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

SWAT Model Report 040900 (Detroit Basin)

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1.0 General Information

The Detroit Basin lies on the southeast edge of Michigan's Lower Peninsula. This basin contains the Clinton River and Huron River, and drains to Lake St. Clair and the Detroit River. The basin, as the rest of the Peninsula, has a mild topography. The minimum elevation is 173m and the maximum elevation reads 365m with a mean of 269m. The catchment has a total area of 818 thousand hectares (or 2.02 million acres). A relief map is shown in figure 1.

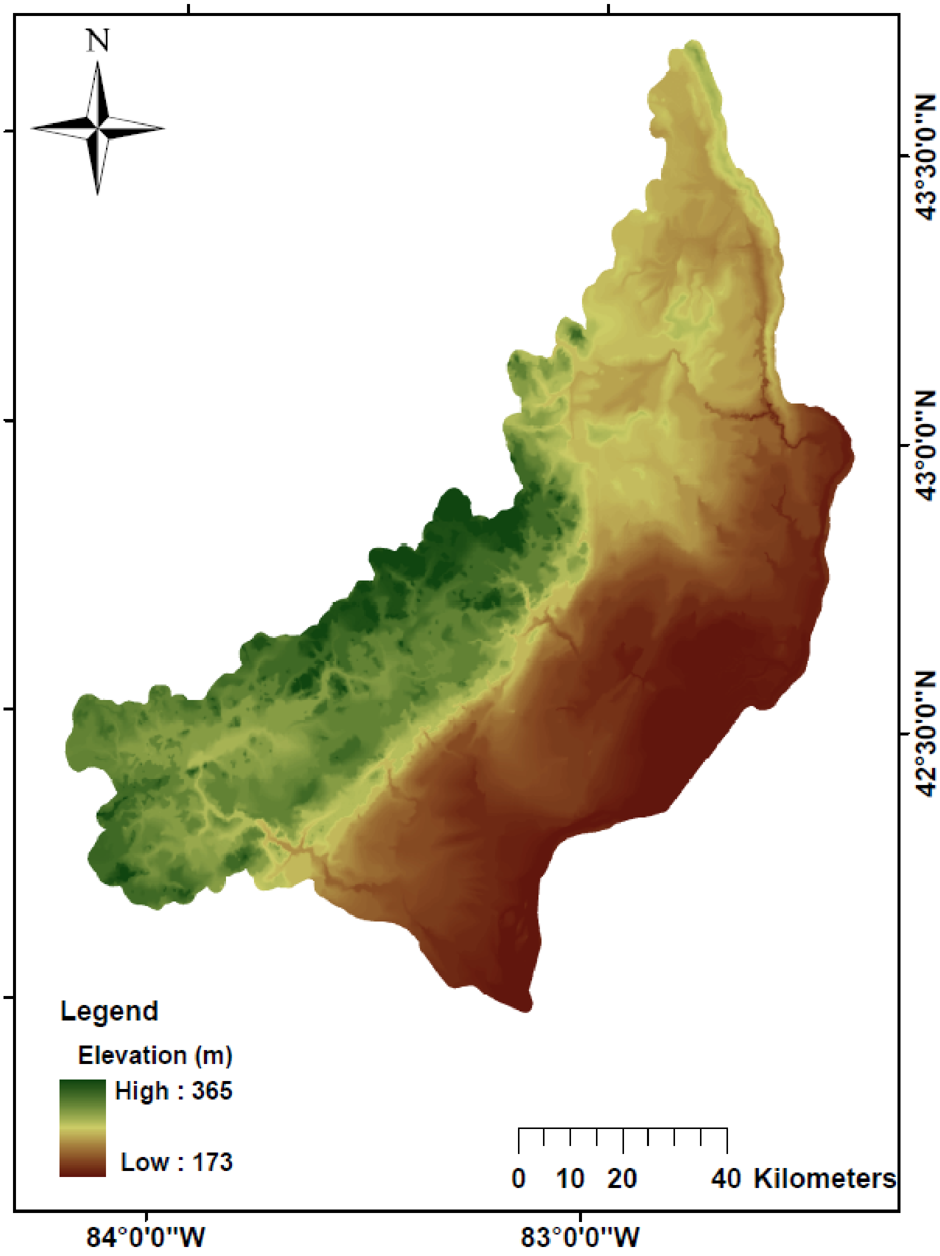


Figure 1. Relief map of the Detroit Basin

2.0 River Network

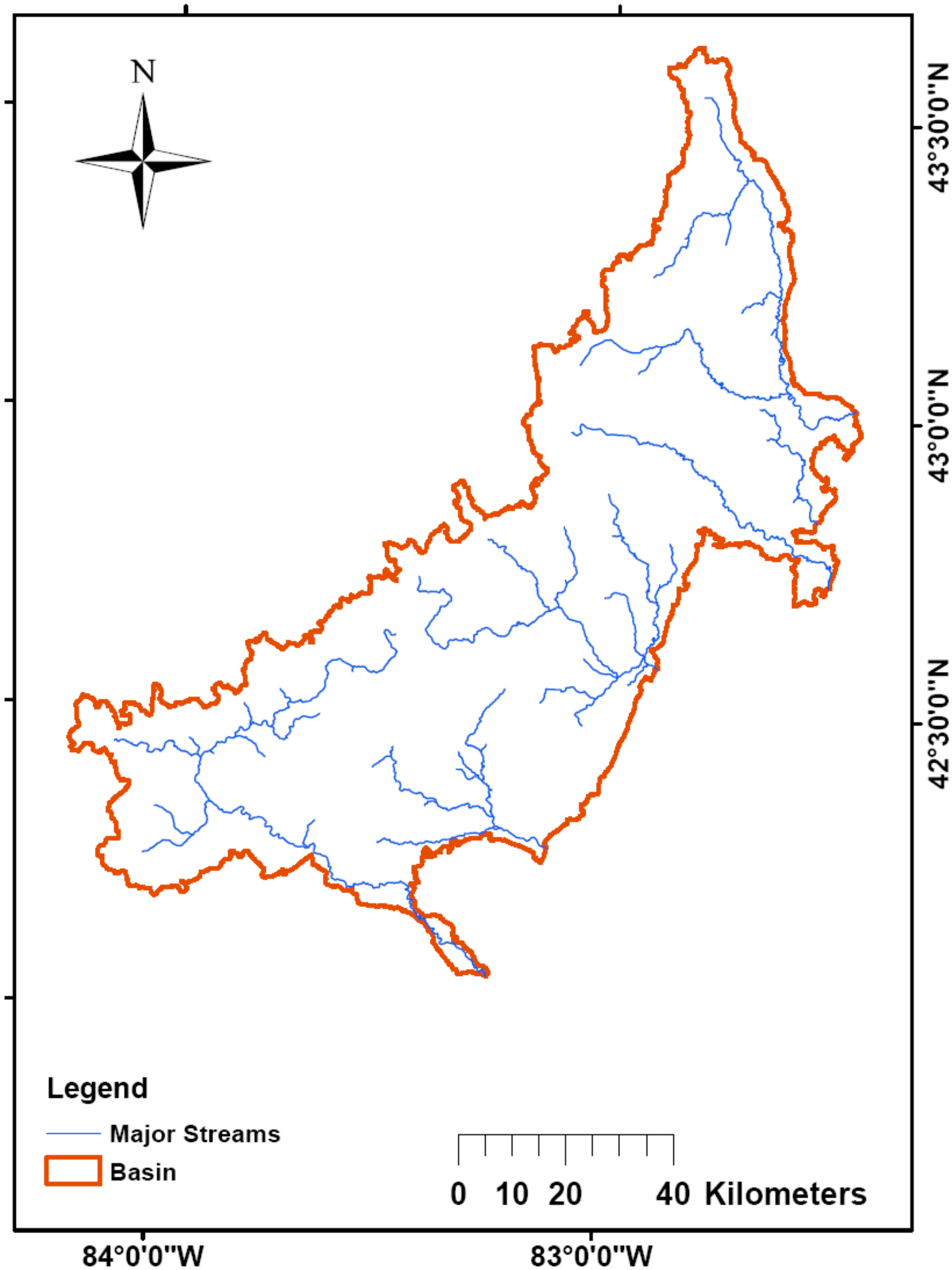


Figure 2. Major streams of the Detroit Basin

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, urban land in the Detroit Basin Watershed is the predominant land usage, covering 38 percent of land area. Agriculture covers 33 percent of the land area. Forest, wetlands, range, and water constitute the remaining 29 percent of land cover (Tables 1a and 1b). In the Detroit Basin, agriculture dominates the northern area and urban land occupies a majority of the south in the Metro-Detroit area (Figure 3). Water, forest, and wetland scatter through the southwest portion of the watershed.

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

Landuse	Area (ha)	Percentage
Agricultural Land-Row Crops	185880.5	22.7
Forest-Deciduous	113904.1	13.9
Residential-Low Density	105420.8	12.9
Residential-Medium Density	103248.6	12.6
Hay	84827.04	10.4
Residential-High Density	73240.24	9.0
Wetlands-Forested	67593.02	8.3
Industrial	30025.68	3.7
Range-Grasses	16111.1	2.0
Water	15888.88	1.9
Wetlands-Non-Forested	8174.996	1.0
Forest-Mixed	5645.136	0.7
Forest-Evergreen	3943.054	0.5
Range-Other	2518.054	0.3
Range-Brush	1881.944	0.2

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

Urban	38.1%
Agriculture	33.1%
Forest	15.1%
Wetland	9.3%
Range	2.5%
Water	1.9%

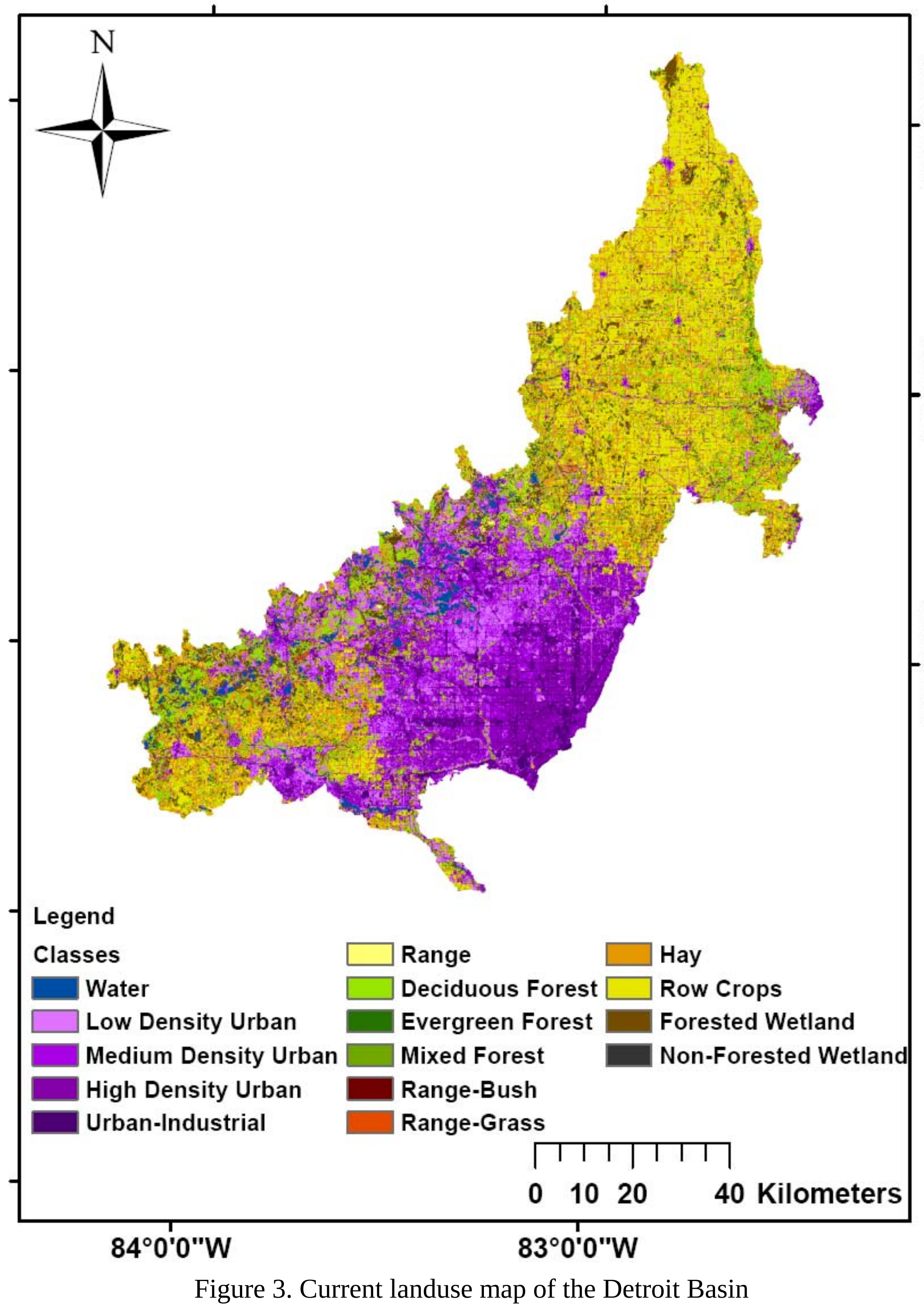


Figure 3. Current landuse map of the Detroit Basin

Based on the Landuse circa 1800 county base (LU1800), forest was the predominant land usage in the Detroit Basin covering 72 percent of land area. Wetlands covered 23 percent of the land area. Rangeland and water constitute the remaining 5 percent of land cover (Tables 2a and 2b). In the Detroit Basin, mixed forest and wetland dominates its northeast upland and deciduous forest dominates the southwest area (Figure 4). Rangeland scatter through the middle and southern sections.

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

Landuse	Area (ha)	Percentage
Forest-Mixed	349098.5	42.7
Forest-Deciduous	213325.6	26.1
Wetlands-Forested	141105.5	17.2
Wetlands-Non-Forested	46765.3	5.7
Range-Brush	29749.3	3.6
Forest-Evergreen	24708.3	3.0
Water	12608.3	1.5
Rye	886.8	0.1
Range-Grasses	20.8	0.0

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

Forest	71.8%
Wetland	23.0%
Rangeland	3.8%
Water	1.5%
Agriculture	0%
Urban	0%

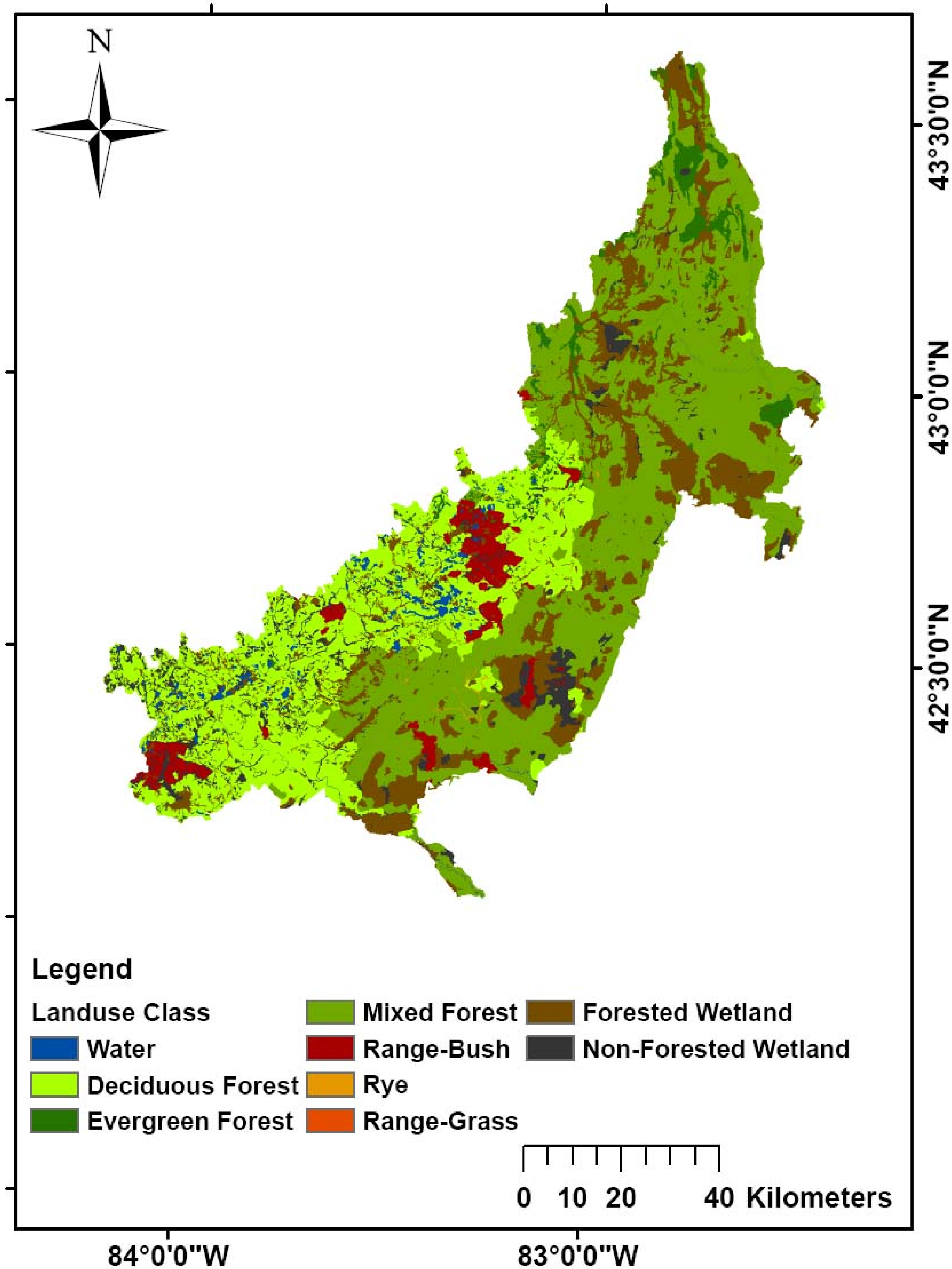


Figure 4. Pre-Settlement landuse map of the Detroit Basin

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 Detroit Basin.

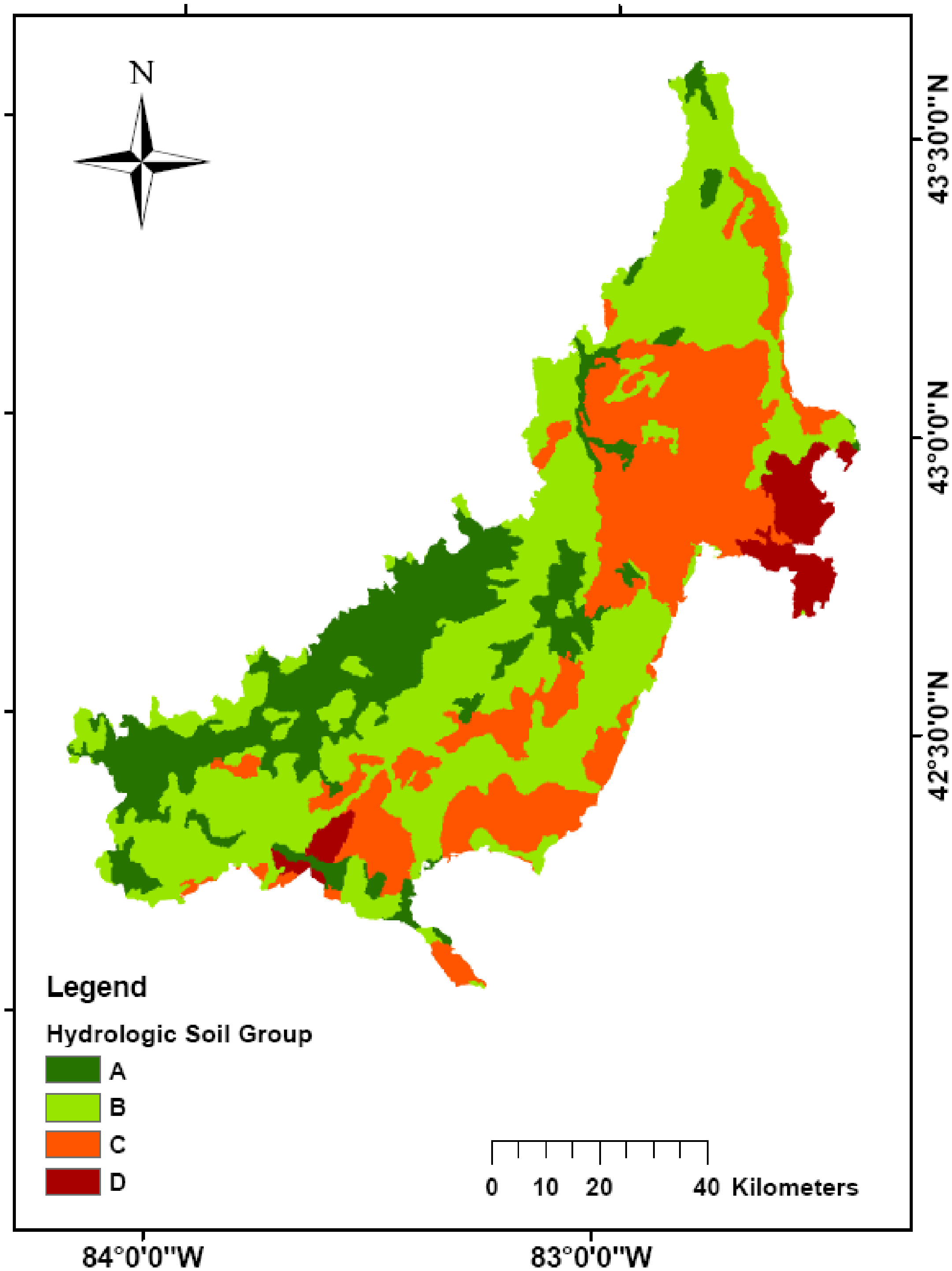


Figure 5. Hydrologic Soil Groups for the Detroit Basin

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.

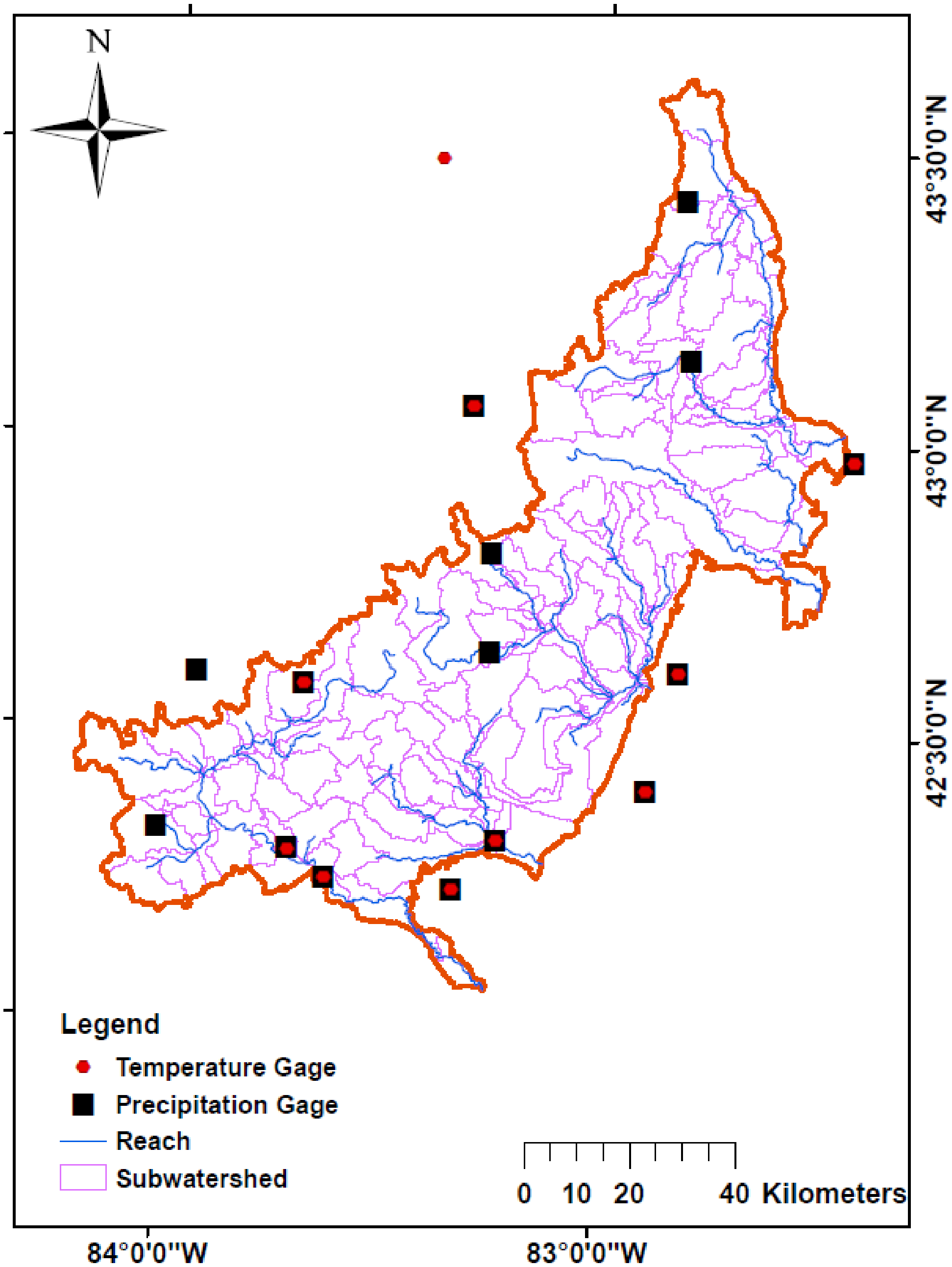


Figure 6. Temperature and precipitation gages in the Detroit Basin

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 149 subwatersheds. Figure 7 shows the boundary and the locations of subwatersheds in the Detroit basin.

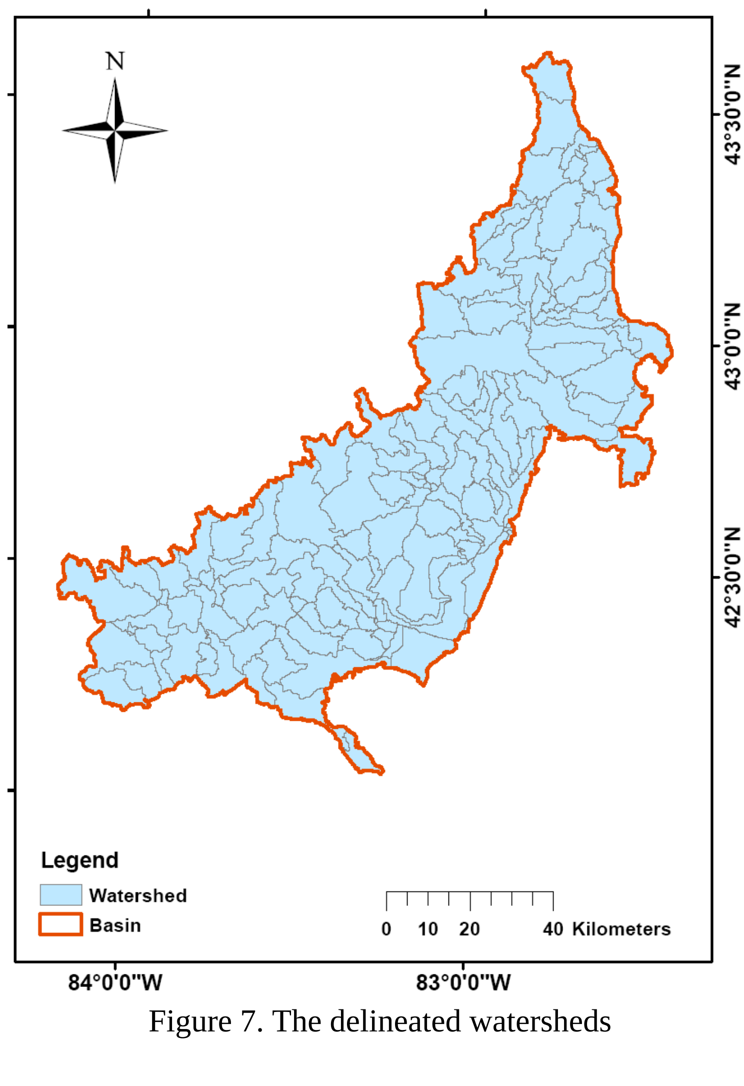


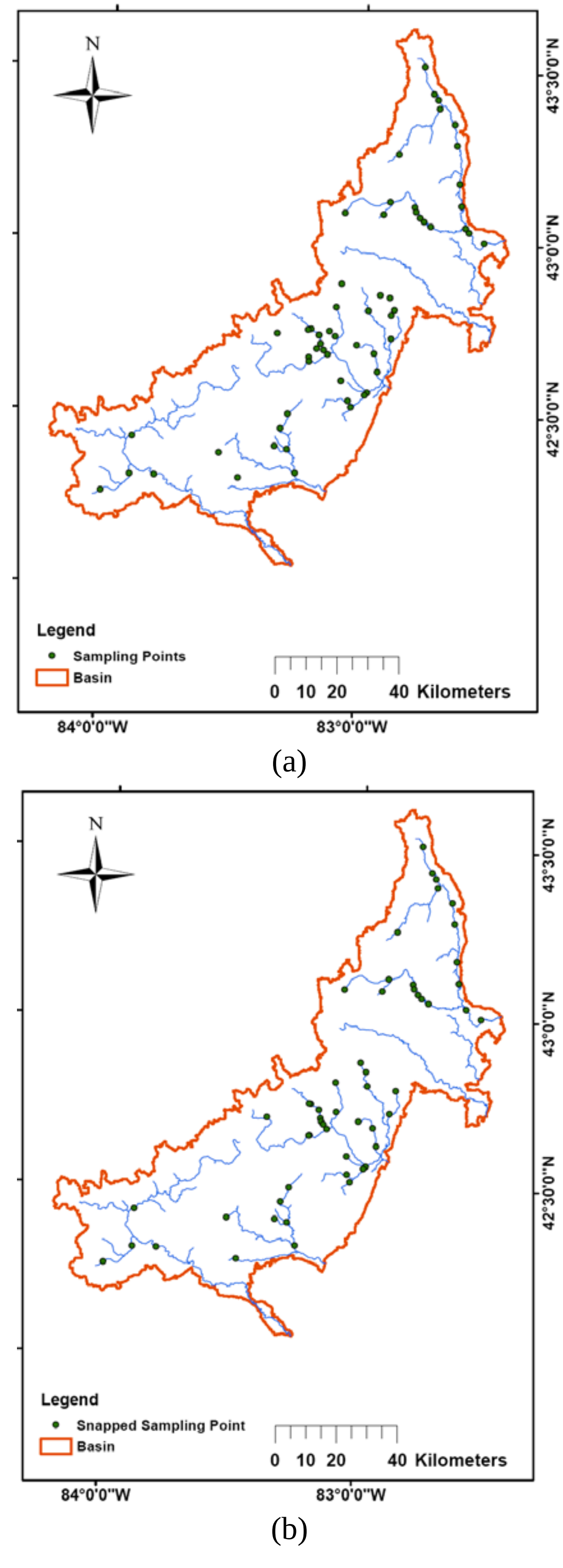
Figure 7. The delineated watersheds

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 subbasin 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	42.2653	-83.9999	1	42.2653	-83.9999
2	42.3125	-83.4666	2	42.3125	-83.4666
3	42.3153	-83.7931	3	42.3153	-83.7931
4	42.3155	-83.8892	4	42.3155	-83.8892
5	42.3302	-83.2445	5	42.3302	-83.2445
6	42.3837	-83.5434	6	42.3837	-83.5434
7	42.3983	-83.2787	7	42.3983	-83.2787
8	42.4071	-83.3273	8	42.4071	-83.3273
9	42.4268	-83.884	9	42.4268	-83.8840
10	42.4587	-83.3054	10	42.4587	-83.3054
11	42.5013	-83.2783	11	42.5013	-83.2783
12	42.5252	-83.0328	12	42.5252	-83.0328
13	42.5432	-83.0451	13	42.5432	-83.0451
14	42.5607	-82.9799	14	42.5607	-82.9799
15	42.5678	-82.9703	15	42.5678	-82.9703
16	42.601	-83.0733	16	42.6010	-83.0733
17	42.601	-83.0733	17	42.6285	-82.9310
18	42.6285	-82.931	18	42.6558	-83.2001
19	42.6558	-83.2001	19	42.6673	-83.2007
20	42.6673	-83.2007	20	42.6768	-83.1280
21	42.6768	-83.128	21	42.6822	-82.9456
22	42.6822	-82.9456	22	42.6898	-83.1436
23	42.6898	-83.1436	23	42.6930	-83.1709
24	42.693	-83.1709	24	42.7061	-83.0143
25	42.7061	-83.0143	25	42.7080	-83.1556
26	42.708	-83.1556	26	42.7259	-82.8806
27	42.7259	-82.8806	27	42.7324	-83.1625
28	42.7304	-83.099	28	42.7349	-83.3268
29	42.7324	-83.1625	29	42.7452	-83.1225
30	42.7324	-83.1625	30	42.7473	-83.2057
31	42.7349	-83.3268	31	42.7502	-83.1943
32	42.7452	-83.1225	32	42.8060	-82.9705
33	42.7473	-83.2057	33	42.8148	-83.0976
34	42.7502	-83.1943	34	42.8448	-82.8875

35	42.7945	-82.8812	35	42.8520	-82.9256
36	42.806	-82.9705	36	42.8833	-83.0782
37	42.8094	-82.8691	37	43.0083	-82.5213
38	42.8148	-83.0976	38	43.0378	-82.5812
39	42.8448	-82.8875	39	43.0537	-82.7328
40	42.852	-82.9256	40	43.0682	-82.7600
41	42.8833	-83.0782	41	43.0790	-82.7757
42	43.0083	-82.5213	42	43.0871	-82.9191
43	43.0378	-82.5812	43	43.0893	-83.0713
44	43.0505	-82.5954	44	43.0960	-82.7921
45	43.0505	-82.5954	45	43.1093	-82.7975
46	43.0537	-82.7328	46	43.1147	-82.6128
47	43.0682	-82.76	47	43.1234	-82.8939
48	43.079	-82.7757	48	43.1793	-82.6213
49	43.0871	-82.9191	49	43.2631	-82.8634
50	43.0893	-83.0713	50	43.2898	-82.6337
51	43.096	-82.7921	51	43.3521	-82.6447
52	43.1093	-82.7975	52	43.3968	-82.7053
53	43.1147	-82.6128	53	43.4224	-82.7117
54	43.1234	-82.8939	54	43.4398	-82.7295
55	43.1793	-82.6213	55	43.5183	-82.7678
56	43.2631	-82.8634	56		
57	43.2898	-82.6337	57		
58	43.3521	-82.6447	58		
59	43.3968	-82.7053	59		
60	43.4224	-82.7117	60		
61	43.4398	-82.7295	61		
62	43.5183	-82.7678	62		



(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 81 observations for each water quality constituent.

The most downstream USGS gaging station on the Clinton River (Station No. 04165500) was used to calibrate the model for flow (Figure 9). Water quality data were obtained from the EPA Storage and Retrieval (STORET) database for the Macomb station (500233) on the Clinton River (Figure 10). Since no flow data was available at the location of water quality observations, discharge from the USGS gage had to be extrapolated to the downstream STORET point.

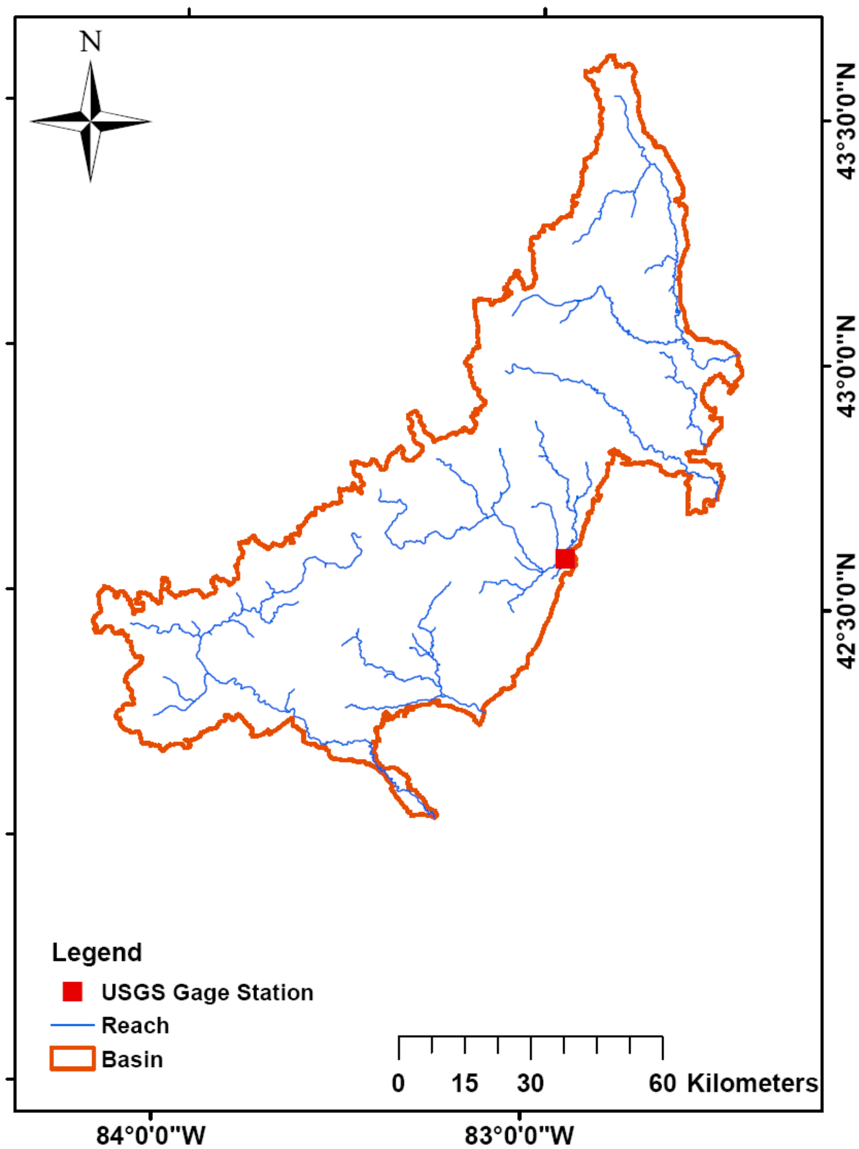


Figure 9. The delineated watersheds and selected USGS station.

In order to scale the flow data, the watershed was first calibrated using daily flow data, then the SWAT output was used to extrapolate the flow for the STORET water quality sample point. The scaled flow and daily water quality data were input to the USGS Load Estimator model (LOADEST) in order to generate monthly average values that were used in the final model calibration.

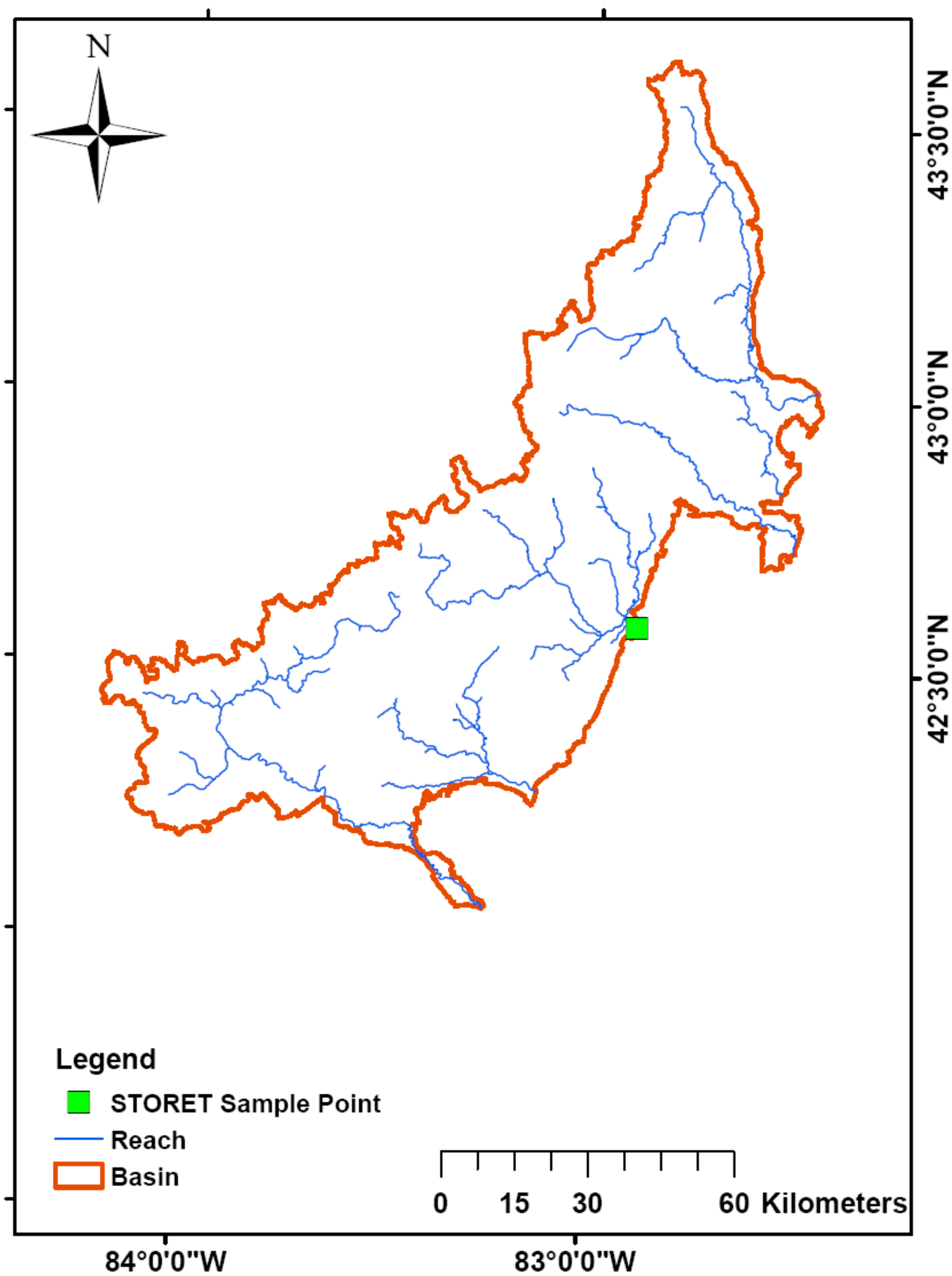


Figure 10. STORET sampling location used to calibrate water quality parameters

6.3 Model Calibration

In the first 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 is given in Table 4.

Table 4: Rank-Based Sensitivity Analysis*

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

The calibrated model has achieved excellent comparisons with observed flow, sediment, and total phosphorus and good comparison with total nitrogen.

Table 5. Statistics of model calibration

	Nash-Sutcliffe	RMSE	R^2
Flow	0.631	1.059	0.710
Total Suspended Solids (TSS)	0.721	14.543	0.733
Total N	0.573	276.566	0.658
Total P	0.789	25.034	0.830

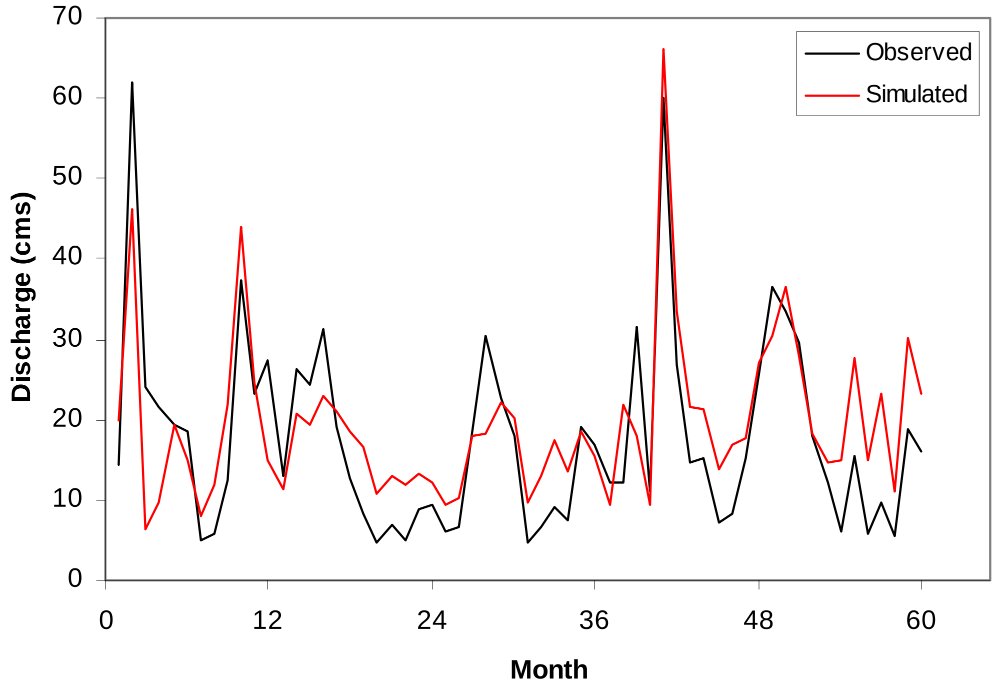


Figure 11. Model simulated results vs. scaled observed flow at STORET Station 500233

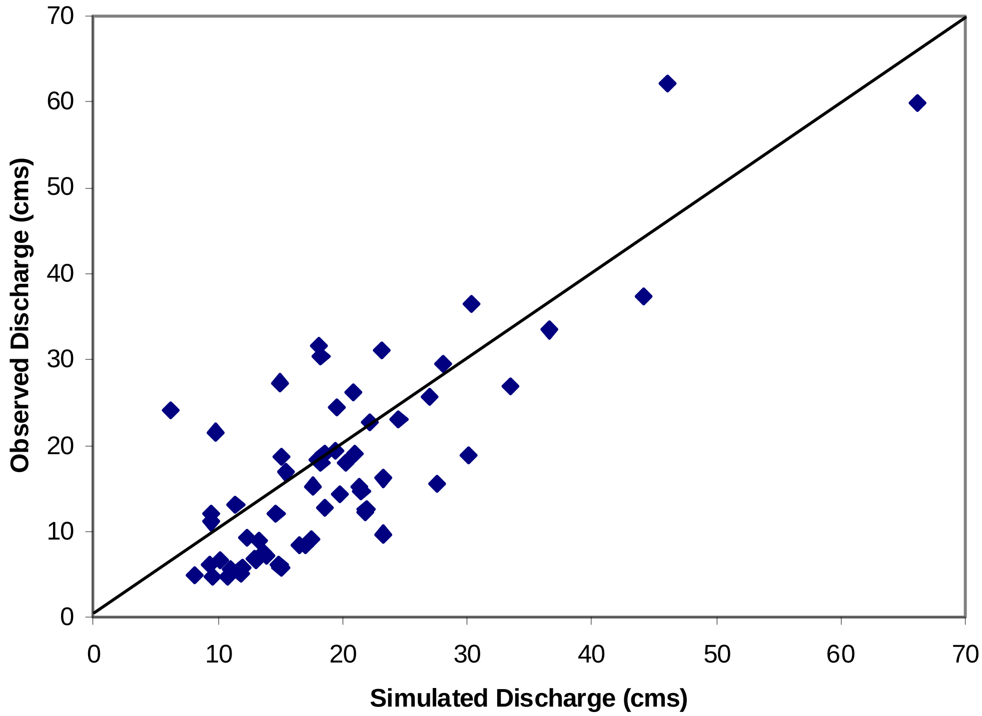


Figure 12. Simulated vs scaled observed flow at STORET Station 500233

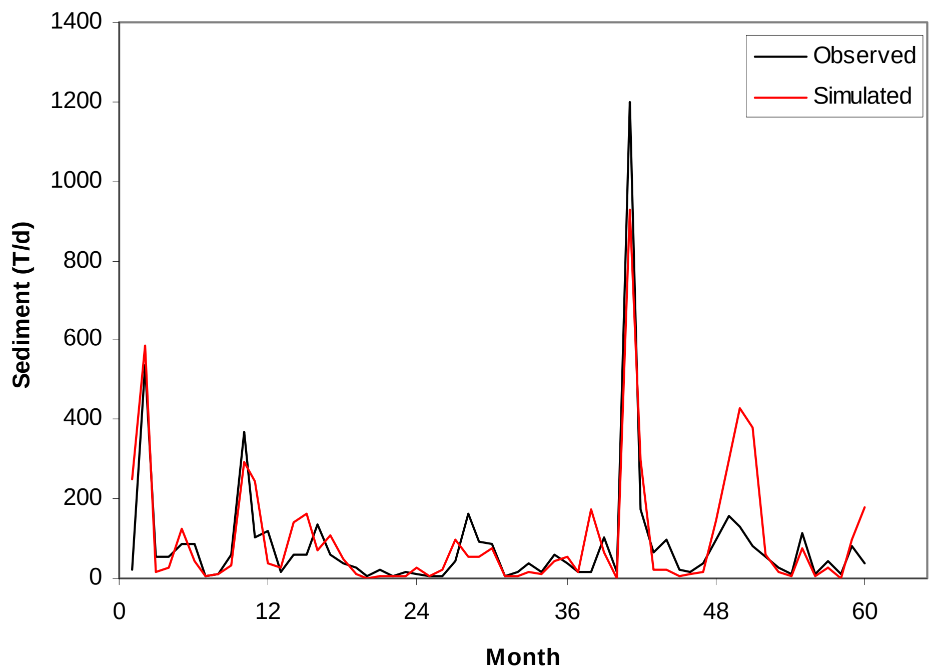


Figure 13. Time series of simulated vs observed TSS

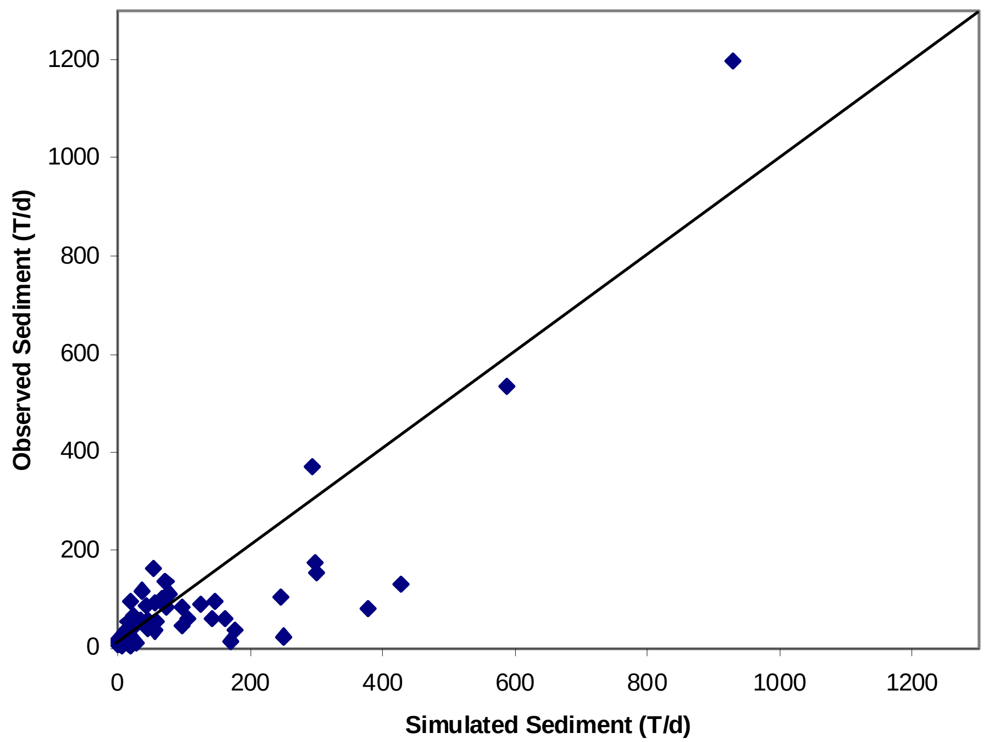


Figure 14. Simulated vs observed TSS

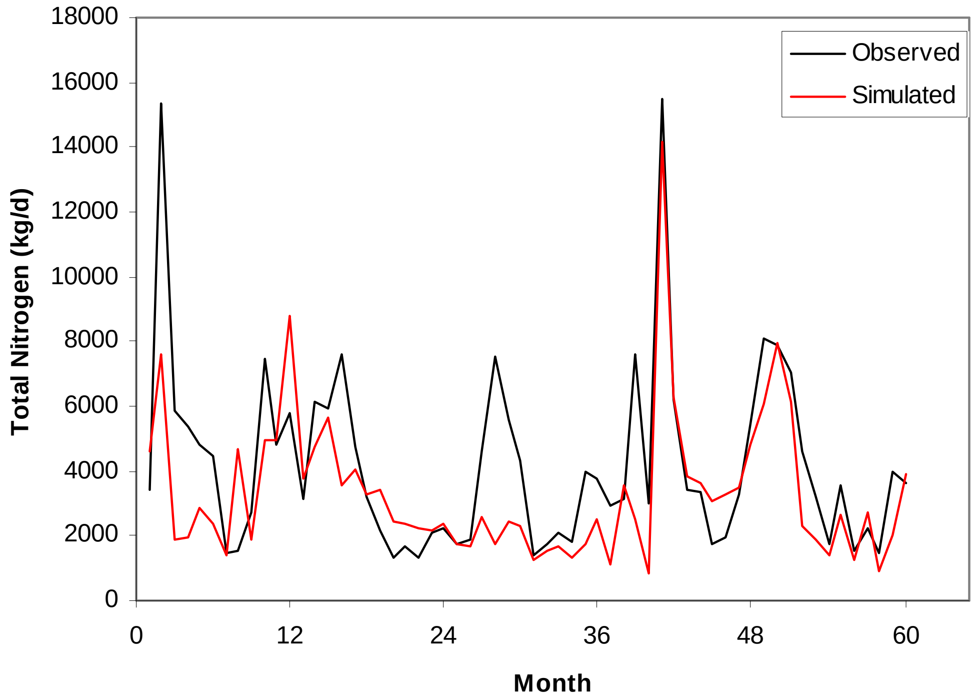


Figure 15. Time series of simulated vs observed Total Nitrogen

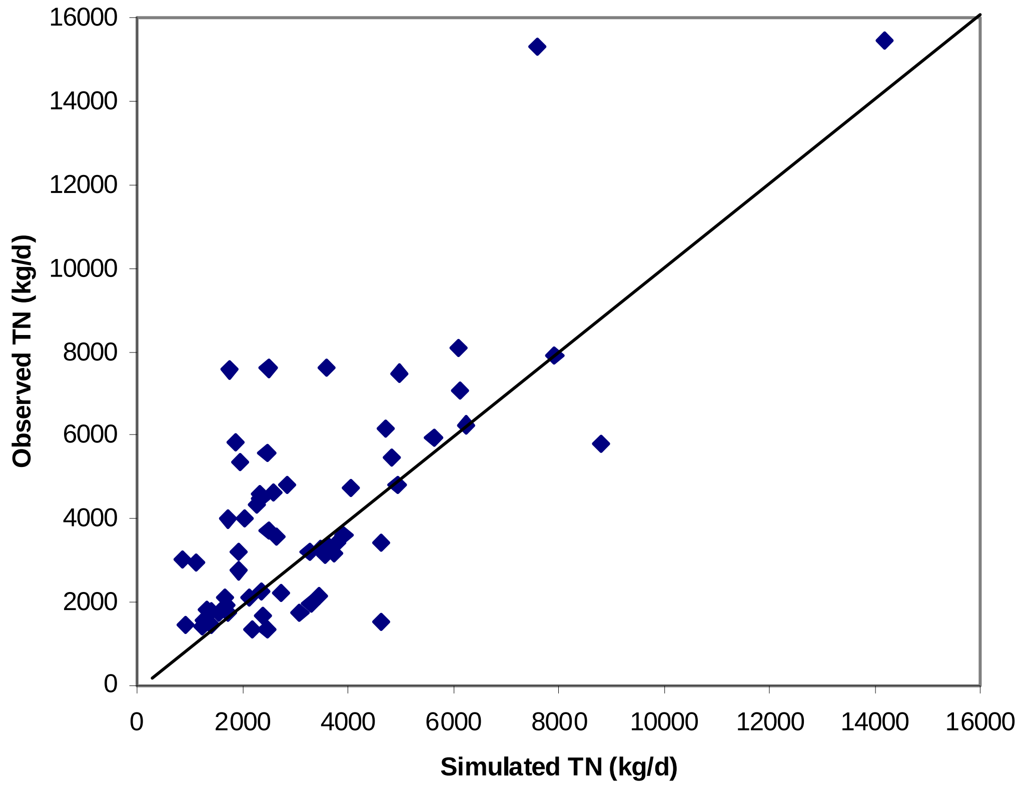


Figure 16. Simulated vs observed Total Nitrogen

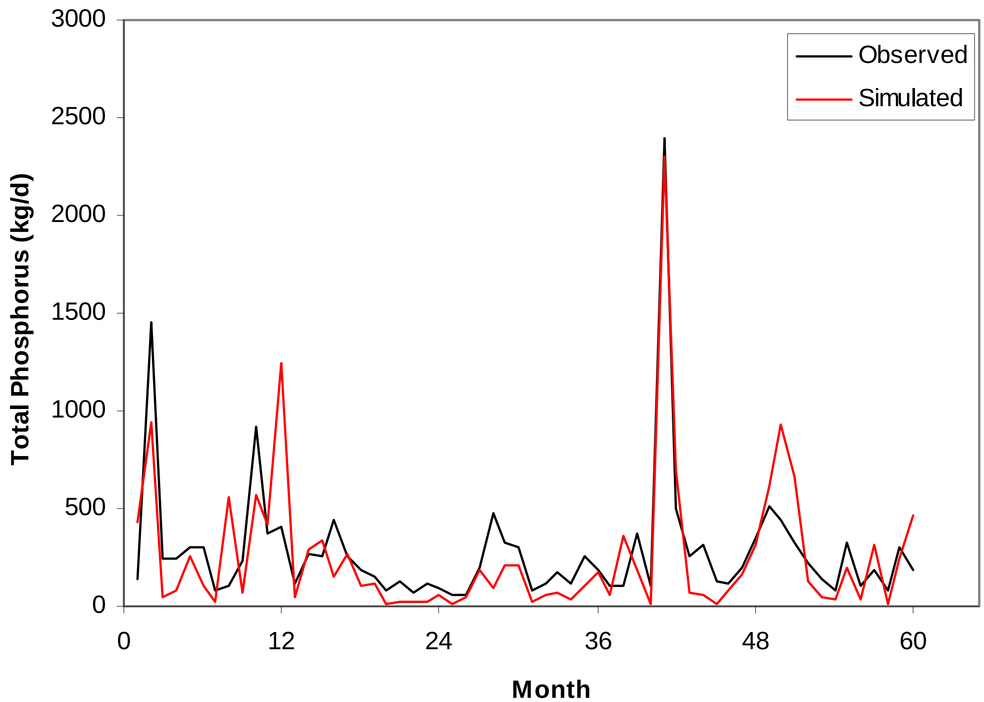


Figure 17. Time series of simulated vs. observed total phosphorus

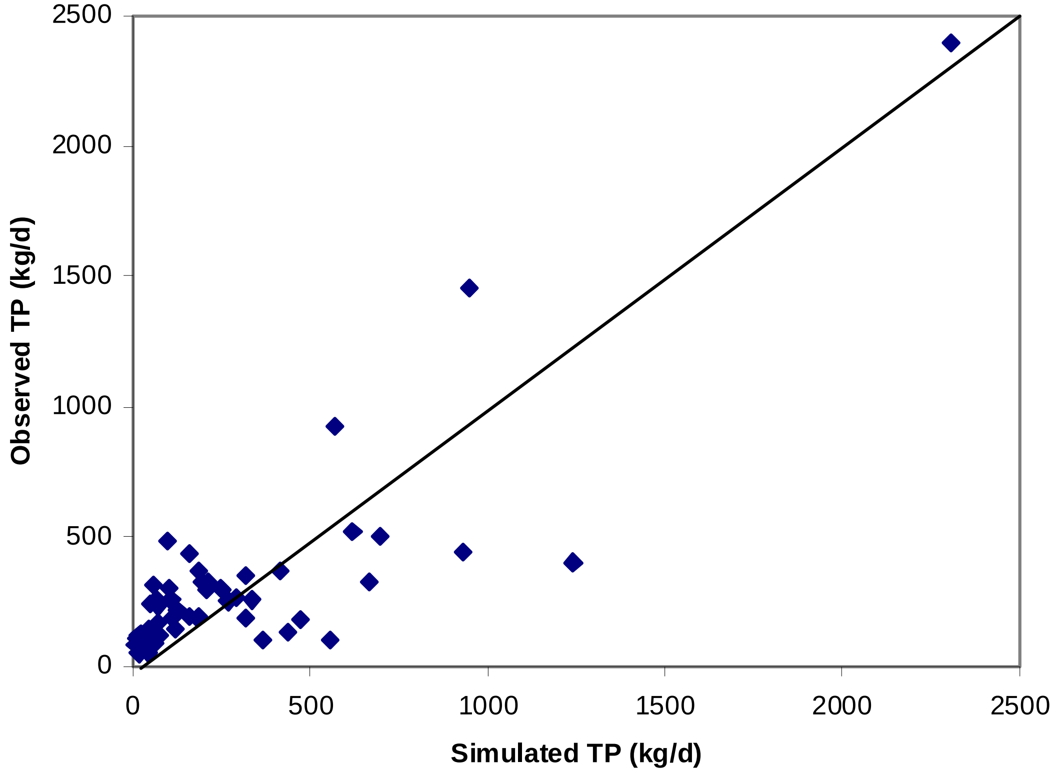


Figure 18. Simulated vs. observed total phosphorus

Table 6. Monthly and annual hydrologic budget for the Detroit 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	56.24	33.19	13.61	0.15	26.1	9.41	0.1	17.27
2	48.24	25.98	19	0.12	30.71	13.1	0.19	23.66
3	50.85	19	16.23	0.25	29	29.75	0.14	61.89
4	71.37	5.17	8.55	0.23	21.38	39.92	0.04	101.51
5	86.4	0	13.18	0.26	26.93	52.28	0.1	145.19
6	87	0	13.07	0.24	26.77	73.81	0.07	172.52
7	84.18	0	9.67	0.2	24.03	100.92	0.02	183.59
8	78.19	0	7.43	0.19	21.67	67.14	0.01	156.76
9	80.73	0	9.83	0.19	23.29	41.97	0.02	123.54
10	69.94	0.32	7.61	0.2	21.19	33.29	0.02	81.08
11	68.14	7.29	7.58	0.21	20.55	21.45	0.02	44.47
12	58.99	27.84	12.46	0.15	25.83	12.68	0.08	23.29
Annual Average	840.27	118.79	138.22	2.39	297.45	495.72	0.81	1134.77

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 19 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).

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

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

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 Detroit Basin

Calibrated	Current	Pre-Settlement	Percent Change	Percent Different
Recharge (mm)	195.81	284.13	-31.09%	-36.81%
Surface Runoff (mm)	134.70	57.64	133.70%	80.13%
Baseflow (mm)	159.74	236.37	-32.42%	-38.69%
Water Yield (mm)	296.81	296.62	0.07%	0.07%
Sediment Yield (t/ha)	0.81	0.06	1184.24%	171.10%
Total N Output (t/ha)	12.09	1.72	601.33%	150.08%
Total P Output (t/ha)	0.72	0.03	2360.84%	184.38%

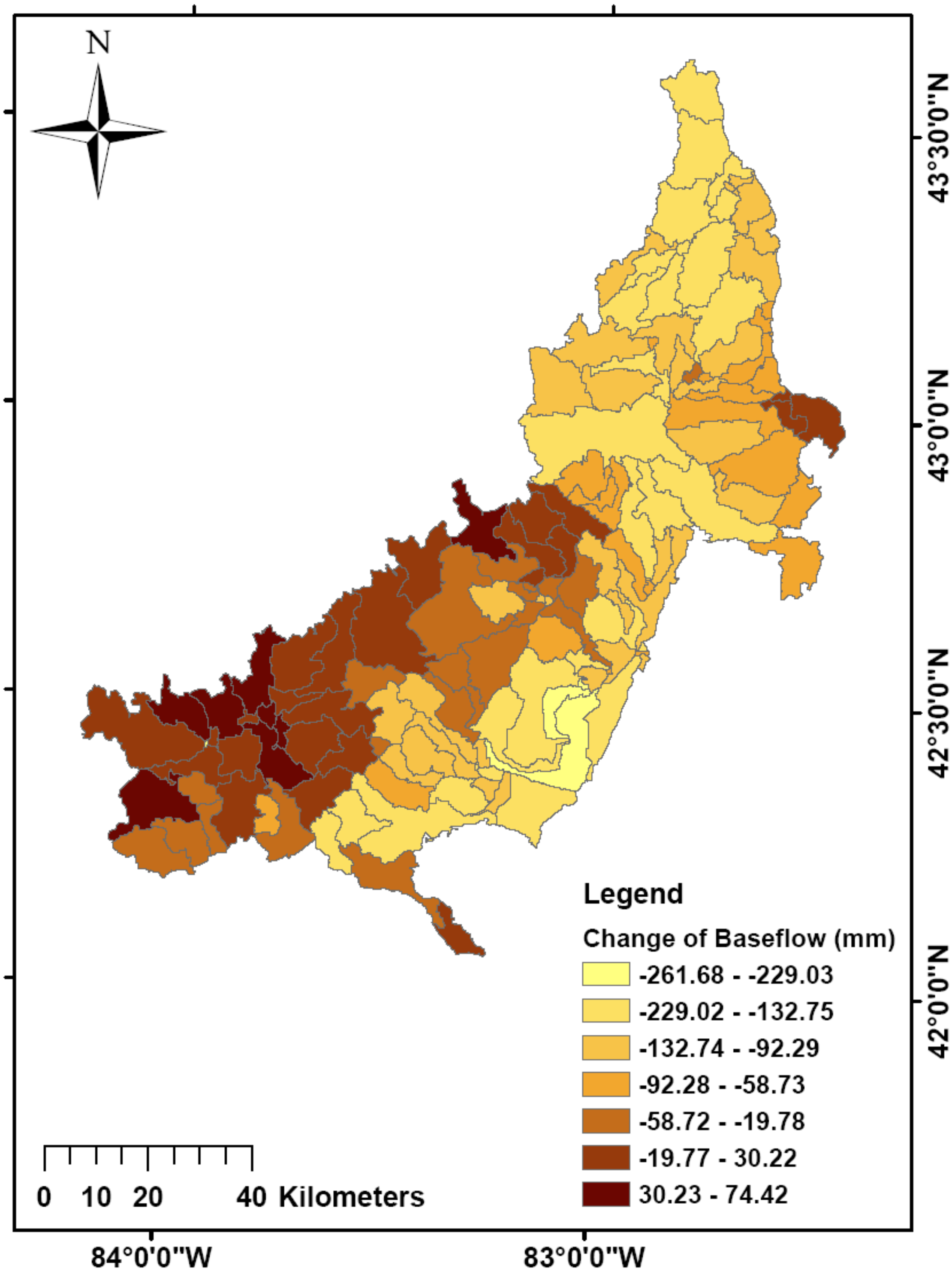


Figure 19. Change of baseflow values resulted from landuse changes (mm)

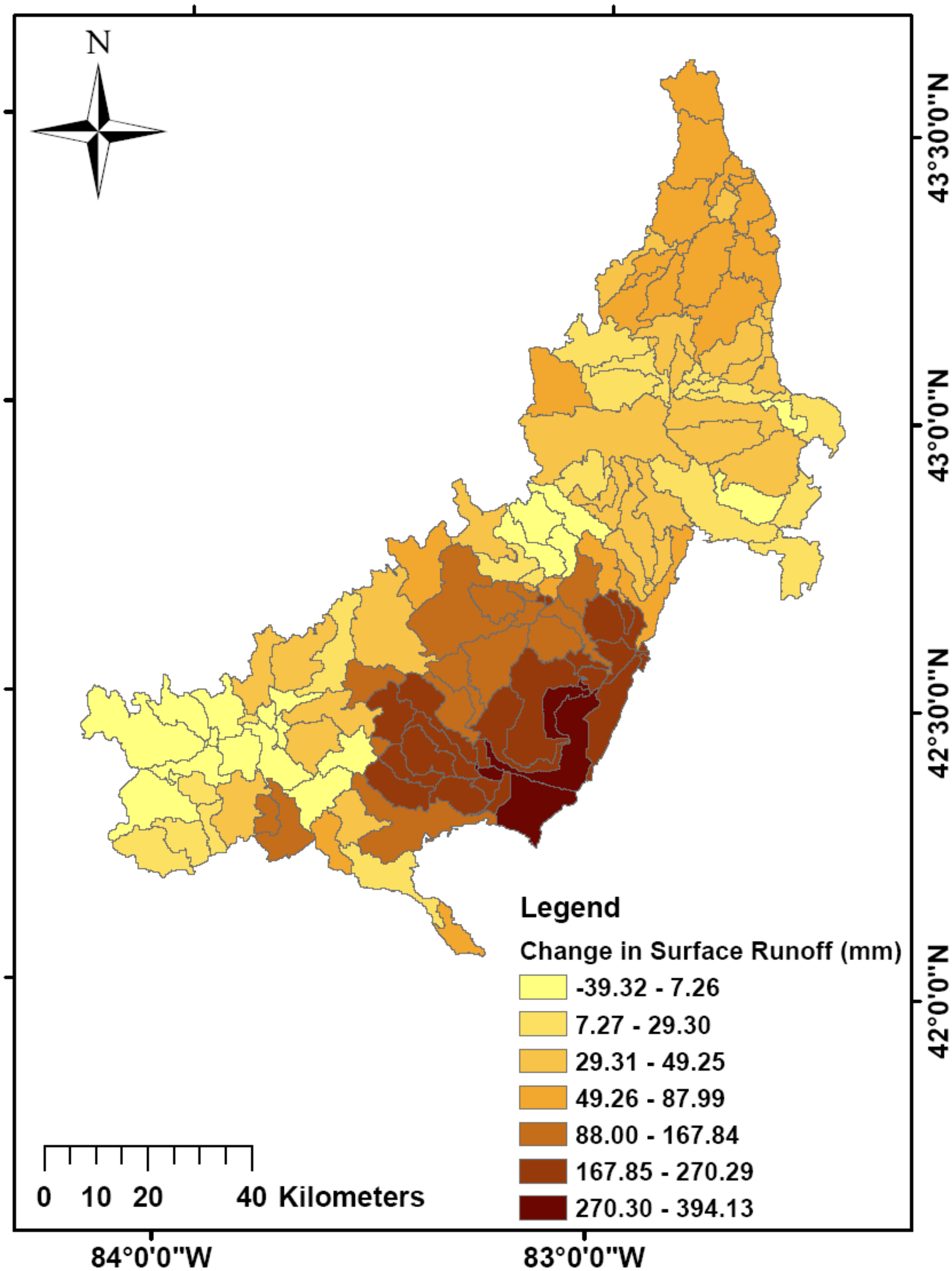


Figure 20. Change of surface runoff values resulted from landuse changes (mm)

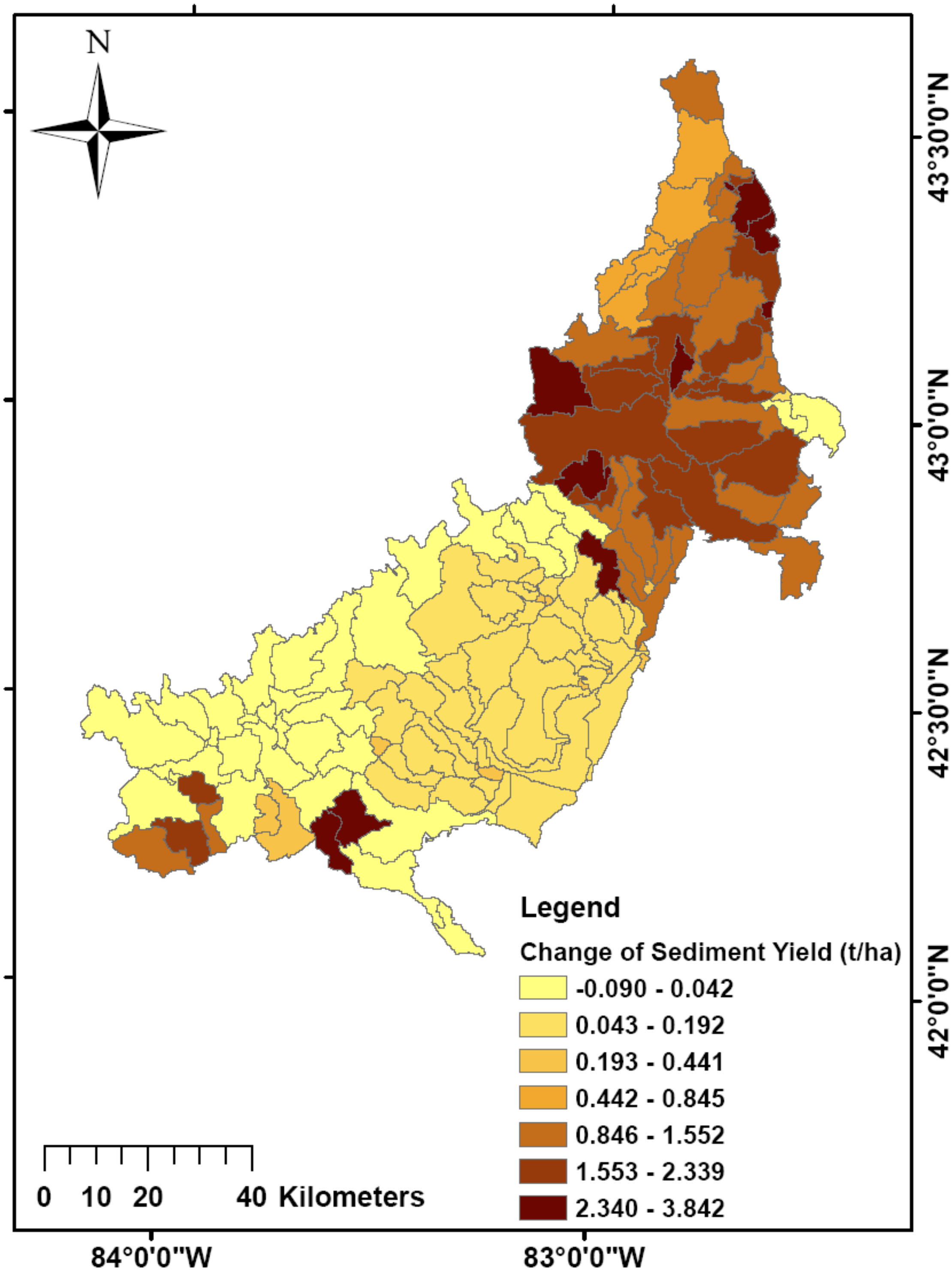


Figure 21. Change of sediment yields resulted from landuse changes (t/ha)

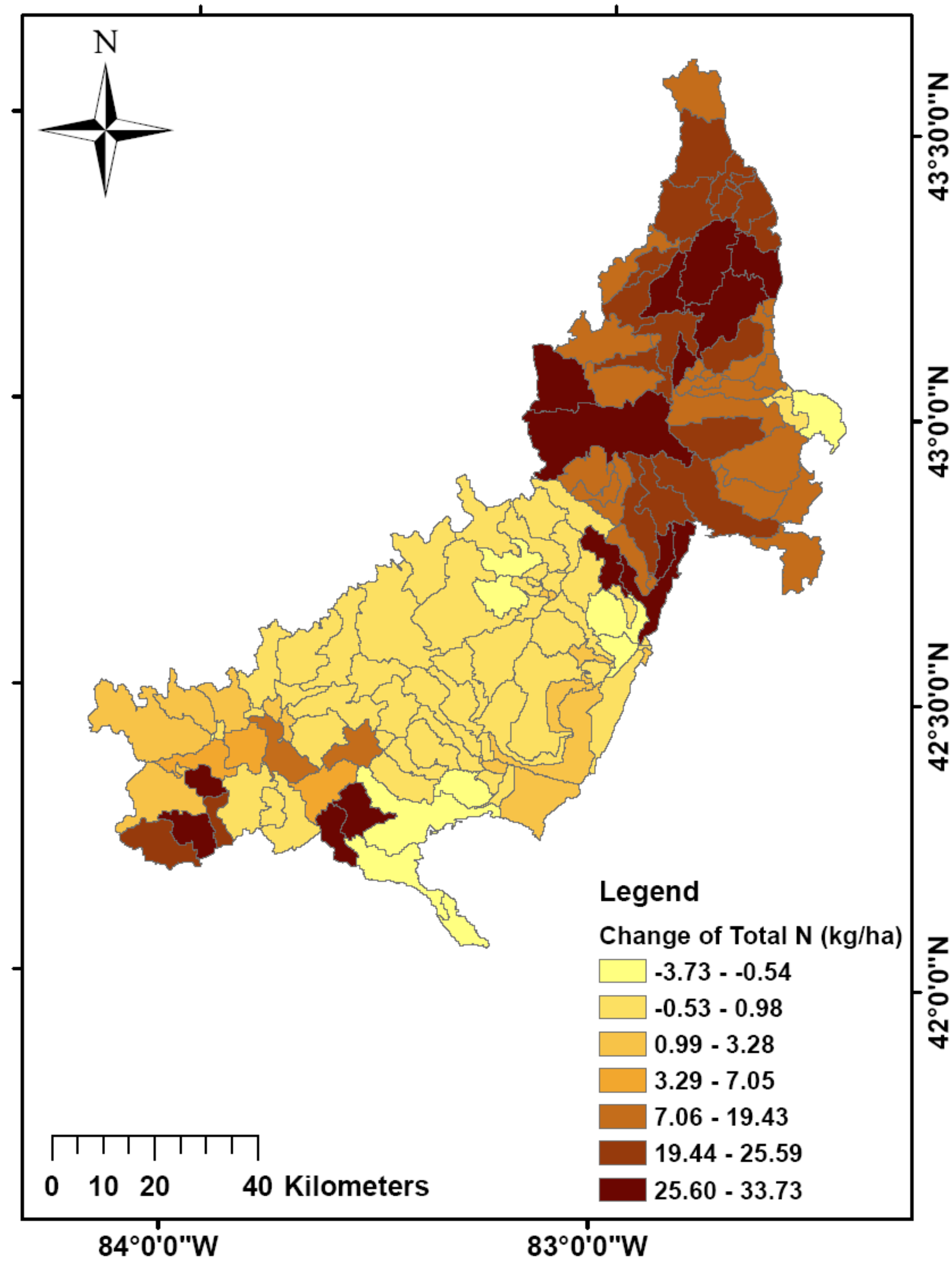


Figure 22. Change of total N output values resulted from landuse changes (kg/ha)

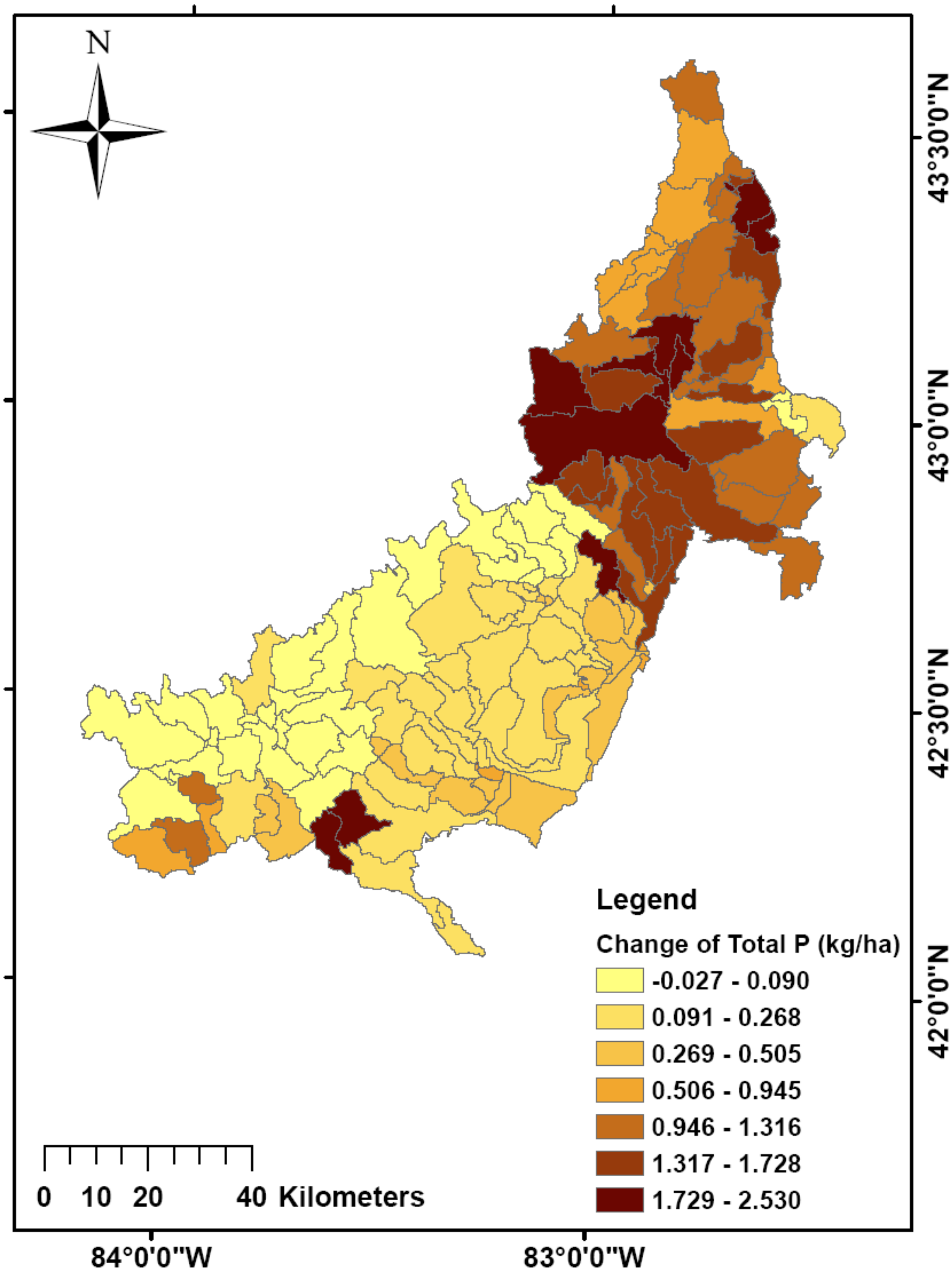


Figure 23. Change of total P output values resulted from landuse changes (kg/ha)

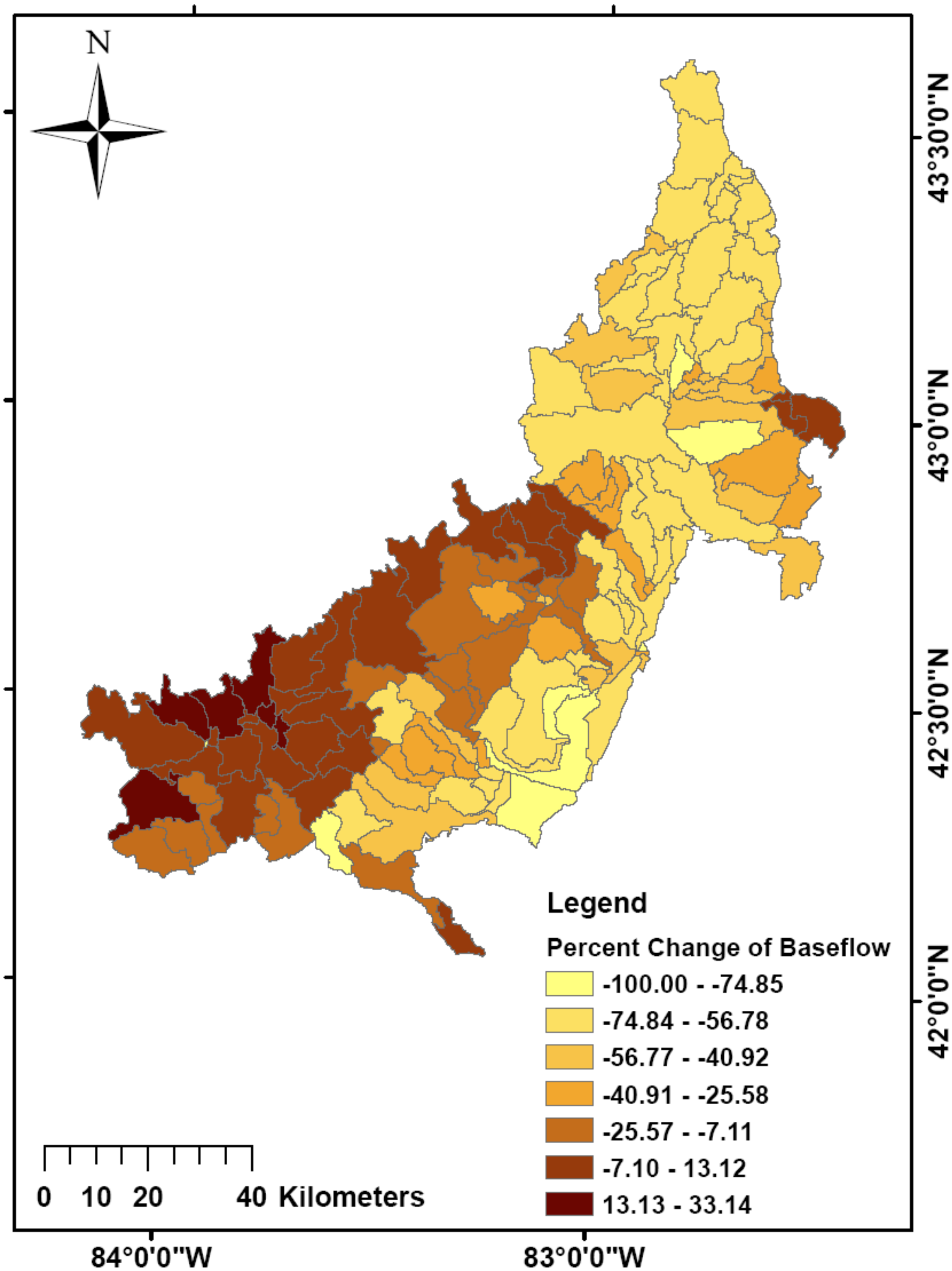


Figure 24. Percent change of baseflow values resulted from landuse changes

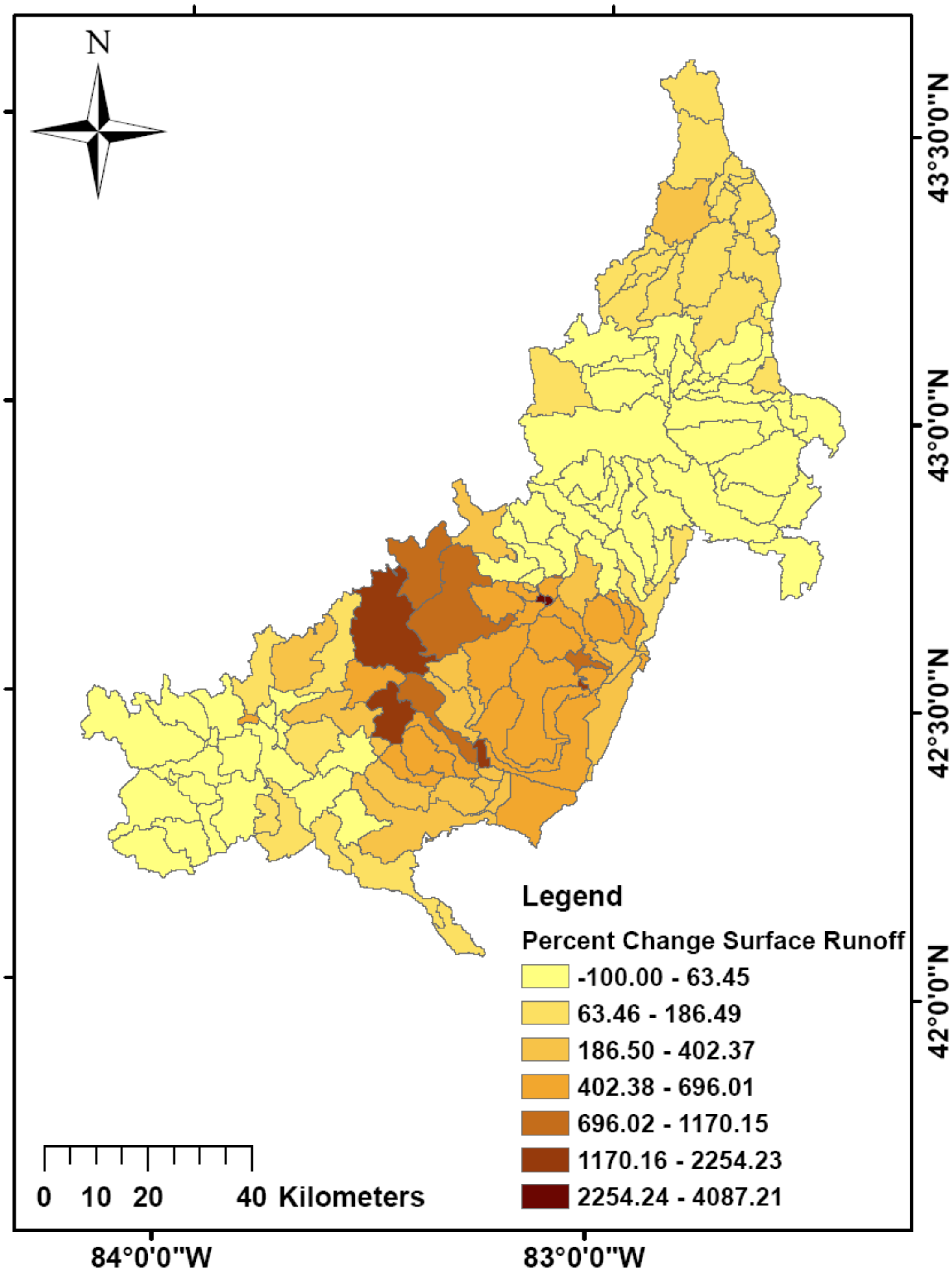


Figure 25. Percent change of surface runoff values resulted from landuse changes

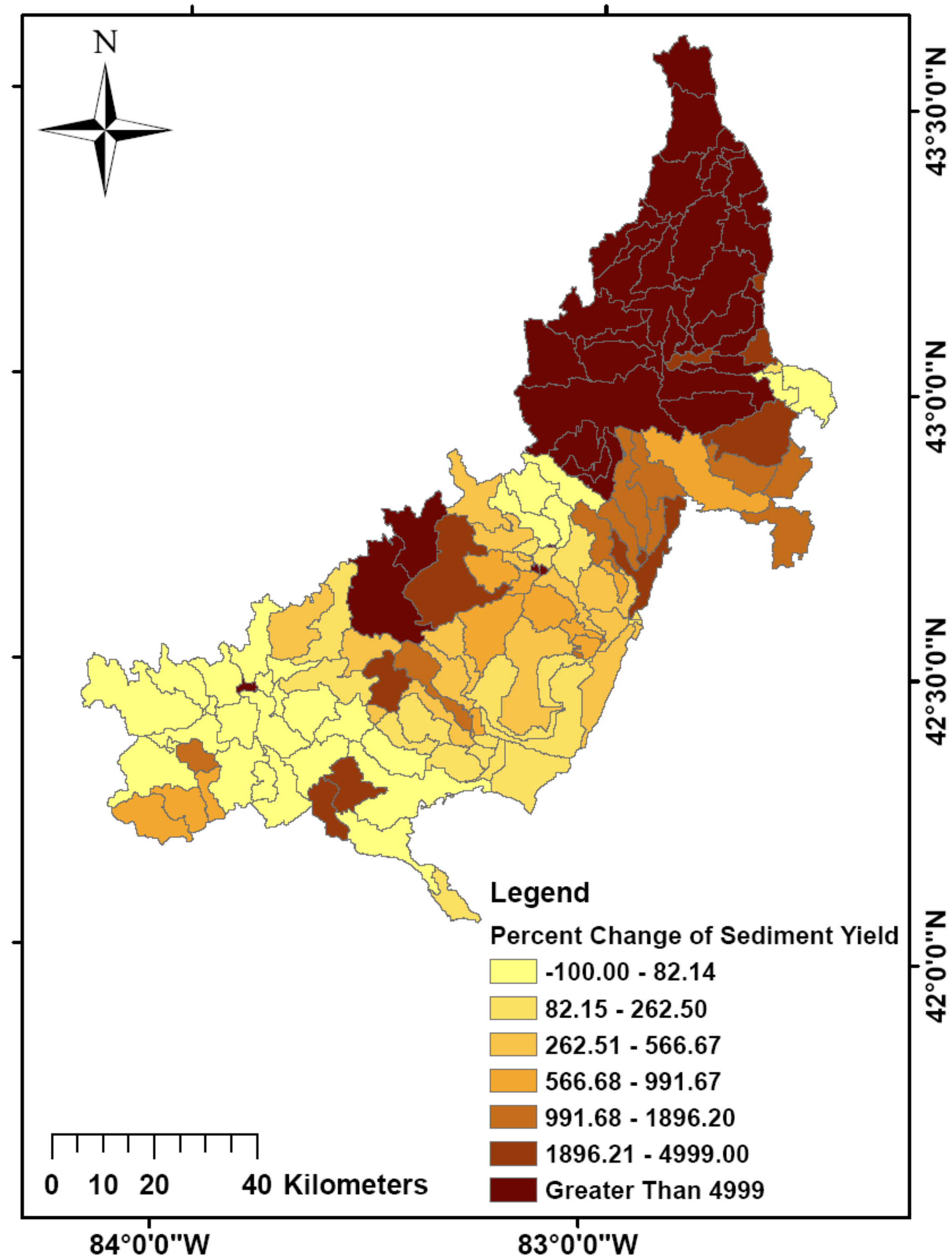


Figure 26. Percent change of sediment yield resulted from landuse changes

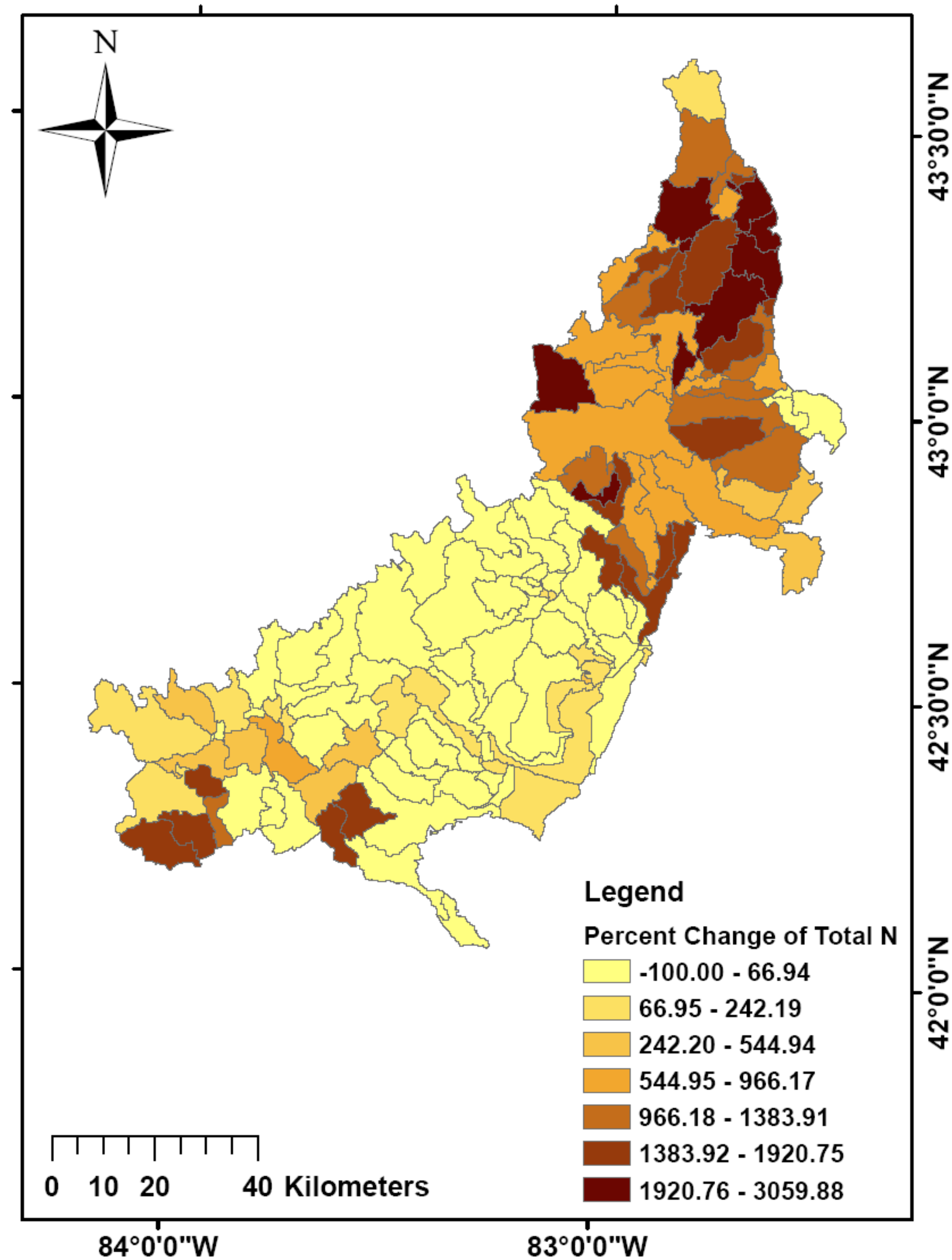


Figure 27. Percent change of total N output values resulted from landuse changes

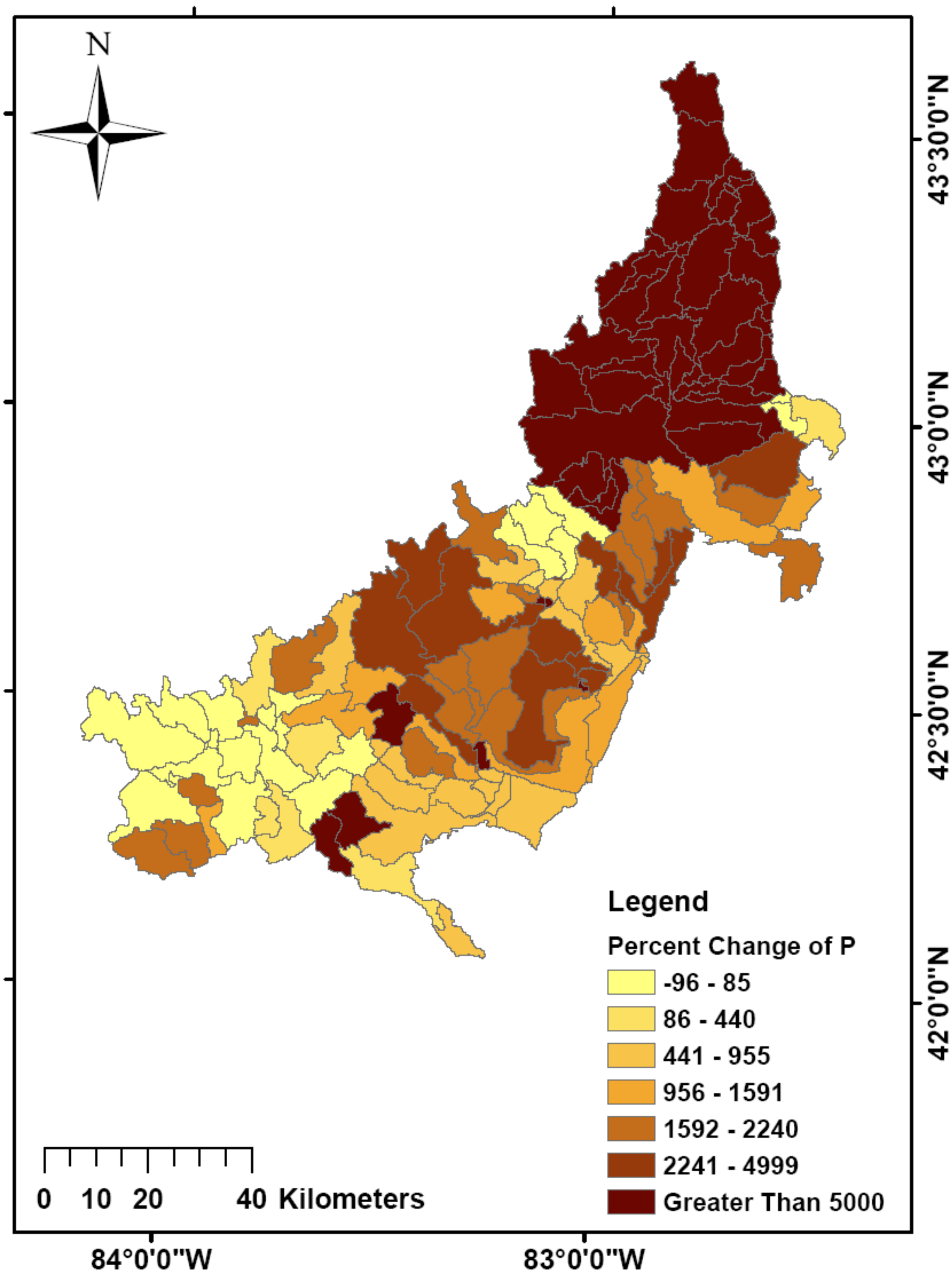


Figure 28. Percent change of total P output values resulted from landuse changes

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8.0 References

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