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

SWAT model Report 070900 (Rock River)

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1.0 General Information

The Rock River Basin is located in southern Wisconsin and northern Illinois. The basin has a mild topography with a minimum elevation of 135m and maximum elevation of 518m, with a mean of 328m. The catchment has a total area of 1.65 million hectares (or 4.07 million acres). A relief map is shown in figure 1.

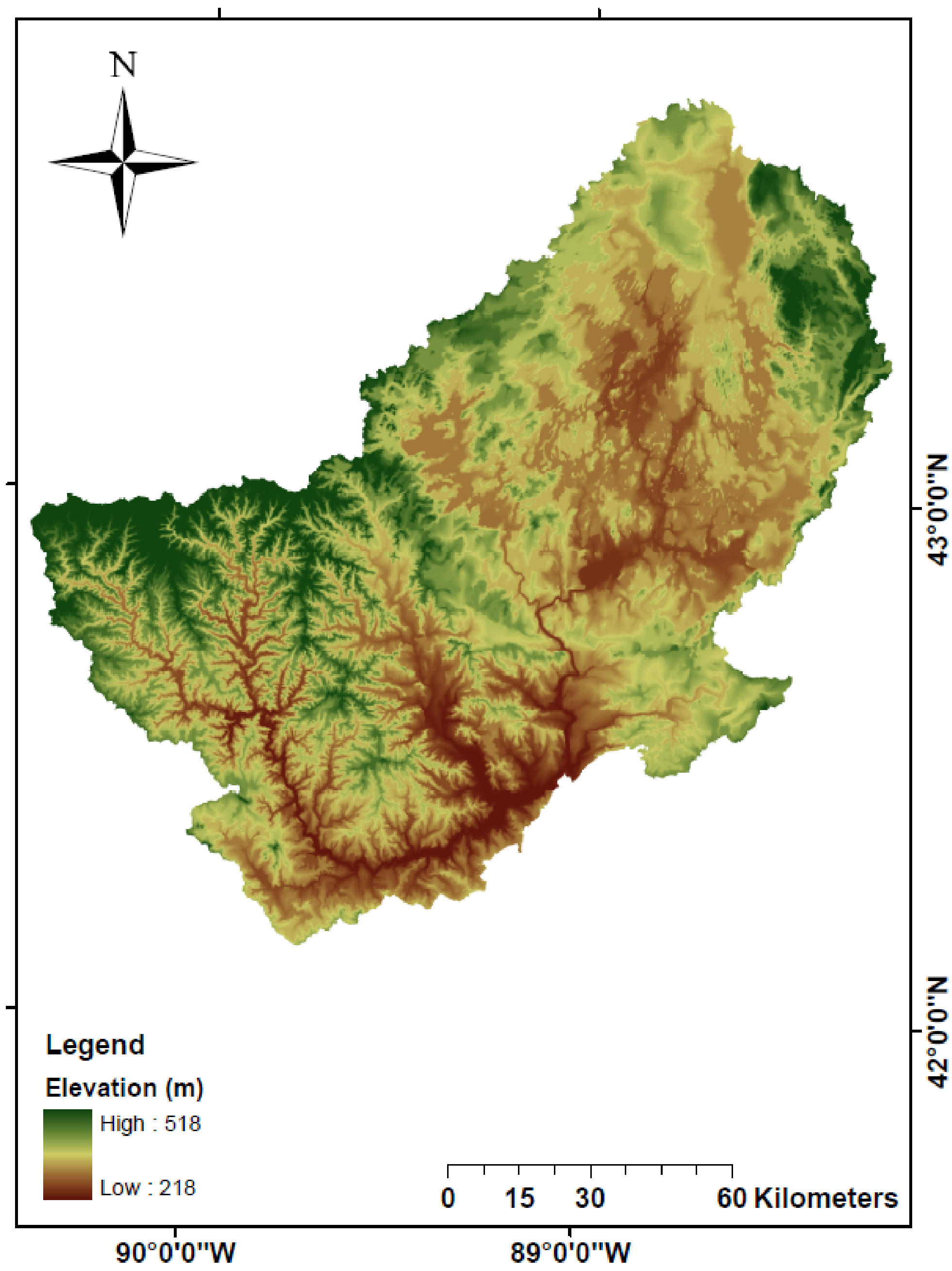


Figure 1. Relief map of the Rock River Basin

2.0 River Network

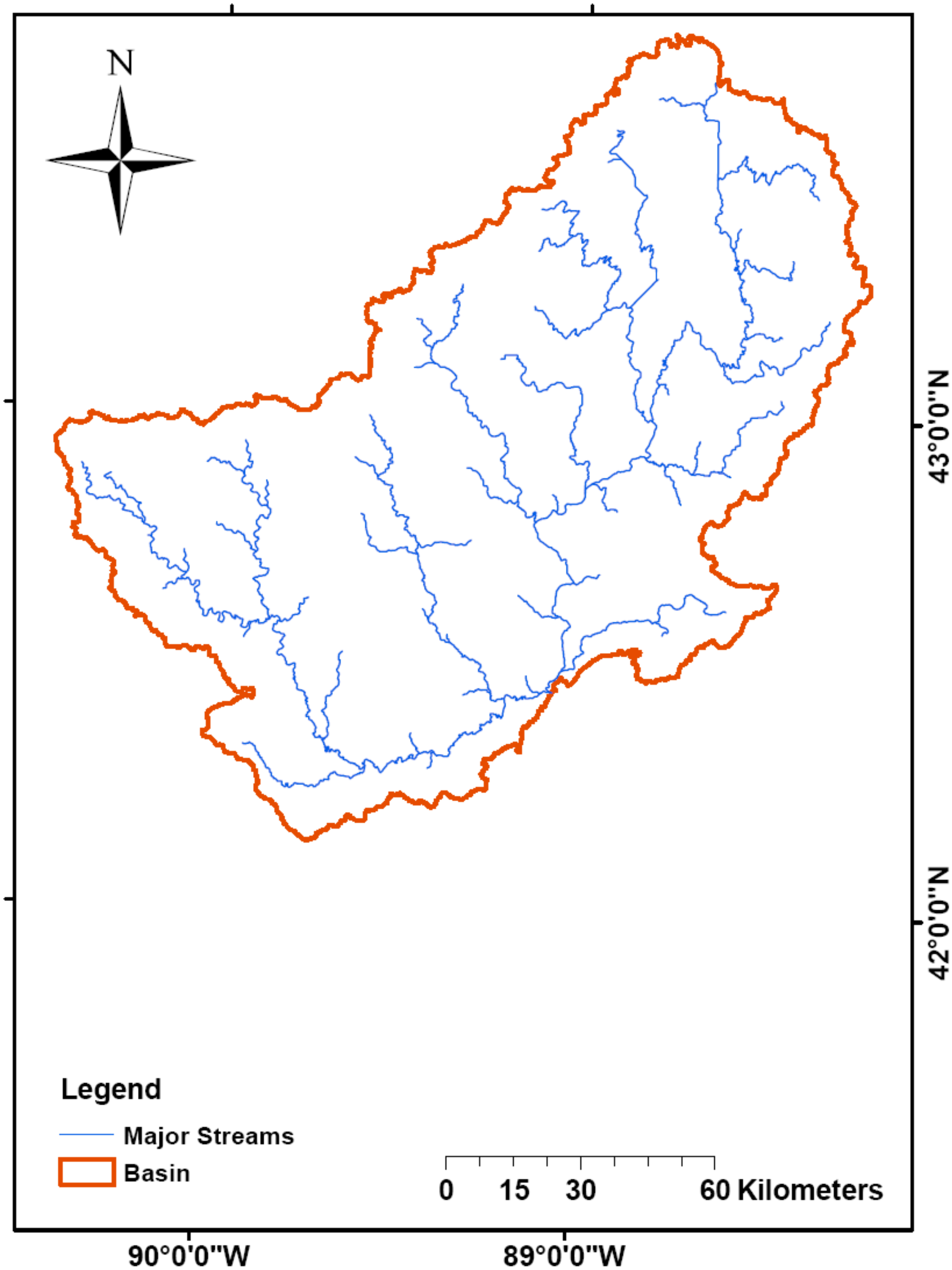


Figure 2. Major streams of the Rock River Basin

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, agricultural land in the Rock River Basin Watershed is the predominant land usage, covering 73 percent of land area. Forest covers 9 percent of the land area. Wetlands, urban, range, and water constitute the remaining 18.5 percent of land cover (Tables 1a and 1b). In the Rock River Basin, urban centers are dispersed throughout the watershed (Figure 3).

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

Landuse	Area (ha)	Percentage
Agricultural Land-Row Crops	864403.8	52.5
Hay	331140.8	20.1
Forest-Deciduous	142995.1	8.7
Wetlands-Non-Forested	64585.4	3.9
Residential-Low Density	62635.4	3.8
Residential-Medium Density	60420.1	3.7
Water	35314.6	2.1
Wetlands-Forested	34811.8	2.1
Range-Grasses	16247.2	1.0
Residential-High Density	13231.2	0.8
Range-Brush	12587.5	0.8
Industrial	4325.0	0.3
Forest-Evergreen	3121.5	0.2
Forest-Mixed	1261.8	0.1
Range-Other	972.9	0.1

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

Agriculture	72.5%
Forest	9.0%
Urban	8.5%
Wetlands	6.0%
Water	2.1%
Rangeland	1.8%

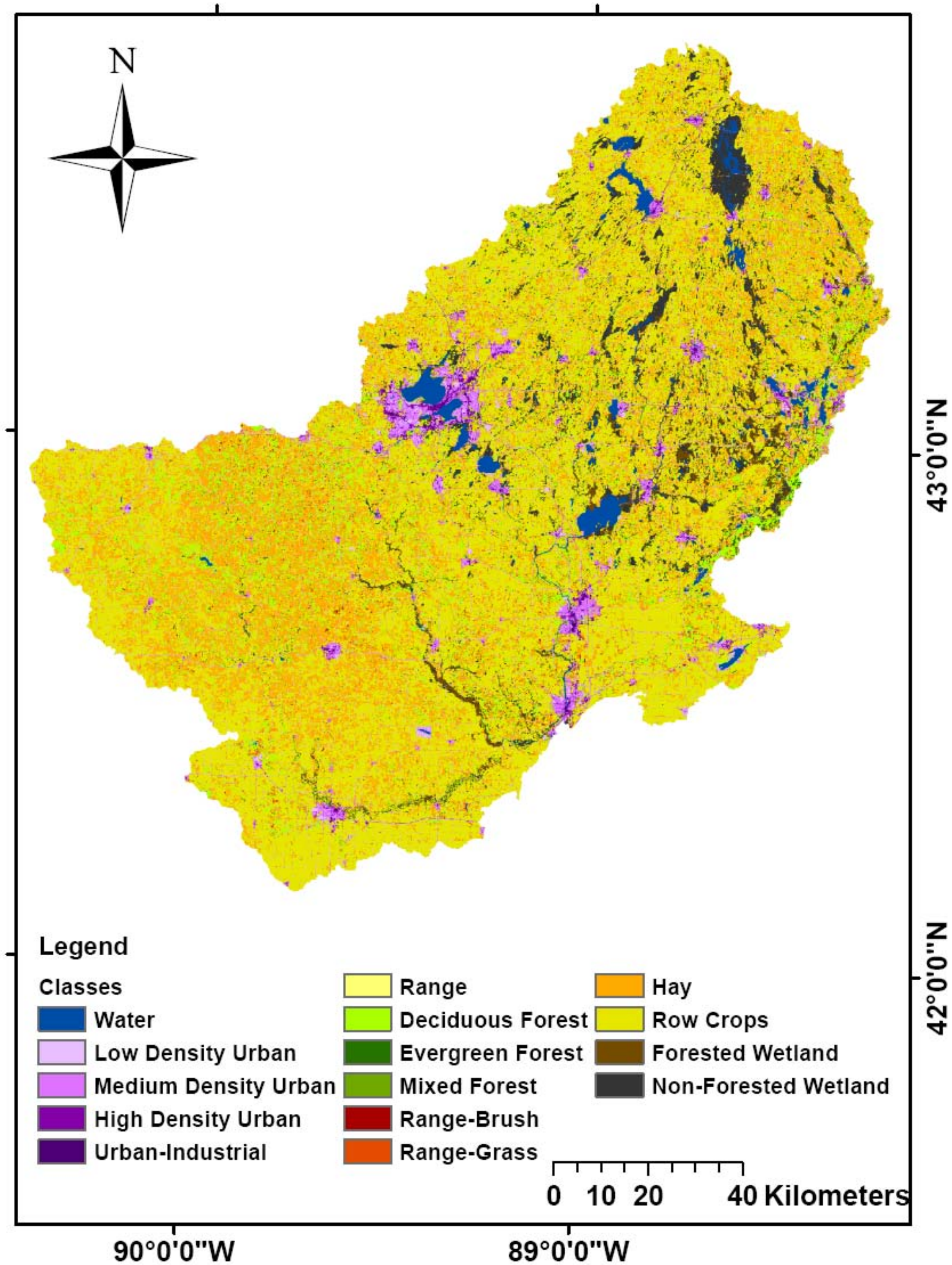


Figure 3. Current landuse map of the Rock River Basin

Based on the Landuse circa 1800 county base (LU1800), forest was the predominant land usage in the Rock River Basin covering 62 percent of land area. Rangeland covered 25 percent of the land area. Wetlands and water constituted the remaining 13 percent of land cover (Tables 2a and 2b; Figure 4).

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

Landuse	Area (ha)	Percentage
Forest-Deciduous	1027008	62.32
Range-Grasses	397826.2	24.14
Wetlands-Non-Forested	161032.6	9.77
Water	27086.1	1.64
Wetlands-Forested	22844.43	1.39
Range-Brush	6713.191	0.41
Rye	2838.888	0.17
Range-Other	654.8608	0.04

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

Forest	62.3%
Rangeland	24.8%
Wetlands	11.2%
Water	1.6%
Agriculture	0%
Urban	0%

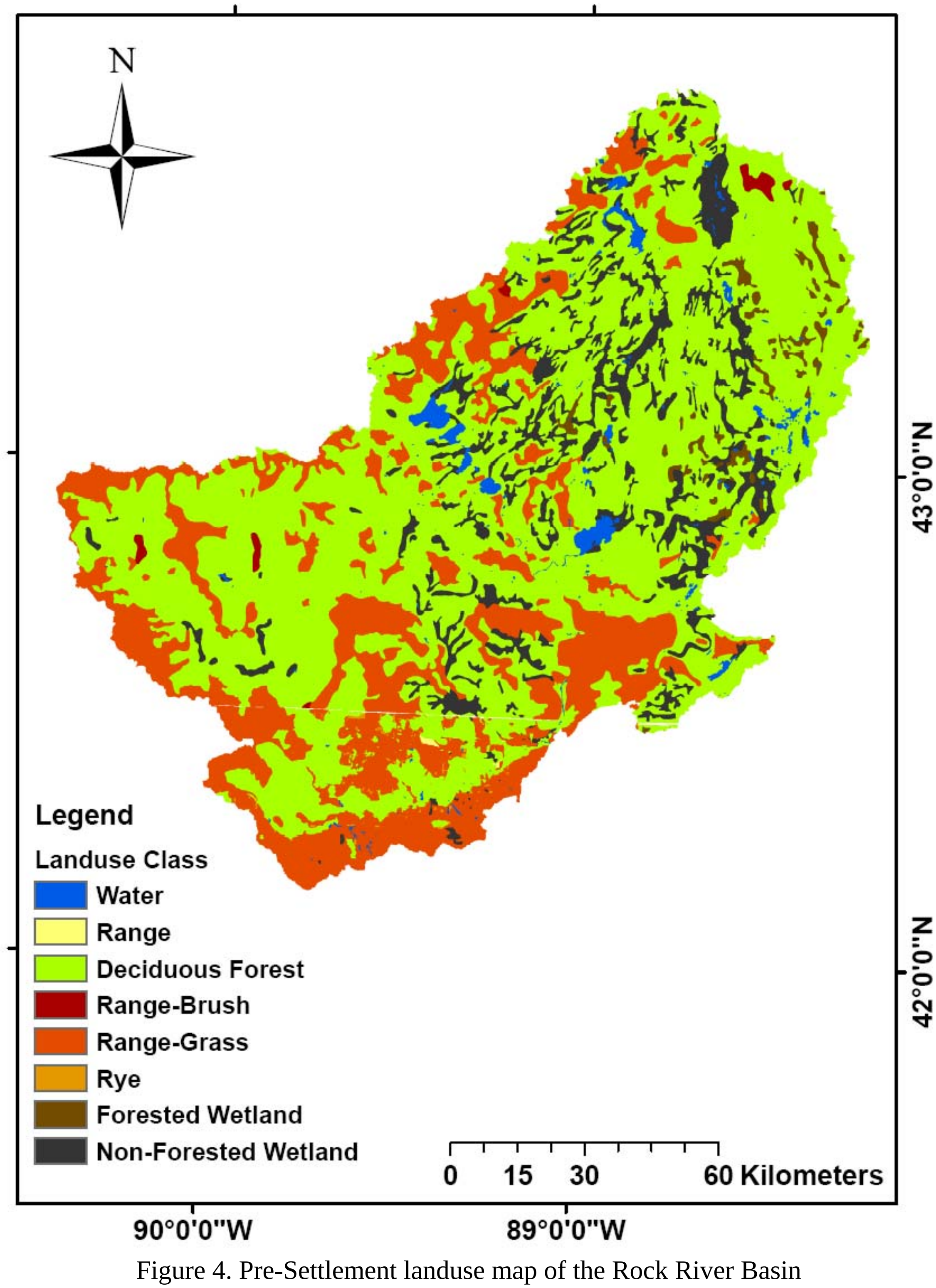


Figure 4. Pre-Settlement landuse map of the Rock River Basin

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 Rock River Basin.

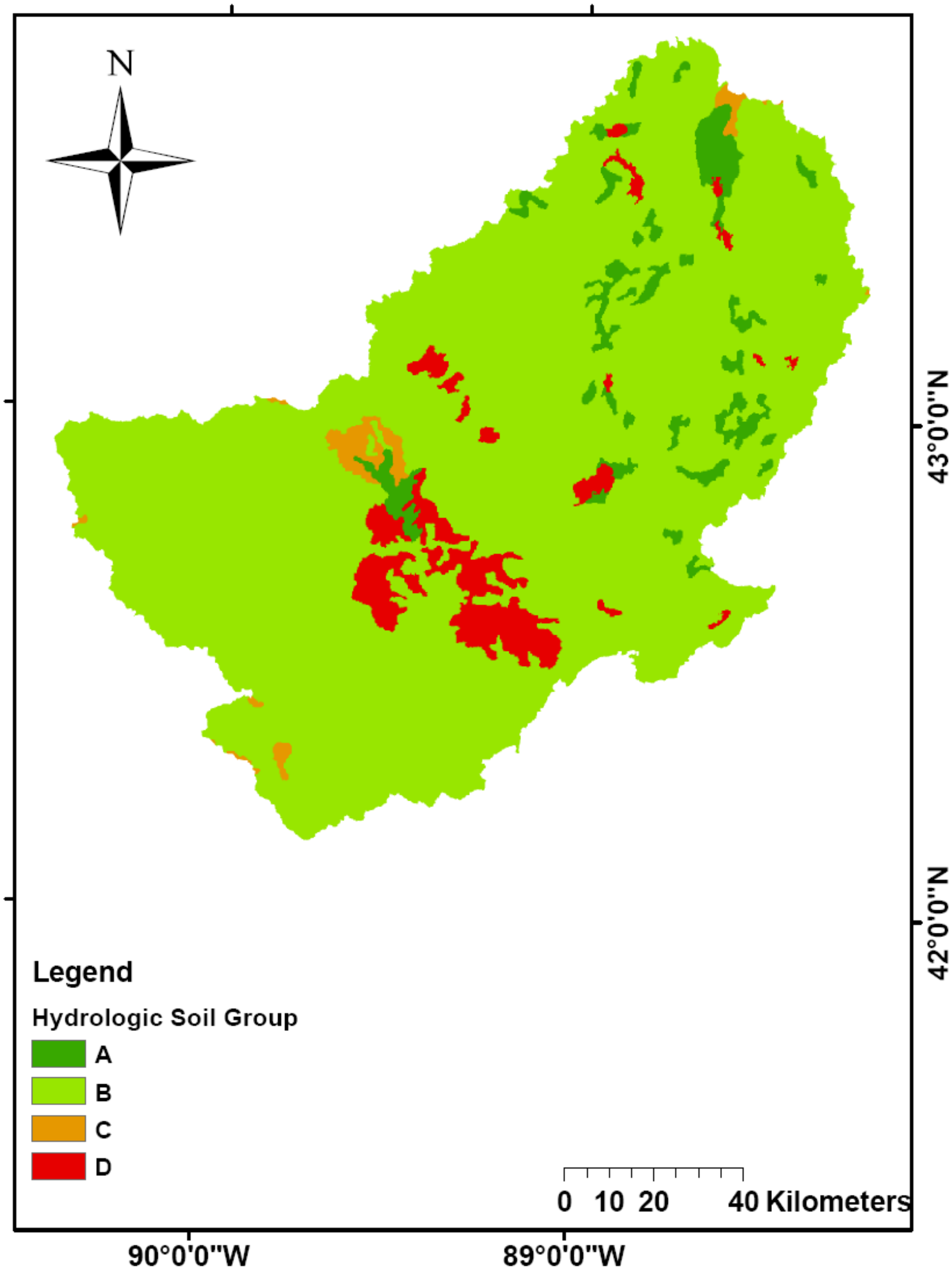


Figure 5. Hydrologic Soil Groups for the Rock River Basin

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.

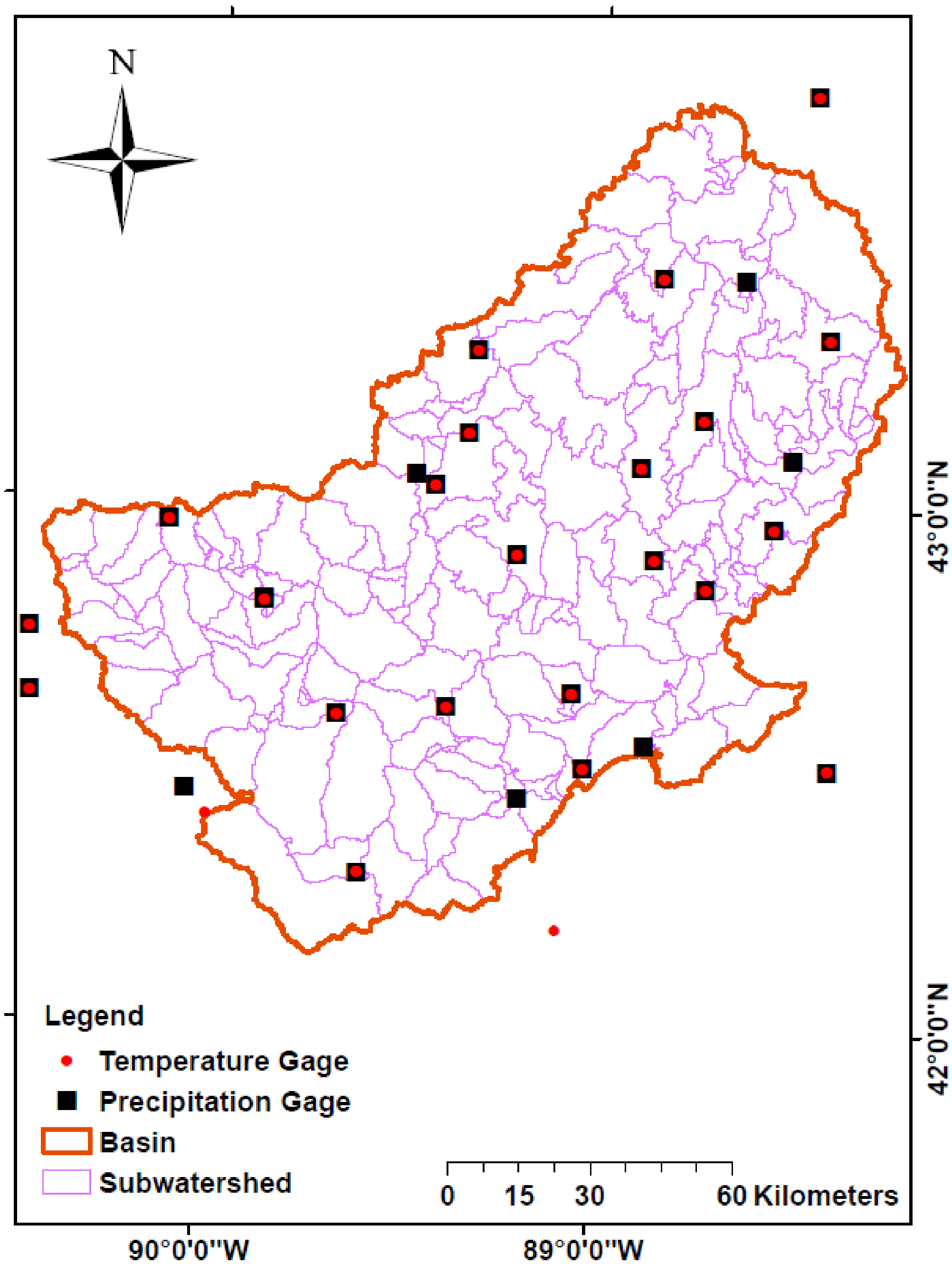


Figure 6. Temperature and precipitation gages in the Rock River Basin

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 175 subwatersheds. Figure 7 shows the boundary and the locations of subwatersheds in the Rock River basin.

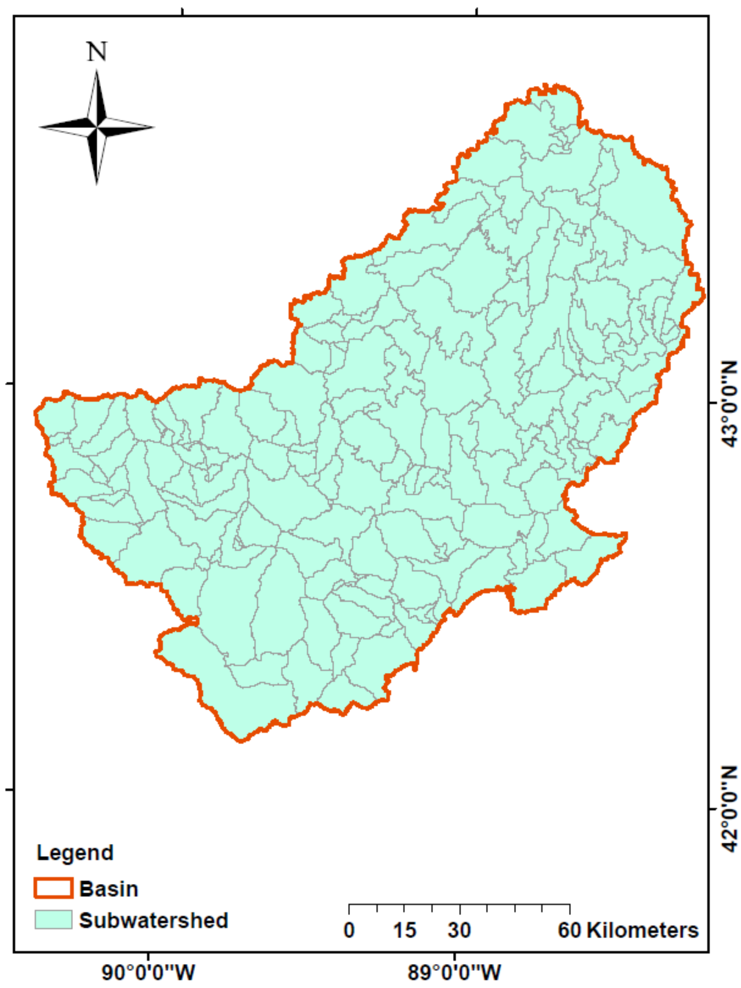


Figure 7. The delineated watersheds

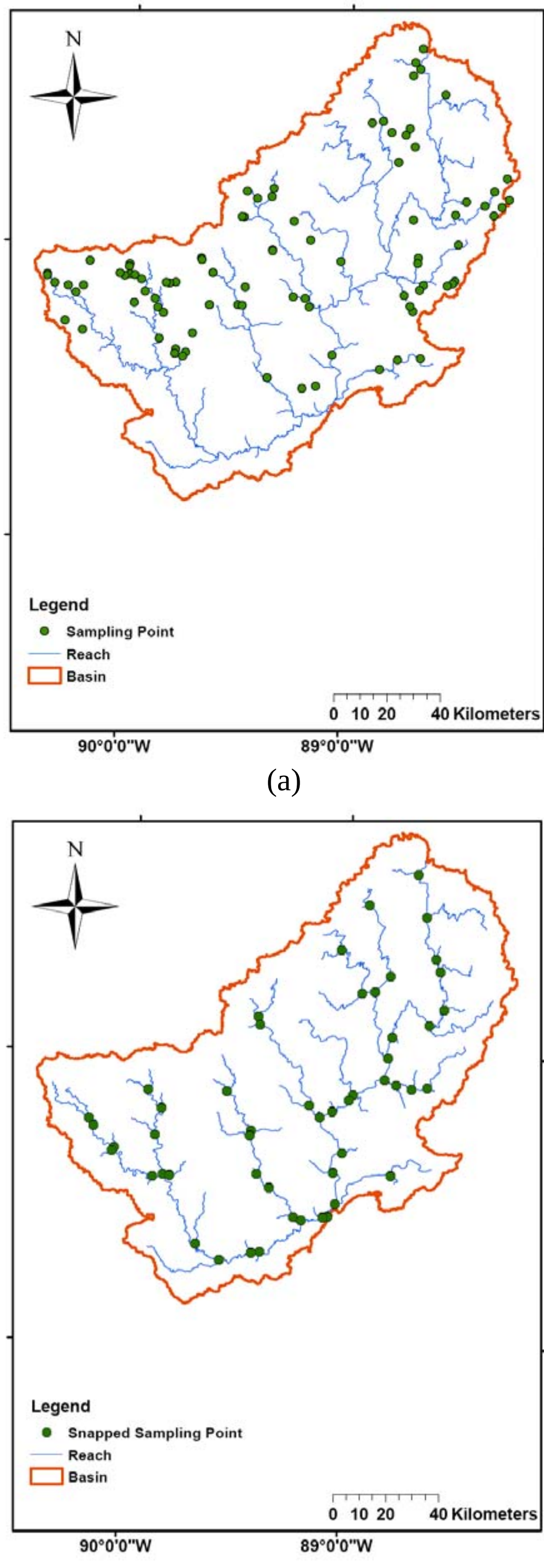
The SWAT model generates results on the outlets of subwatersheds. Since our goal is to obtain the model results on the locations of fish sampling points, these points were introduced to the model. In some cases, the fish sampling points lie on small creeks, which are too small for the model to recognize. 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	42.5280	-89.1971	1	42.5280	-89.1971
2	42.5372	-89.1339	2	42.5372	-89.1339
3	42.5621	-89.3571	3	42.5621	-89.3571
4	42.5621	-89.3571	4	42.5985	-88.8435
5	42.5985	-88.8435	5	42.6315	-88.7625
6	42.6256	-89.7463	6	42.6347	-89.7829
7	42.6315	-88.7625	7	42.6372	-88.6572
8	42.6347	-89.7829	8	42.6398	-89.7332
9	42.6372	-88.6572	9	42.6441	-89.0626
10	42.6398	-89.7332	10	42.6493	-89.7786
11	42.6441	-89.0626	11	42.6841	-89.8560
12	42.6493	-89.7786	12	42.7049	-90.2082
13	42.6841	-89.8560	13	42.7344	-90.2901
14	42.7049	-90.2082	14	42.7718	-89.8401
15	42.7058	-89.7049	15	42.7898	-89.8665
16	42.7344	-90.2901	16	42.7974	-88.6962
17	42.7718	-89.8401	17	42.8032	-89.9760
18	42.7898	-89.8665	18	42.8032	-89.6306
19	42.7974	-88.6962	19	42.8046	-89.4807
20	42.8032	-89.9760	20	42.8048	-89.1726
21	42.8032	-89.6306	21	42.8059	-89.4998
22	42.8032	-89.6306	22	42.8194	-89.8810
23	42.8046	-89.4807	23	42.8335	-89.1919
24	42.8048	-89.1726	24	42.8381	-89.2469
25	42.8059	-89.4998	25	42.8419	-89.9274
26	42.8145	-88.7103	26	42.8506	-88.7375
27	42.8194	-89.8810	27	42.8530	-90.2819
28	42.8307	-90.2459	28	42.8551	-90.2113
29	42.8335	-89.1919	29	42.8603	-90.3440
30	42.8381	-89.2469	30	42.8669	-89.4692
31	42.8419	-89.9274	31	42.8703	-88.6668
32	42.8506	-88.7375	32	42.8721	-89.8166
33	42.8530	-90.2819	33	42.8763	-89.7877
34	42.8551	-90.2113	34	42.8825	-89.9452
35	42.8603	-90.3440	35	42.8863	-88.6504

36	42.8669	-89.4692	36	42.8908	-90.3793
37	42.8703	-88.6668	37	42.8939	-90.0236
38	42.8721	-89.8166	38	42.8965	-89.9772
39	42.8748	-89.8317	39	42.8992	-89.9993
40	42.8763	-89.7877	40	42.9026	-88.5059
41	42.8825	-89.9452	41	42.9123	-89.6191
42	42.8847	-90.3794	42	42.9338	-90.0014
43	42.8850	-88.5403	43	42.9611	-89.6738
44	42.8863	-88.6504	44	42.9623	-89.0317
45	42.8908	-90.3793	45	42.9790	-88.6755
46	42.8936	-88.5165	46	42.9956	-89.3481
47	42.8939	-90.0236	47	43.0257	-88.4922
48	42.8965	-89.9772	48	43.0324	-89.1734
49	42.8992	-89.9993	49	43.0942	-89.2521
50	42.9009	-90.0463	50	43.1050	-89.4823
51	42.9026	-88.5059	51	43.1084	-88.7014
52	42.9123	-89.6191	52	43.1268	-88.5074
53	42.9123	-89.6191	53	43.1270	-88.3305
54	42.9246	-90.0041	54	43.1555	-88.2940
55	42.9338	-90.0014	55	43.1599	-88.3727
56	42.9395	-90.1852	56	43.1690	-89.4240
57	42.9559	-89.6710	57	43.1724	-88.4584
58	42.9607	-88.6780	58	43.1760	-89.3572
59	42.9611	-89.6738	59	43.1926	-89.4719
60	42.9623	-89.0317	60	43.2050	-89.3490
61	42.9790	-88.6755	61	43.2530	-88.2714
62	42.9921	-89.3473	62	43.3024	-88.7755
63	42.9956	-89.3481	63	43.3563	-88.7005
64	43.0257	-88.4922	64	43.3951	-88.7445
65	43.0324	-89.1734	65	43.4033	-88.8100
66	43.0942	-89.2521	66	43.4179	-88.7252
67	43.1050	-89.4823	67	43.4407	-88.8499
68	43.1055	-89.4926	68	43.5350	-88.5630
69	43.1084	-88.7014	69	43.5980	-88.7144
70	43.1268	-88.5074	70	43.6201	-88.6818
71	43.1270	-88.3305	71	43.6422	-88.7065
72	43.1555	-88.2940	72	43.6885	-88.6719
73	43.1599	-88.3727	73		
74	43.1690	-89.4240	74		
75	43.1724	-88.4584	75		
76	43.1760	-89.3572	76		
77	43.1808	-88.2599	77		
78	43.1926	-89.4719	78		
79	43.2050	-89.3490	79		

80	43.2087	-88.3294	80		
81	43.2530	-88.2714	81		
82	43.3024	-88.7755	82		
83	43.3563	-88.7005	83		
84	43.3951	-88.7445	84		
85	43.4033	-88.8100	85		
86	43.4179	-88.7252	86		
87	43.4344	-88.9012	87		
88	43.4407	-88.8499	88		
89	43.5350	-88.5630	89		
90	43.5980	-88.7144	90		
91	43.6201	-88.6818	91		
92	43.6422	-88.7065	92		
93	43.6885	-88.6719	93		



(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.

The most downstream USGS gaging station on Rock River (Station No. 05437500) 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.

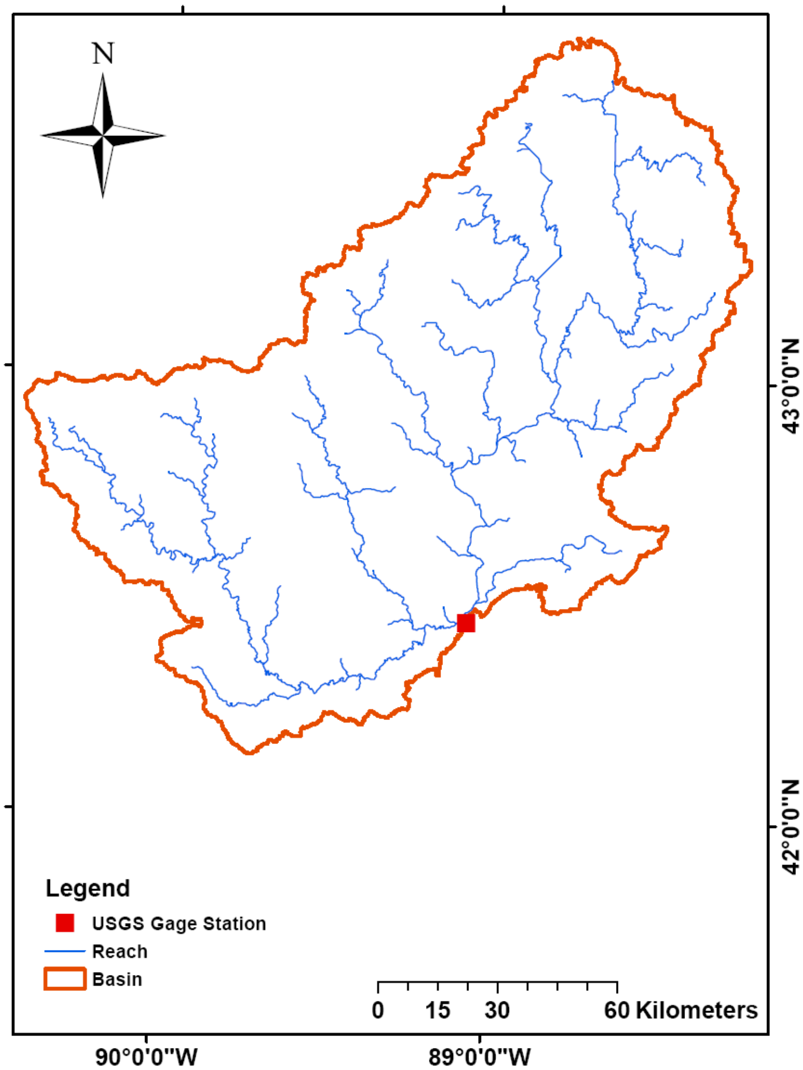


Figure 9. The delineated watersheds and selected USGS station.

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, total Kjeldahl 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	TotalKN	TotalP
Alpha_Bf	1	1	2	2
Biomix	2	4	3	1
Blai	3	6	11	11
Canmx	4	10	1	3
Ch_Cov	5	5	7	6
Ch_Erod	6	13	5	5
Ch_K2	7	15	10	10
Ch_N2	8	11	17	17
Cn2	9	12	13	12
Epco	10	7	4	4
Esco	11	16	12	14
Gw_Delay	12	3	16	15
Gw_Revap	13	14	14	13
Gwqmn	14	23	19	20
Nperco	15	21	15	16
Phoskd	16	22	6	7
Pperco	17	20	23	22
Rchrg_Dp	18	17	18	18
Revapmn	19	24	22	25
Sftmp	20	26	26	26
Shallst_N	21	19	8	8
Slope	22	25	21	24
Slsubbsn	23	9	9	9
Smfmn	24	27	27	28
Smfmx	25	29	42	27
Smtmp	26	42	24	21
Sol_Alb	27	28	25	23
Sol_Awc	42	2	42	42
Sol_K	42	8	42	42
Sol_Labp	42	18	20	19
Sol_No3	42	42	42	42
Sol_Orgn	42	42	42	42
Sol_Orgp	42	42	42	42
Sol_Z	42	42	42	42
Spcon	42	42	42	42
Spexp	42	42	42	42
Surlag	42	42	42	42
Timp	42	42	42	42
Tlaps	42	42	42	42
Usle_C	42	42	42	42
Usle_P	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 good comparisons with observed flow and sediment. Comparisons of nutrients were not as good because the observed data did not provide enough information and because the statistics were skewed by a single peak in the generated values. 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	0.640	9.911	0.769
Total Suspended Solids (TSS)	0.476	239.056	0.885
Total N	0.215	6539.669	0.656
Total P	-1.054	-1.409	0.724

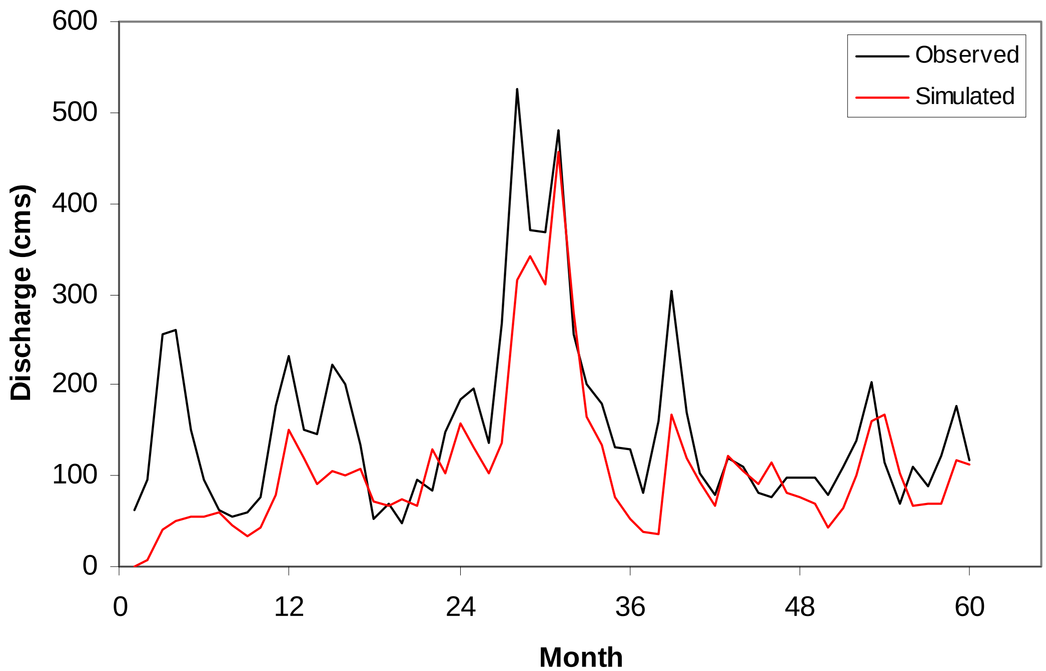


Figure 10. Model simulated results vs. USGS measurements at USGS 05437500 station

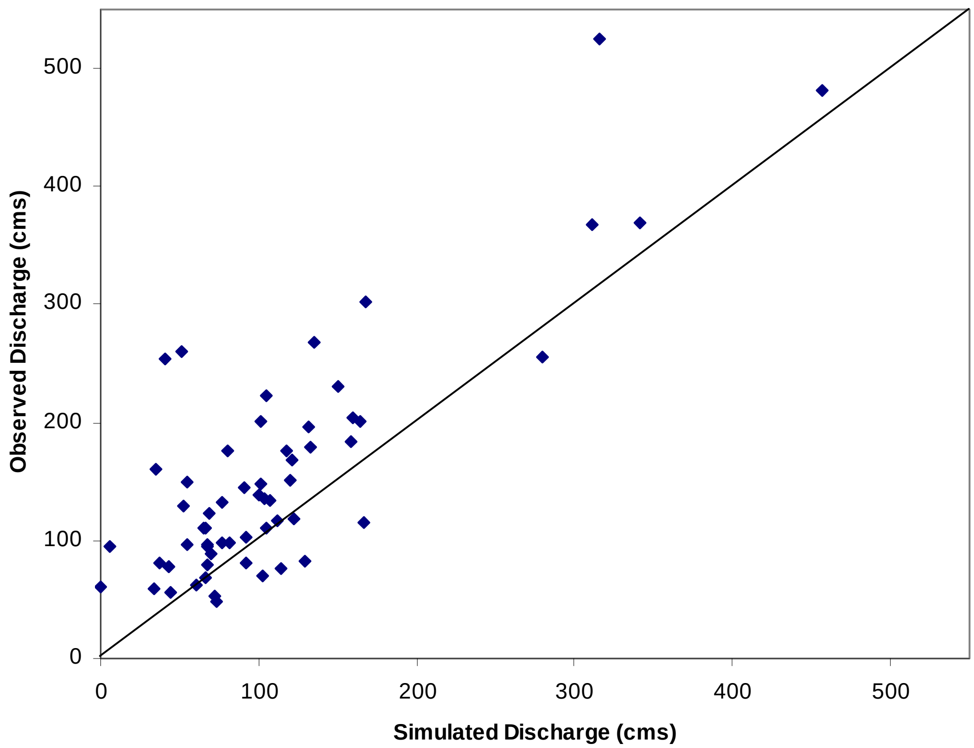


Figure 11. Simulated vs observed flow at USGS 05437500 station

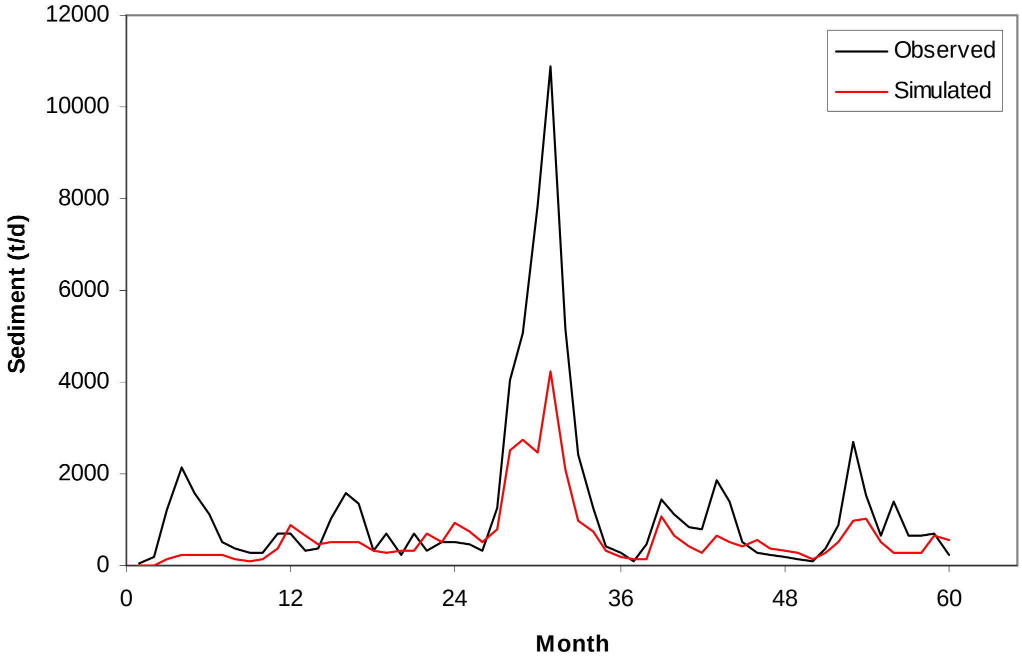


Figure 12. Time series of simulated vs observed TSS

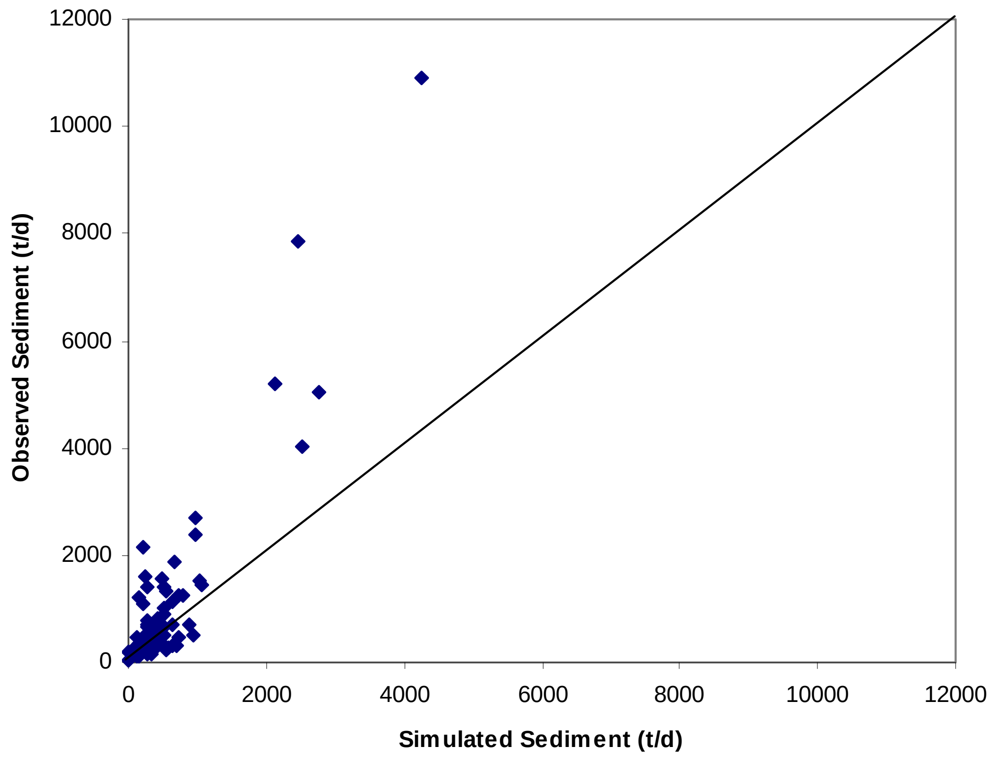


Figure 13. Simulated vs observed TSS

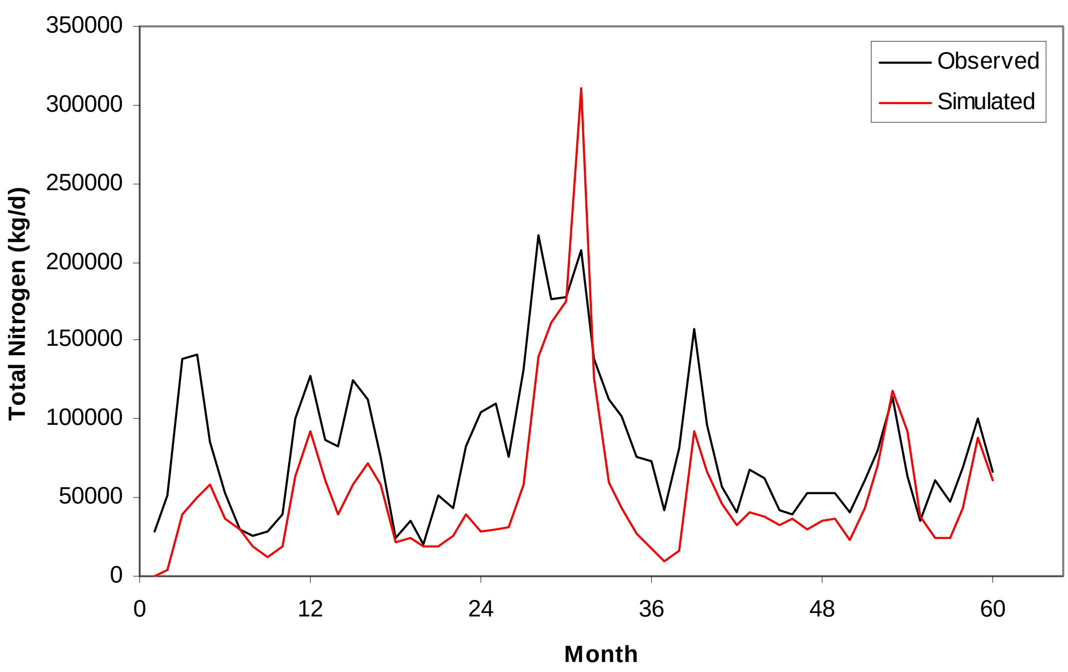


Figure 14. Time series of simulated vs observed Total Nitrogen

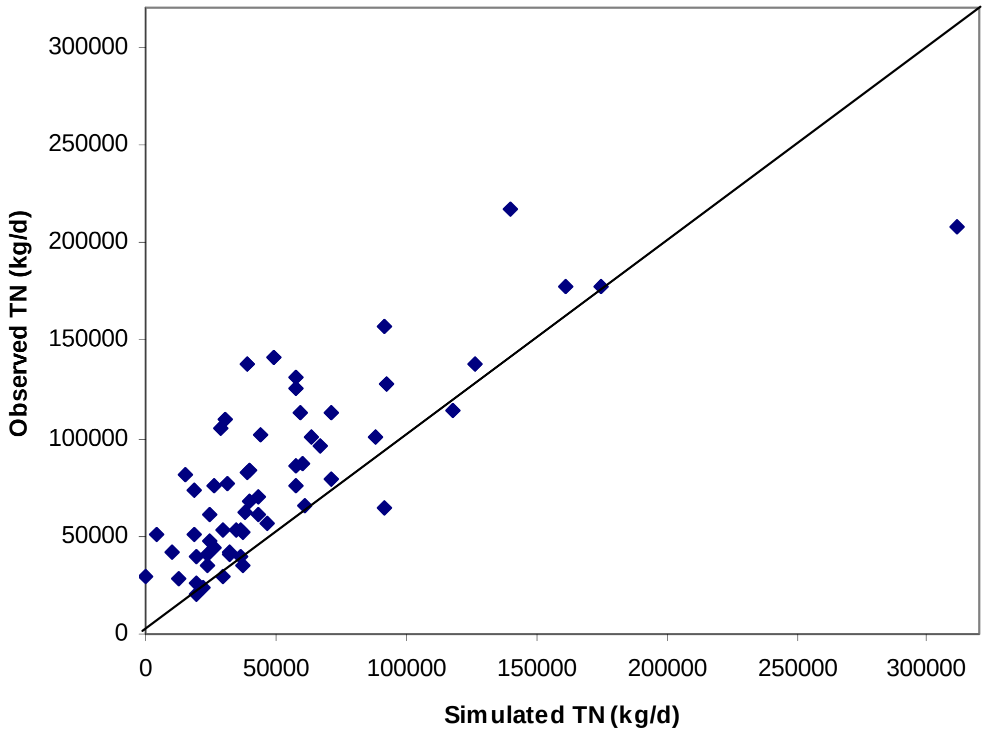


Figure 15. Simulated vs observed Total Nitrogen

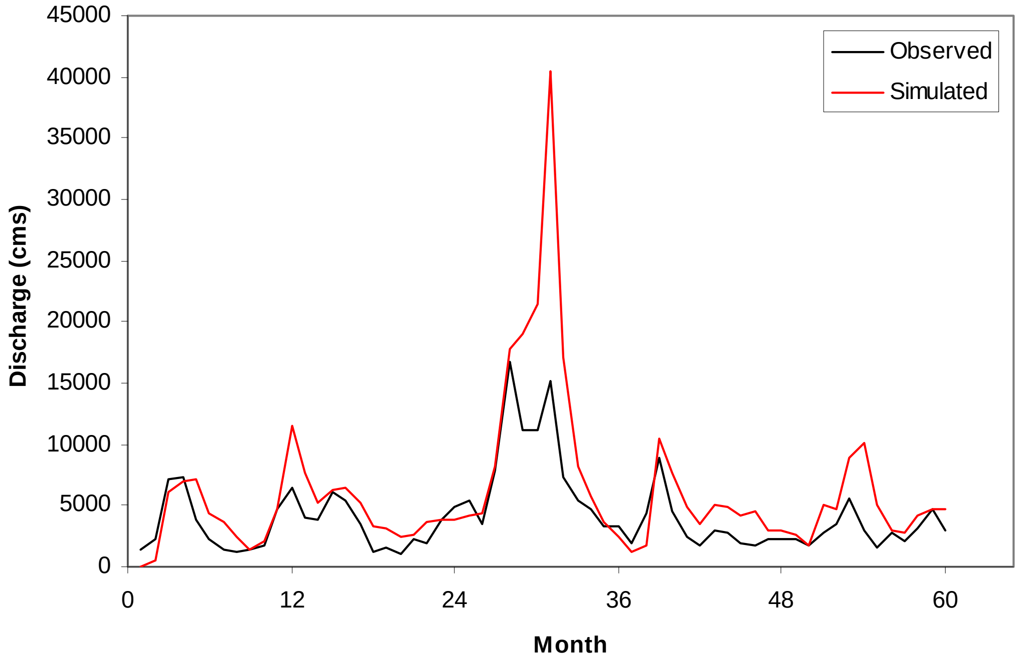


Figure 16. Time series of simulated vs. observed total phosphorus

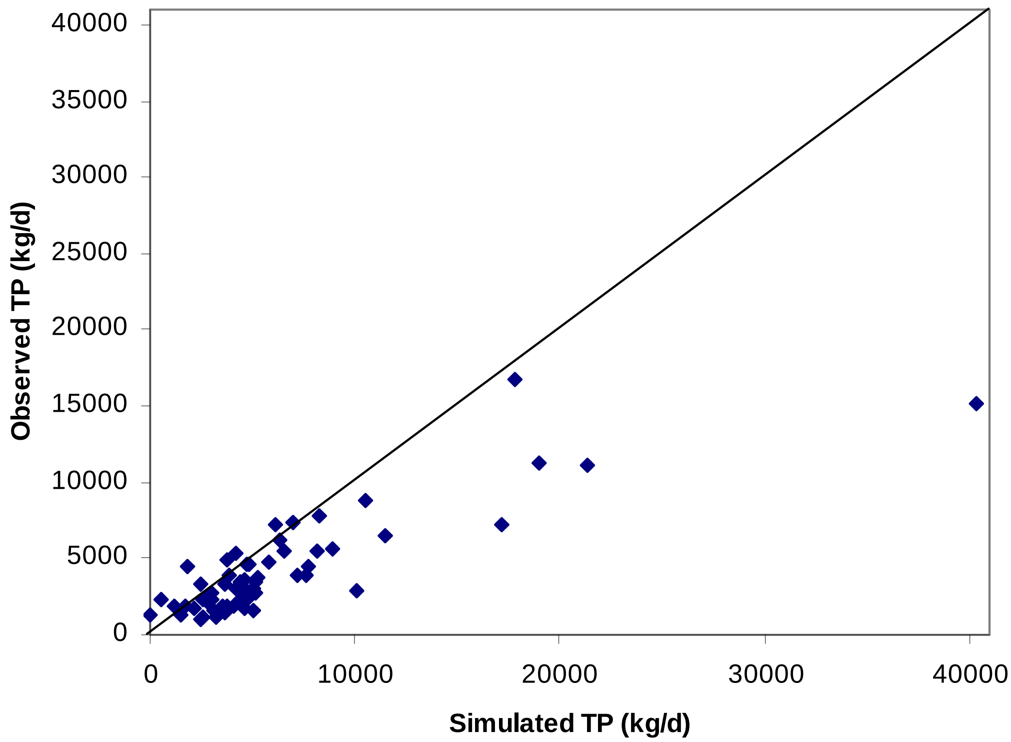


Figure 17. Simulated vs. observed total phosphorus

Table 6. Monthly and annual hydrologic budget from the Rock 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	32.35	28.18	8.7	0.01	9.73	5.62	0.08	14.02
2	24.16	18.73	9.66	0.01	9.89	10.31	0.11	21.69
3	52.69	15.55	18.82	0.08	19.38	31.8	0.31	62.5
4	101.68	6.46	18.85	0.23	23.39	45.45	0.31	98.74
5	77.6	0.33	17.25	0.14	23.26	57.53	0.29	154.27
6	103.4	0	17.27	0.14	21.88	93.53	0.31	182.18
7	125.25	0	21.36	0.14	25.91	142.83	0.34	164.35
8	99.81	0	14.06	0.07	16.46	93.98	0.15	149.97
9	111.08	0	12.76	0.1	14.22	42.8	0.12	104.08
10	65.34	1.71	13.14	0.09	14.83	30.66	0.12	74.98
11	84.12	16.59	12.79	0.15	15.35	18.02	0.12	36.55
12	30.49	21.58	14.42	0.05	17.14	8.1	0.14	15.11
Annual Average	907.97	109.13	179.08	1.21	211.44	580.63	2.4	1078.44

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 difference was 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 Rock Basin

Calibrated	Current	Pre-Settlement	Percent Change	Percent Difference
Recharge (mm)	112.04	213.75	-47.58%	-62.44%
Surface Runoff (mm)	196.99	130.98	50.40%	40.26%
Baseflow (mm)	35.56	65.82	-45.97%	-59.70%
Water Yield (mm)	233.75	198.37	17.84%	16.38%
Sediment Yield (t/ha)	2.96	0.10	2985.52%	187.44%
Total N Output (t/ha)	15.72	1.16	1260.87%	172.62%
Total P Output (t/ha)	1.43	0.05	2650.57%	185.97%

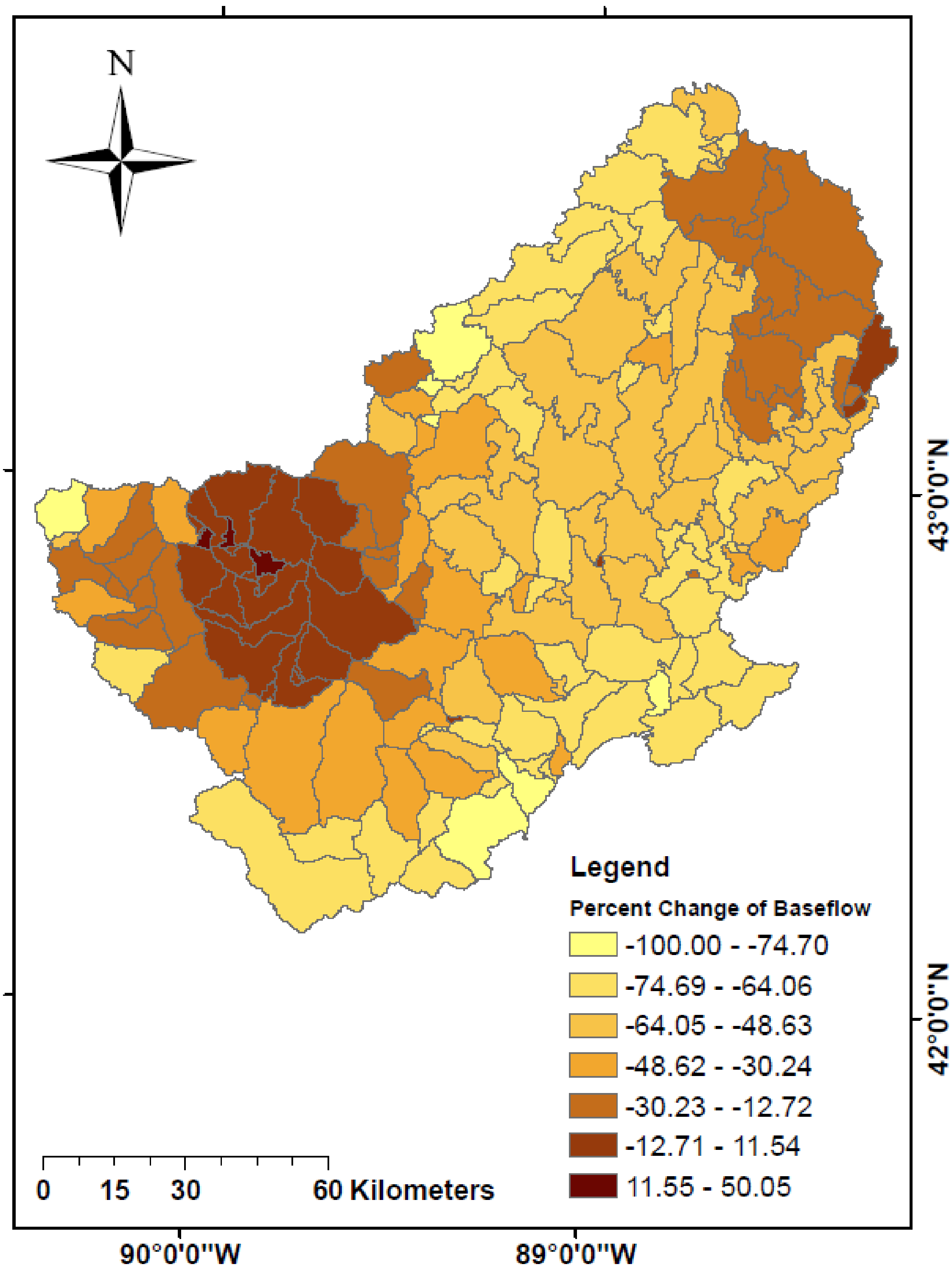


Figure 18. Change of baseflow values resulted from landuse changes (mm)

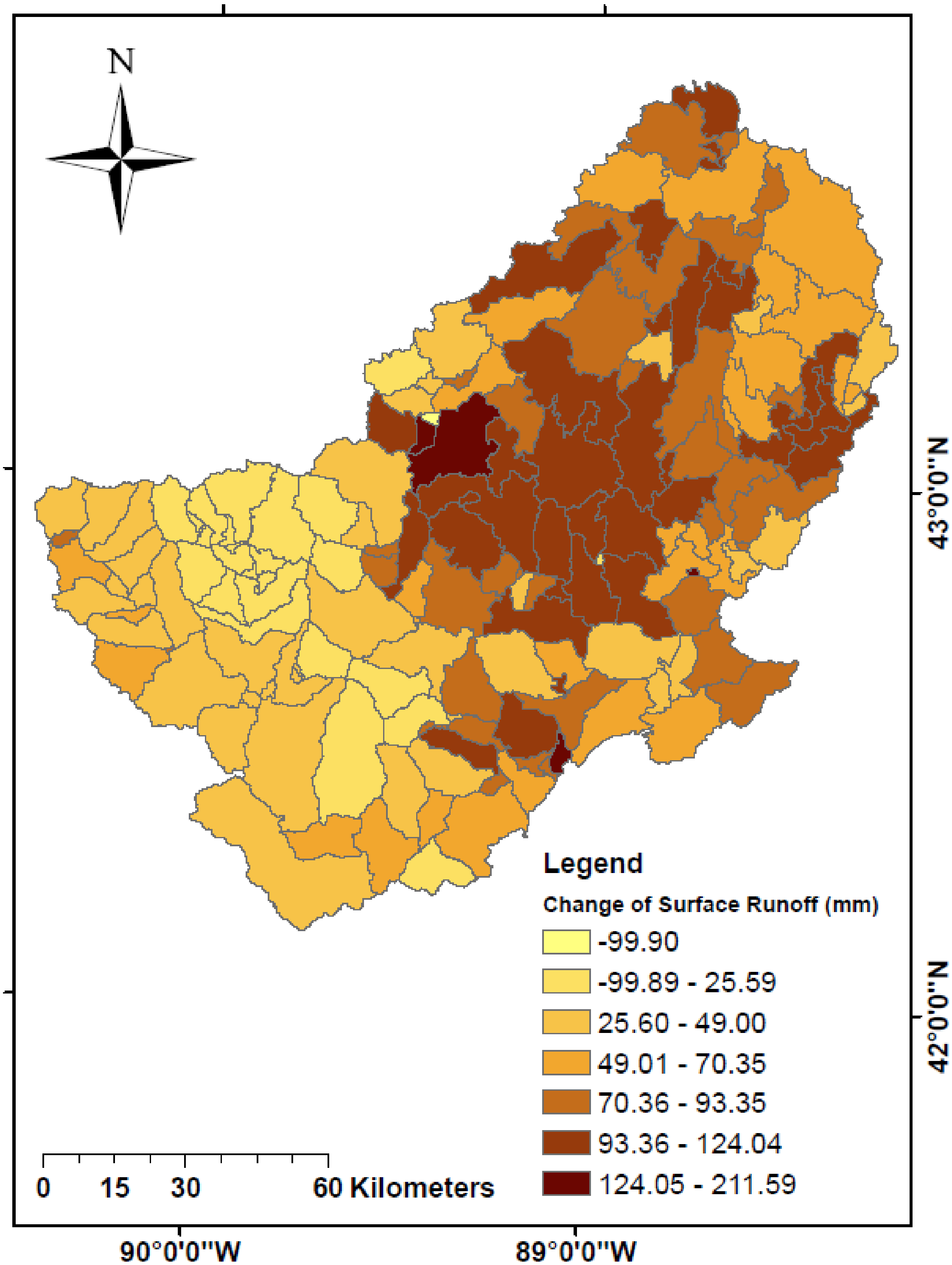


Figure 19. Change of surface runoff values resulted from landuse changes (mm)Figure 18.

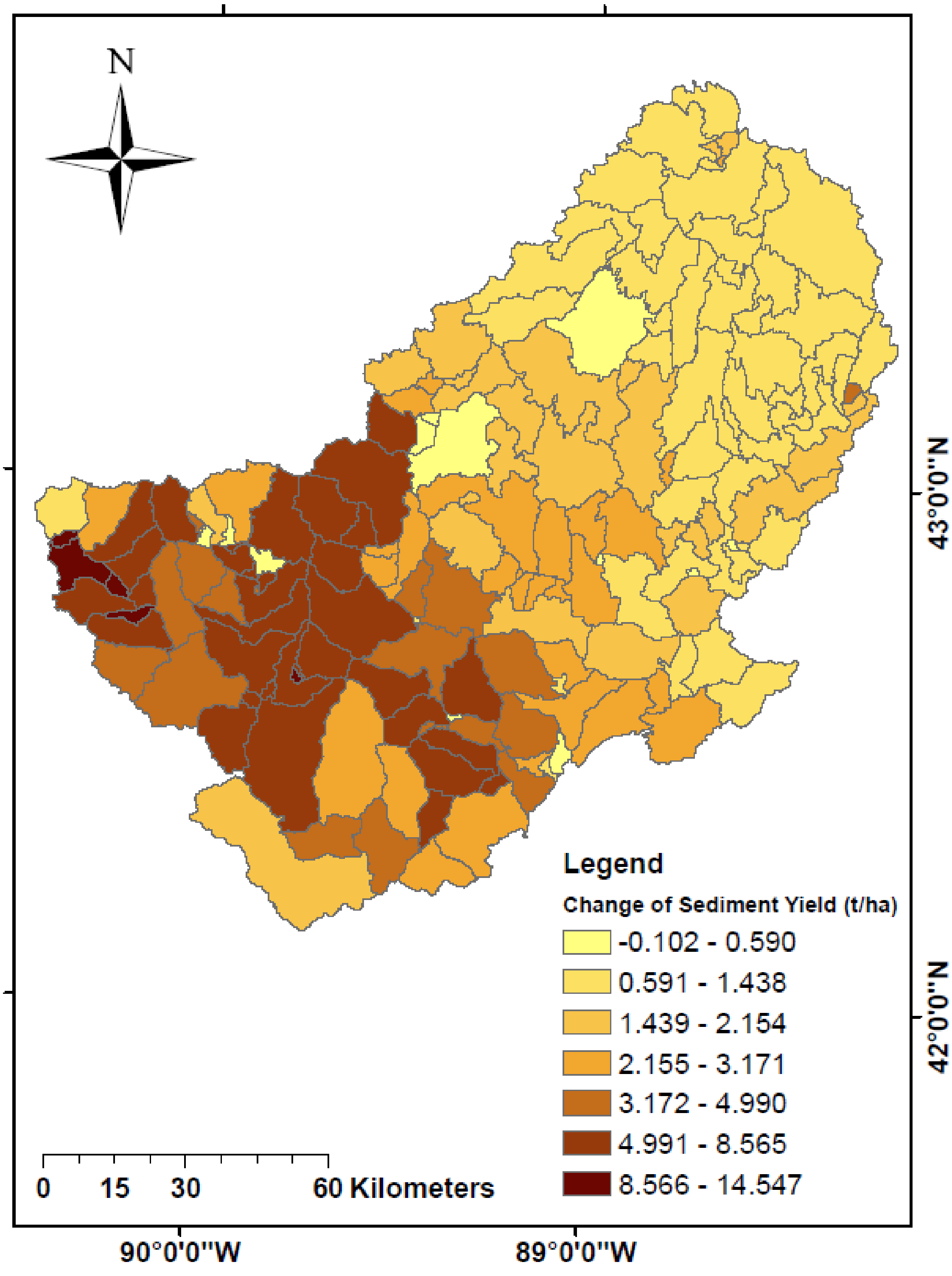


Figure 20. Change of sediment yields resulted from landuse changes (t/ha)

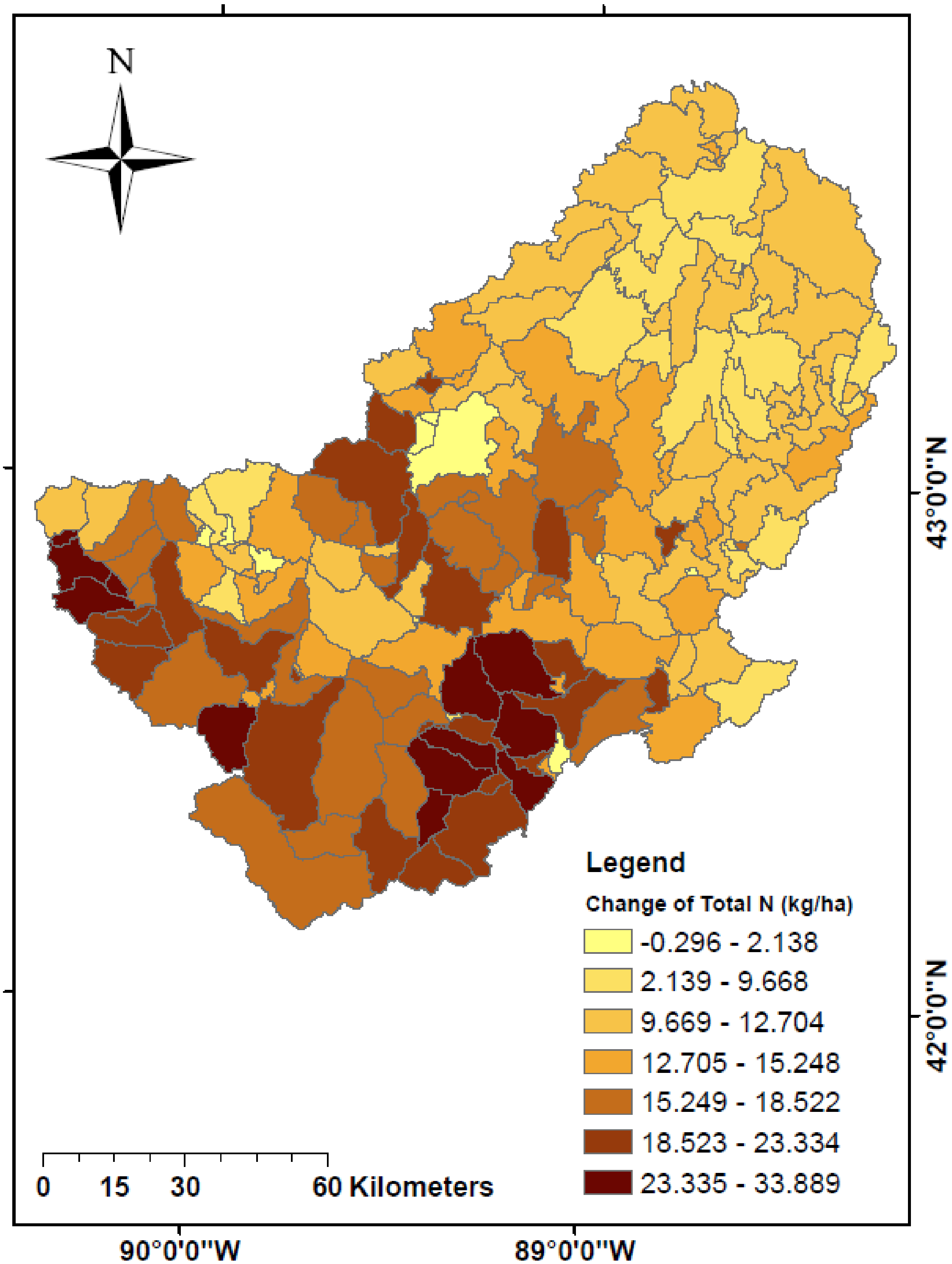


Figure 21. Change of total N output values resulted from landuse changes (kg/ha)

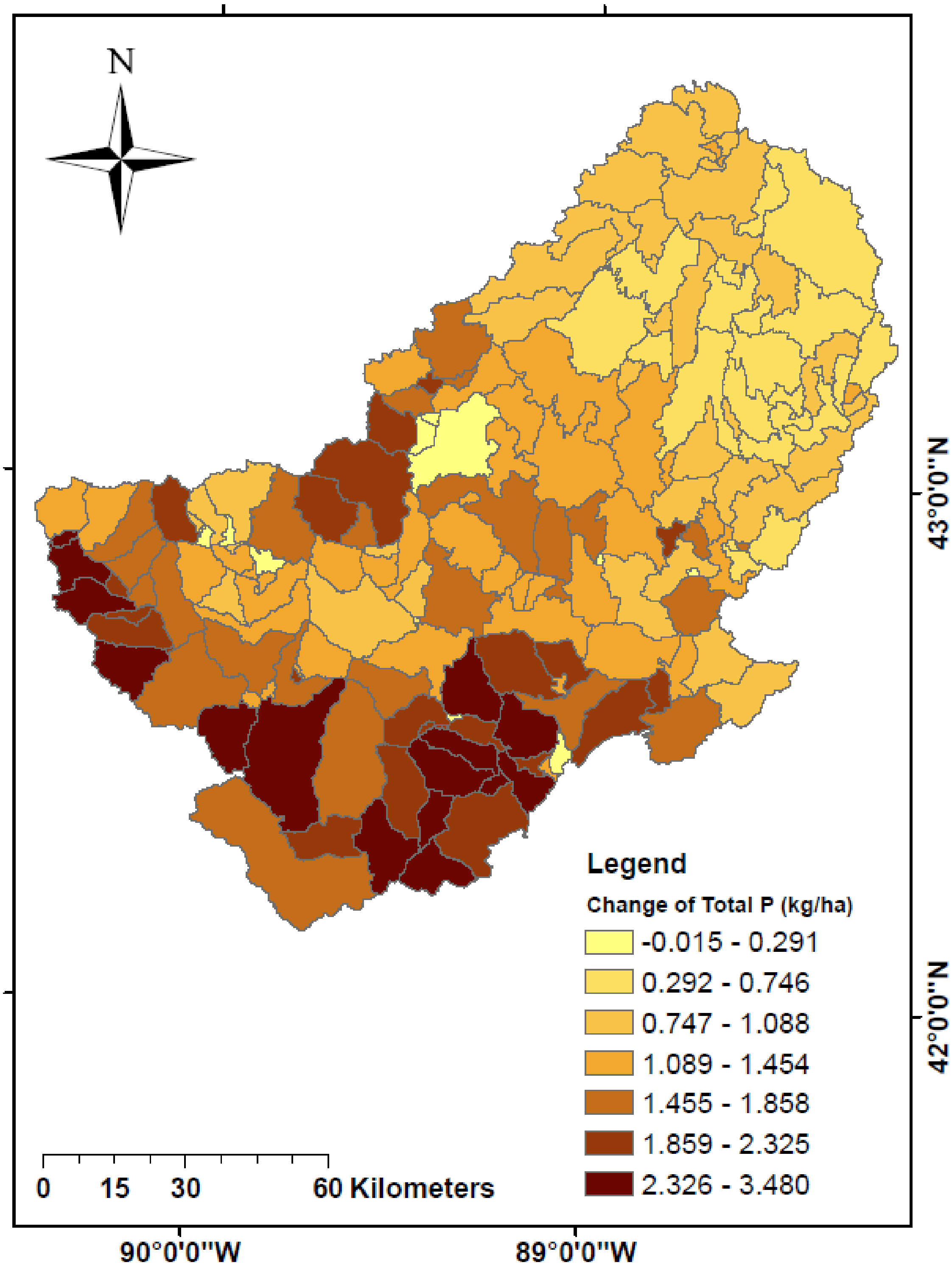


Figure 22. Change of total P output values resulted from landuse changes (kg/ha)

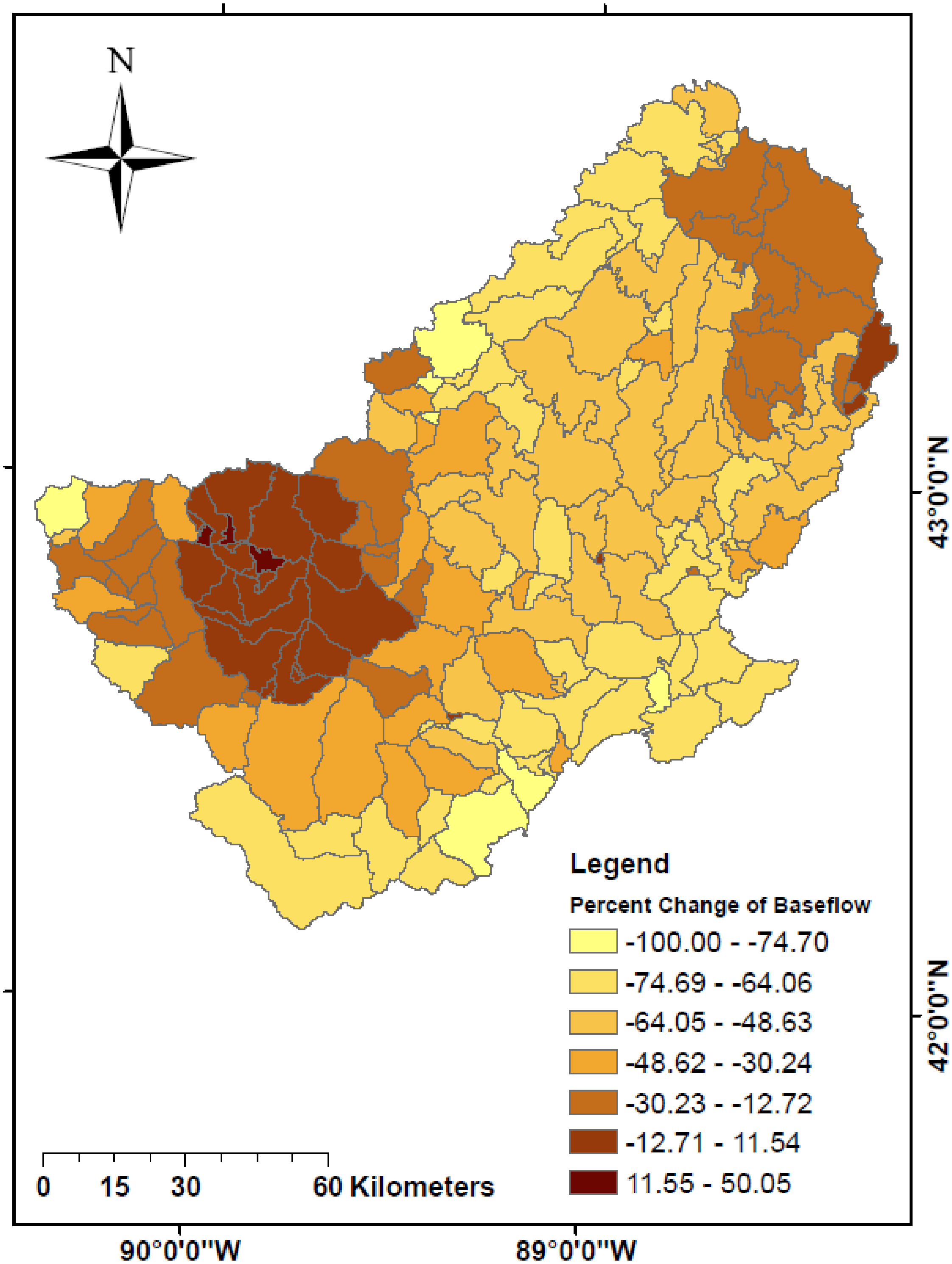


Figure 23. Percent change of baseflow values resulted from landuse changes

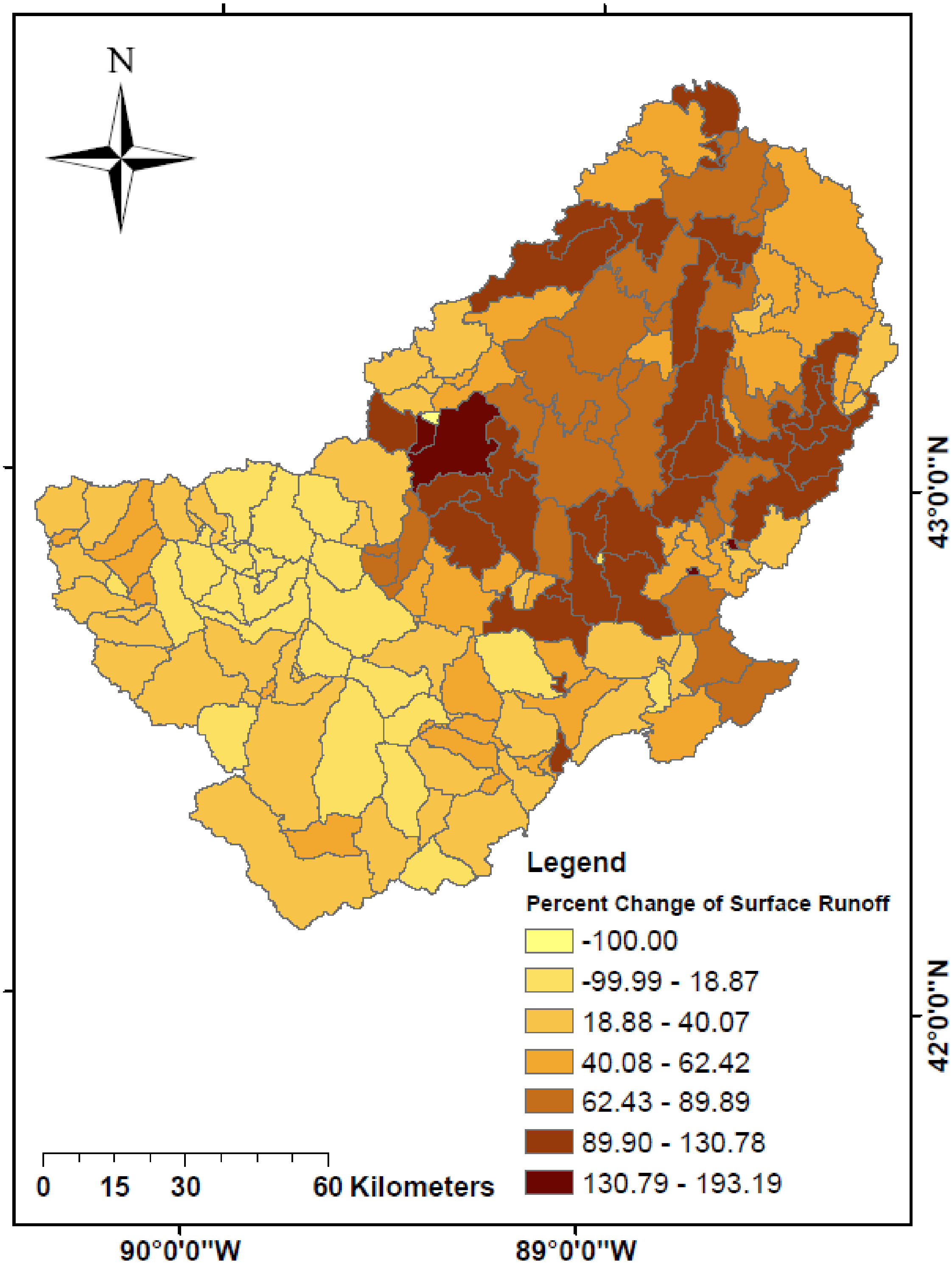


Figure 24. Percent change of surface runoff values resulted from landuse changes

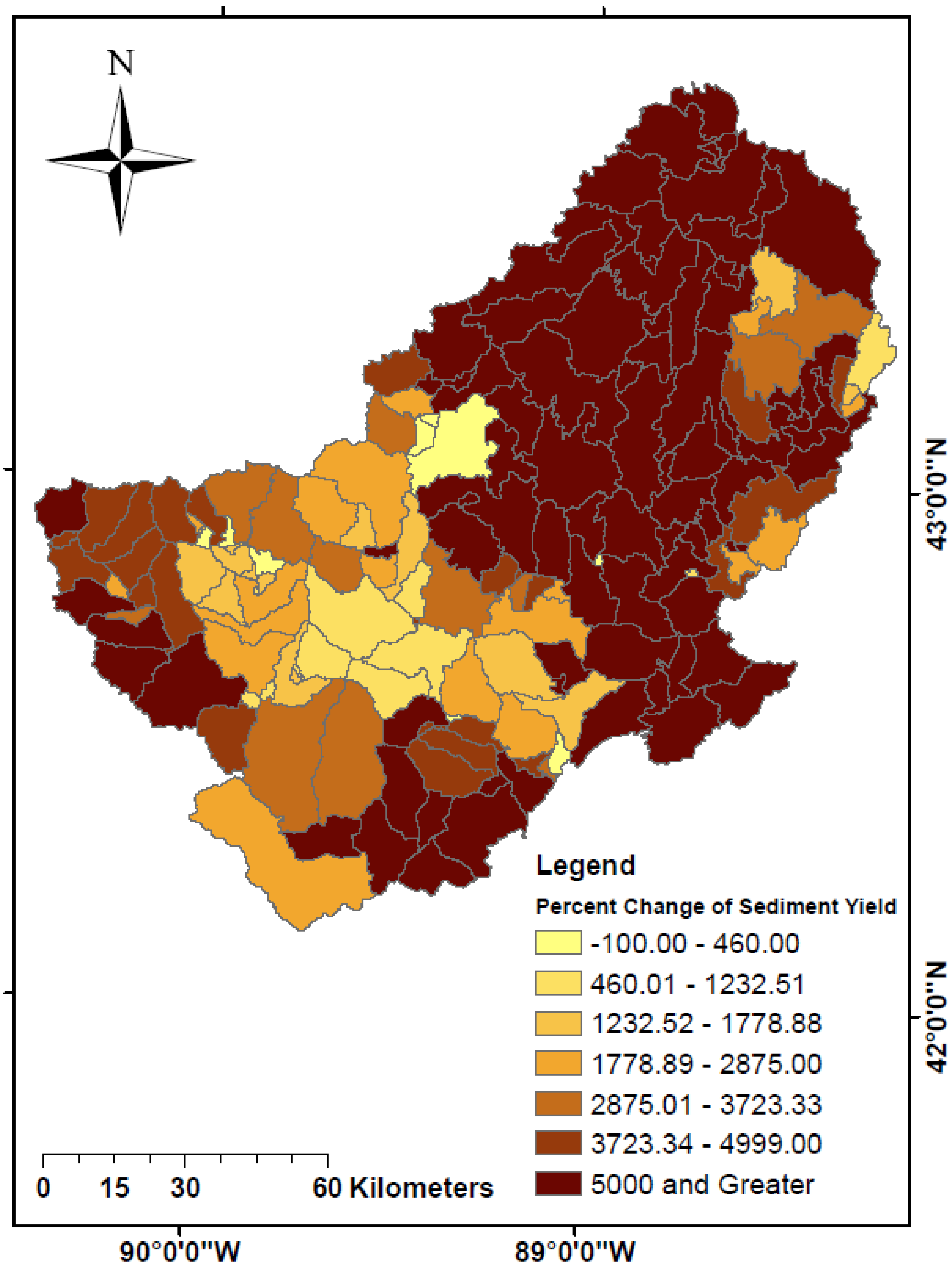


Figure 25. Percent change of sediment yield resulted from landuse changes

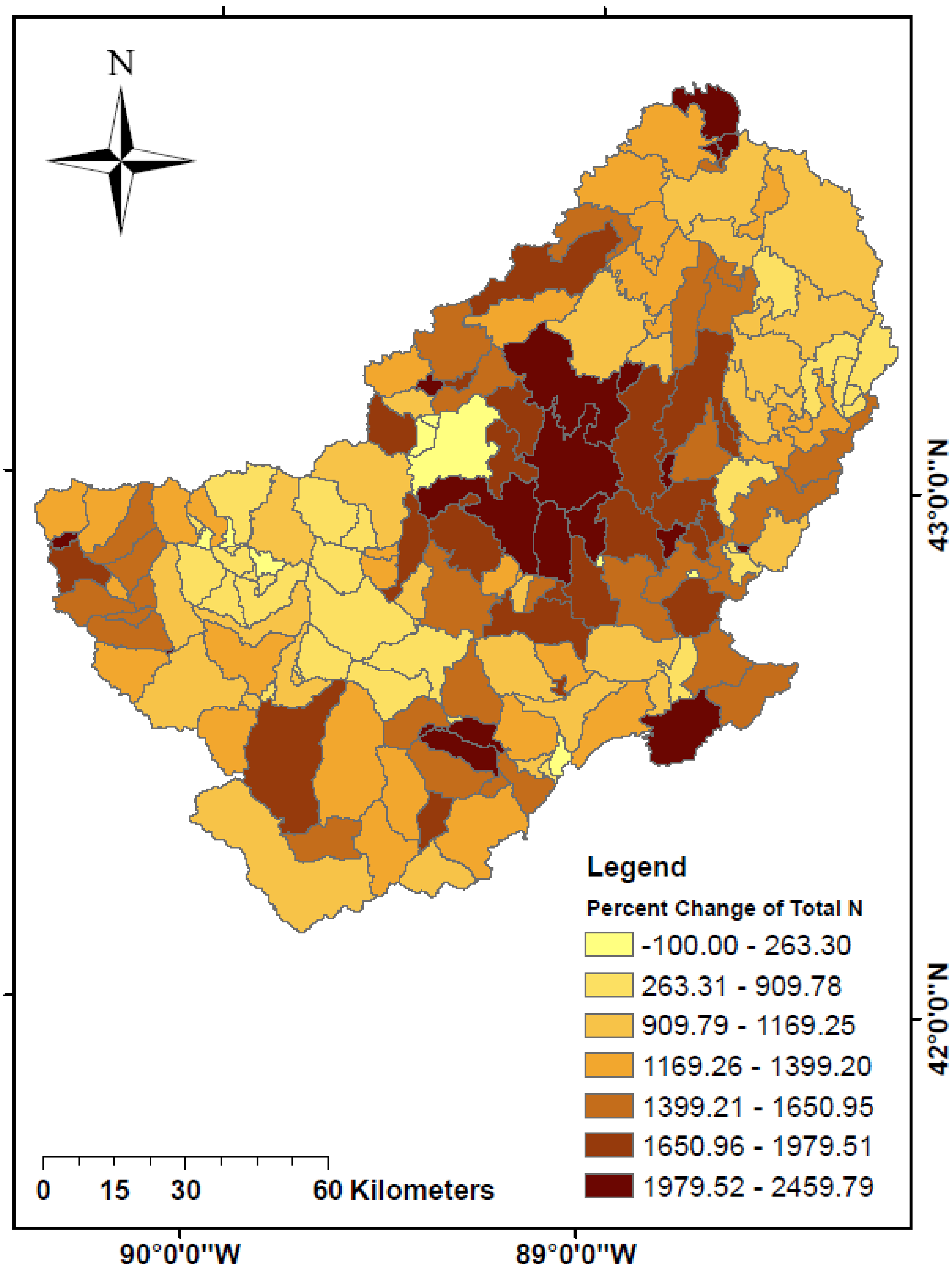


Figure 27. Percent change of total N output values resulted from landuse changes

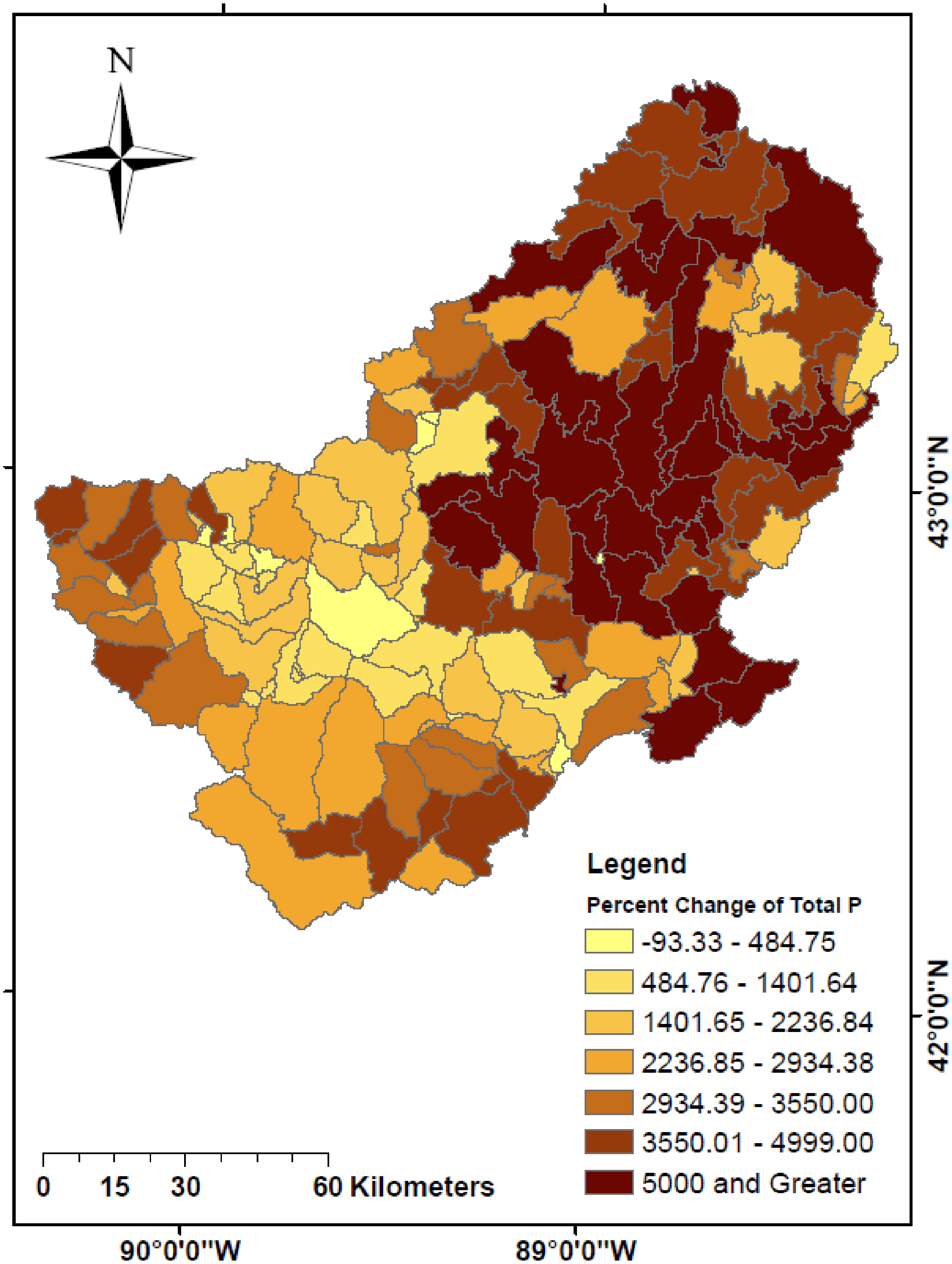


Figure 28. Percent change of total P output values resulted from landuse changes

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8.0 References

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