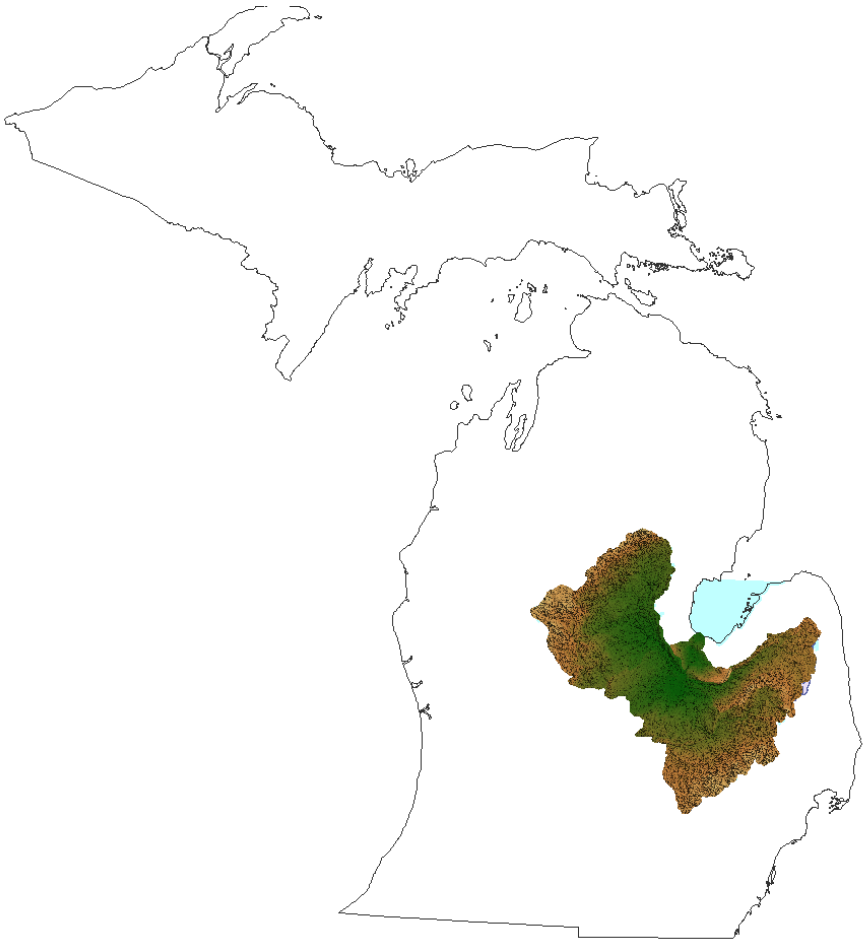
Effects of Historic and Current Land Covers on Water Budget and Water Quality in Agricultural Regions of Michigan and Wisconsin:

SWAT model Report 040802 (Saginaw Bay)



Brad Wardynski, Pouyan Nejadhashemi ©

1.0 General Information

The Saginaw Basin lies on the east edge of Michigan's Lower Peninsula. The basin, as the rest of the Peninsula, has a mild topography. The minimum elevation is 177m and the maximum elevation reads 457m with a mean of 242m. The catchment has a total area of 1.53 million hectares (or 3.77 million acres). The Saginaw River drains into Lake Huron with an annual average flow rate of 4322 cubic feet per second (cfs), or 122 cubic meters per second (cms). The relief map is shown in figure 1.

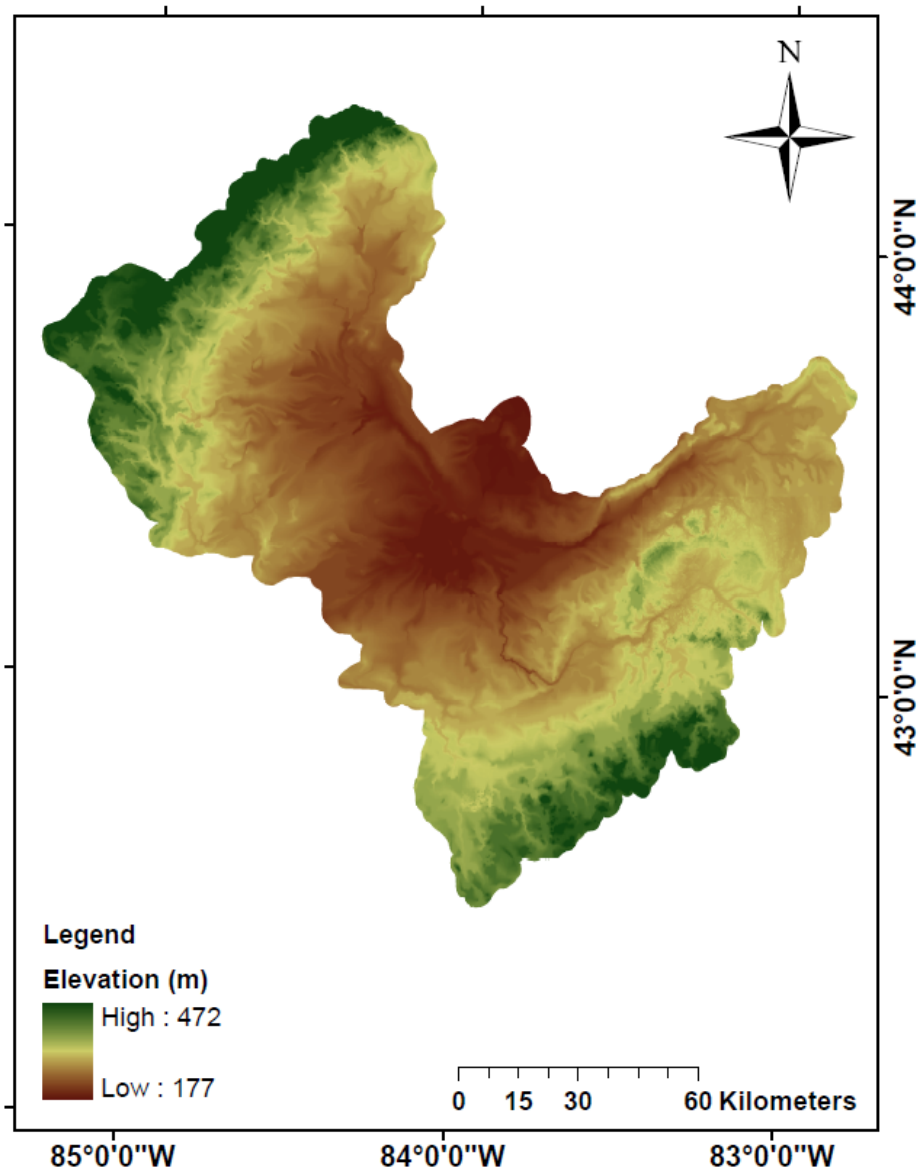


Figure 1. Relief map of the Saginaw Basin

2.0 River Network

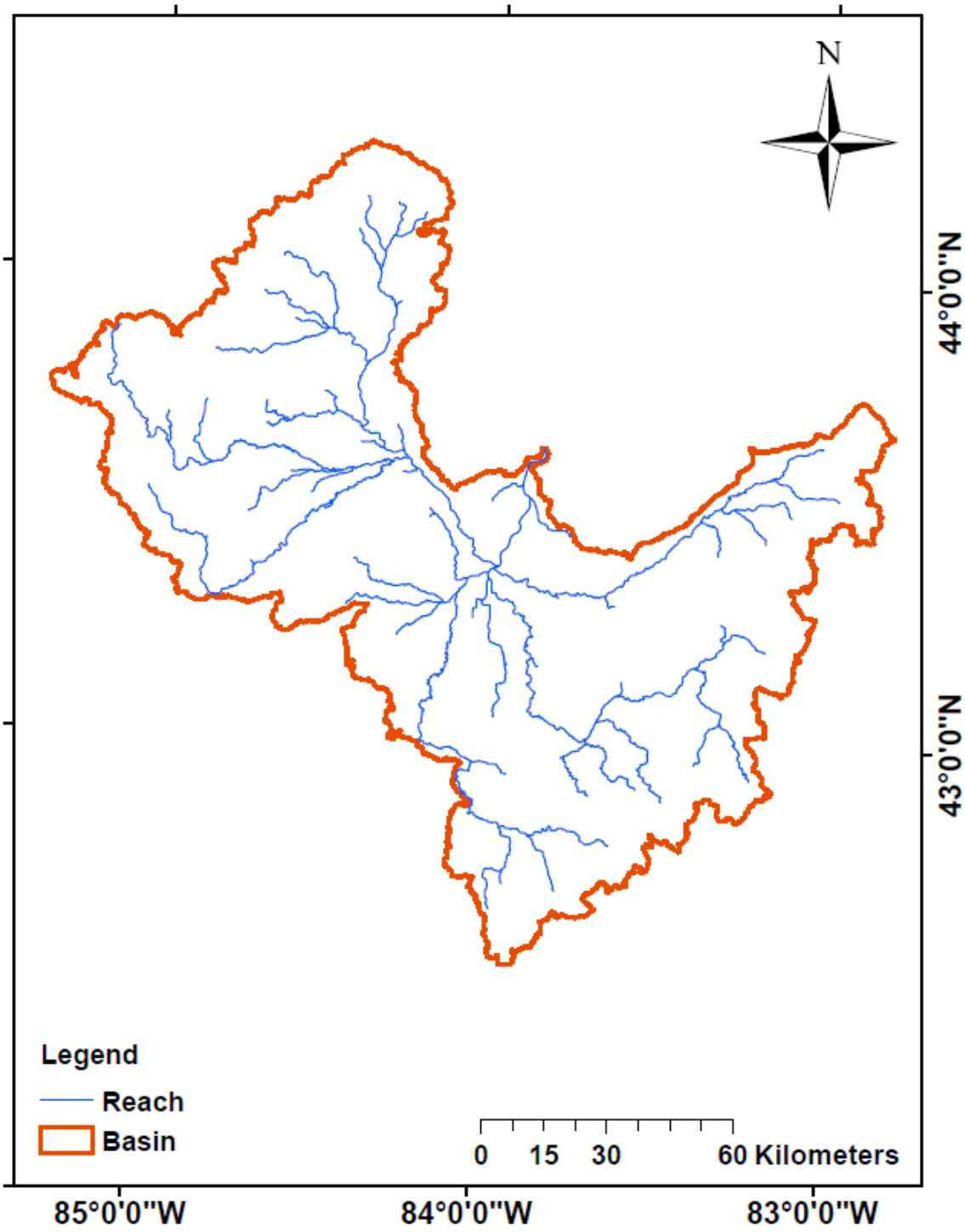


Figure 2. Major streams of the Saginaw Basin

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 Saginaw Basin Watershed is the predominant land usage covering 44 percent of land area. Forest covers 22 percent of the land area. Urban areas, wetlands, rangelands, and water constitute the remaining 34 percent of land cover (Tables 1a and 1b). In the Saginaw Basin, forest and wetland dominates its northeast upland and agricultural land occupies a majority of the middle plane and the west (Figure 3). Rangeland and hay farming scatter through the middle and southern section; and two urban centers are found in the basin.

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

LANDUSE:	hectare	percentage
Agricultural Land-Row Crops	473916.451	31.1%
Forest-Deciduous	295064.449	19.3%
Wetlands-Forested	203785.324	13.4%
Hay	197815.882	13.0%
Residential-Low Density	97482.5945	6.4%
Range-Grasses	72681.2169	4.8%
Residential-Medium Density	70567.329	4.6%
Forest-Evergreen	22020.1289	1.4%
Water	19974.2965	1.3%
Residential-High Density	19040.2691	1.2%
Wetlands-Non-Forested	16473.6036	1.1%
Forest-Mixed	13477.7716	0.9%
Range-Brush	12250.6889	0.8%
Industrial	7488.191	0.5%
Range-Other	4204.8592	0.3%

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

Agriculture	44.0%
Forest	21.7%
Urban	12.7%
Wetland	14.4%
Range	5.8%
Water	1.3%

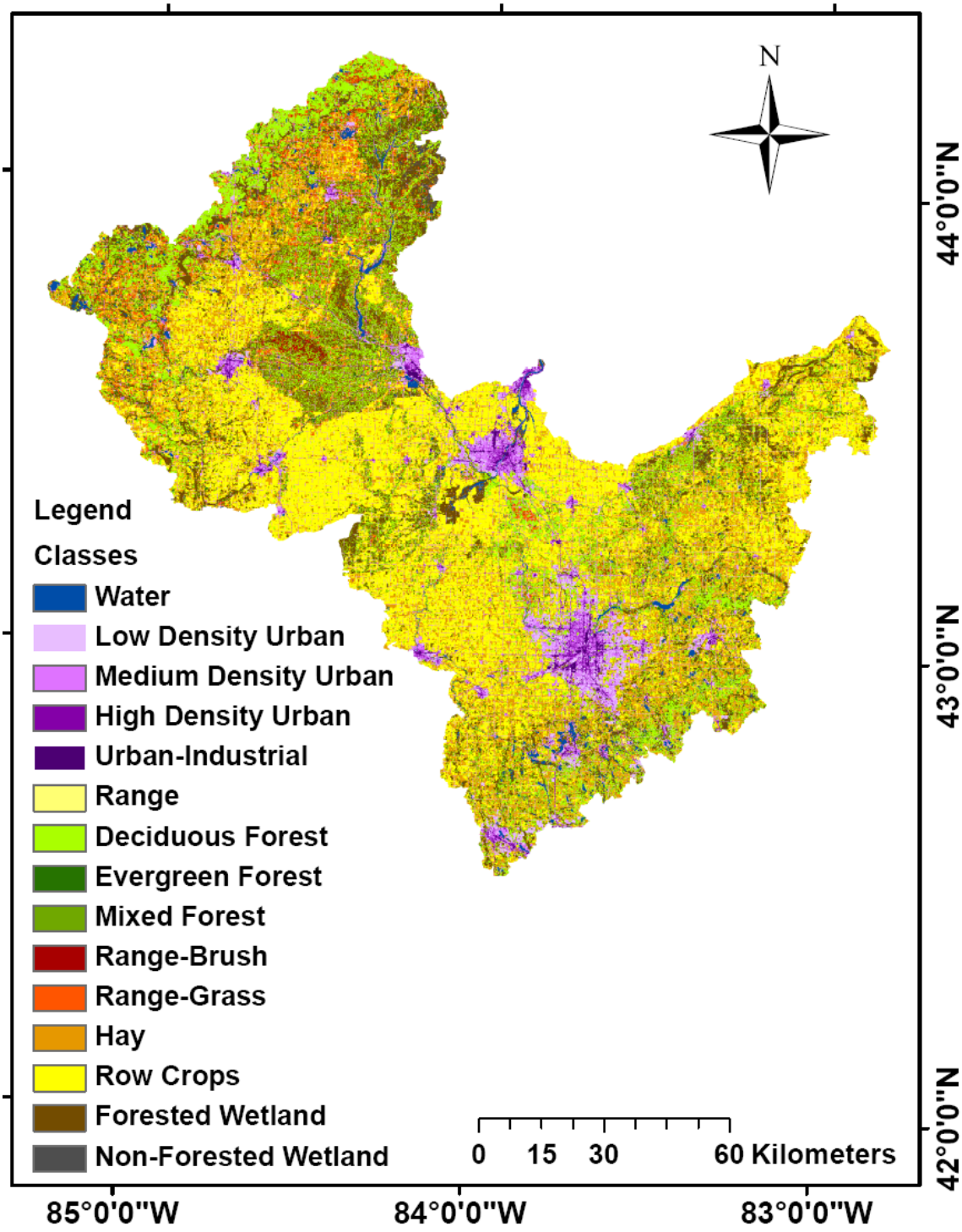


Figure 3. Current landuse map of the Saginaw Basin

Based on the Landuse circa 1800 county base (LU1800), mixed forested is the predominant land usage in the Saginaw Basin covering 59 percent of land area. Forested wetlands cover 14 percent of the land area. Evergreen and deciduous forests, wetlands, and water constitute the remaining 27 percent of land cover (Tables 2a and 2b). In the Saginaw Basin forest, and wetland dominates its northeast upland and agricultural land occupies a majority of the middle plane and the west (Figure 4). Rangeland and hay farming scatter through the middle and southern sections; and two urban centers are found in the basin.

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

Landuse	Area (ha)	Percentage
Forest-Mixed	900978.1	59.04%
Wetlands-Forested	207282.5	13.58%
Forest-Evergreen	190924.9	12.51%
Forest-Deciduous	158903.4	10.41%
Wetlands-Non-Forested	32175.68	2.11%
Range-Brush	23084.02	1.51%
Water	12215.27	0.80%
Range-Grasses	43.0555	0.03%

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

Forest	82.0%
Wetland	15.7%
Rangeland	1.5%
Water	0.8%
Urban	0.0%
Agriculture	0.0%

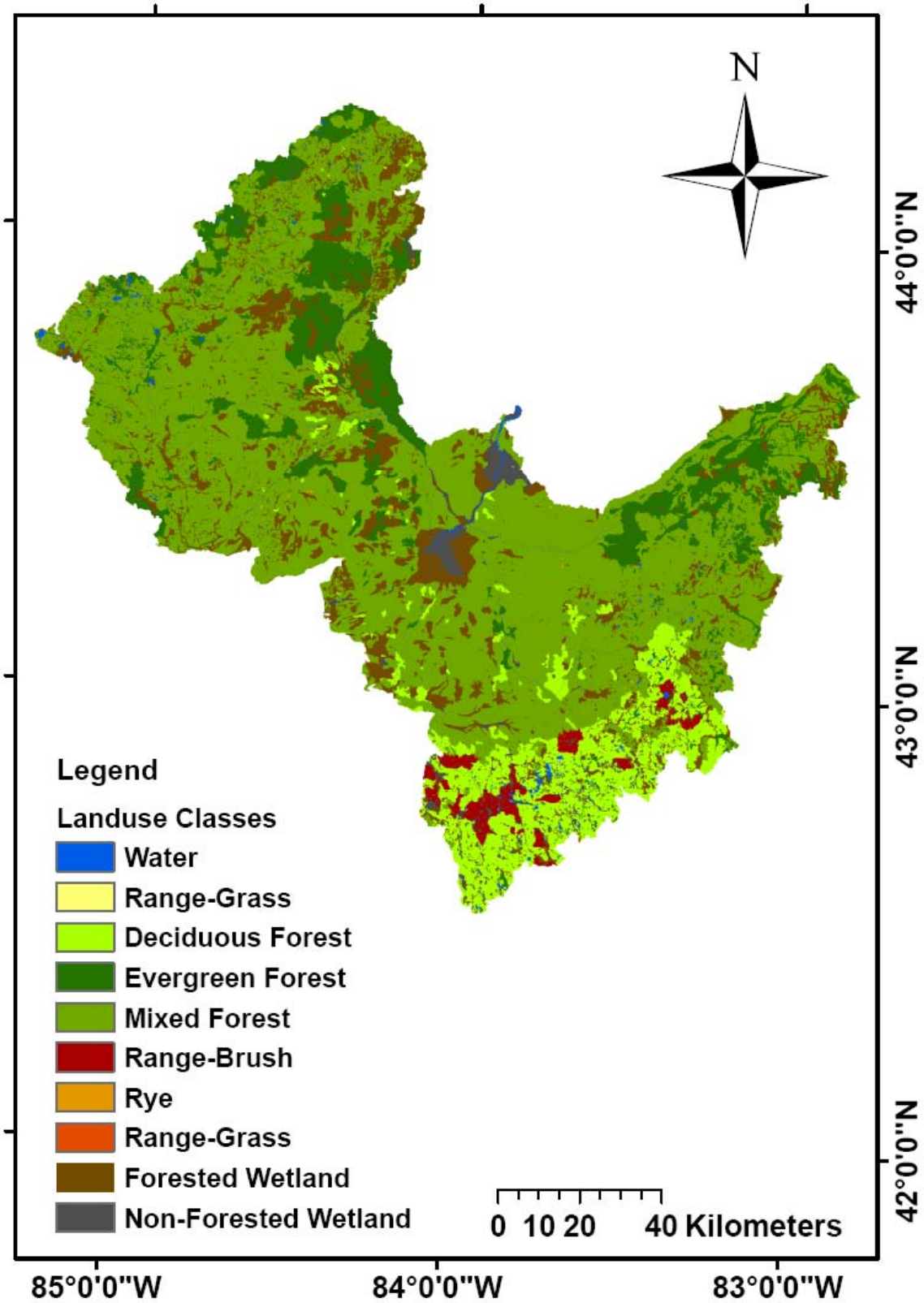


Figure 4. Pre-Settlement landuse map of the Saginaw Basin

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 Saginaw Basin.

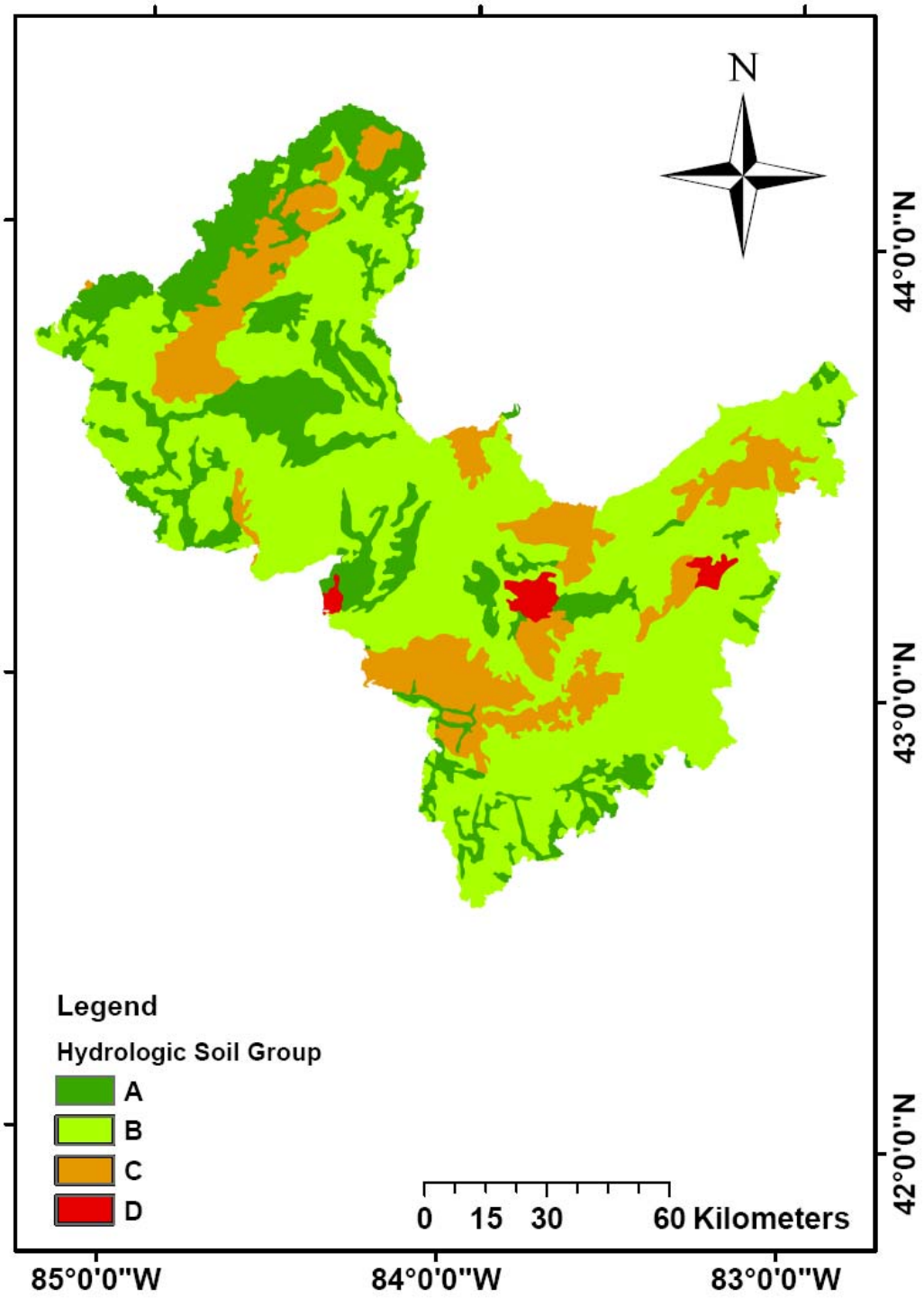


Figure 5. Hydrologic Soil Groups for the Saginaw Basin

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.

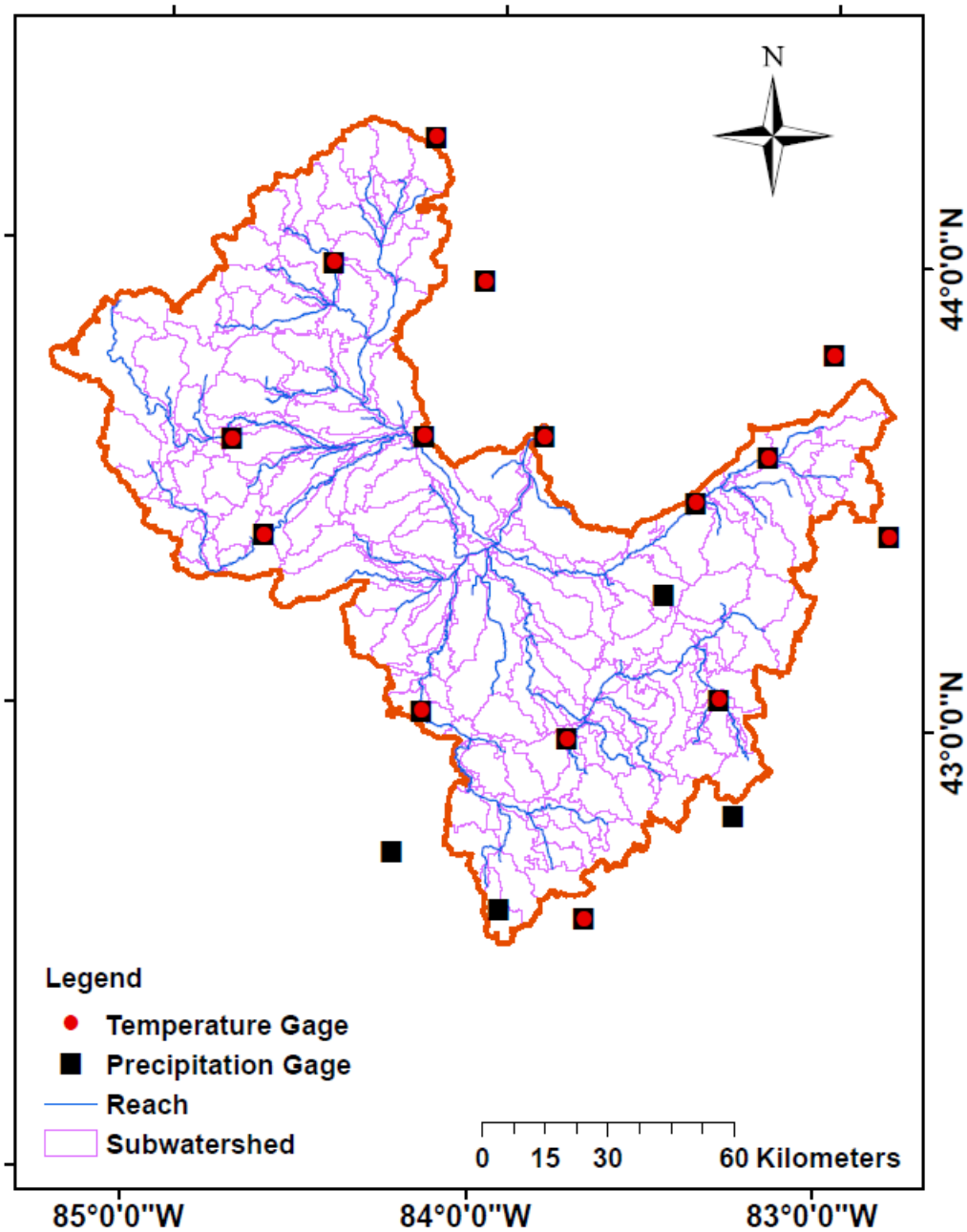


Figure 6. Temperature and precipitation gages in the Saginaw Basin

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 254 subwatersheds. Figure 7 shows the boundary and the locations of subwatersheds in the Saginaw basin.

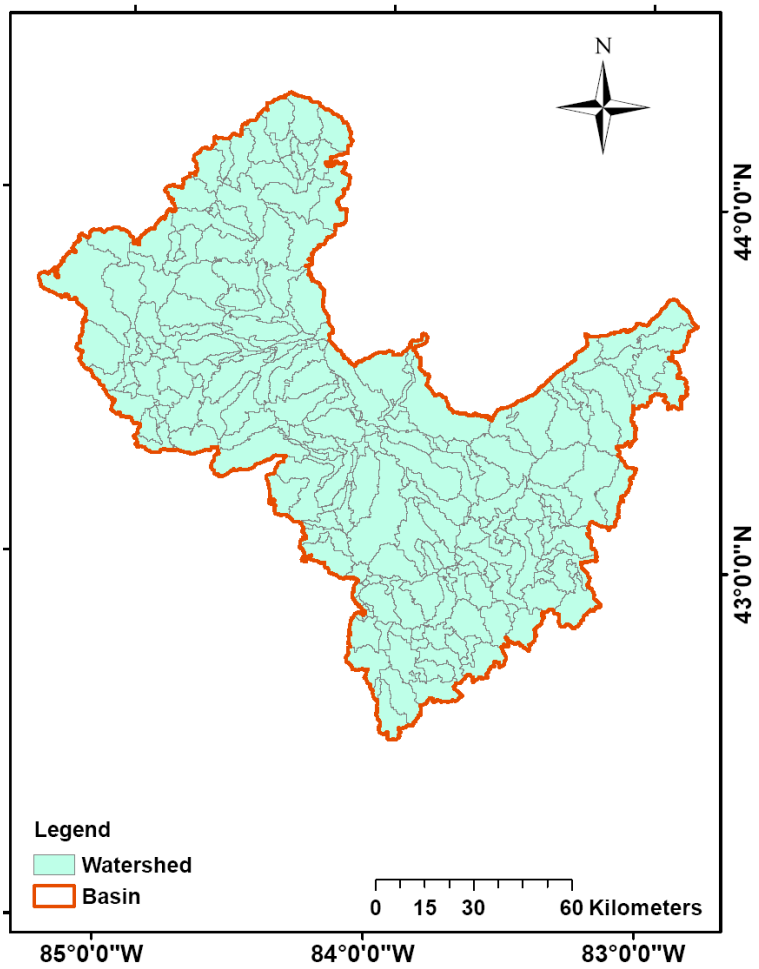


Figure 7. The delineated watersheds

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

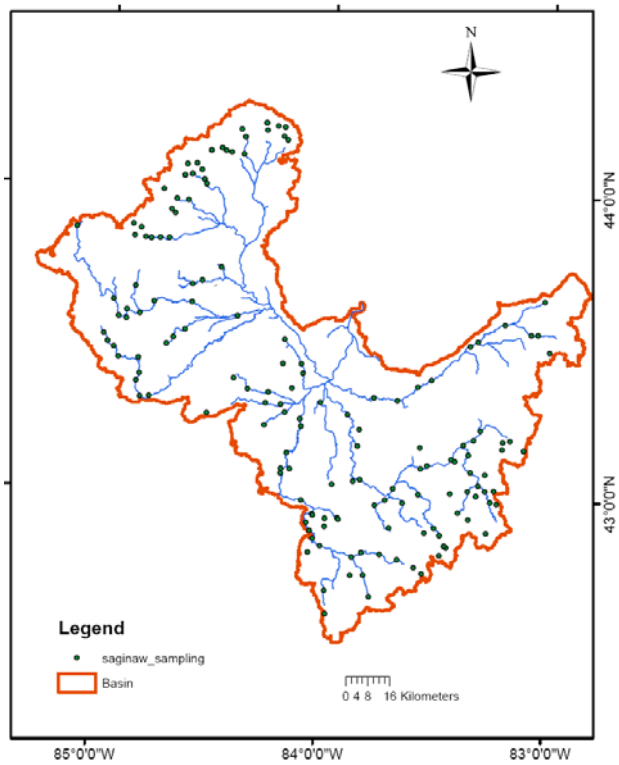
Original	LAT	LONG	Snapped	LAT	LONG
1	44.2214	-84.3041	1	44.2214	-84.3041
2	44.2214	-84.3041	2	44.2125	-84.2519
3	44.2125	-84.2519	3	44.2093	-84.2202
4	44.2093	-84.2202	4	44.1975	-84.4167
5	44.1970	-84.3001	5	44.1337	-84.5019
6	44.1975	-84.4167	6	44.1160	-84.4018
7	44.1794	-84.2239	7	44.0800	-84.6135
8	44.1727	-84.3987	8	44.0763	-84.6565
9	44.1673	-84.2063	9	44.0595	-84.5893
10	44.1727	-84.3987	10	44.0445	-84.6318
11	44.1337	-84.5019	11	44.0388	-84.6656
12	44.1257	-84.4831	12	44.0275	-84.5763
13	44.1248	-84.5501	13	44.0131	-84.5658
14	44.1248	-84.5501	14	43.9915	-84.7577
15	44.1204	-84.4582	15	43.9585	-84.6442
16	44.1160	-84.4018	16	43.9260	-84.7182
17	44.0800	-84.6135	17	43.9135	-84.7012
18	44.0763	-84.6565	18	43.8737	-84.8873
19	44.0595	-84.5893	19	43.8568	-85.1418
20	44.0445	-84.6318	20	43.8309	-84.8303
21	44.0388	-84.6656	21	43.8306	-84.7648
22	44.0388	-84.6656	22	43.8312	-84.7240
23	44.0445	-84.6318	23	43.8283	-84.8054
24	44.0275	-84.5763	24	43.7414	-84.4841
25	44.0275	-84.5763	25	43.6960	-84.5674
26	44.0131	-84.5658	26	43.6588	-83.0236
27	43.9915	-84.7577	27	43.6694	-84.8659
28	43.9613	-84.6973	28	43.6235	-84.6091
29	43.9585	-84.6442	29	43.5803	-83.1998
30	43.9260	-84.7182	30	43.6208	-84.7795
31	43.9135	-84.7012	31	43.5835	-84.4028
32	43.8737	-84.8873	32	43.5490	-83.0512
33	43.8614	-84.8515	33	43.5483	-83.0810
34	43.8568	-85.1418	34	43.5800	-84.8418

35	43.8346	-84.8798	35	43.5905	-84.9000
36	43.8309	-84.8303	36	43.5683	-84.9360
37	43.8306	-84.7648	37	43.5217	-83.3185
38	43.8312	-84.7240	38	43.5069	-83.3530
39	43.8283	-84.8054	39	43.5623	-84.9011
40	43.7414	-84.4841	40	43.5115	-84.1864
41	43.6960	-84.5674	41	43.5329	-84.6357
42	43.6588	-83.0236	42	43.5098	-85.0000
43	43.6825	-84.6106	43	43.4921	-82.9974
44	43.6694	-84.8659	44	43.5057	-84.6870
45	43.6235	-84.6091	45	43.4845	-84.9809
46	43.6230	-84.9609	46	43.4832	-84.7170
47	43.5803	-83.1998	47	43.4667	-84.9517
48	43.6208	-84.7795	48	43.4335	-84.1085
49	43.5835	-84.4028	49	43.4343	-84.9292
50	43.5490	-83.0512	50	43.4338	-84.8401
51	43.5483	-83.0810	51	43.4322	-84.1911
52	43.5800	-84.8418	52	43.3922	-83.5228
53	43.5905	-84.9000	53	43.4019	-84.0992
54	43.5683	-84.9360	54	43.3683	-83.5835
55	43.5217	-83.3185	55	43.3828	-84.8327
56	43.5069	-83.3530	56	43.3526	-84.1471
57	43.5623	-84.9011	57	43.3792	-84.4095
58	43.5115	-84.1864	58	43.3577	-84.8457
59	43.5329	-84.6357	59	43.3451	-84.3453
60	43.5098	-85.0000	60	43.3287	-83.7785
61	43.4921	-82.9974	61	43.3222	-83.6728
62	43.5057	-84.6870	62	43.3367	-84.2521
63	43.4845	-84.9809	63	43.3071	-84.8256
64	43.4845	-84.9809	64	43.3011	-84.2628
65	43.4832	-84.7170	65	43.2982	-84.1947
66	43.4667	-84.9517	66	43.3093	-84.7855
67	43.4335	-84.1085	67	43.3082	-84.0175
68	43.4343	-84.9292	68	43.2717	-84.1755
69	43.4338	-84.8401	69	43.2711	-83.8940
70	43.4322	-84.1911	70	43.2297	-83.2990
71	43.3922	-83.5228	71	43.2280	-84.1002
72	43.4019	-84.0992	72	43.1982	-83.1653
73	43.3683	-83.5835	73	43.2523	-84.1065
74	43.3828	-84.8327	74	43.2284	-84.2652
75	43.3526	-84.1471	75	43.1812	-83.3733
76	43.3792	-84.4095	76	43.2238	-83.8395
77	43.3577	-84.8457	77	43.1936	-83.1979

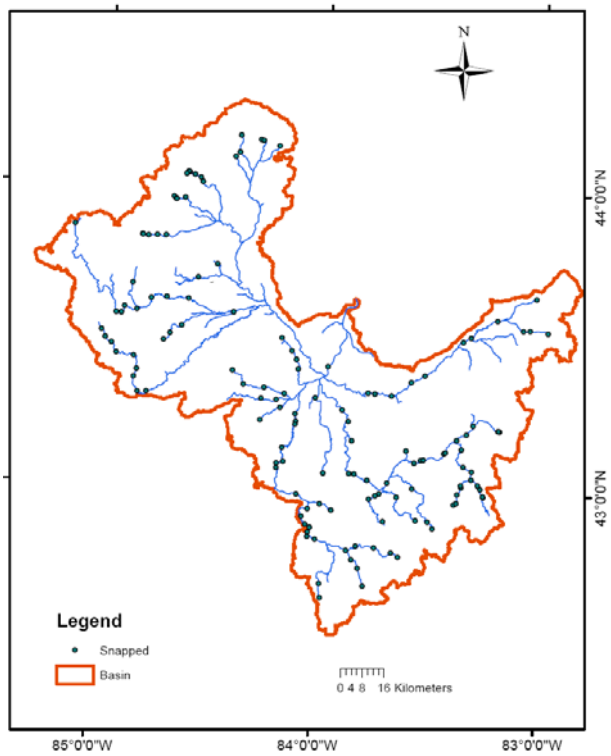
78	43.3451	-84.3453	78	43.1689	-83.5665
79	43.3287	-83.7785	79	43.1702	-83.1998
80	43.3222	-83.6728	80	43.1976	-83.3286
81	43.3367	-84.2521	81	43.1337	-83.4250
82	43.3071	-84.8256	82	43.1110	-83.5326
83	43.3011	-84.2628	83	43.1389	-84.1607
84	43.2982	-84.1947	84	43.1273	-83.4097
85	43.3093	-84.7855	85	43.1691	-83.8452
86	43.3082	-84.0175	86	43.0923	-83.3389
87	43.2717	-84.1755	87	43.1493	-83.3496
88	43.2711	-83.8940	88	43.0851	-83.2738
89	43.2297	-83.2990	89	43.0871	-84.1838
90	43.2601	-84.5243	90	43.0872	-84.1446
91	43.2280	-84.1002	91	43.1003	-83.5612
92	43.1982	-83.1653	92	43.0718	-84.1843
93	43.2523	-84.1065	93	43.0531	-83.8607
94	43.2284	-84.2652	94	43.0490	-83.3026
95	43.1812	-83.3733	95	43.0404	-83.9543
96	43.2238	-83.8395	96	43.0324	-83.6815
97	43.1936	-83.1979	97	43.0310	-83.2722
98	43.1670	-83.1037	98	43.0149	-83.3113
99	43.1689	-83.5665	99	43.0330	-83.2325
100	43.1702	-83.1998	100	43.0293	-83.3493
101	43.1976	-83.3286	101	43.0211	-83.4276
102	43.1337	-83.4250	102	43.0588	-83.8302
103	43.1110	-83.5326	103	42.9943	-83.7155
104	43.1389	-84.1607	104	43.0155	-83.5687
105	43.1273	-83.4097	105	42.9852	-84.0889
106	43.1691	-83.8452	106	42.9861	-83.6378
107	43.0923	-83.3389	107	42.9900	-83.2192
108	43.1493	-83.3496	108	42.9951	-83.2483
109	43.0851	-83.2738	109	42.9587	-83.3903
110	43.0871	-84.1838	110	42.9369	-83.3440
111	43.0872	-84.1446	111	42.9764	-83.7608
112	43.1003	-83.5612	112	42.9309	-83.9251
113	43.0718	-84.1843	113	42.9280	-83.9807
114	43.0531	-83.8607	114	42.9063	-83.4945
115	43.0490	-83.3026	115	42.9376	-84.0349
116	43.0404	-83.9543	116	42.8895	-83.5368
117	43.0324	-83.6815	117	42.9127	-84.0631
118	43.0310	-83.2722	118	42.8821	-83.4687
119	43.0149	-83.3113	119	42.9029	-83.6943
120	43.0330	-83.2325	120	42.8866	-84.0468

121	43.0293	-83.3493	121	42.9014	-83.9809
122	43.0211	-83.4276	122	42.8603	-84.0314
123	43.0588	-83.8302	123	42.8150	-83.7320
124	42.9943	-83.7155	124	42.8369	-83.9984
125	43.0155	-83.5687	125	42.8191	-83.8135
126	42.9852	-84.0889	126	42.8154	-84.0504
127	42.9861	-83.6378	127	42.8035	-83.8564
128	42.9900	-83.2192	128	42.7992	-83.6544
129	42.9951	-83.2483	129	42.7746	-83.5800
130	42.9587	-83.3903	130	42.7451	-83.8027
131	42.9369	-83.3440	131	42.7430	-83.8603
132	42.9764	-83.7608	132	42.6746	-83.7742
133	42.9419	-84.0375	133	42.6908	-83.9728
134	42.9309	-83.9251	134	42.6138	-83.9648
135	42.9280	-83.9807	135	43.2178	-84.1050
136	42.9260	-83.9201	136	43.1111	-83.5194
137	42.9063	-83.4945	137	42.9878	-83.7325
138	42.9376	-84.0349	138	43.0389	-83.7716
139	42.8895	-83.5368	139	43.3278	-83.7480
140	42.9127	-84.0631	140	43.6261	-84.7078
141	42.8930	-83.2634	141	43.4128	-83.9630
142	42.8821	-83.4687			
143	42.9029	-83.6943			
144	42.8866	-84.0468			
145	42.9014	-83.9809			
146	42.8477	-83.4468			
147	42.8429	-83.4382			
148	42.8603	-84.0314			
149	42.8477	-83.4468			
150	42.8150	-83.7320			
151	42.8369	-83.9984			
152	42.8165	-83.4677			
153	42.8191	-83.8135			
154	42.8154	-84.0504			
155	42.8035	-83.8564			
156	42.7992	-83.6544			
157	42.7746	-83.5800			

158	42.7550	-83.5436			
159	42.7451	-83.8027			
160	42.7430	-83.8603			
161	42.6746	-83.7742			
162	42.6908	-83.9728			
163	42.6138	-83.9648			
164	43.2178	-84.1050			
165	43.1111	-83.5194			
166	42.9878	-83.7325			
167	43.0389	-83.7716			
168	43.3278	-83.7480			
169	43.6261	-84.7078			
170	43.4128	-83.9630			



(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 Kjeldahl nitrogen, and total phosphorus. Five years of data were used for calibration, including 68 observations for each water quality constituent.

The most downstream USGS gaging station on the Saginaw River (Station No. 04157000) 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 Essexville station (90177) on the Saginaw 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.

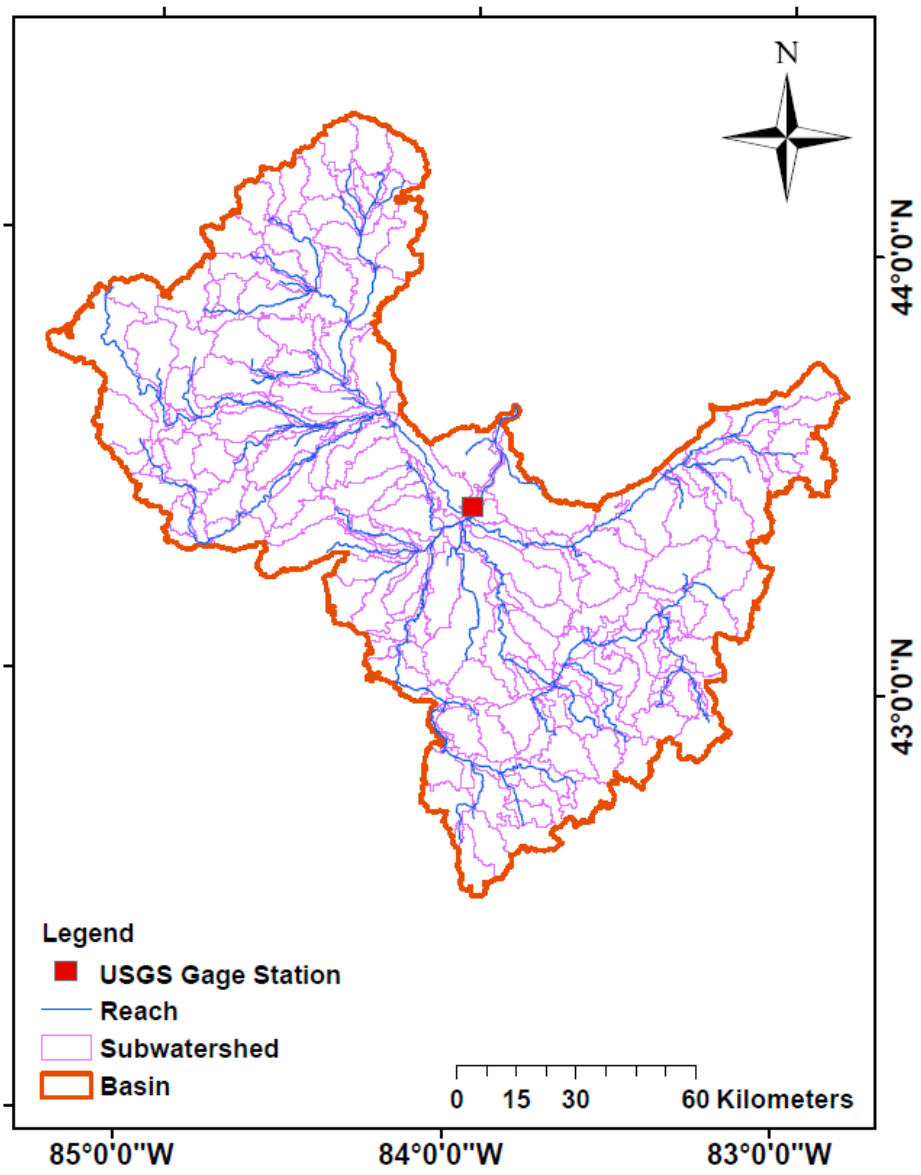


Figure 9. The delineated watersheds and selected USGS station.

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.

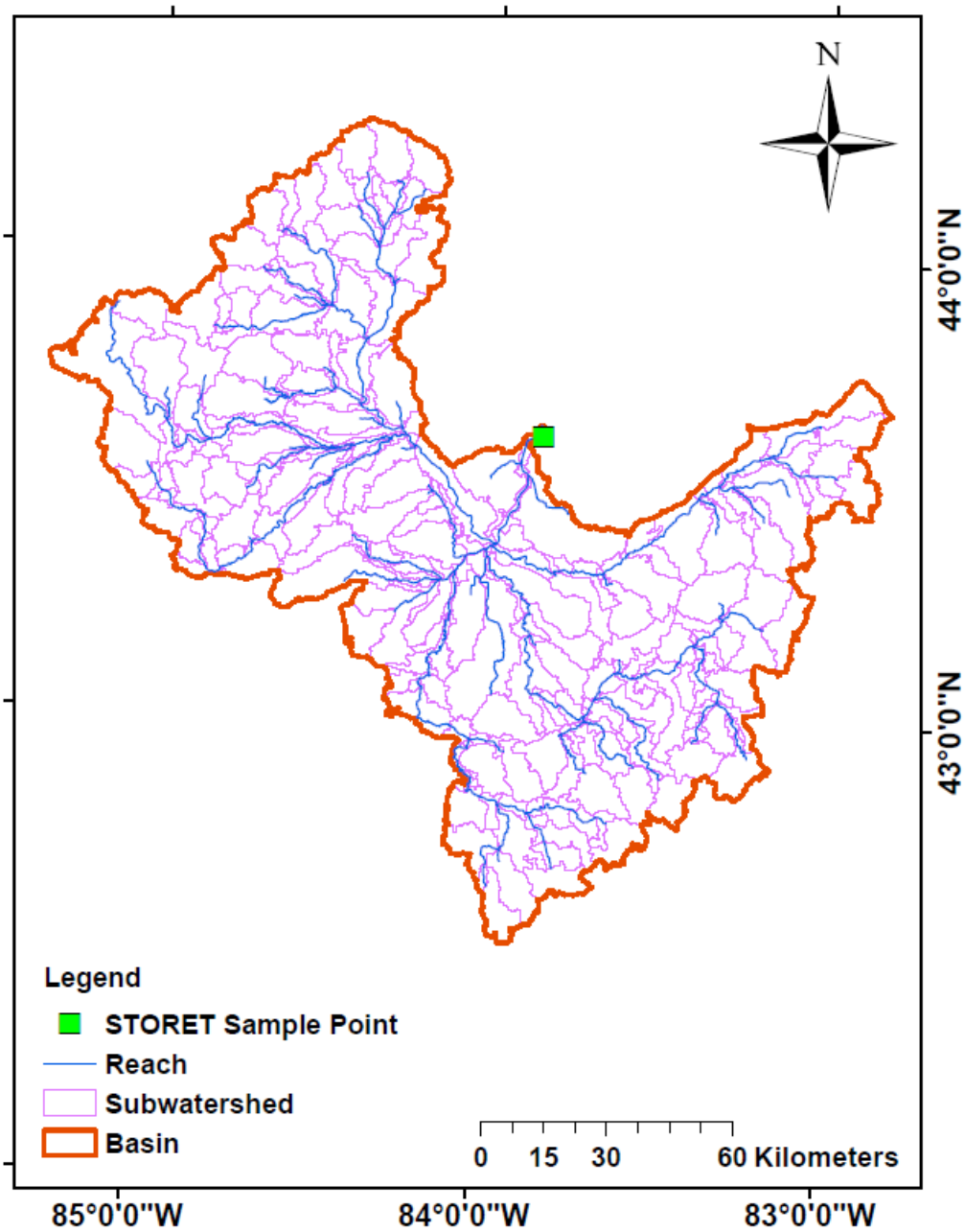


Figure 10. STORET sampling location used to calibrate water quality parameters

6.3 Model Calibration

In the 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	TotalN	TotalP
Alpha_Bf	1	2	3	3
Cn2	2	1	4	4
Esco	3	9	12	11
Rchrg_Dp	4	12	14	14
Timp	5	6	1	2
Ch_K2	6	5	8	5
Sol_Awc	7	14	6	7
Sol_Z	8	15	10	10
Gwqmn	9	18	23	24
Canmx	10	16	5	6
Surlag	11	8	2	1
Blai	12	13	13	13
Ch_N2	13	4	17	17
Epco	14	20	20	19
Biomix	15	10	11	12
Slope	16	17	16	16
Gw_Revap	17	27	26	22
Smtmp	18	21	7	8
Gw_Delay	19	25	24	20
Sol_K	20	23	18	18
Revapmn	21	29	27	28
Slsubbsn	22	22	15	15
Sol_Alb	23	26	25	26
Nperco	24	24	19	25
Usle_C	25	19	22	23
Spcon	42	3	42	42
Usle_P	42	7	9	9
Spexp	42	11	42	42
Pperco	42	28	28	27
Phoskd	42	30	21	21
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 phosphorus. Total Kjeldahl nitrogen was consistently underpredicted by the model because ammonia is not an output of the model at the reach-scale. 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	0.762	10.278	0.734
Total Suspended Solids (TSS)	0.664	84.112	0.703
TKN	-0.032	1857.286	0.740
Total P	0.911	100.816	0.900

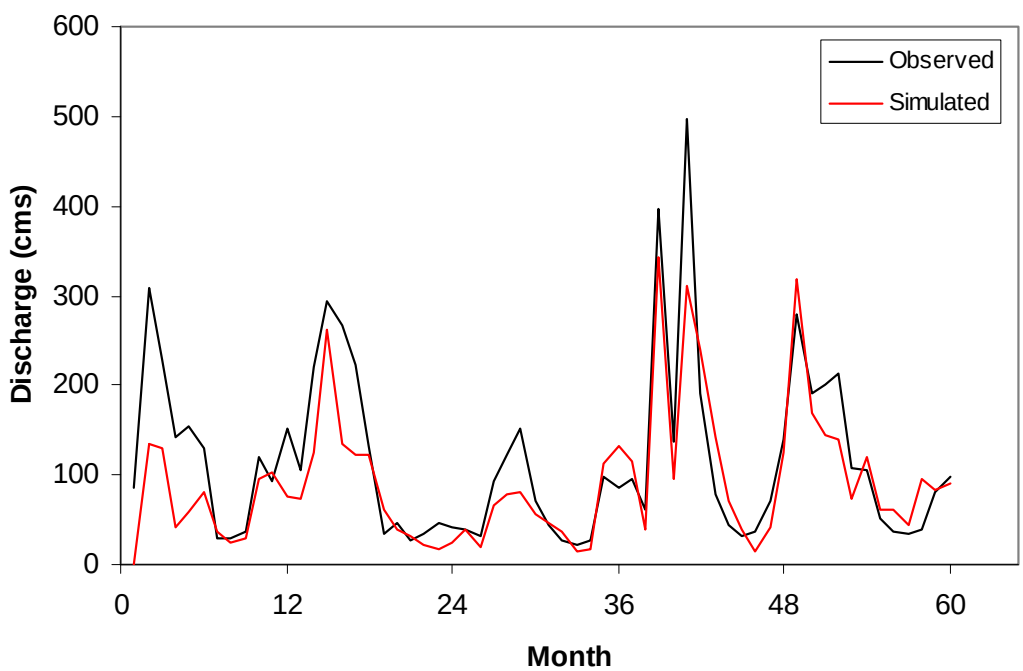


Figure 11. Model simulated results vs. scaled observed flow at STORET Station 90177

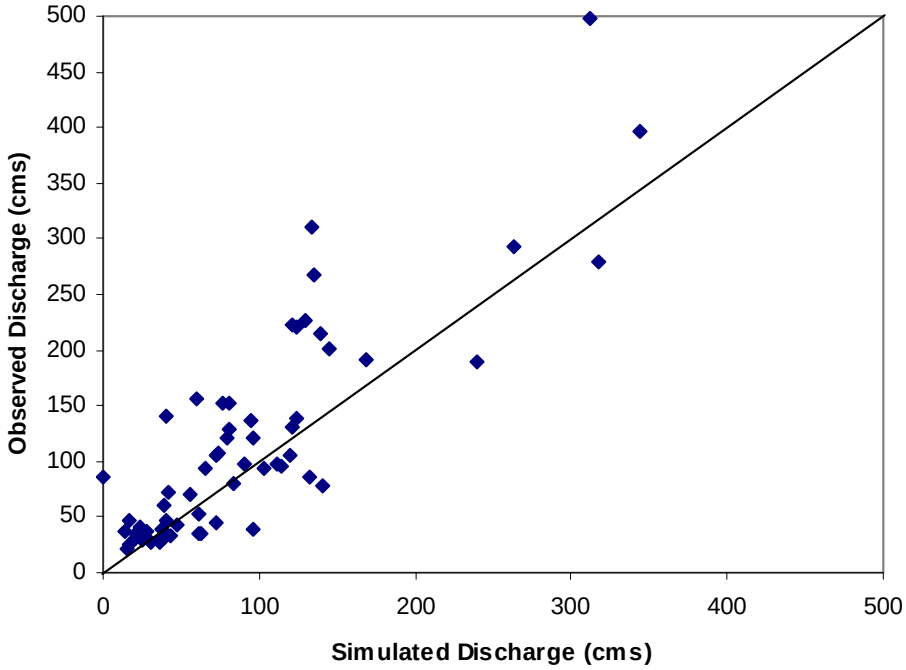


Figure 12. Simulated vs scaled observed flow at STORET Station 90177

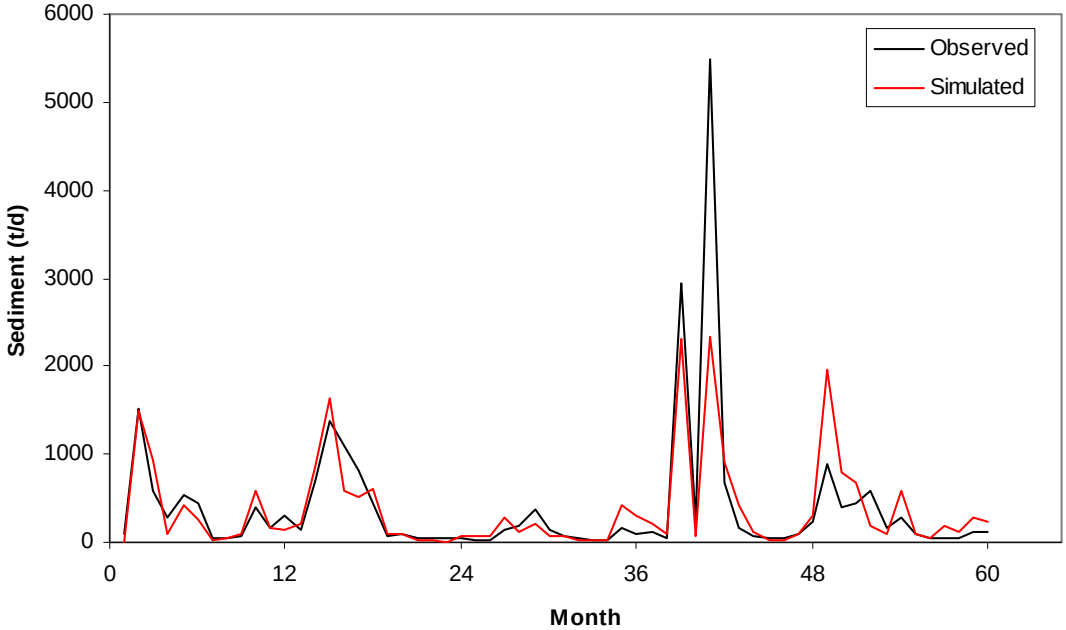


Figure 13. Time series of simulated vs observed TSS

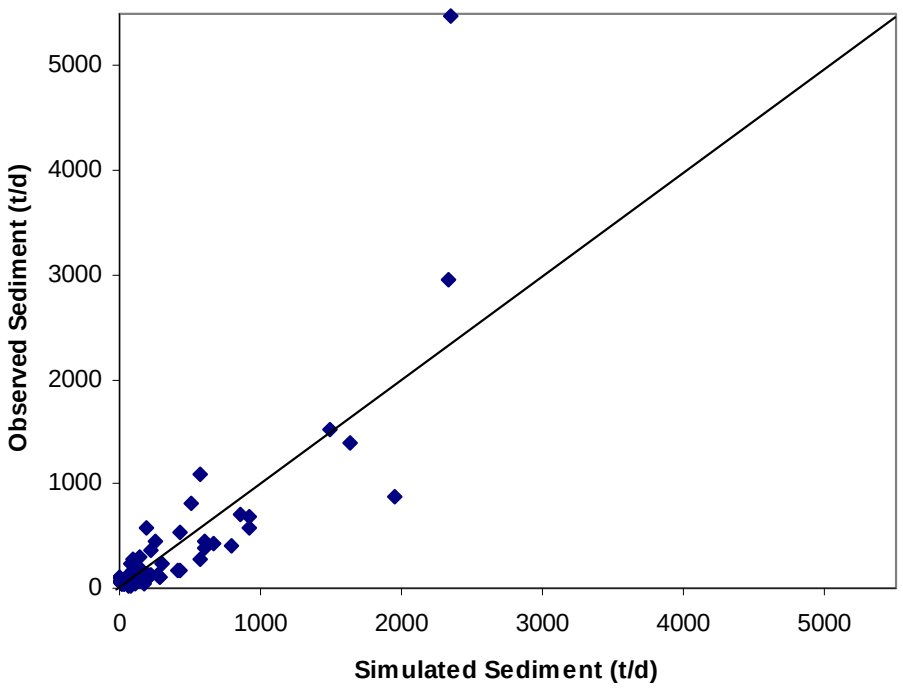


Figure 14. Simulated vs observed TSS

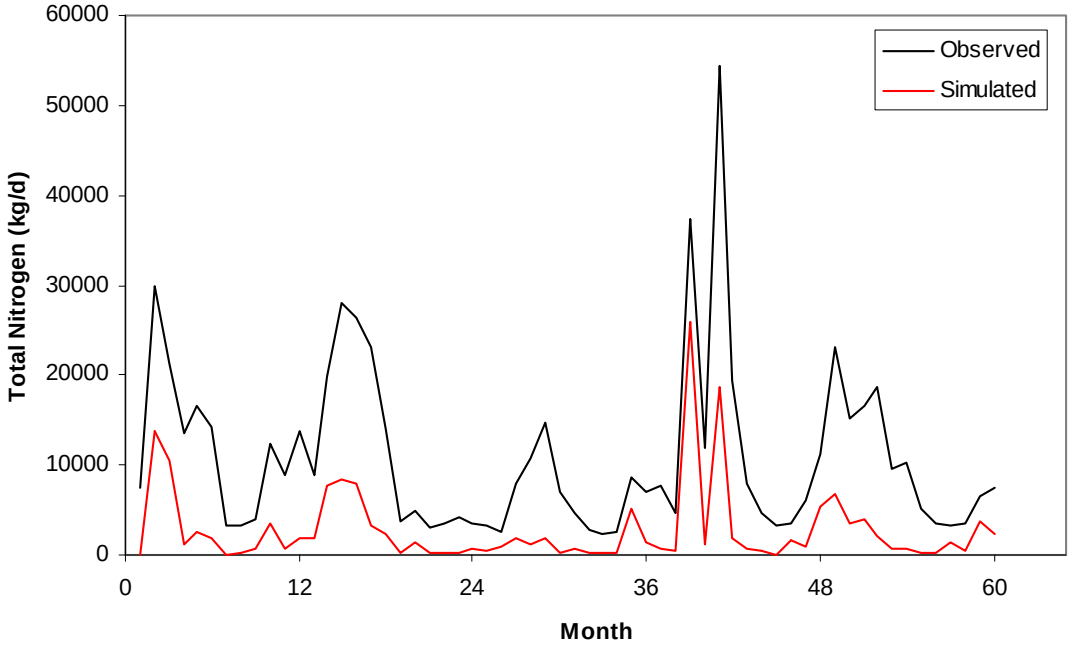


Figure 15. Time series of simulated vs observed Total Kjedahl Nitrogen

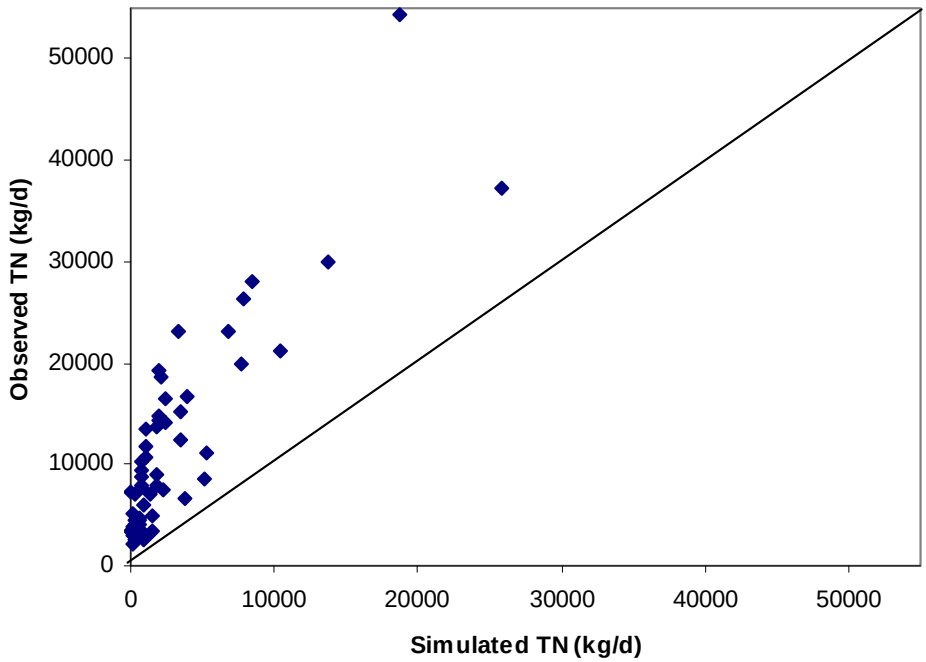


Figure 16. Simulated vs observed Total Kjedahl Nitrogen

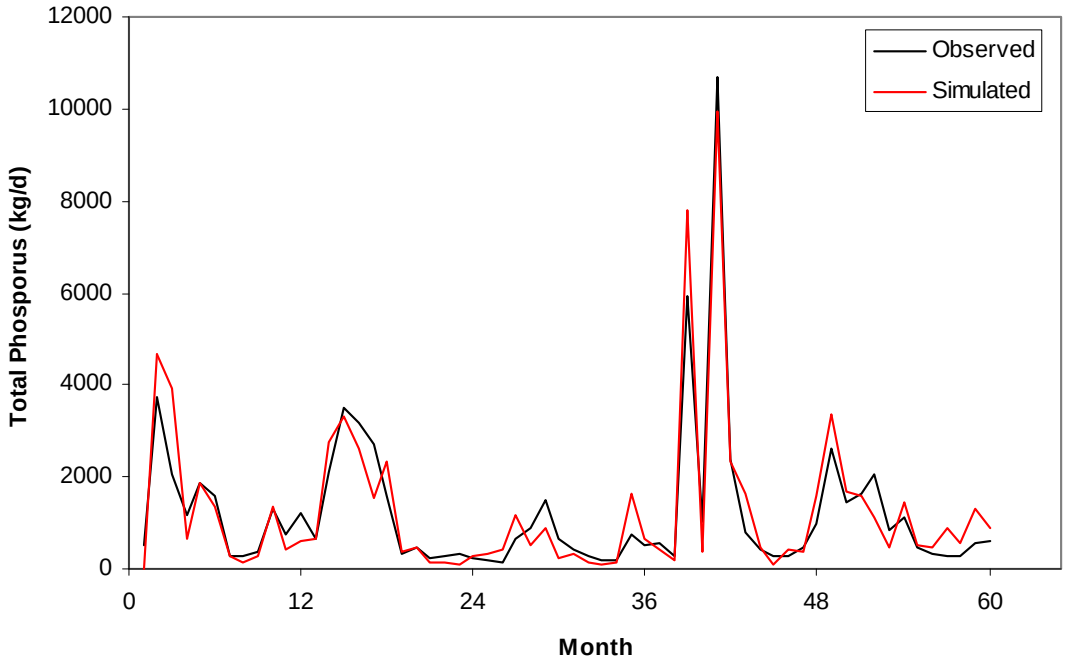


Figure 17. Time series of simulated vs. observed total phosphorus

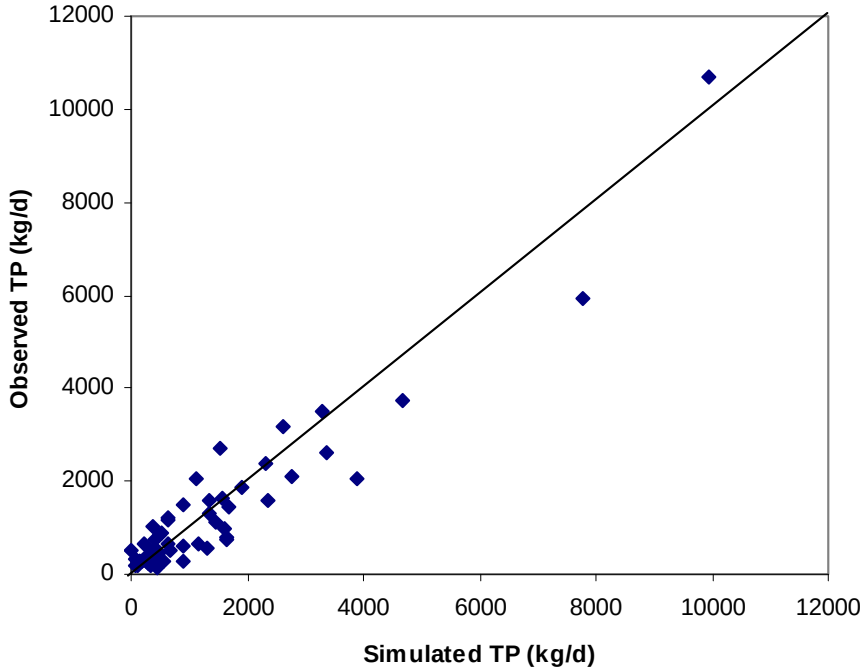


Figure 18. Simulated vs. observed total phosphorus

Table 6. Monthly and annual hydrologic budget from the Saginaw 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	54.49	36.35	16.45	0.05	21.66	7.59	0.02	12.76
2	43.1	28.94	19.88	0.04	22.93	10.75	0.03	17.99
3	47.46	19.14	33.38	0.25	39.85	33.98	0.04	55.02
4	76.96	6.09	11.86	0.39	25.26	54.4	0.01	96.92
5	86.69	0	12.24	0.33	24.3	70.1	0.02	140.81
6	82.38	0	10.99	0.28	19.58	86.78	0.01	169.69
7	84.6	0	7.44	0.26	13.43	100.05	0.01	177.14
8	79.32	0	5.03	0.29	9.64	65.62	0	147.1
9	76.25	0	7.08	0.26	11.05	43.66	0.01	115.26
10	69.84	0.95	6.66	0.29	12.13	37.9	0.01	71.34
11	69.71	7.93	8.02	0.3	15.32	24.12	0.01	38.51
12	51.18	29.65	10.77	0.12	18.51	13.13	0.01	20.48
Annual Average	821.98	129.05	149.8	2.86	233.66	548.08	0.18	1063.02

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 Saginaw Basin

Calibrated	Current	Pre-Settlement	Percent Change	Percent Different
Recharge (mm)	112.97	186.80	-39.52%	-49.26%
Surface Runoff (mm)	145.42	87.65	65.91%	49.58%
Baseflow (mm)	84.86	137.28	-38.18%	-47.19%
Water Yield (mm)	233.14	227.38	2.53%	2.50%
Sediment Yield (t/ha)	0.18	0.01	2749.58%	186.44%
Total N Output (t/ha)	4.55	2.10	116.89%	73.77%
Total P Output (t/ha)	0.27	0.01	2383.41%	184.52%

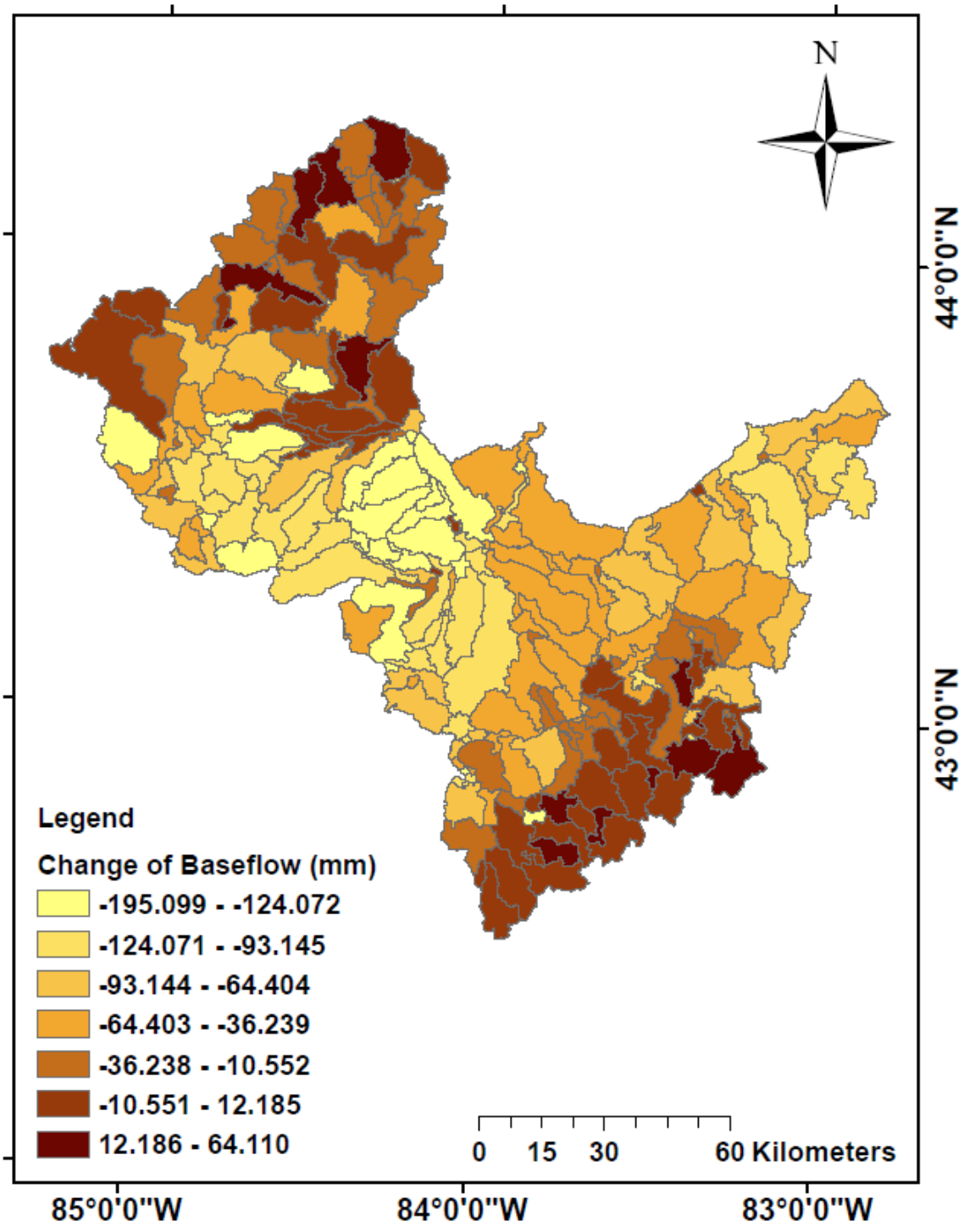


Figure 19. Change of baseflow values resulted from landuse changes (mm)

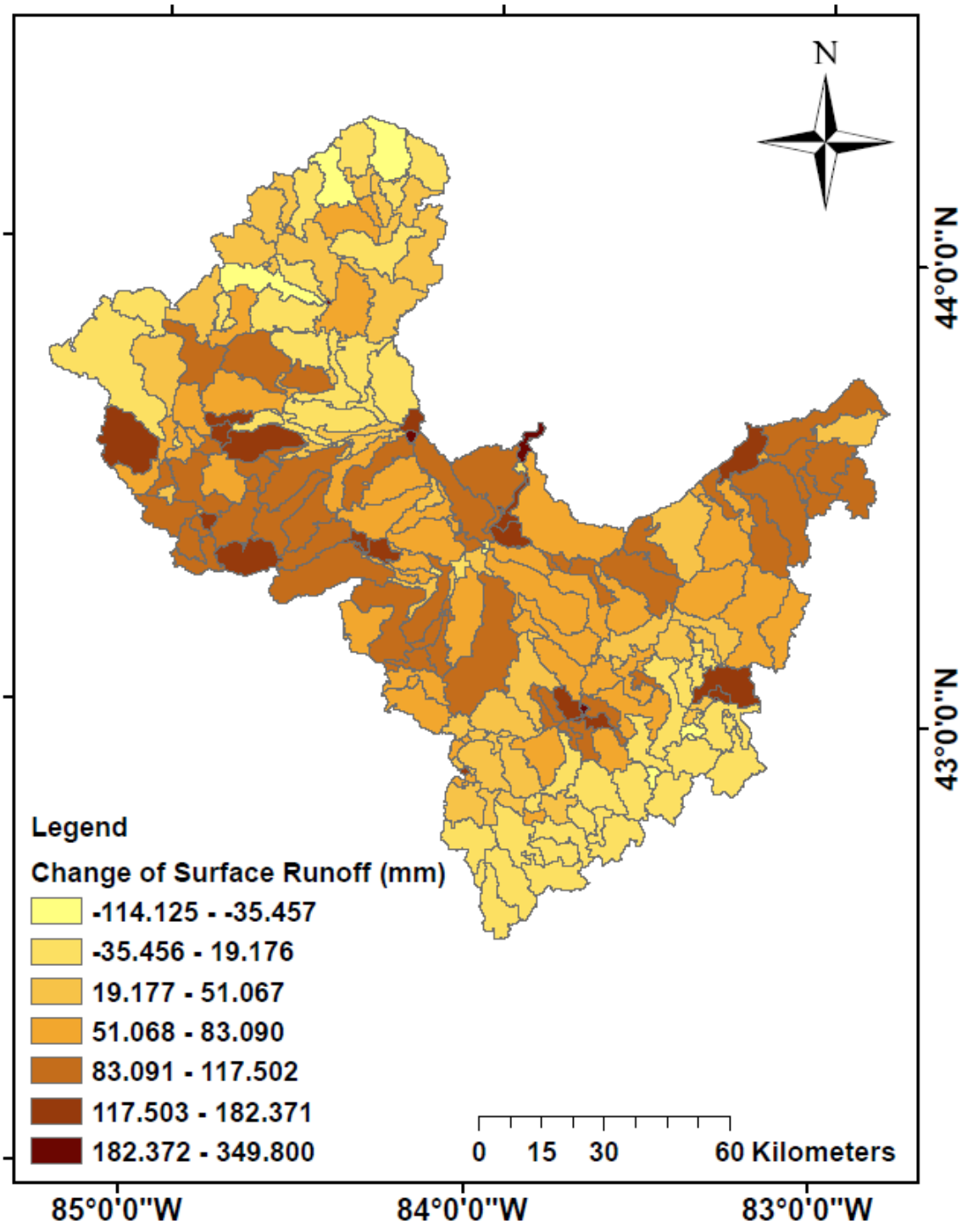


Figure 20. Change of surface runoff values resulted from landuse changes (mm)

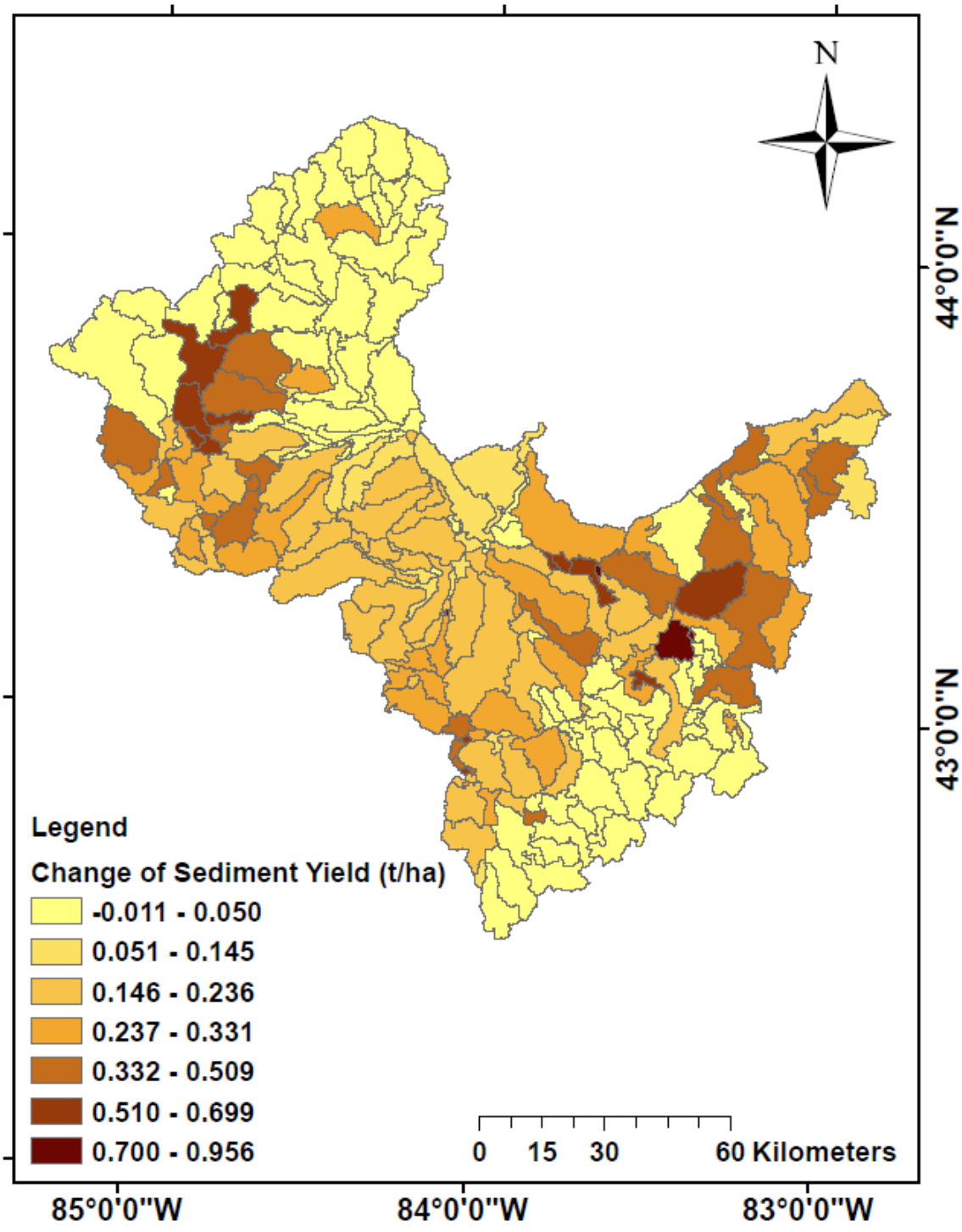


Figure 21. Change of sediment yields resulted from landuse changes (t/ha)

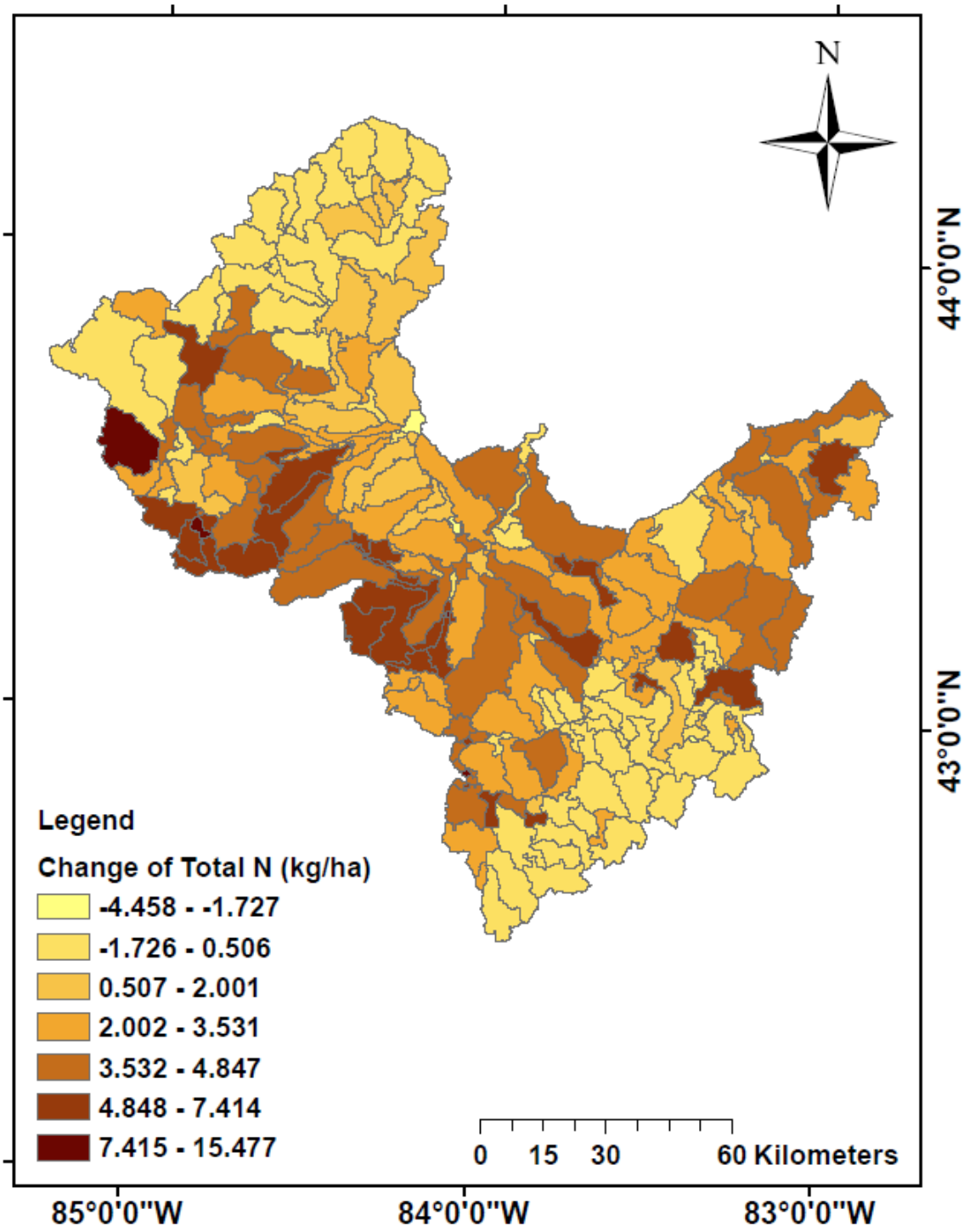


Figure 22. Change of total N output values resulted from landuse changes (kg/ha)

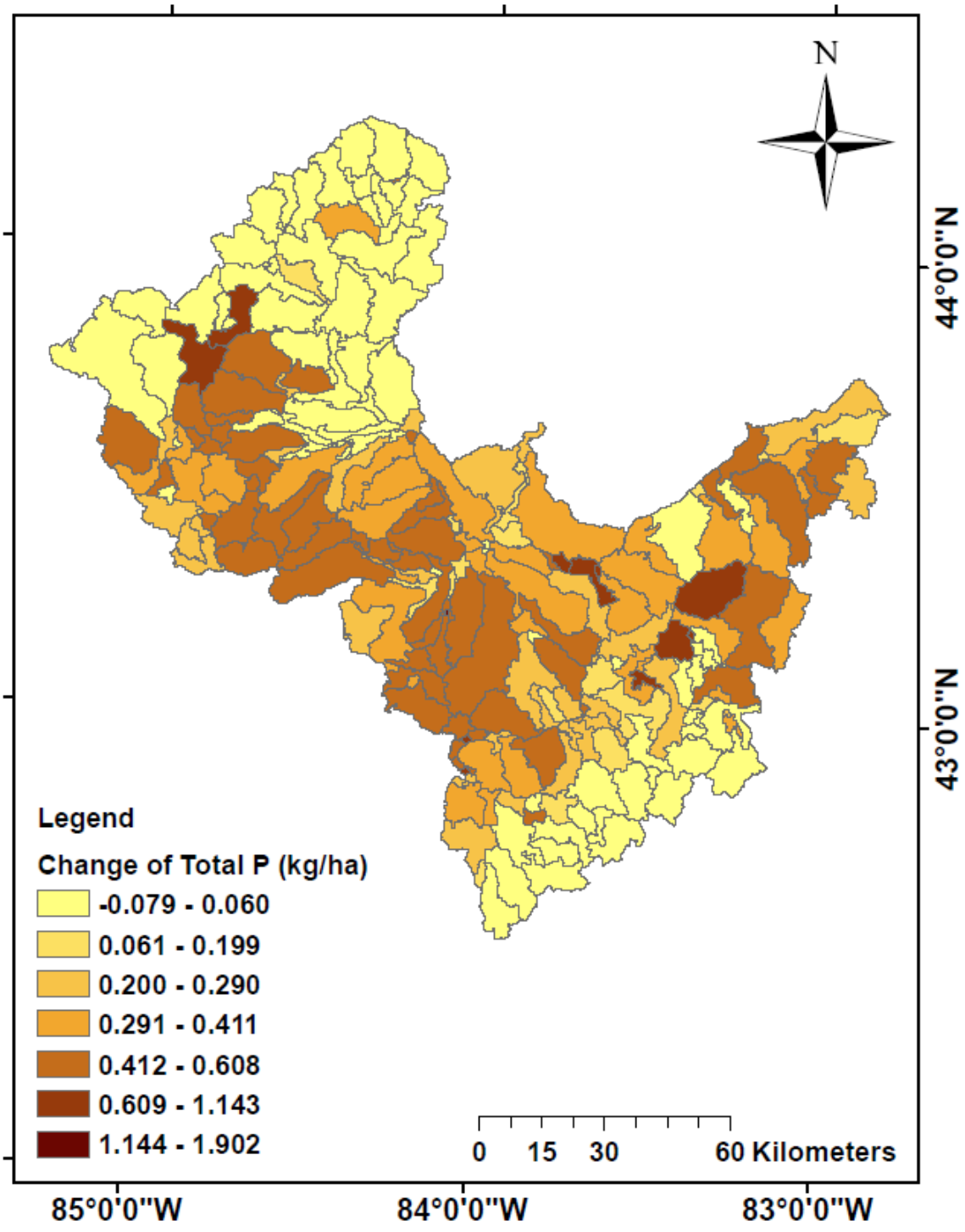


Figure 23. Change of total P output values resulted from landuse changes (kg/ha)

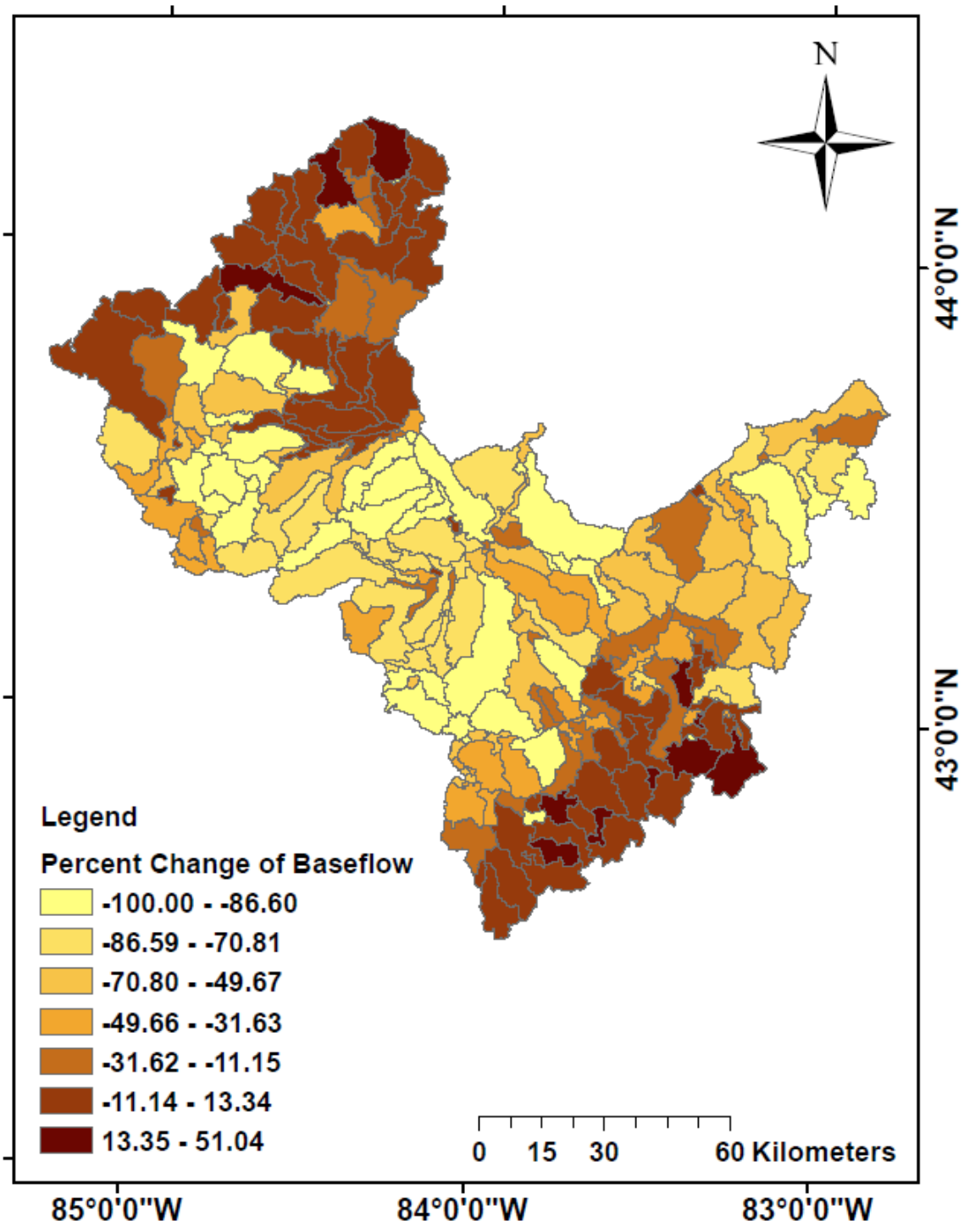


Figure 24. Percent change of baseflow values resulted from landuse changes

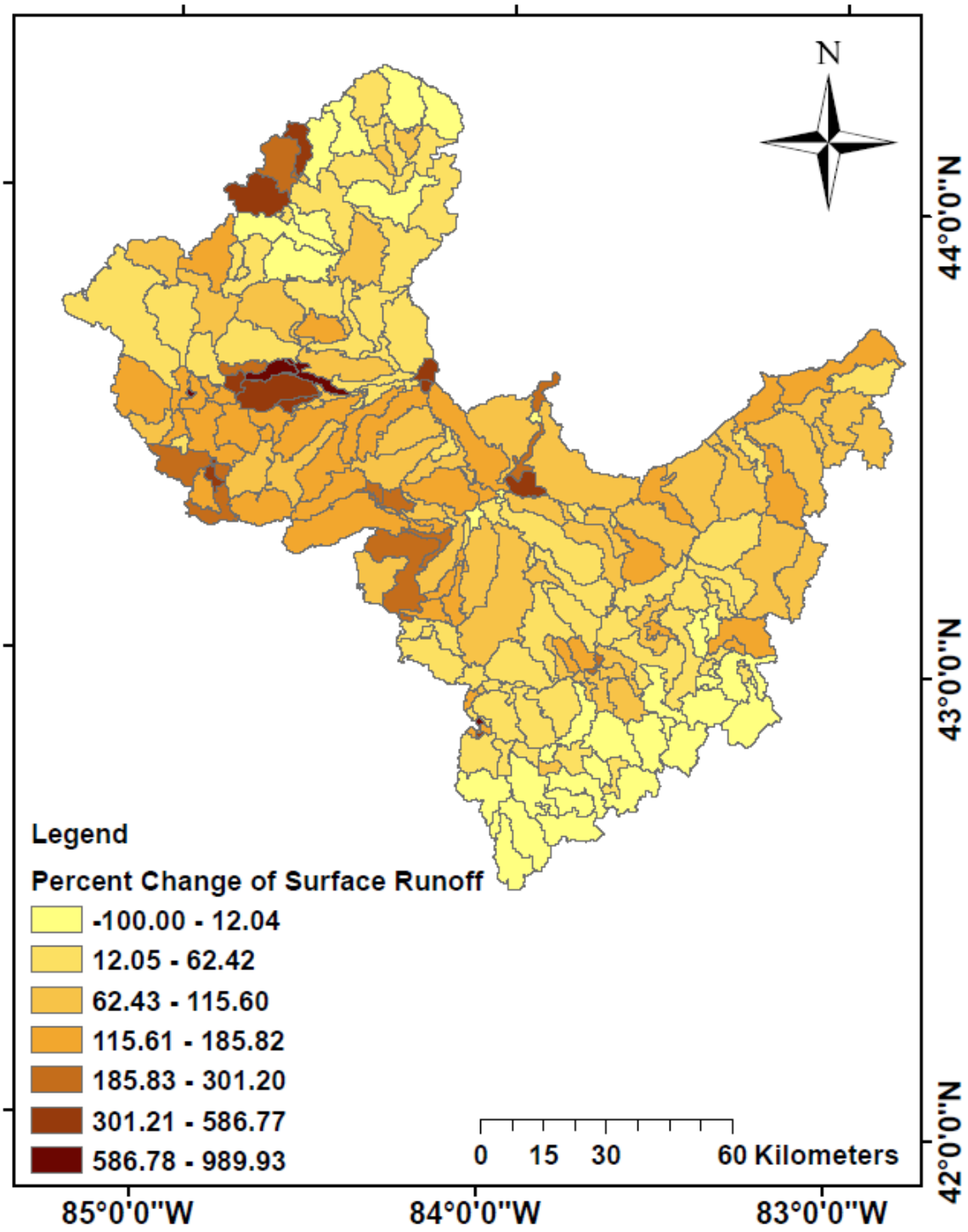


Figure 25. Percent change of surface runoff values resulted from landuse changes

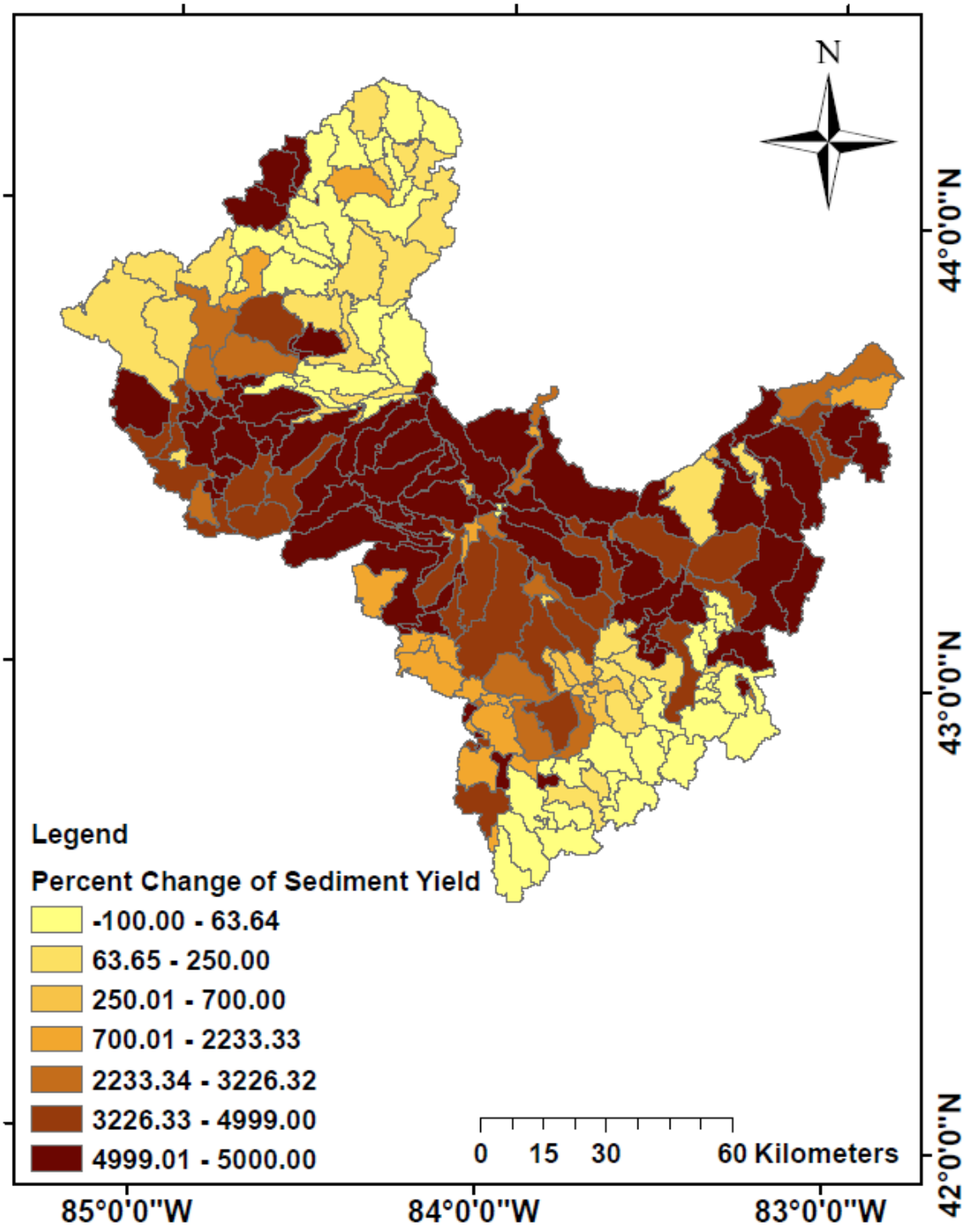


Figure 26. Percent change of sediment yield resulted from landuse changes

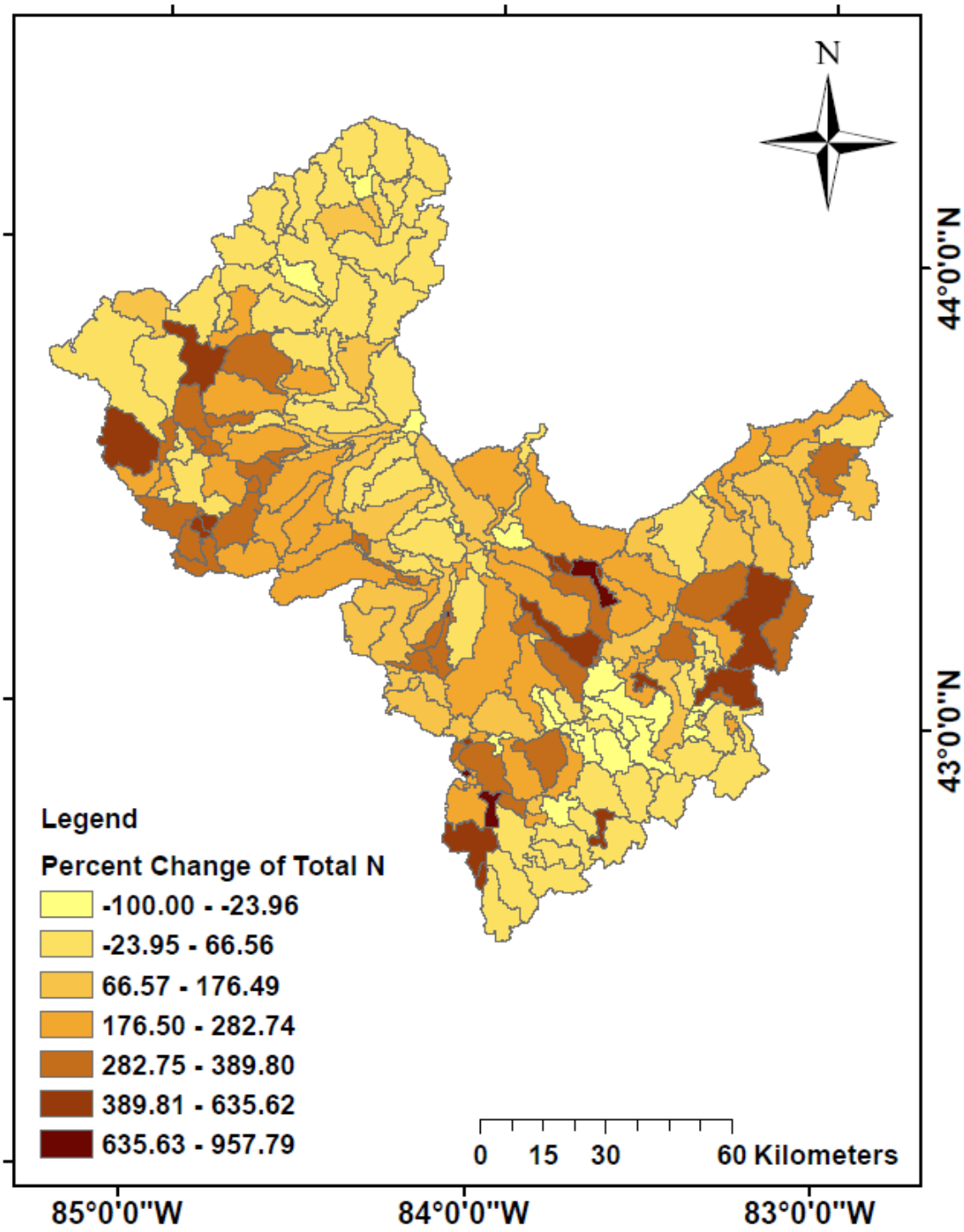


Figure 27. Percent change of total N output values resulted from landuse changes

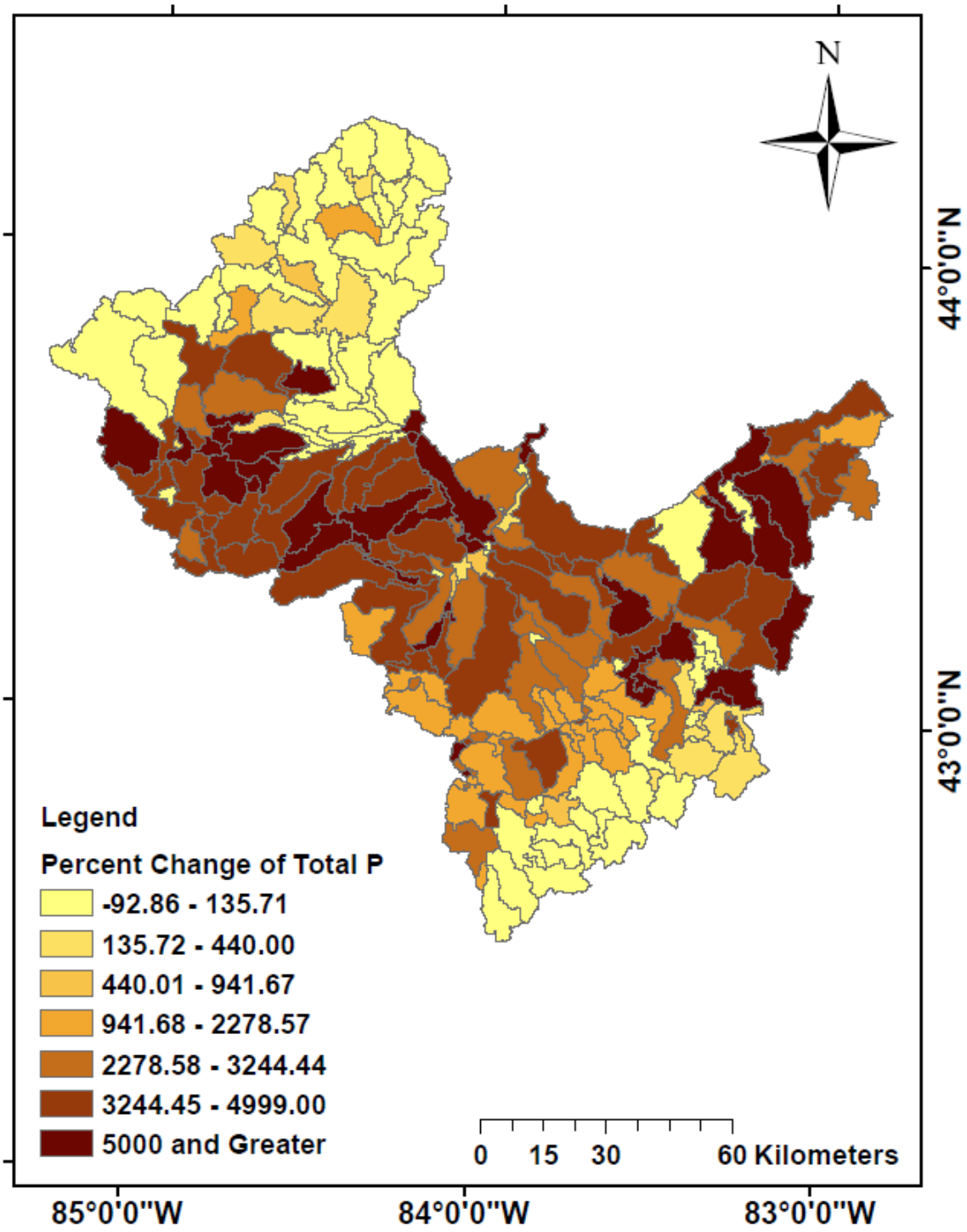


Figure 28. Percent change of total P output values resulted from landuse changes

7.0 Acknowledgment:

The authors would like to acknowledge useful discussions and help with Chaopeng Shen, Scott Sowa, Jon Bartholic, Yi Shi, Sean Woznicki, and Brad Love. Funding for this project was provided by the United State Department of Agriculture – Natural Resource Conservation Service as a part of Conservation Effects Assessment Project.

8.0 References

Van Griensven, A., T. Meixner, et al. (2006). "A global sensitivity analysis tool for the parameters of multi-variable catchment models." Journal of Hydrology 324: 10-23.