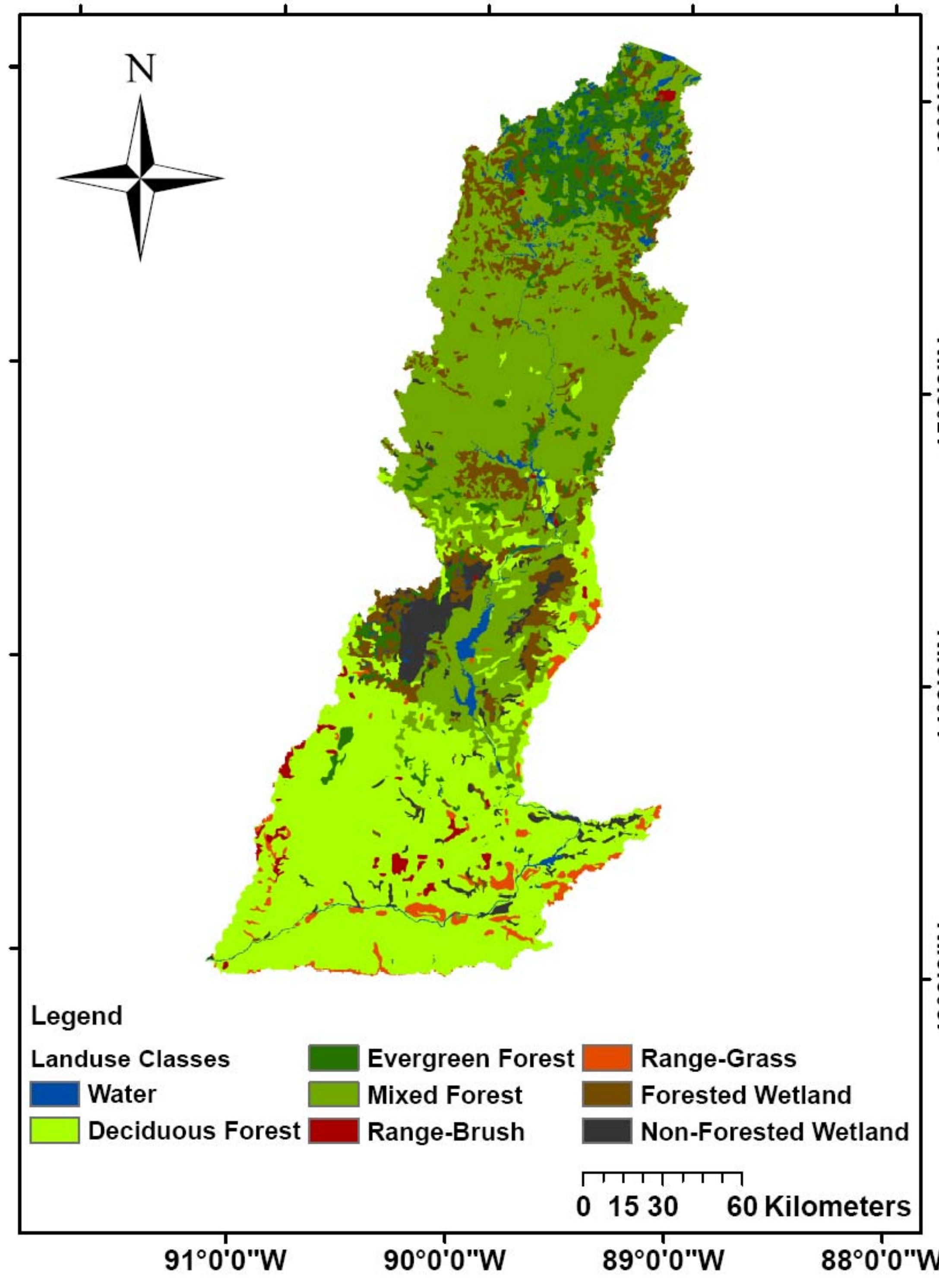


Figure 4. Pre-Settlement landuse map of the Wisconsin River Basin

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 Wisconsin Basin.

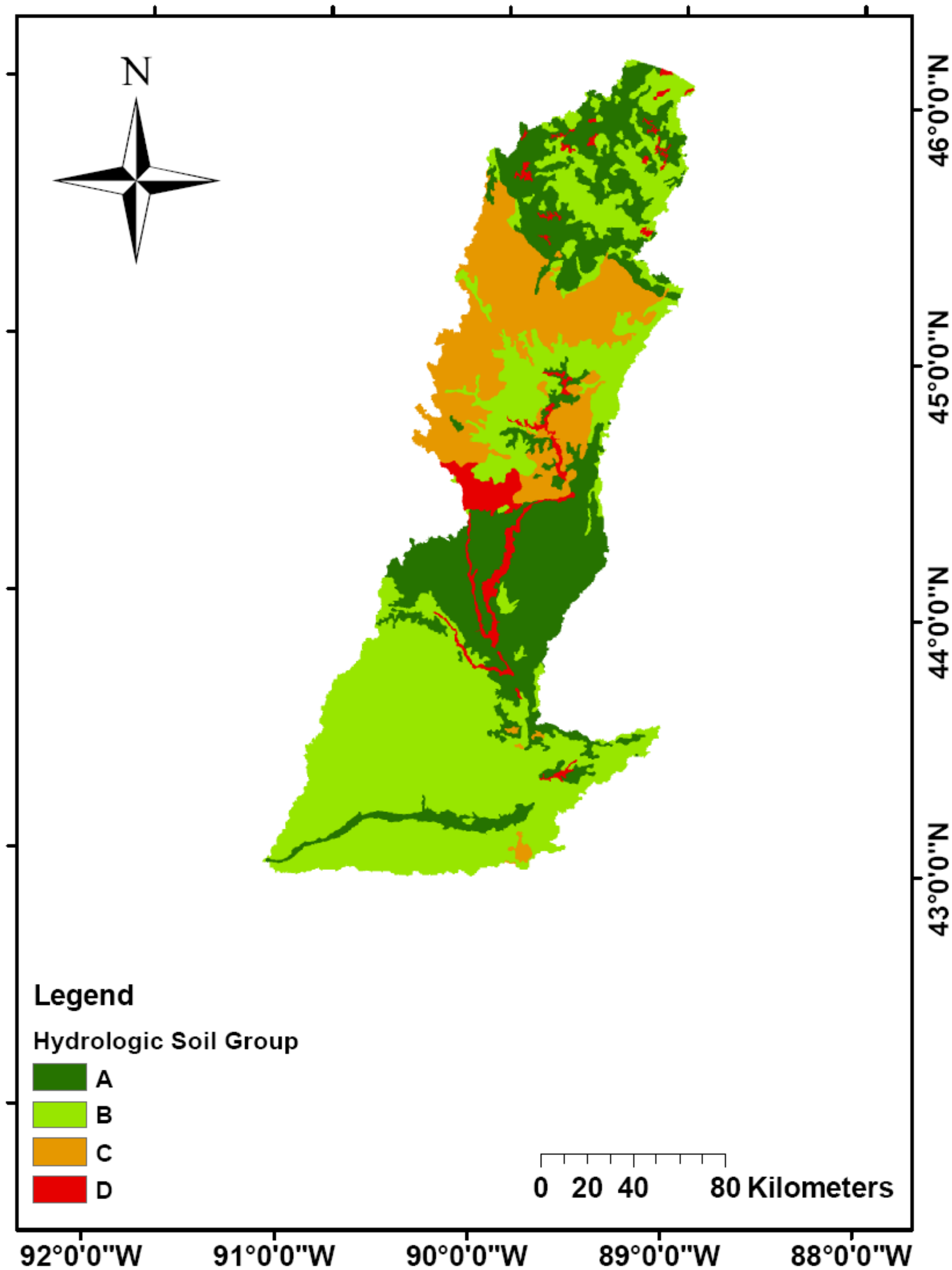


Figure 5. Hydrologic Soil Groups for the Wisconsin Basin

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.

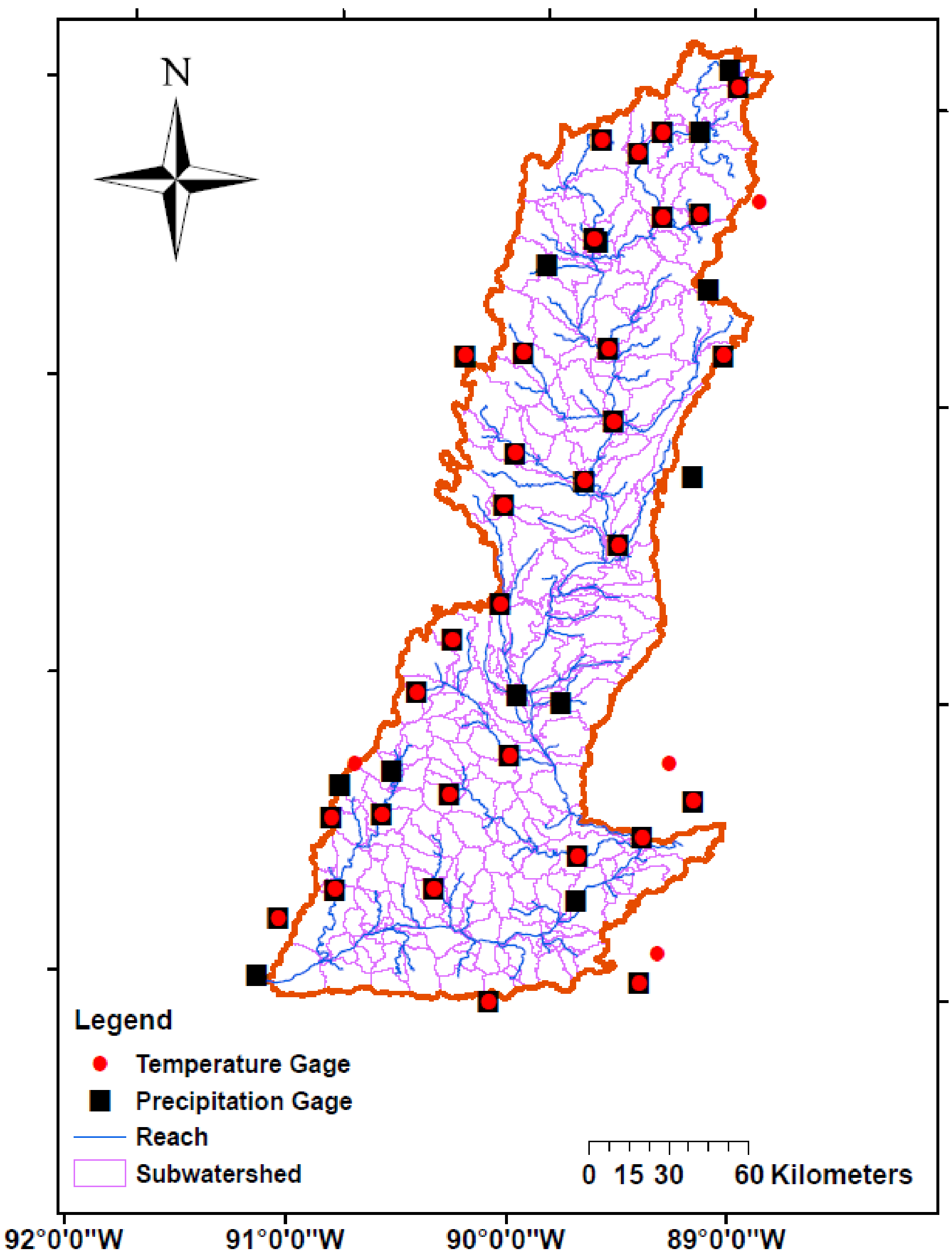


Figure 6. Temperature and precipitation gages in the Wisconsin Basin

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 282 subwatersheds. Figure 7 shows the boundary and the locations of subwatersheds in the Wisconsin Basin.

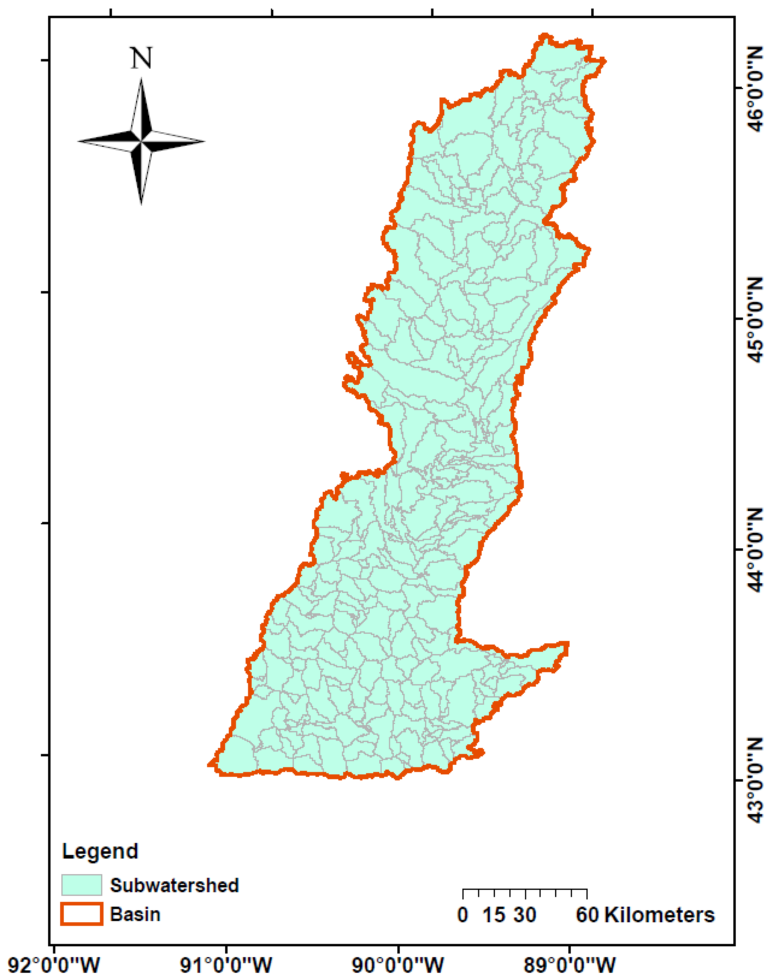


Figure 7. The delineated watersheds

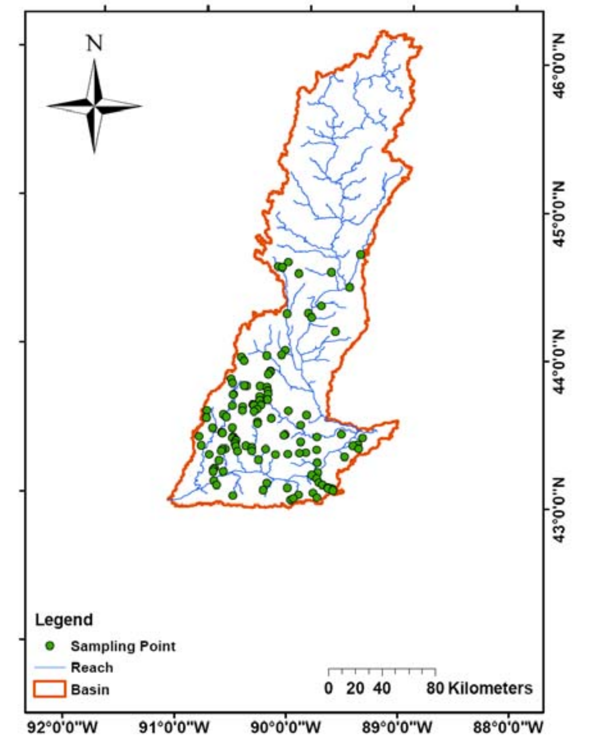
The SWAT model generates results on the outlets of subwatersheds. Since our goal is to obtain the model results on the locations of fish sampling points, these points were introduced to the model. In some cases, the fish sampling points lie on small creeks, which are too small for the model to recognize.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

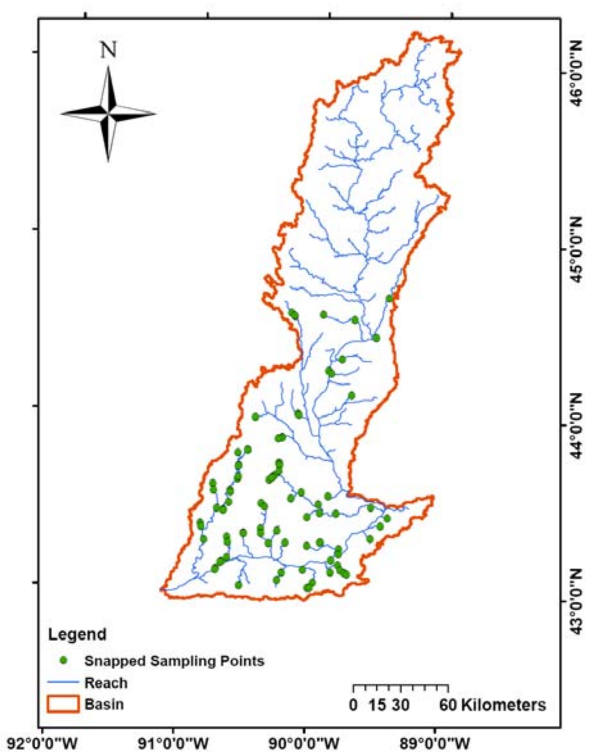
Original	LAT	LONG	Snapped	LAT	LONG
1	43.0258	-90.0222	1	43.0258	-90.0222
2	43.0354	-89.9966	2	43.0354	-89.9966
3	43.0405	-90.5532	3	43.0405	-90.5532
4	43.0468	-89.7792	4	43.0622	-89.9505
5	43.0622	-89.9505	5	43.0783	-89.8187
6	43.0783	-89.8187	6	43.0851	-90.2762
7	43.0851	-90.2762	7	43.1058	-90.7062
8	43.0981	-89.6355	8	43.1059	-90.0554
9	43.1058	-90.7062	9	43.1113	-89.6465
10	43.1059	-90.0554	10	43.1342	-89.7335
11	43.1106	-89.6814	11	43.1346	-90.2449
12	43.1113	-89.6465	12	43.1350	-90.7335
13	43.1174	-89.6830	13	43.1478	-89.7660
14	43.1342	-89.7335	14	43.1762	-89.7880
15	43.1346	-90.2449	15	43.1981	-89.8343
16	43.1350	-90.7335	16	43.1994	-90.6505
17	43.1478	-89.7660	17	43.2112	-90.7413
18	43.1762	-89.7880	18	43.2162	-89.7800
19	43.1971	-90.7431	19	43.2201	-90.7310
20	43.1981	-89.8343	20	43.2727	-90.6938
21	43.1994	-90.6505	21	43.2814	-89.7886
22	43.2112	-90.7413	22	43.2873	-90.3310
23	43.2162	-89.7800	23	43.3092	-90.7871
24	43.2201	-90.7310	24	43.3268	-90.1753
25	43.2727	-90.6938	25	43.3284	-89.5378
26	43.2814	-89.7886	26	43.3328	-90.0609
27	43.2873	-90.3310	27	43.3395	-90.5274
28	43.3092	-90.7871	28	43.3426	-89.9555
29	43.3268	-90.1753	29	43.3449	-90.3944
30	43.3284	-89.5378	30	43.3479	-89.8973
31	43.3328	-90.0609	31	43.3535	-90.6402
32	43.3384	-90.6767	32	43.3619	-90.2688
33	43.3395	-90.5274	33	43.3693	-90.8647
34	43.3426	-89.9555	34	43.3787	-90.4518

35	43.3449	-90.3944	35	43.4122	-89.4170
36	43.3479	-89.8973	36	43.4145	-90.5478
37	43.3516	-90.6684	37	43.4199	-89.9482
38	43.3535	-90.6402	38	43.4301	-90.8886
39	43.3619	-90.2688	39	43.4567	-89.7978
40	43.3689	-90.3966	40	43.4590	-90.6735
41	43.3693	-90.8647	41	43.4595	-89.3772
42	43.3704	-89.7964	42	43.4637	-90.6804
43	43.3732	-90.5449	43	43.4661	-90.0938
44	43.3787	-90.4518	44	43.4805	-89.5737
45	43.3861	-89.4096	45	43.4906	-90.7673
46	43.3916	-90.5533	46	43.4975	-90.5840
47	43.4051	-89.4631	47	43.5319	-90.3542
48	43.4122	-89.4170	48	43.5327	-89.9537
49	43.4125	-90.5448	49	43.5466	-90.3528
50	43.4145	-90.5478	50	43.5581	-90.8281
51	43.4199	-89.9482	51	43.5694	-90.6431
52	43.4267	-90.5615	52	43.5717	-90.2273
53	43.4280	-90.5798	53	43.5846	-90.6713
54	43.4301	-90.8886	54	43.6016	-89.9023
55	43.4385	-90.5736	55	43.6066	-90.8254
56	43.4567	-89.7978	56	43.6263	-90.0733
57	43.4590	-90.6735	57	43.6427	-90.4959
58	43.4595	-89.3772	58	43.6472	-90.5923
59	43.4598	-90.1054	59	43.6586	-90.3274
60	43.4637	-90.6804	60	43.6592	-90.4026
61	43.4661	-90.0938	61	43.6879	-90.3416
62	43.4805	-89.5737	62	43.6973	-90.2693
63	43.4906	-90.7673	63	43.7160	-90.3436
64	43.4975	-90.5840	64	43.7206	-90.5895
65	43.5319	-90.3542	65	43.7234	-90.5872
66	43.5327	-89.9537	66	43.7342	-90.2667
67	43.5466	-90.3528	67	43.7570	-90.2692
68	43.5581	-90.8281	68	43.7841	-90.4680
69	43.5581	-90.8281	69	43.7848	-90.4905
70	43.5694	-90.6431	70	43.7856	-90.3415
71	43.5717	-90.2273	71	43.8276	-90.6163
72	43.5846	-90.6713	72	43.8687	-90.2699
73	43.6016	-89.9023	73	43.8843	-90.2534
74	43.6066	-90.8254	74	43.8909	-90.2521
75	43.6141	-90.3894	75	43.9760	-90.5283
76	43.6151	-90.4974	76	44.0029	-90.1528
77	43.6263	-90.0733	77	44.0356	-90.1206

78	43.6295	-90.3598	78	44.1709	-89.6590
79	43.6427	-90.4959	79	44.2631	-89.8847
80	43.6472	-90.5923	80	44.2896	-89.9177
81	43.6562	-90.3942	81	44.3435	-89.7990
82	43.6586	-90.3274	82	44.4730	-89.5379
83	43.6592	-90.4026	83	44.5556	-90.0212
84	43.6879	-90.3416	84	44.5715	-89.7137
85	43.6879	-90.3416	85	44.5931	-90.1794
86	43.6973	-90.2693	86	44.5975	-90.2177
87	43.7160	-90.3436	87	44.6304	-90.1237
88	43.7206	-90.5895	88	44.6979	-89.4458
89	43.7234	-90.5872	89		
90	43.7342	-90.2667	90		
91	43.7570	-90.2692	91		
92	43.7793	-90.2780	92		
93	43.7841	-90.4680	93		
94	43.7848	-90.4905	94		
95	43.7856	-90.3415	95		
96	43.7976	-90.5999	96		
97	43.8276	-90.6163	97		
98	43.8687	-90.2699	98		
99	43.8843	-90.2534	99		
100	43.8909	-90.2521	100		
101	43.9528	-90.5001	101		
102	43.9760	-90.5283	102		
103	43.9939	-90.2920	103		
104	44.0029	-90.1528	104		
105	44.0356	-90.1206	105		
106	44.1709	-89.6590	106		
107	44.2631	-89.8847	107		
108	44.2815	-90.1169	108		
109	44.2896	-89.9177	109		
110	44.3435	-89.7990	110		
111	44.4730	-89.5379	111		
112	44.5556	-90.0212	112		
113	44.5715	-89.7137	113		
114	44.5931	-90.1794	114		
115	44.5931	-90.1794	115		
116	44.5975	-90.2177	116		
117	44.6304	-90.1237	117		
118	44.6979	-89.4458	118		



(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 89 observations for sediment and 40 observations for each nutrient constituent.

The USGS gaging station on the Wisconsin River near Muscoda (Station No. 05407000) was used to calibrate the model for flow and water quality (Figure 9). It should be noted that flow of the Wisconsin River is regulated by over 23 dams and reservoirs along the network. Daily water quality data were input to the USGS Load Estimator model (LOADEST) in order to generate monthly average values based on daily flow.

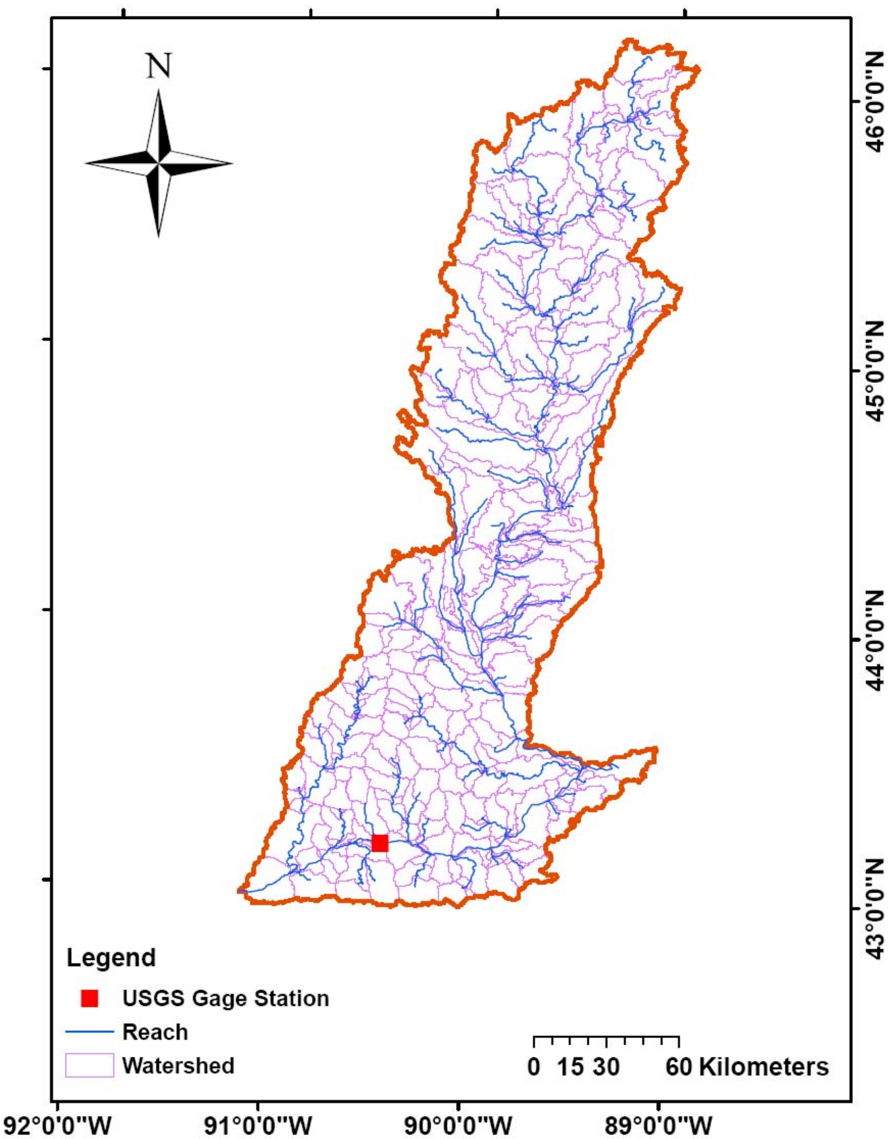


Figure 9. The delineated watersheds and selected USGS station.

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, 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
Alpha_Bf	1	1	1	1
Cn2	2	4	3	3
Ch_K2	3	5	2	2
Rchrg_Dp	4	6	4	6
Esco	5	9	6	8
Gwqmn	6	14	8	9
Timp	7	8	5	4
Canmx	8	12	9	10
Sol_Awc	9	16	14	14
Sol_Z	10	17	15	15
Blai	11	13	11	7
Surlag	12	11	7	5
Ch_N2	13	3	17	16
Slope	14	18	18	18
Biomix	15	15	16	12
Gw_Revap	16	24	25	22
Gw_Delay	17	22	19	20
Smtmp	18	19	10	13
Epco	19	23	22	24
Sol_K	20	25	20	17
Revapmn	21	26	23	25
Sol_Alb	22	27	26	26
Slsubbsn	23	21	21	19
Nperco	24	28	12	27
Spcon	42	2	42	42
Usle_P	42	7	13	11
Spexp	42	10	42	42
Usle_C	42	20	24	21
Phoskd	42	29	27	23
Pperco	42	30	42	28
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 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	0.381	19.486	0.656
Total Suspended Solids (TSS)	0.418	133.786	0.602
Total N	0.281	3238.564	0.495
Total P	0.164	216.897	0.473

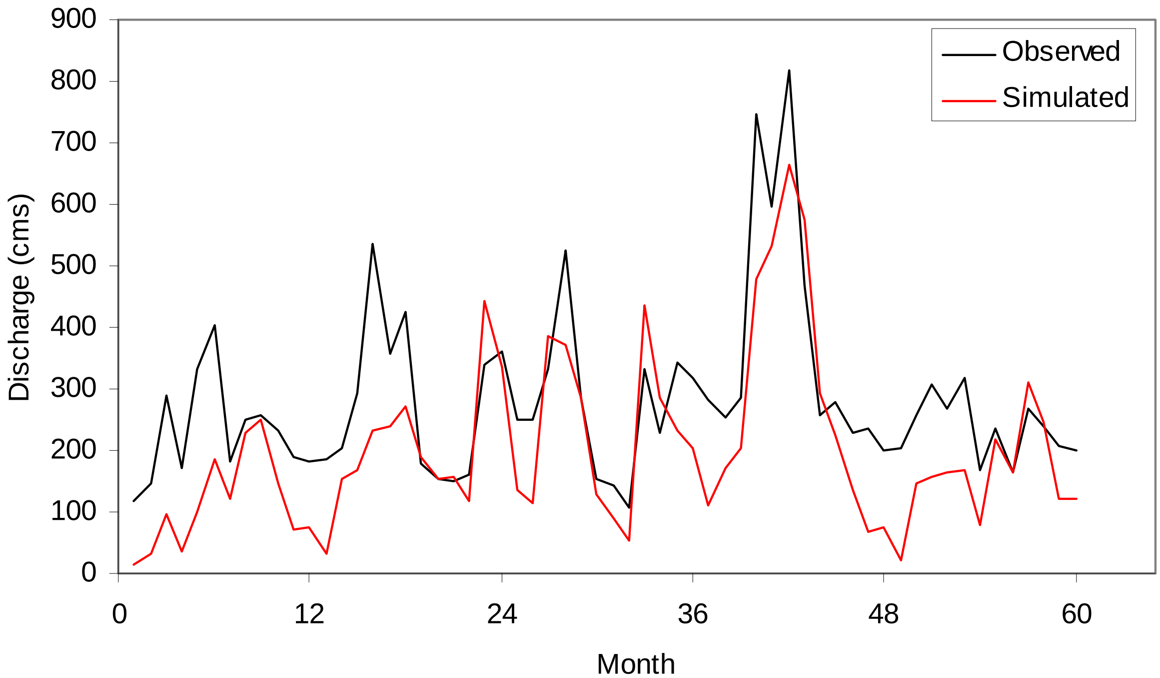


Figure 10. Model simulated results vs. USGS measurements at USGS 05407000 station

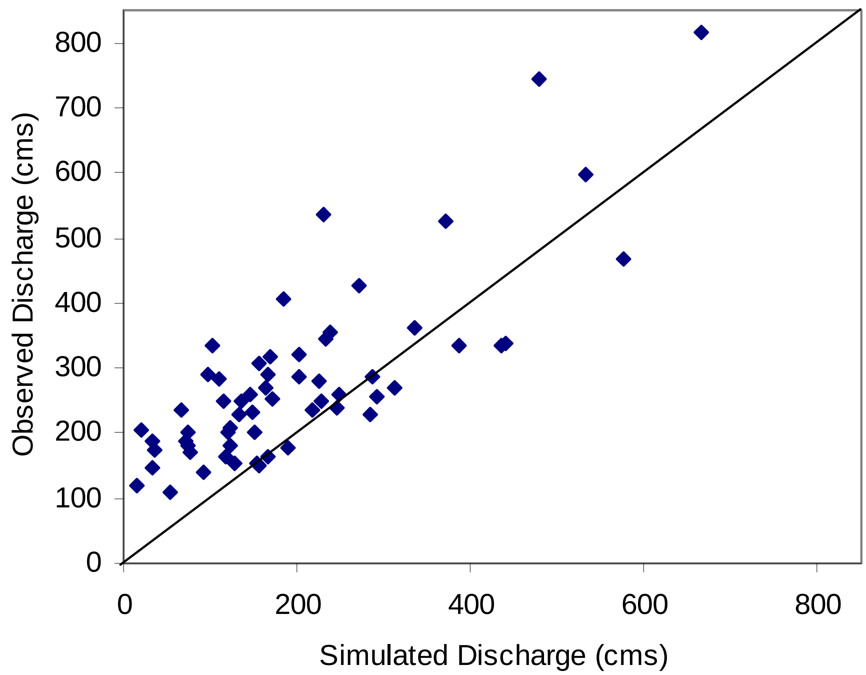


Figure 11. Simulated vs observed flow at USGS 05407000 station

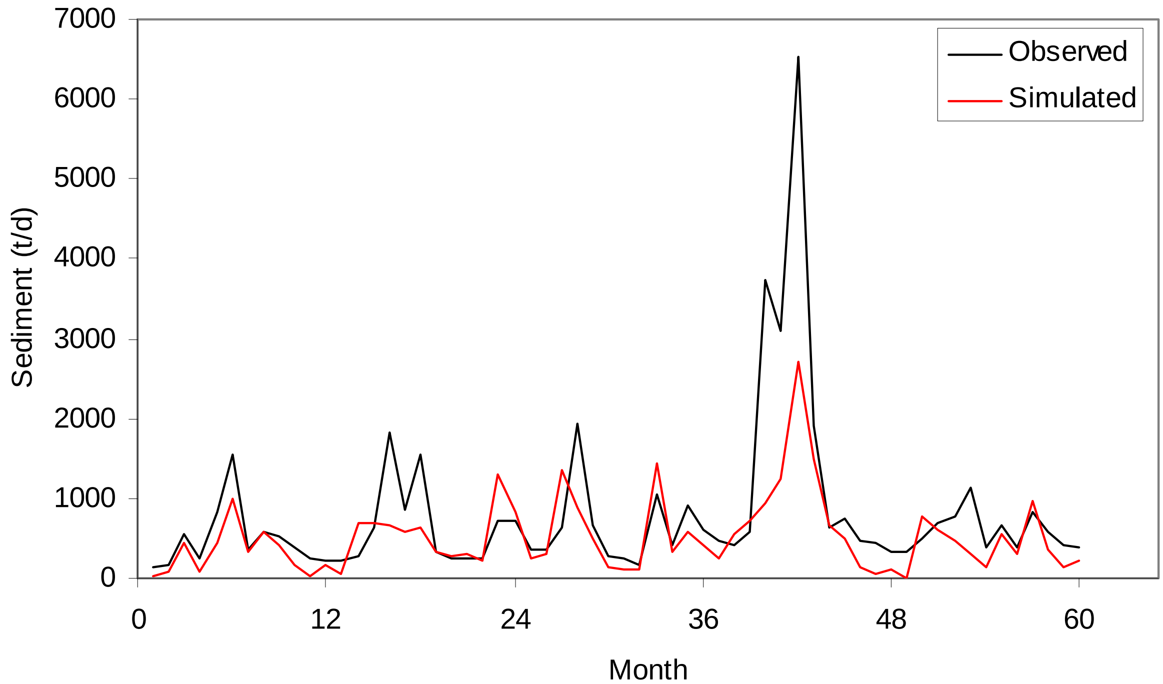


Figure 12. Time series of simulated vs observed TSS

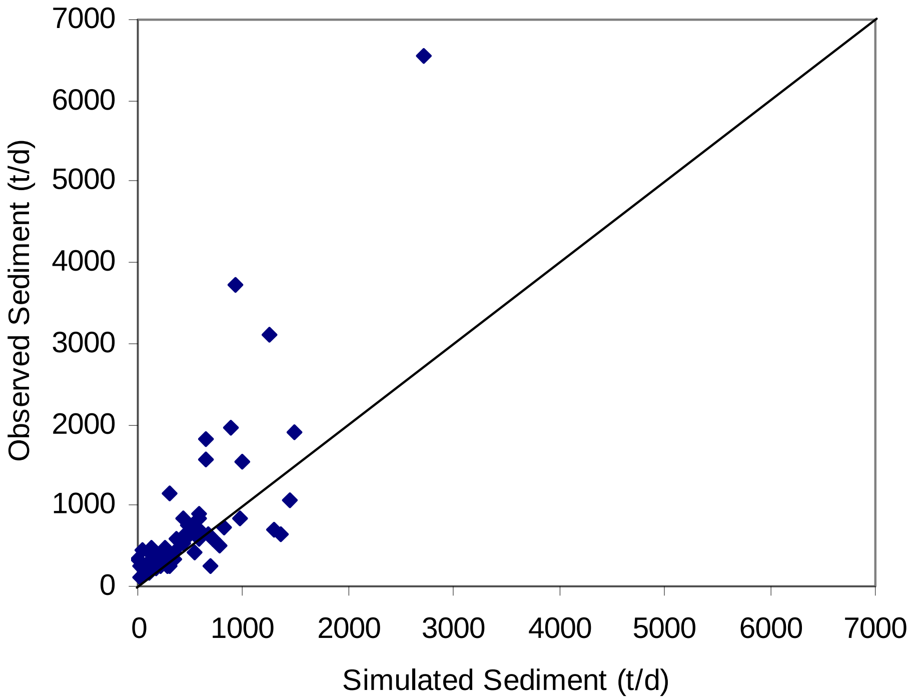


Figure 13. Simulated vs observed TSS

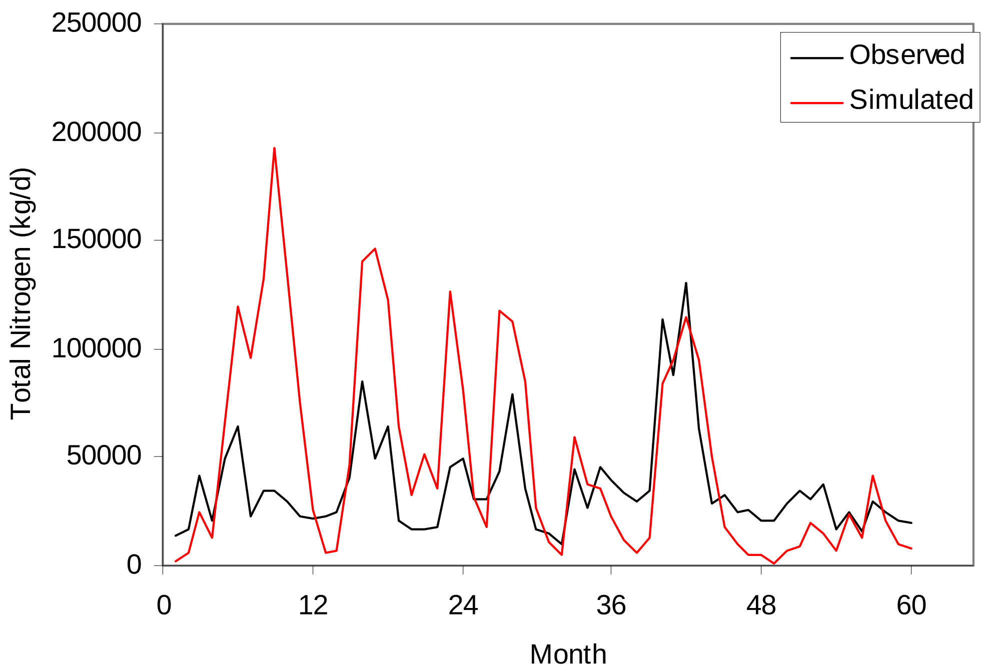


Figure 14. Time series of simulated vs observed Total Nitrogen

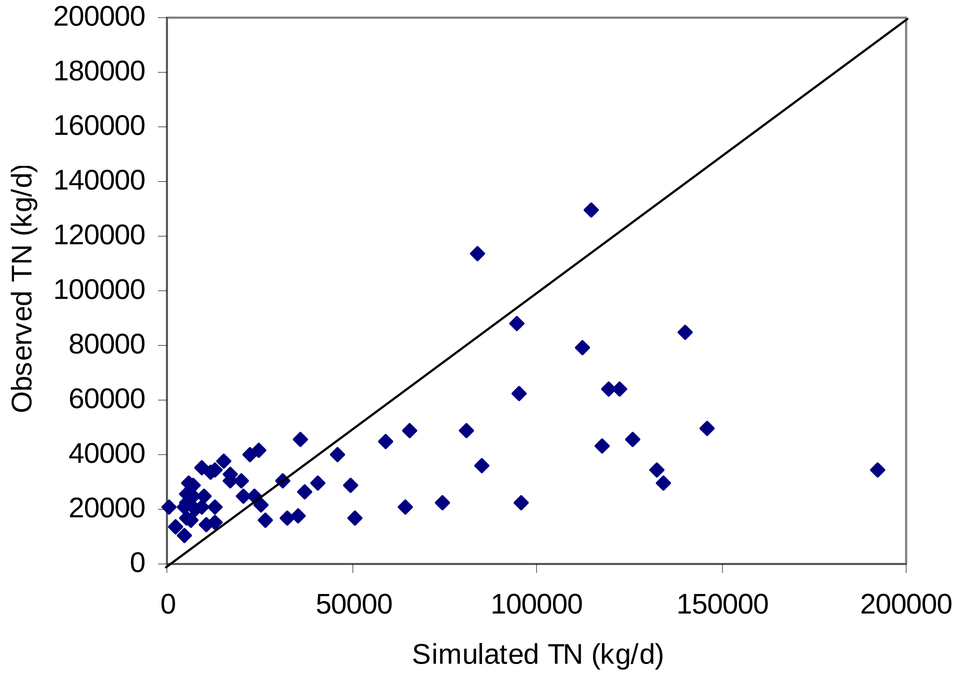


Figure 15. Simulated vs observed Total Nitrogen

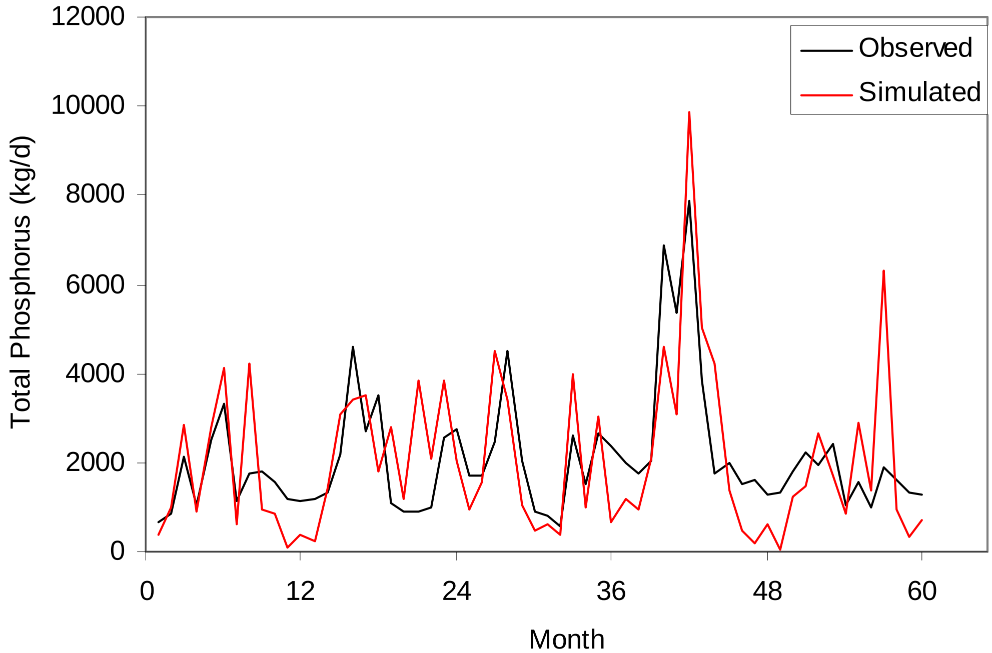


Figure 16. Time series of simulated vs. observed total phosphorus

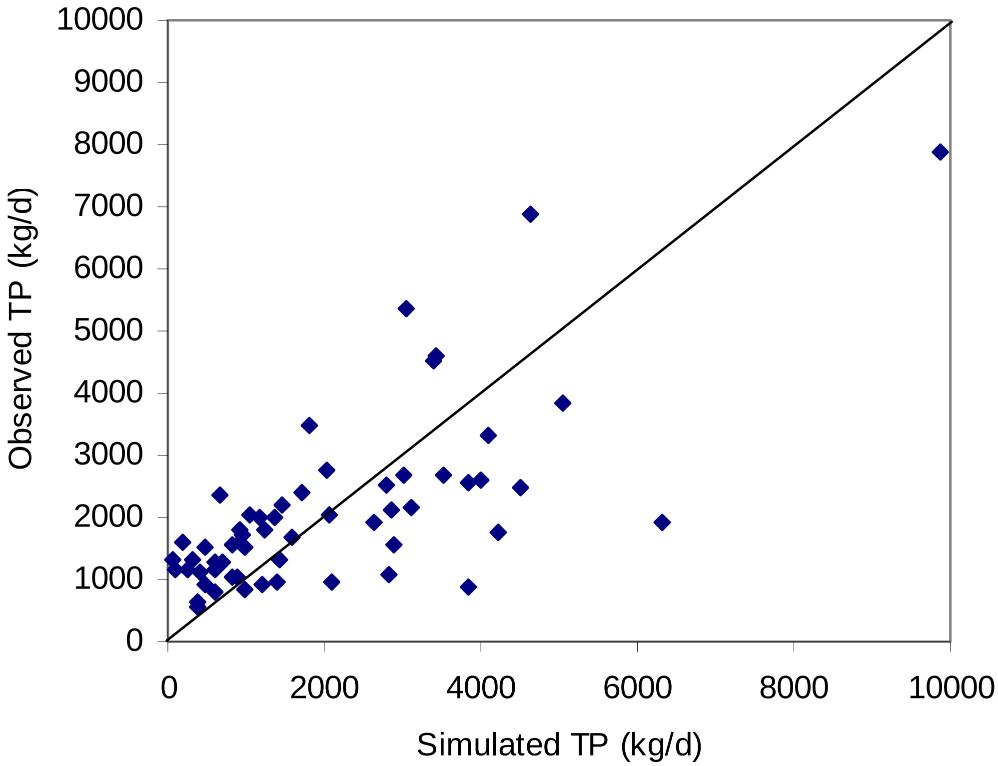


Figure 17. Simulated vs. observed total phosphorus

Table 6. Monthly and annual hydrologic budget from the Wisconsin 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	30.62	25.98	6.01	0.04	7	6.05	0.01	8.95
2	26.68	19.86	11.14	0.09	11.54	10.75	0.02	15.47
3	46.86	20.02	18.75	0.78	21.02	33.64	0.03	47.87
4	83.56	7.67	14.31	2.3	25.04	63.03	0.02	96.46
5	102.57	0.05	11.5	1.57	21.9	85.27	0.02	141.83
6	121.22	0	17.88	1.83	27.69	103.8	0.04	157.95
7	103.6	0	10.87	0.88	18.12	111.4	0.01	161.68
8	107.51	0	9.78	1.08	15.22	83.11	0.01	135.4
9	87.72	0	8.75	0.98	13.98	55.95	0.01	100.44
10	62.96	1.39	6.02	0.87	11.53	40.15	0	63.62
11	51.92	15.59	5.47	0.46	9.48	21.22	0.01	32.38
12	32.2	24.69	5.97	0.09	8.37	8.98	0.01	12.94
Annual Average	857.42	115.25	126.45	10.97	190.89	623.35	0.19	974.99

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).

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

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

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 Wisconsin Basin

Calibrated	Current	Pre-Settlement	Percent Change	Percent Difference
Recharge (mm)	91.12	134.24	-32.12%	-38.27%
Surface Runoff (mm)	122.28	86.77	40.94%	33.98%
Baseflow (mm)	57.39	137.88	-58.38%	-82.44%
Water Yield (mm)	190.65	236.89	-19.52%	-21.63%
Sediment Yield (t/ha)	0.17	0.07	155.45%	87.47%
Total N Output (t/ha)	2.99	2.34	27.84%	24.43%
Total P Output (t/ha)	0.10	0.03	243.32%	109.77%

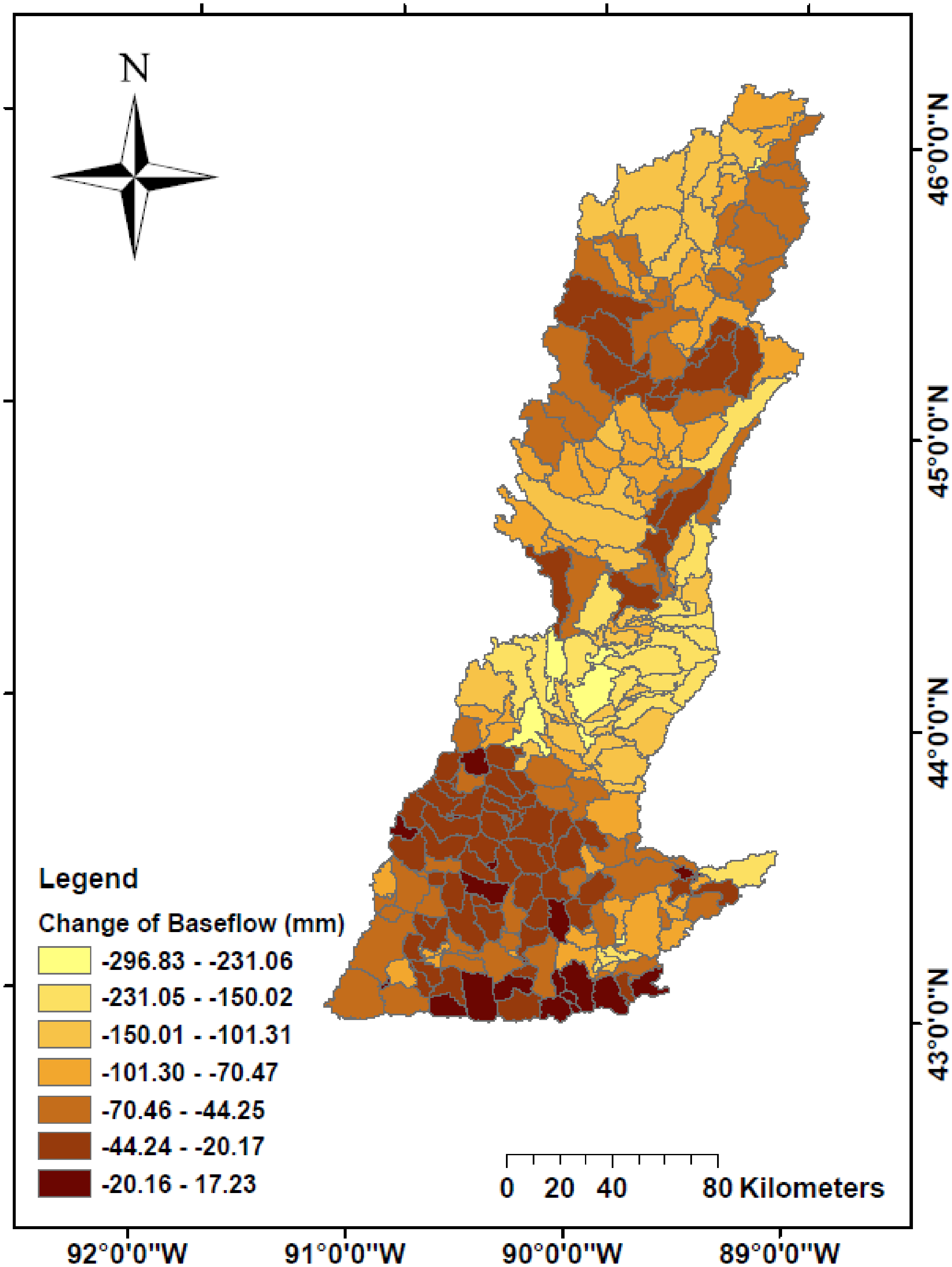


Figure 18. Change of baseflow values resulted from landuse changes (mm)

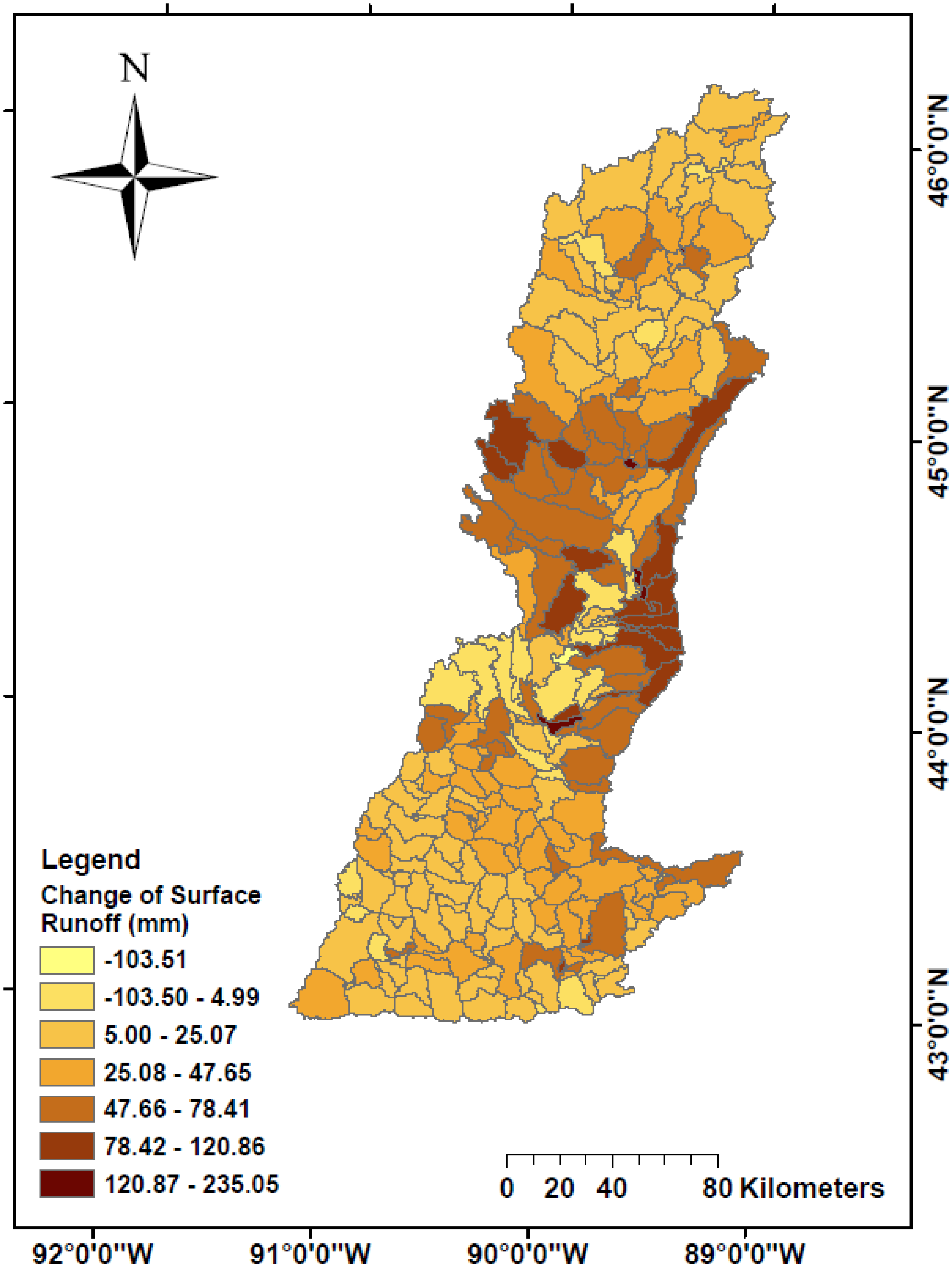


Figure 19. Change of surface runoff values resulted from landuse changes (mm)

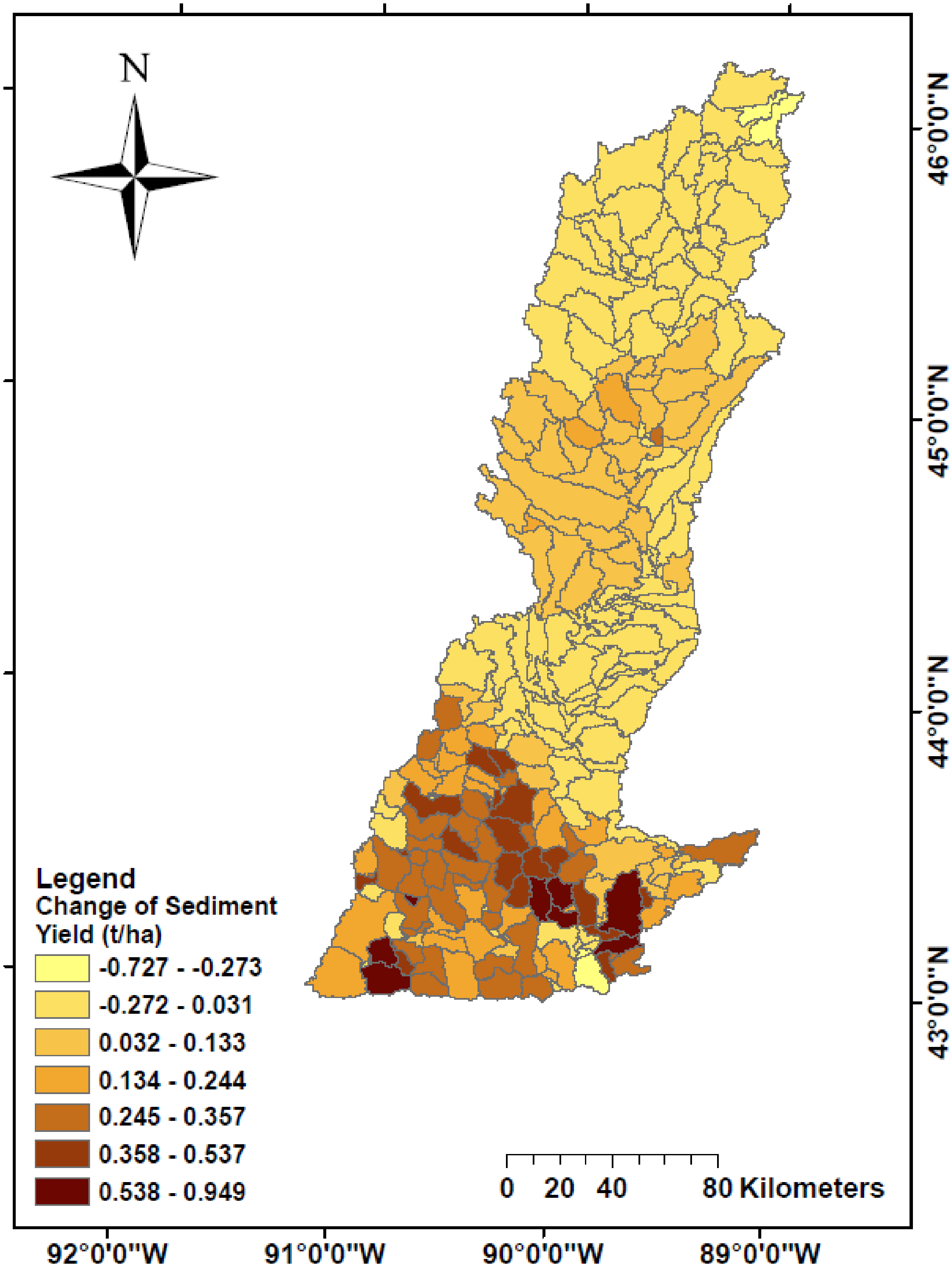


Figure 20. Change of sediment yields resulted from landuse changes (t/ha)

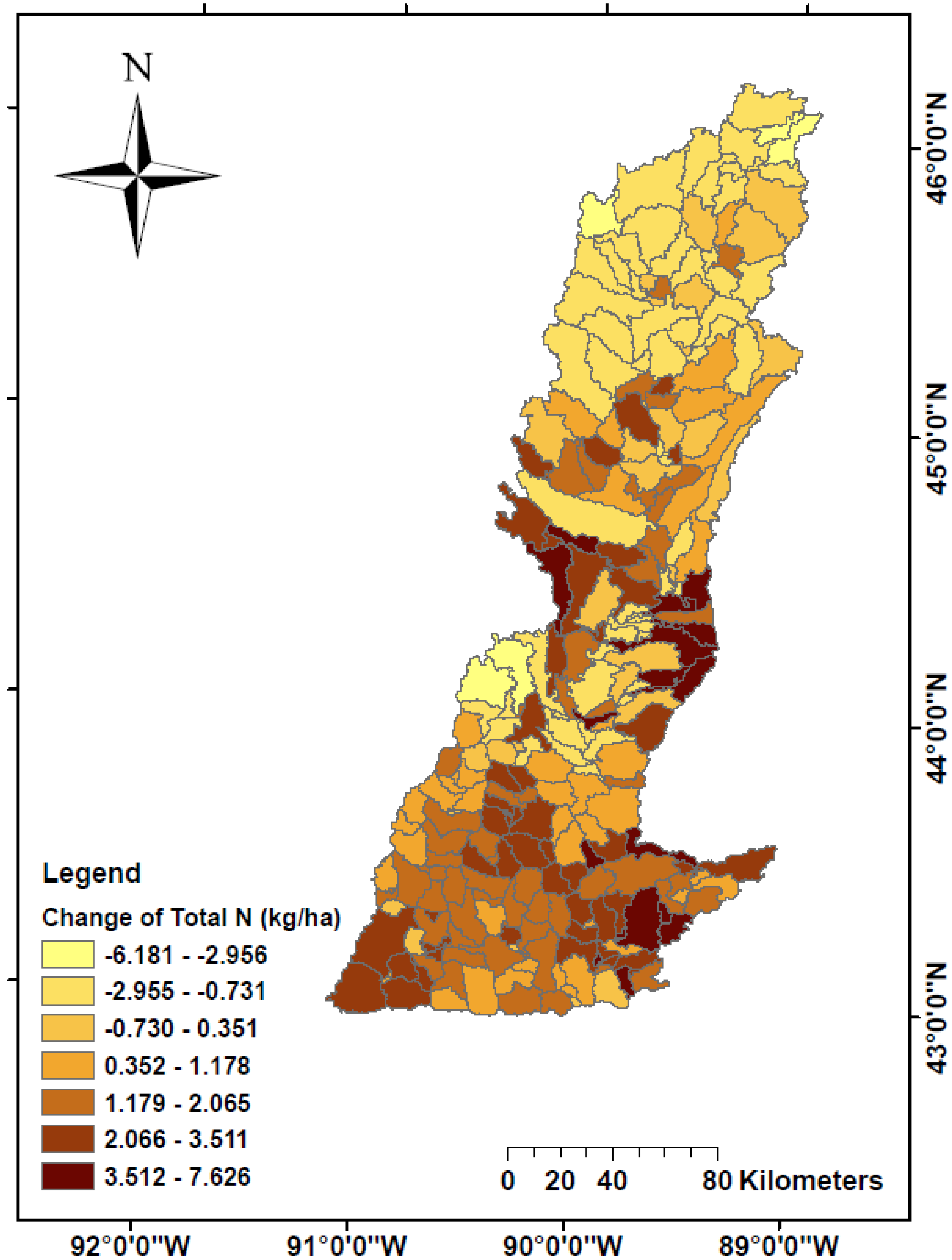


Figure 21. Change of total N output values resulted from landuse changes (kg/ha)

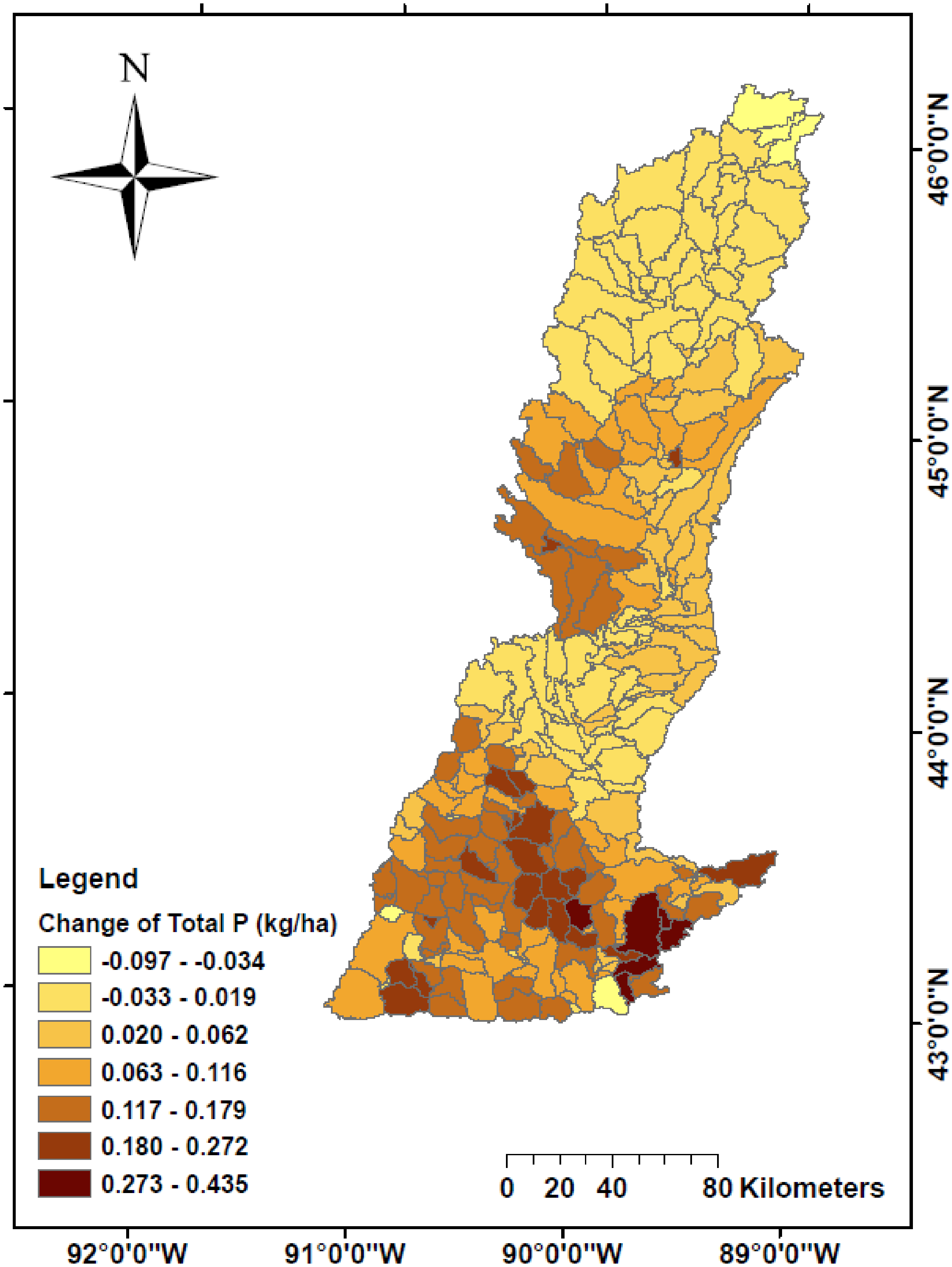


Figure 22. Change of total P output values resulted from landuse changes (kg/ha)

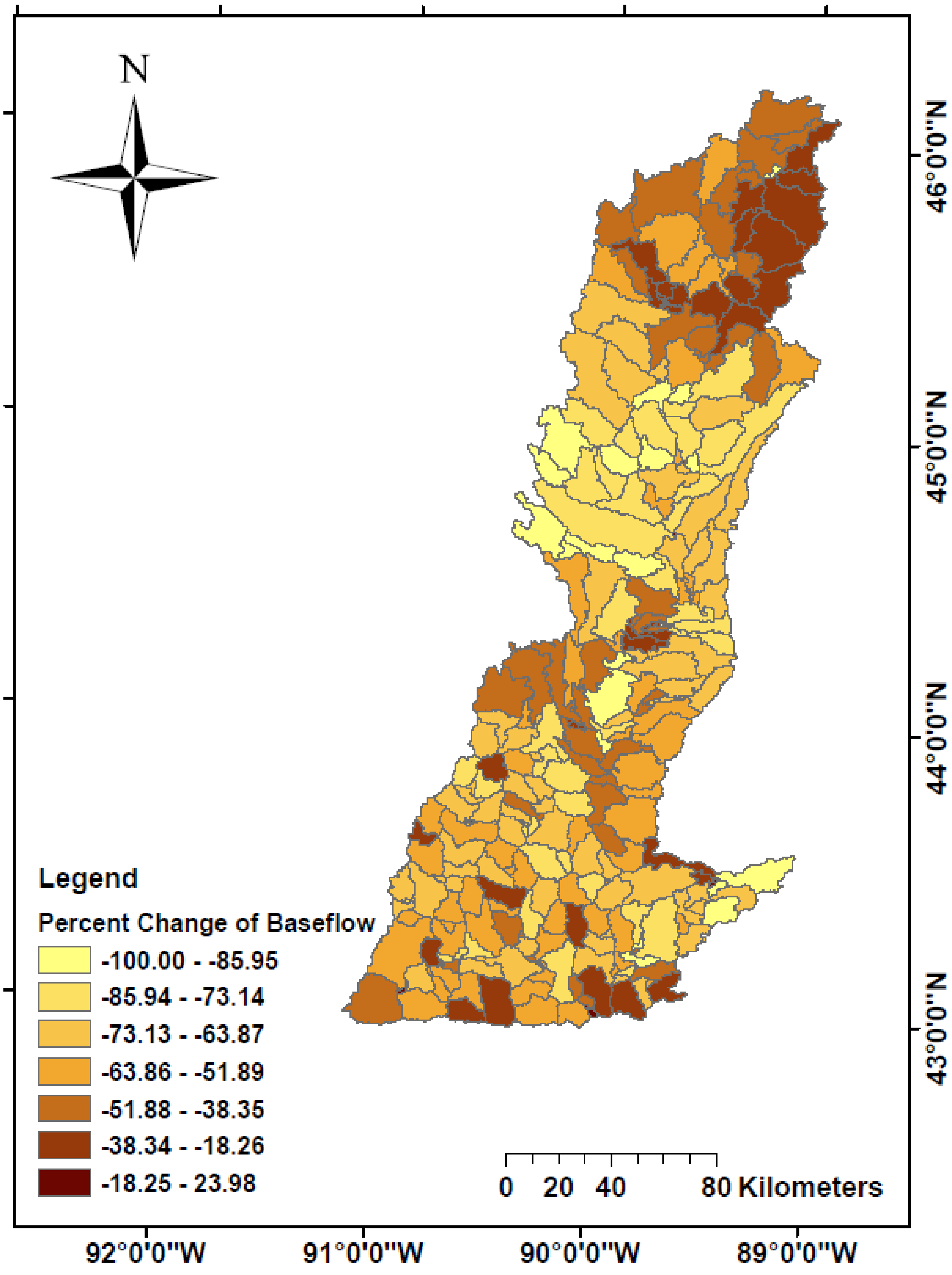


Figure 23. Percent change of baseflow values resulted from landuse changes

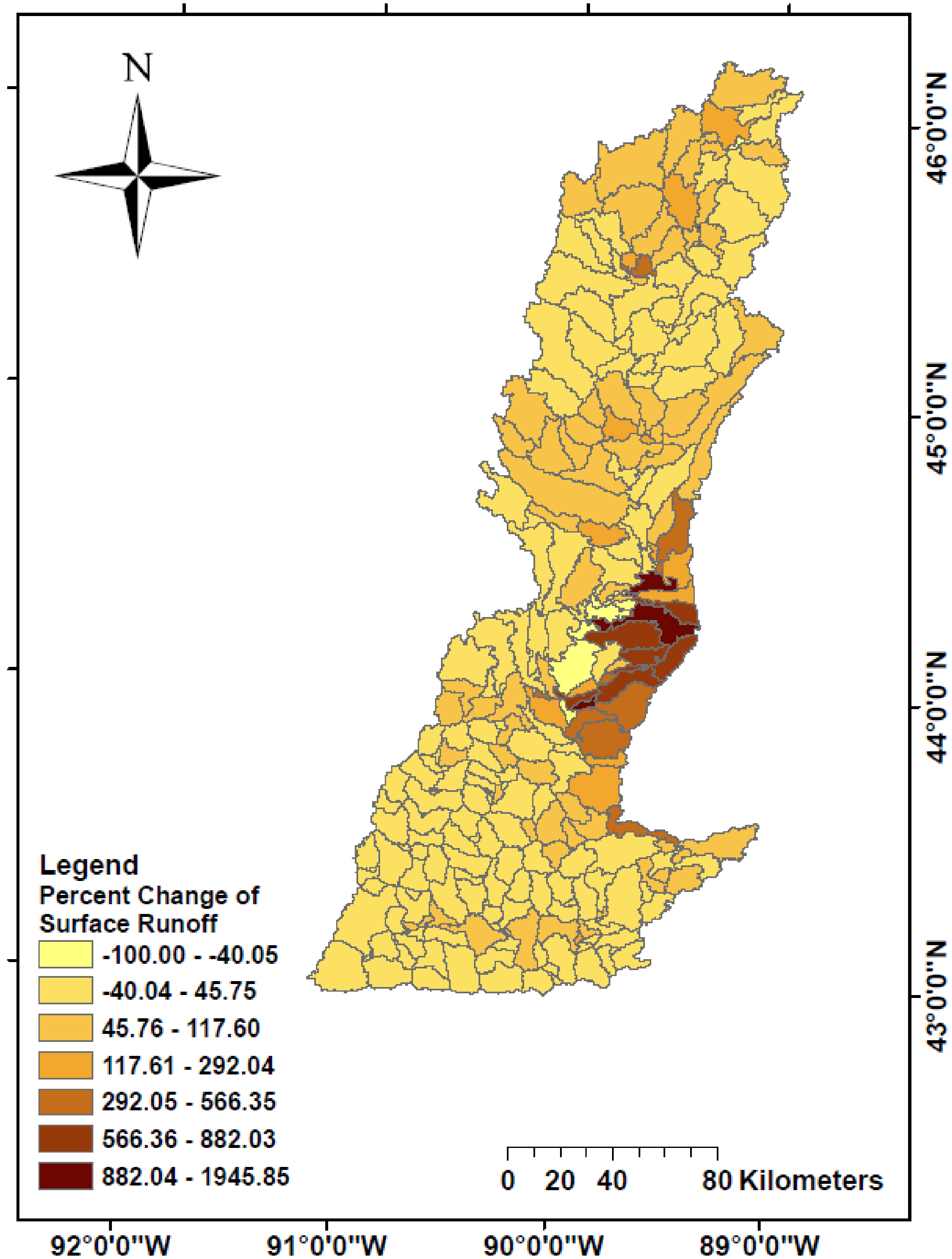


Figure 24. Percent change of surface runoff values resulted from landuse changes

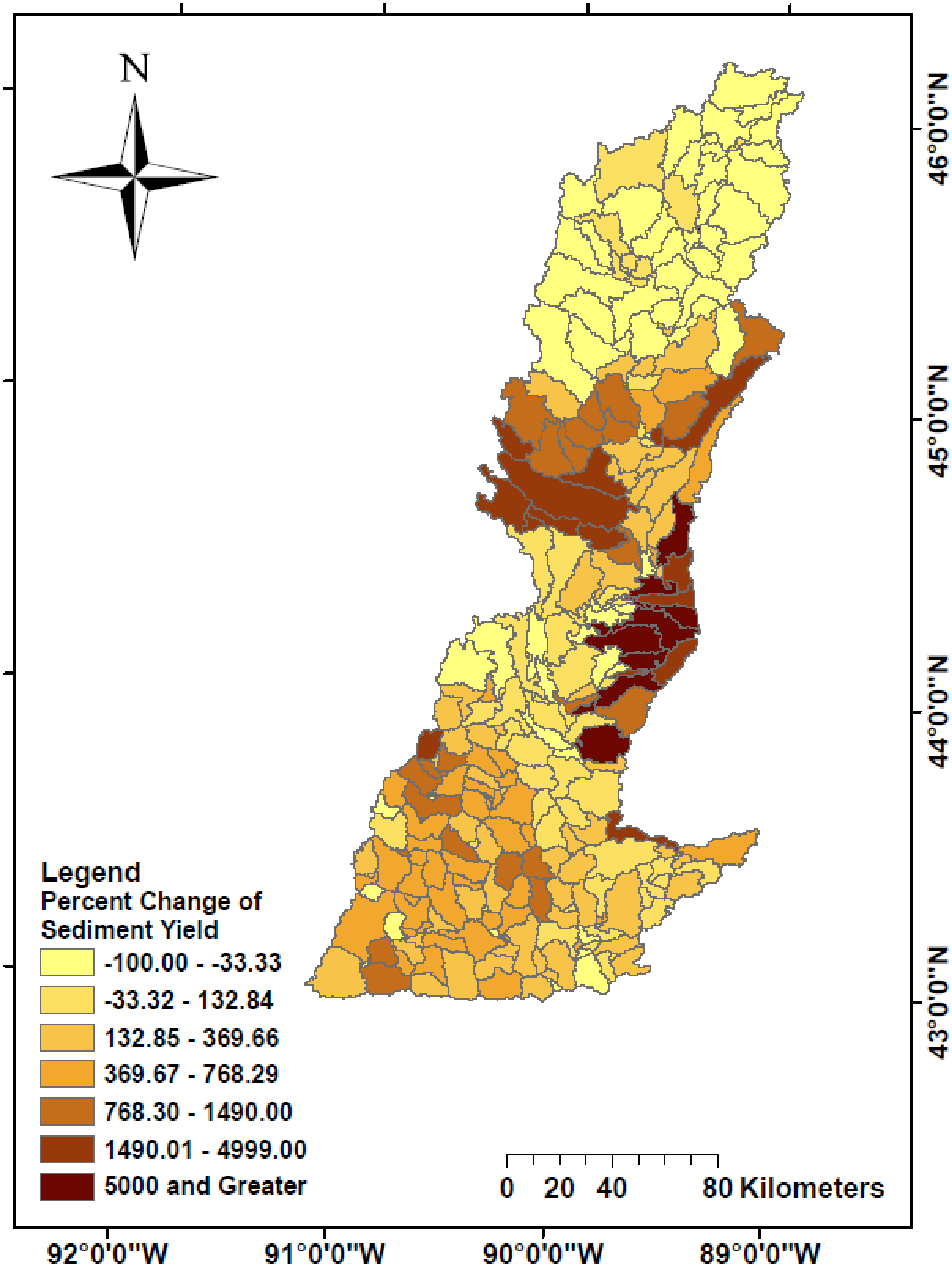


Figure 25. Percent change of sediment yield resulted from landuse changes

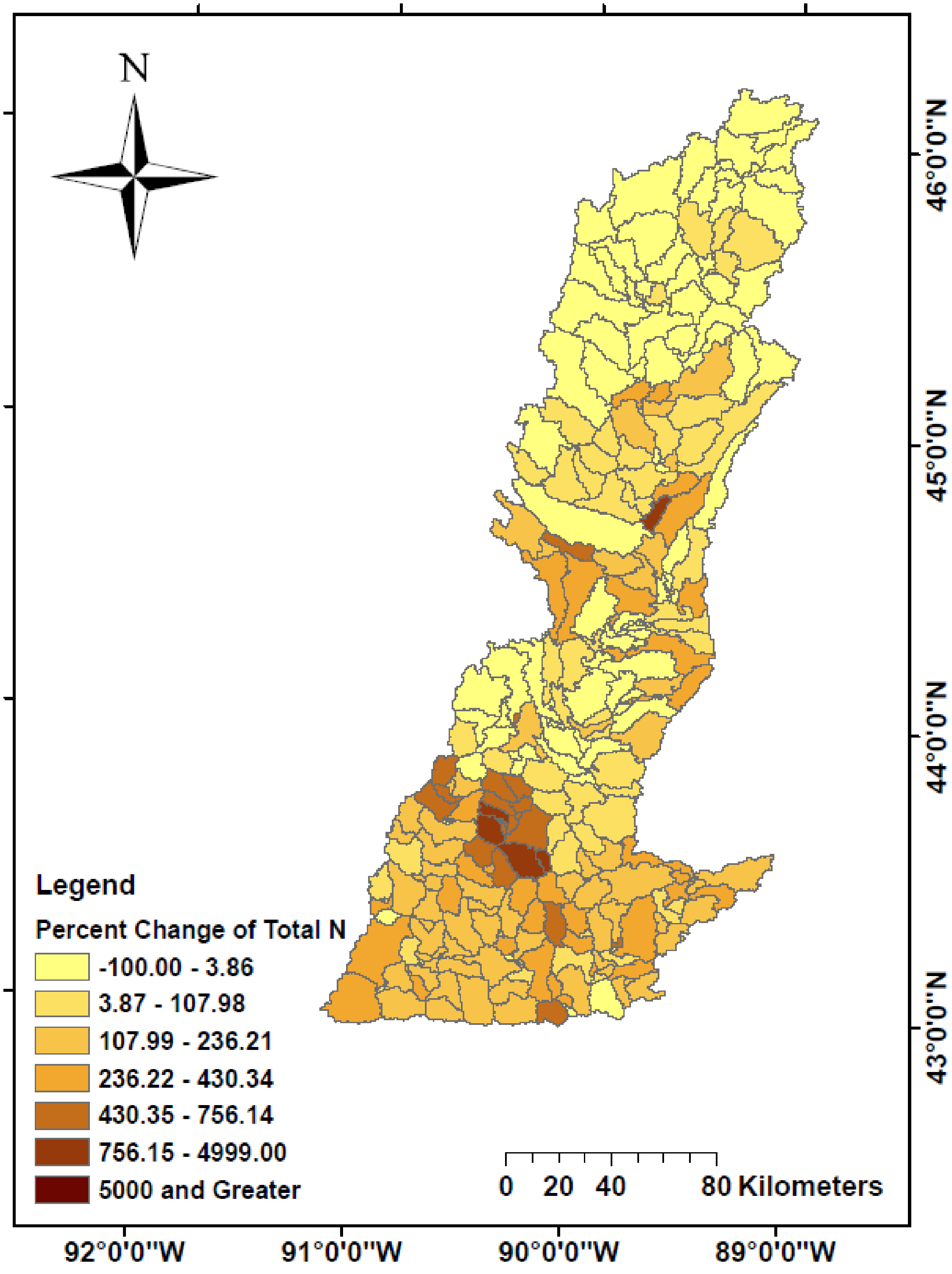


Figure 27. Percent change of total N output values resulted from landuse changes

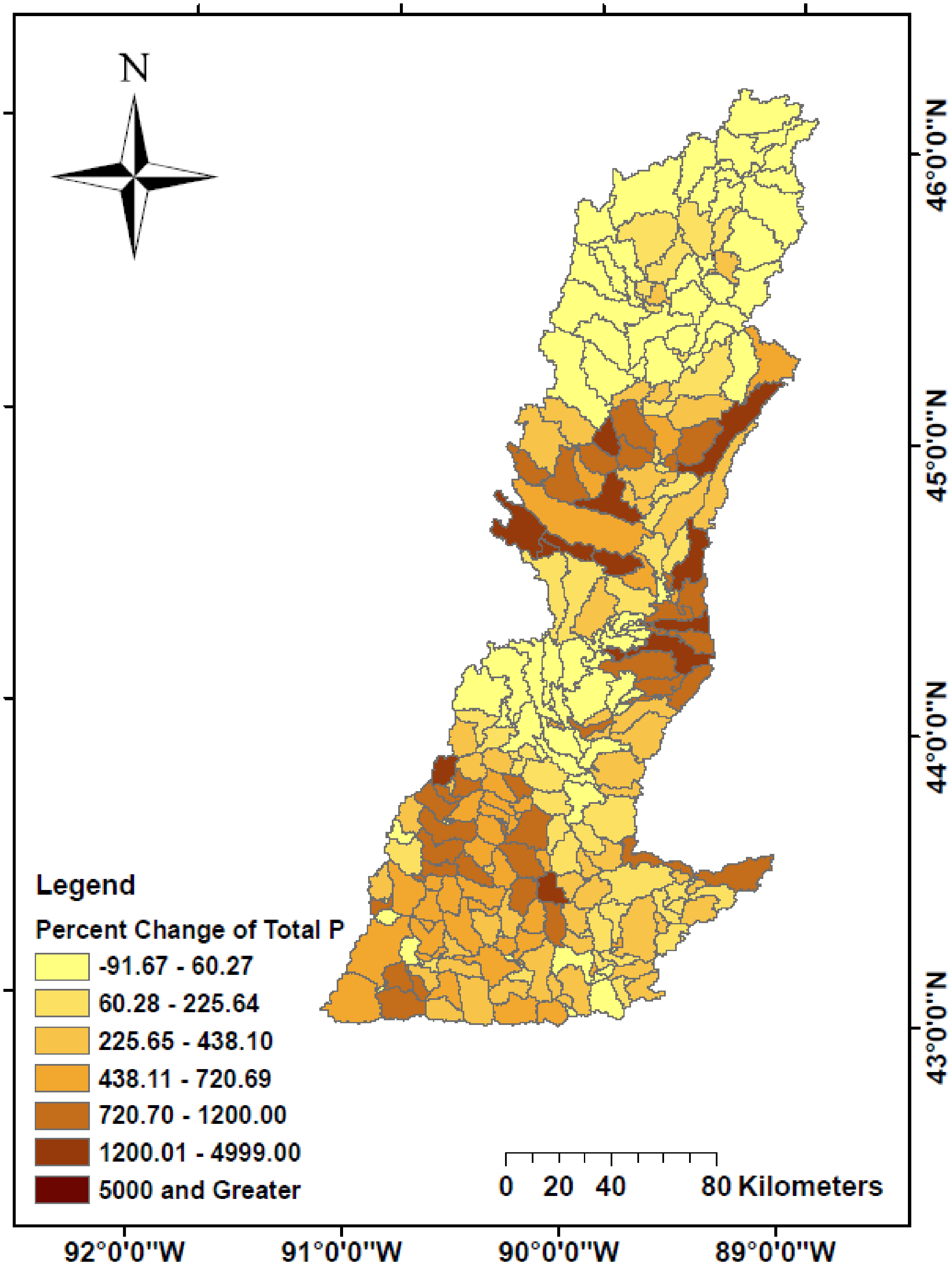


Figure 28. Percent change of total P output values resulted from landuse changes

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8.0 References

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