

Section 4

Water Quality Model Results

4.1 Water Quality Model

Water quality conditions within and around the Spruce Run Reservoir currently are considered good, but may be threatened as the land around the reservoir becomes urbanized. The purpose of constructing SWMM models for the Spruce Run and Mulhockaway Creek study areas was to establish tools for assessing potential stormwater runoff pollutant loadings for various levels of development (only existing and build out for this study). The land use build out scenario was created using existing zoning regulations in the study areas with consideration of environmental constraints that may impede or prevent development. Using the SWMM models, annual stormwater runoff pollutant loadings for both study areas were estimated under existing and build out land uses. The comparison of the results for existing and build out conditions for each pollutant evaluated are presented in Section 4.6.

4.1.1 Flow

SWMM models were developed for the entirety of both study areas even though portions were downstream of the gage stations, and thus, without data for calibration. Given the size of the study areas, their relative homogeneity, and that changes to the models for calibration were made uniformly, the models were considered adequately calibrated, especially for the estimation of annual runoff volumes. Adequate estimates of annual runoff volumes are necessary to determine pollutant loads, since those loads are primarily transported via stormwater runoff.

4.1.2 Pollutants

Pollutant loads are not simulated but calculated using event mean concentrations and modeled annual runoff volumes. Estimates of annual non-point source pollutant loadings were obtained using simulated runoff volumes obtained from the stormwater model runs along with land use based event mean concentrations (EMCs) compiled from several data sources (Section 2.4.1). Local stormwater quality data were not sufficient for the development of local EMCs, so literature values were used to calculate pollutant loads. The water quality data that were available within the study area were obtained primarily during dry weather, providing little information about wet weather water quality concentrations. The literature EMCs are based on extensive amounts of observed data from stormwater runoff studies and are considered more reliable than local values determined from limited datasets.

4.2 Spruce Run Existing Land Use Conditions

The pollutant loading rates and annual pollutant loads for the Spruce Run study area existing conditions simulation are presented in Tables 4.1 and 4.2. The results are discussed in detail for each pollutant in Section 4.5.

Table 4.1

Spruce Run Existing Conditions Average Annual Stormwater Runoff Pollutant Loading Rates* (lbs/acre)											
Parameter	Subwatershed										
	101	102	103	104	105	106	107	108	109	110	111
BOD	3.93	4.23	18.4	4.98	3.19	31.25	10.5	8.98	19.5	16.4	12.0
COD	874	536	354	309	54.0	322	112	199	278	222	330
TSS	41.0	45.6	187	61.8	24.9	383	124	98	237	191	155
TP	0.43	0.36	0.64	0.26	0.10	0.89	0.31	0.32	0.61	0.50	0.47
TN	8.47	4.48	4.06	3.02	0.68	5.37	1.94	1.95	3.66	3.06	2.79
Pb	0.027	0.034	0.081	0.020	0.017	0.064	0.031	0.029	0.046	0.044	0.029
Cu	0.013	0.009	0.014	0.006	0.003	0.014	0.005	0.006	0.010	0.009	0.007
Zn	0.362	0.255	0.290	0.152	0.051	0.282	0.110	0.134	0.212	0.183	0.189
Runoff Volume (in)	23.09	15.27	12.41	8.69	2.06	10.16	4.07	6.06	8.60	7.21	9.43

**based on EMCs, land use, and runoff volumes*

Table 4.2

Spruce Run Existing Conditions Average Annual Stormwater Runoff Pollutant Loads* (lbs)											
Parameter	Subwatershed										
	101	102	103	104	105	106	107	108	109	110	111
BOD	2,932	292	2,330	4,338	2,119	8,563	6,725	14,062	12,207	65,928	42,579
COD	651,873	37,026	44,794	268,957	35,863	88,353	71,579	311,565	174,477	896,615	1,173,968
TSS	30,601	3,152	23,727	53,835	16,562	105,054	79,233	153,484	148,560	769,003	551,370
TP	318	25	81	227	67	245	199	496	380	2,026	1,684
TN	6,318	310	514	2,626	449	1,470	1,240	3,052	2,297	12,356	9,952
Pb	20	2	10	17	11	18	20	45	29	178	102
Cu	10	1	2	5	2	4	3	10	6	36	27
Zn	270	18	37	133	34	77	71	210	133	736	673
Runoff Volume (MG)	468	29	43	205	37	76	71	258	146	790	912

**based on EMCs, land use, and runoff volumes*

4.3 Spruce Run Build Out Land Use Conditions

The build out land use scenario was incorporated into the SWMM model for the Spruce Run study area so that the potential impacts of development could be assessed. A large lot residential land use classification was added for this scenario to identify parcels zoned for residential development with lot sizes greater than 3 acres. EMCs for forested land use were used to represent stormwater runoff originating from large lot residential areas since large portions of individual parcels would remain undeveloped (in forest or open space land use)¹. The pollutant loading rates and annual pollutant loads for the Spruce Run study area build out conditions simulation are presented in Tables 4.3 and 4.4 and compared to existing conditions in Table 4.5.

Table 4.3

Spruce Run Build Out Average Annual Stormwater Runoff Pollutant Loading Rates* (lbs/acre)											
Parameter	Subwatershed										
	101	102	103	104	105	106	107	108	109	110	111
BOD	9.67	11.05	35.84	3.22	8.25	24.21	7.48	7.38	9.77	10.44	4.35
COD	908.50	578.41	458.55	320.82	98.53	341.44	112.67	190.96	243.47	226.17	318.79
TSS	68.77	81.55	236.73	35.90	55.86	163.98	77.66	51.26	77.99	86.66	47.66
TP	0.55	0.51	0.98	0.23	0.22	0.69	0.25	0.26	0.36	0.37	0.30
TN	9.40	5.61	6.98	2.90	1.58	4.78	1.59	1.76	2.34	2.41	1.83
Pb	0.06	0.07	0.18	0.02	0.04	0.12	0.03	0.04	0.05	0.06	0.03
Cu	0.02	0.02	0.03	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Zn	0.43	0.33	0.50	0.16	0.11	0.35	0.11	0.14	0.18	0.19	0.17
Runoff Volume (in)	24.73	17.16	17.57	9.25	3.96	12.75	4.36	6.20	8.16	8.03	9.55
<i>*based on EMCs, land use, and runoff volumes</i>											

¹ Applying a forest EMC to large lot residential areas may be inappropriate if the building envelope or homestead is adjacent to a stream, reducing the buffering benefit of undisturbed land.

Table 4.4

Spruce Run Build Out Average Annual Stormwater Runoff Pollutant Loads* (lbs)											
Parameter	Subwatershed										
	101	102	103	104	105	106	107	108	109	110	111
BOD	7,211	763	4,539	2,806	5,478	6,635	4,782	11,560	6,120	42,104	15,491
COD	677,661	39,939	58,075	279,436	65,454	93,562	71,980	298,973	152,580	911,877	1,135,363
TSS	51,296	5,631	29,981	31,267	37,113	44,933	49,614	80,249	48,874	349,382	169,739
TP	409	35	124	202	149	188	157	410	223	1,487	1,079
TN	7,015	387	884	2,524	1,052	1,310	1,014	2,753	1,469	9,710	6,506
Pb	41	5	23	20	28	33	22	61	32	227	105
Cu	14	1	4	5	5	6	3	13	6	40	22
Zn	319	23	64	137	76	96	69	221	116	758	603
Runoff Volume (MG)	501	32	60	219	72	95	76	263	139	879	923
<i>*based on EMCs, land use, and runoff volumes</i>											

Table 4.5

Spruce Run Existing Land Use Conditions vs. Build Out Land Use Conditions - Percent Change in Loading Rate and Load											
Parameter	Subwatershed										
	101	102	103	104	105	106	107	108	109	110	111
BOD	146.0%	161.3%	94.8%	-35.3%	158.5%	-22.5%	-28.9%	-17.8%	-49.9%	-36.1%	-63.6%
COD	4.0%	7.9%	29.6%	3.9%	82.5%	5.9%	0.6%	-4.0%	-12.6%	1.7%	-3.3%
TSS	67.6%	78.6%	26.4%	-41.9%	124.1%	-57.2%	-37.4%	-47.7%	-67.1%	-54.6%	-69.2%
TP	28.5%	39.8%	53.1%	-11.1%	121.9%	-23.2%	-21.0%	-17.3%	-41.4%	-26.6%	-35.9%
TN	11.0%	25.1%	71.7%	-3.9%	134.4%	-10.9%	-18.2%	-9.8%	-36.0%	-21.4%	-34.6%
Pb	105.4%	93.3%	121.9%	14.4%	151.5%	89.1%	9.5%	35.3%	13.0%	27.3%	2.4%
Cu	43.7%	72.6%	144.1%	0.6%	161.5%	64.9%	-2.3%	25.3%	-1.2%	10.5%	-16.6%
Zn	17.9%	29.4%	73.2%	3.2%	123.9%	24.7%	-2.0%	5.3%	-12.8%	2.9%	-10.4%
Runoff Volume	7.1%	12.4%	41.6%	6.4%	92.0%	25.5%	7.2%	2.3%	-5.2%	11.4%	1.2%
<i>*based on EMCs, land use, and runoff volumes; the percent change in load and loading rates is the same since the difference is a constant factor, the subwatershed area, which does not change.</i>											

4.4 Mulhockaway Creek Existing Land Use Conditions

The calibrated model for the Mulhockaway Creek study area was used to simulate stormwater runoff and quality for existing land use conditions. The pollutant loading rates and annual pollutant loads for the Spruce Run study area existing conditions simulation are presented in Tables 4.6 and 4.7. The results are discussed in detail in Section 4.5.

Table 4.6

Mulhockaway Creek Existing Conditions Average Annual Stormwater Runoff Pollutant Loading Rates* (lbs/acre)								
Parameter	Subwatershed							
	202	203	204	205	206	207	208	209
BOD	14.13	23.27	16.08	12.46	22.44	8.17	10.87	19.09
COD	343.78	383.52	332.68	145.06	384.93	156.37	175.93	508.08
TSS	179.72	247.08	172.55	147.44	234.75	100.28	111.60	282.76
TP	0.49	0.75	0.55	0.37	0.72	0.28	0.34	0.74
TN	4.45	4.65	3.51	2.25	4.43	1.68	2.12	4.71
Pb	0.04	0.08	0.05	0.03	0.07	0.02	0.04	0.02
Cu	0.01	0.02	0.01	0.01	0.02	0.00	0.01	0.01
Zn	0.21	0.31	0.23	0.13	0.29	0.10	0.14	0.26
Runoff Volume (in)	10.13	12.70	10.32	4.79	12.11	4.64	5.61	13.56
Subwatershed								
Parameter	211	212	213	214	215	216	217	218
BOD	10.98	15.84	16.56	29.31	10.27	16.40	9.77	6.19
COD	209.86	241.73	203.82	303.92	143.34	234.37	850.62	913.96
TSS	132.72	209.33	191.83	347.84	121.59	238.77	163.77	101.90
TP	0.38	0.54	0.49	0.84	0.32	0.53	0.64	0.55
TN	2.24	3.16	3.00	5.09	1.94	3.47	8.41	8.87
Pb	0.03	0.04	0.04	0.07	0.03	0.03	0.04	0.03
Cu	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zn	0.14	0.19	0.17	0.28	0.12	0.16	0.39	0.39
Runoff Volume (in)	6.42	8.14	6.54	9.93	4.77	7.09	23.63	24.62
<i>*based on EMCs, land use, and runoff volumes</i>								

Table 4.7

Mulhockaway Creek Existing Conditions Average Annual Stormwater Runoff Pollutant Loads* (lbs)								
Parameter	Subwatershed							
	202	203	204	205	206	207	208	209
BOD	3,342	14,638	13,287	22,070	14,954	9,264	28,201	3,663
COD	81,319	241,239	274,968	256,982	256,487	177,363	456,440	97,472
TSS	42,512	155,415	142,616	261,194	156,421	113,741	289,548	54,244
TP	116	472	455	653	477	315	878	141
TN	1,052	2,927	2,902	3,979	2,949	1,905	5,511	904
Pb	9	50	44	56	47	22	91	4
Cu	2	10	10	11	10	5	20	2
Zn	50	194	194	226	195	118	360	50
Runoff Volume (MG)	65	217	232	230	219	143	396	71
Subwatershed								
Parameter	211	212	213	214	215	216	217	218
BOD	12,207	13,132	14,246	12,614	1,510	2,386	6,509	6,205
COD	233,273	200,428	175,315	130,802	21,083	34,105	566,853	915,855
TSS	147,524	173,559	164,996	149,703	17,884	34,745	109,135	102,113
TP	420	445	421	360	47	77	430	546
TN	2,485	2,620	2,579	2,189	286	506	5,606	8,892
Pb	33	36	36	29	4	4	23	28
Cu	7	6	8	6	1	1	7	12
Zn	161	158	148	119	17	24	257	388
Runoff Volume (MG)	194	183	153	116	19	28	428	670
<i>*based on EMCs, land use, and runoff volumes</i>								

4.5 Mulhockaway Creek Build Out Land Use Conditions

The build out land use scenario was incorporated into the SWMM model for the Mulhockaway Creek study area to assess the potential impacts of development. The pollutant loading rates and annual pollutant loads for the Spruce Run study area build out conditions are presented in Tables 4.8 and 4.9 and compared to existing conditions in Table 4.10.

Table 4.8

Mulhockaway Creek Build Out Average Annual Stormwater Runoff Pollutant Loading Rates* (lbs/acre)								
Subwatershed								
Parameter	202	203	204	205	206	207	208	209
BOD	13.92	28.89	20.75	6.20	24.91	6.04	10.11	19.13
COD	349.11	409.48	364.12	134.12	420.19	155.92	190.27	511.05
TSS	174.85	240.10	182.31	54.88	186.30	67.33	74.83	283.90
TP	0.49	0.84	0.64	0.22	0.75	0.23	0.32	0.74
TN	4.46	5.57	4.31	1.44	5.02	1.43	2.15	4.73
Pb	0.04	0.12	0.08	0.03	0.11	0.02	0.05	0.02
Cu	0.01	0.02	0.02	0.01	0.02	0.00	0.01	0.01
Zn	0.22	0.38	0.30	0.11	0.37	0.10	0.16	0.26
Runoff Volume (in)	10.39	14.28	11.87	4.84	14.28	4.81	6.54	13.67
Subwatershed								
Parameter	211	212	213	214	215	216	217	218
BOD	6.92	8.88	8.54	41.93	12.77	16.62	9.35	6.52
COD	204.25	234.88	189.02	401.03	167.14	258.37	854.08	915.45
TSS	78.38	110.89	77.54	396.19	80.95	247.34	158.96	88.81
TP	0.29	0.38	0.31	1.11	0.35	0.56	0.64	0.54
TN	1.72	2.29	1.96	7.30	2.47	3.63	8.38	8.94
Pb	0.03	0.04	0.04	0.14	0.06	0.03	0.04	0.04
Cu	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01
Zn	0.13	0.17	0.15	0.44	0.18	0.18	0.39	0.40
Runoff Volume (in)	6.46	8.38	6.53	14.38	6.35	8.03	23.80	24.85
<i>*based on EMCs, land use, and runoff volumes</i>								

Table 4.9

Mulhockaway Creek Build Out Average Annual Stormwater Runoff Pollutant Loads* (lbs)								
Parameter	Subwatershed							
	202	203	204	205	206	207	208	209
BOD	3,293	18,175	17,149	10,988	16,595	6,856	26,232	3,669
COD	82,579	257,567	300,956	237,603	279,981	176,850	493,644	98,041
TSS	41,359	151,023	150,689	97,227	124,135	76,369	194,142	54,463
TP	116	526	530	397	498	262	830	142
TN	1,054	3,506	3,565	2,558	3,346	1,620	5,572	908
Pb	9	75	68	59	75	25	129	4
Cu	2	15	14	10	16	5	26	2
Zn	51	242	244	199	246	116	422	50
Runoff Volume (MG)	67	244	266	233	258	148	461	71
Mulhockaway Creek Build Out Average Annual Stormwater Runoff Pollutant Loads* (lbs)								
Parameter	Subwatershed							
	211	212	213	214	215	216	217	218
BOD	7,694	7,359	7,346	18,045	1,878	2,418	6,231	6,534
COD	227,040	194,744	162,578	172,596	24,584	37,597	569,159	917,355
TSS	87,125	91,939	66,692	170,513	11,907	35,992	105,933	88,996
TP	321	318	264	478	51	82	427	543
TN	1,908	1,900	1,685	3,143	363	529	5,586	8,960
Pb	32	37	36	60	9	4	24	36
Cu	6	5	7	12	2	1	7	13
Zn	148	145	129	189	26	26	258	399
Runoff Volume (MG)	195	189	153	168	25	32	431	676
<i>*based on EMCs, land use, and runoff volumes</i>								



Table 4.10

Mulhockaway Creek Existing Land Use Conditions vs. Build Out Land Use Conditions - Percent Change in Loading Rate and Load+								
Subwatershed								
Parameter	202	203	204	205	206	207	208	209
BOD	-1.5%	24.2%	29.1%	-50.2%	11.0%	-26.0%	-7.0%	0.2%
COD	1.5%	6.8%	9.5%	-7.5%	9.2%	-0.3%	8.2%	0.6%
TSS	-2.7%	-2.8%	5.7%	-62.8%	-20.6%	-32.9%	-33.0%	0.4%
TP	-0.1%	11.6%	16.7%	-39.2%	4.4%	-16.9%	-5.6%	0.6%
TN	0.2%	19.8%	22.9%	-35.7%	13.4%	-15.0%	1.1%	0.4%
Pb	6.0%	49.1%	53.7%	6.1%	58.6%	10.6%	41.5%	1.9%
Cu	2.6%	52.3%	49.8%	-11.0%	49.8%	-1.2%	30.0%	0.0%
Zn	2.3%	24.3%	26.1%	-11.9%	25.8%	-1.8%	17.2%	0.7%
Runoff Volume	2.6%	12.4%	15.0%	1.1%	17.9%	3.7%	16.5%	0.9%
Subwatershed								
Parameter	211	212	213	214	215	216	217	218
BOD	-37.0%	-44.0%	-48.4%	43.1%	24.3%	1.3%	-4.3%	5.3%
COD	-2.7%	-2.8%	-7.3%	32.0%	16.6%	10.2%	0.4%	0.2%
TSS	-40.9%	-47.0%	-59.6%	13.9%	-33.4%	3.6%	-2.9%	-12.8%
TP	-23.5%	-28.5%	-37.4%	32.9%	8.1%	6.0%	-0.7%	-0.6%
TN	-23.2%	-27.5%	-34.6%	43.6%	27.0%	4.6%	-0.4%	0.8%
Pb	-2.6%	3.5%	1.1%	105.2%	128.8%	13.2%	1.6%	26.7%
Cu	-13.8%	-14.5%	-14.2%	98.0%	124.7%	0.0%	-0.8%	12.7%
Zn	-8.2%	-8.1%	-13.0%	59.0%	54.2%	9.4%	0.4%	2.9%
Runoff Volume	0.6%	2.9%	-0.1%	44.9%	33.2%	13.2%	0.7%	0.9%
<i>*based on EMCs, land use, and runoff volumes; + the percent change in load and loading rates is the same since the difference is a constant factor, the subwatershed area, which does not change.</i>								

4.6 Results

The potential impacts of stormwater runoff pollutant loadings of the build out scenario are better assessed by individually discussing results for each parameter. Increases in stormwater runoff pollutant loadings may trigger concern or even proactive, preventive or remedial actions, especially if that pollutant has been identified as a pollutant of concern within the watershed or water quality concentrations have exceeded or threatened to exceed standards.

4.6.1 Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) measures the amount of oxygen necessary to assimilate organic compounds in water. Higher BOD concentrations and loads decrease the amount of available dissolved oxygen (DO) and may lead to anaerobic conditions. Low levels of DO can result in fish kills and unpleasant aesthetic

properties, such as foul odor and taste. The primary source of BOD in receiving waters is organic matter.

Dissolved oxygen and BOD are not identified as water quality concerns for any of the streams within either study area². At this time, BOD does not pose a significant threat to the health of the watershed.

4.6.1.1 BOD: Existing Conditions Spruce Run

The simulation of the Spruce Run study area with existing land use conditions estimates that the total BOD load is approximately 81 tons per year. As shown in Figure 4.1, subwatershed 106 contributes the highest BOD loadings on a per acre basis. Those subwatersheds closest to the reservoir have the lowest loading rates and account for little of the total BOD load. Three of these watersheds (102, 104, and 105) have greater than 50 percent of their land use in forest, which contributes minor amounts of BOD (1 mg/l or 0.28lb/acre/inch of runoff).

4.6.1.2 BOD: Build Out Spruce Run

Simulation of the Spruce Run study area under build out land use conditions revealed that BOD loadings are likely to decrease in most of the subwatersheds, with the exception of subwatersheds 101, 102, 103 and 105, as shown in Figure 4.2. Under build out land use conditions, the total annual BOD load from the study area was simulated to be approximately 54 tons. While there is an overall reduction of 34% (approximately 27 tons), BOD is predicted to increase in areas closest to the reservoir. The overall decrease in BOD can be attributed to the reduction in agricultural land and the increase in large lot residential land use. Large lot residential land acts more like forested land than urban land, and therefore contributes lower pollutant concentrations than the original land use type (forested land contributes only 5 percent of the BOD load that agriculture does on a per acre basis). The largest increase in BOD loading rate (161%) was found in subwatershed 102. Subwatersheds 101, 103 and 105 experienced average annual BOD loading rate increases of 146%, 95%, and 158%, respectively. The common characteristic among these subwatersheds at build out is an increase in urban and residential land use through a reduction in primarily forested area. This pattern differed from the other subwatersheds where BOD loading rates were reduced because the large lot residential land use increased through a reduction in agricultural land use. These results suggest that additional zoning regulations or re-zoning may be needed to prevent urbanization from occurring in areas closest to the reservoir to prevent increases in local (near-reservoir) BOD loads.

4.6.1.3 BOD: Existing Conditions Mulhockaway

The simulation of the Mulhockaway Creek study area with existing land use conditions indicates that the total BOD load is approximately 89 tons per year. The Mulhockaway Creek study area contributes an average of 1 pound per acre more BOD annually (approximately 8 tons) to the reservoir than the Spruce Run study area.

² Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

Under existing land use conditions, subwatersheds 203, 206 and 214 contribute the greatest amount of BOD load on a per acre basis within the Mulhockaway Creek study area, as shown in Figure 4.3.

4.6.1.4 BOD: Build Out Mulhockaway

Simulation of the Mulhockaway Creek study area under build out land use conditions revealed that BOD loadings decrease in about half of the subwatersheds. Under build out land use conditions, the total annual BOD load from the study area was approximately 80 tons. The overall change across the study area results in a 10% reduction in annual BOD load, or approximately 1.36 pounds per acre. The areas with significant increases in annual BOD loading (greater than 20%) are subwatersheds 203, 204, 214 and 215. A common trend among these subwatersheds was an increase in urban land uses through the reduction of forested, recreational, and open land uses, similar to the Spruce Run subwatersheds that exhibited the largest percentage increases in annual BOD loading. Subwatershed 214, projected to experience a 43% percent increase in annual BOD loading, had a 27% conversion to urban land use. Prior to build out, approximately 50% of this subwatershed (214) was forested, recreational or open land use; following build out that portion was reduced to 27%. By contrast, those subwatersheds projected to experience increases in urban land use through the reduction of agricultural land use, did not experience BOD increases of the same magnitude, although their BOD loadings did increase. The average annual BOD loading rates under build out land use conditions are presented in Figure 4.4.

4.6.2 Chemical Oxygen Demand

Chemical oxygen demand (COD) measures the amount of oxygen required to oxidize organic compounds in water. Dissolved oxygen, and thus COD, is not a water quality issue of concern for any of the streams within the study area³. At this time, COD does not pose a significant threat to the health of the watershed. EMCs for COD range from 100 mg/l for urban land uses to 220 mg/l for agricultural crops.

4.6.2.1 COD: Spruce Run Existing Conditions

The simulation of the Spruce Run study area with existing land use conditions predicts a total COD load of approximately 1,880 tons. As shown in Figure 4.6, subwatersheds 101, 102 and 103 contribute the highest COD loadings on a per acre basis of 910, 580, and 460 lbs/acre, respectively. These subwatersheds are located adjacent to the reservoir.

4.6.2.2 COD: Spruce Run Build Out

The simulated average annual COD runoff loading under build out conditions was similar to existing conditions, with a total COD load of approximately 1,890 tons per year. The average annual COD loading rates under build out land use conditions are shown in Figure 4.7. The largest increases to COD loading rates occurred in subwatersheds 103 and 105, with increases of 30% and 83%, respectively. As with

³ Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

BOD, the largest increases to COD loading rates occurred in subwatersheds closest to the reservoir. In addition, the subwatersheds with the highest overall COD loading rates in both the existing and build out land use conditions are those that neighbor the reservoir. Subwatershed 111 contributes the largest load of COD of 590 tons.

4.6.2.3 COD: Mulhockaway Existing Conditions

The simulation of the Mulhockaway Creek study area with existing land use conditions indicates a total COD load of approximately 2,060 tons. The Mulhockaway Creek study area contributes an average of 27 pounds per acre more COD annually (approximately 182 tons) to the reservoir than the Spruce Run study area. As shown in Figure 4.8, subwatersheds 217 and 218 provide direct runoff to the Spruce Run Reservoir and contribute the highest amounts (total and per acre) of COD within the study area. Since dissolved oxygen is not a water quality concern for the Mulhockaway Creek study area, COD does not pose a significant threat to the health of the watershed.

4.6.2.4 COD: Mulhockaway Build Out

The simulated average annual COD load under build out conditions in the Mulhockaway Creek study area was estimated to be 2,120 tons, an increase of 56 tons compared to existing land use. The simulated average annual COD subwatershed runoff loadings differed little from existing conditions (less than a 10% increase or reduction for all but 3 subwatersheds). Subwatersheds 214, and 215 have projected increases of 32% and 17%, respectively. These subwatersheds are projected to experience the greatest increase in urban land use (220% and 147%, respectively) through the reduction of forested and agricultural land uses. Although COD concentrations in urban land use are generally lower than concentration in agricultural or forest runoff, the increased runoff volume generated from the urban land use results in increased COD loadings. Dissolved oxygen concentrations are not likely to be depleted through increased COD loading under build out zoning. COD loads are not and should not become a water quality issue in the Mulhockaway study area.

4.6.3 Total Suspended Solids

The total suspended solids (TSS) measurement estimates the amount of sediment loading to a receiving water body. TSS runoff concentrations are typically larger in high production agricultural crop lands and may diminish over the long term through urbanization. Development and construction activities associated with urbanization also contribute high levels of TSS to stormwater runoff. The impacts of elevated TSS concentrations are manifested in streams, rivers, ponds and reservoirs by the deposition of silt, decreased macroinvertebrate diversity in the streams, and impaired habitat for fish spawning. TSS loadings contribute to the decline of submerged aquatic vegetation (SAV) by increasing turbidity and reducing the light available for photosynthesis. In addition, TSS loads can act as either sinks or sources of nutrients and toxicants through adsorption and desorption. High TSS loadings also can damage

or destroy natural aquatic habitats by in-filling and eliminating habitat space between rocks and other features.

TSS is not a pollutant of concern in either the Spruce Run or the Mulhockaway Creek study areas⁴. However, elevated concentrations of TSS magnify the impacts of some pollutants that are of concern as they are desorbed from the particles. The Spruce Run is classified as a trout stream, and is subject to surface water criteria of 25 mg/L for TSS. Water quality data from USGS water quality gage 01396588 lists suspended sediment concentrations at a maximum of 9 mg/L. These measurements were taken during periods of low flow, and therefore may not represent the concentrations found in stormwater runoff. Stream concentrations of TSS may be higher than the data suggest during and following storm events.

4.6.3.1 TSS: Spruce Run Existing Conditions

The annual TSS load for the Spruce Run study area under existing land use conditions is approximately 967 tons. As shown in Figure 4.11, subwatershed 106 contributes the highest TSS loadings on a per acre basis. Those subwatersheds closest to the reservoir have the lowest loading rates and account for little of the total TSS load. Three of these watersheds (102, 104, and 105) have greater than 50 percent of their land use in forest, which contributes minor amounts of TSS (40 mg/l or 9lb/acre/inch of runoff).

4.6.3.2 TSS: Spruce Run Build Out

The simulation of build out conditions estimated that the total suspended solids load from the Spruce Run study area would be 449 tons, a reduction of 518 tons or 54% of the load from existing conditions. The load changes were similar to those predicted for BOD. TSS loading rates under build out land use conditions are shown in Figure 4.12. The large reduction can be attributed to the conversion of agricultural land uses to large lot residential developments. Subwatersheds 101,102,103, and 105 would experience increases of 68%, 79%, 26% and 124%, respectively, while subwatersheds 106 and 109, the two subwatersheds with the largest loading rates (per acre) of TSS in existing conditions, experience reductions of 57% and 67%, respectively. The transformation from agricultural land use to large lot residential land use results in reduced in TSS loadings while the transformation of non-developed or open land uses to urban land use results in increased TSS loadings. Total suspended solid concentrations do not pose a serious threat to the health of the watershed under build out because the total load is reduced by 54% from 967 tons to 450 tons.

4.6.3.3 TSS: Mulhockaway Existing Conditions

The Mulhockaway Creek study area under existing land use conditions produces an annual TSS load of approximately 1,060 tons, which is an average of 14 pounds per acre more TSS annually (approximately 91 tons) than the Spruce Run study area. The estimated annual TSS loadings are shown in Figure 4.13.

⁴ Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

Total suspended solids loadings are not a concern for the Mulhockaway Creek study area under existing land use conditions. The maximum suspended sediment concentration found in the water quality data from USGS water quality station 01396660, Mulhockaway Creek at Van Syckel, was 19 mg/L, below the 25 mg/L surface water quality criteria for trout streams. Also, the existing water quality data reflect low flow conditions. The sample with the 19 mg/L TSS concentration coincided with the largest flow rate of any samples analyzed for TSS. The Mulhockaway Creek may experience larger suspended sediment concentrations during wet weather and may be in excess of the surface water quality standards. Additional wet weather sampling is needed to assess such conditions. Also, the subwatersheds with the largest total suspended solids loading rates (per acre) are located downstream of the monitoring location, possibly providing larger sediment loads to the reservoir than indicated from sampling data.

4.6.3.4 TSS: Mulhockaway Build Out

The simulation of build out conditions estimated that total suspended solids loading from the Mulhockaway Creek study area would be 774 tons, a reduction of 283 tons or 27% of the existing conditions. The changes in load were similar to those simulated for BOD. TSS loading rates under build out land use conditions are shown in Figure 4.14. Of the 4 subwatersheds with projected increases in annual TSS loading rate, subwatershed 214 had the largest increase of 14%; others were increased by less than 6%. Subwatershed 214 is expected to experience a large increase in urban land use through the reduction of forested areas (about 60 acres). The greatest reduction in TSS loading rates, approximately 63%, was from subwatershed 205, where a large portion of agricultural land was converted to large lot residential development. The majority of a large residential lot remains in forested or open space land use with lower TSS loading rates than agricultural or urban land uses. Total suspended solids are not a threat to the health of the watershed under these build out conditions, and are reduced under the build out scenario.

4.6.4 Phosphorus

Phosphorus is an important nutrient that serves as a limiting factor for biological activity. Increased concentrations of phosphorus in a waterbody contribute to eutrophication (over-enrichment of nutrients) and algal blooms. Algal blooms contribute to the decline of SAV and aquatic species by reducing the light available for photosynthesis, and decreasing the level of DO available to support aquatic species, and may cause changes in the population of plankton and fish species. Algae are also a major cause of taste and odor problems for drinking water suppliers and produce toxic compounds that are released into the water. Major sources of phosphorus in stormwater runoff include fertilizers and industrial products. Agricultural crop fields and treated lawns are two of the more common land uses that contribute to the total phosphorus loading in runoff.

4.6.4.1 Phosphorus: Spruce Run Existing Conditions

Phosphorus has been identified as a pollutant of concern in the Spruce Run⁵. While average phosphorus concentrations have decreased along with other nutrients, violations of the phosphorus water quality standard are still observed. Approximately 32% of the water quality samples from the Spruce Run (1991-1997) exceeded the 0.05 mg/L criteria.

The annual phosphorus load from the Spruce Run study area under existing land use conditions is approximately 5,750 pounds. As shown in Figure 4.16, subwatershed 106 exhibits the greatest phosphorus loading rate on a per acre basis. Almost 50% of the existing land use within this subwatershed is agricultural. Runoff from agricultural land uses, whether crop or pasture land, has the highest loading rate for phosphorus (500 or 295 mg/l, respectively) of all the land uses.

4.6.4.2 Phosphorus: Spruce Run Build Out

Under build out land use conditions, the estimated annual phosphorus load from the Spruce Run study area is approximately 4,450 pounds, a reduction of 1,300 pounds (22%) from existing conditions. The results from the model simulation of build out land use conditions for phosphorus loading are shown in Figure 4.17. Total phosphorus loadings increased in subwatersheds 101, 102, 103 and 105, where forested areas are replaced by urban land use. The total phosphorus loading rate for subwatershed 103, the second largest rate under existing conditions, increased by 53%. The largest increase was observed in subwatershed 105, where the total phosphorus loading rate was 122% higher in build out conditions due to a greater than 50% reduction in forested land use.

Phosphorus is a pollutant of concern within the Spruce Run study area. Even though the total phosphorus load from the study area decreases for the build out conditions, the increased phosphorus load from individual drainage areas may result in instances of eutrophication in the waterways draining to the Spruce Run reservoir. Stormwater management and land use planning actions should be targeted at subwatersheds where predicted phosphorus loadings increase.

4.6.4.3 Phosphorus: Mulhockaway Existing Conditions

Phosphorus also is as a pollutant of concern for the Mulhockaway Creek⁴. Of water quality samples from USGS gage 01396660 between 1991 and 1997, 18% exceeded the water quality criterion for Mulhockaway Creek.

The Mulhockaway Creek study area under existing land use conditions contributes an annual phosphorus load of approximately 6,250 pounds, 500 pounds greater than the load from the Spruce Run study area (approximately equal on a per acre basis). As

⁵ Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

shown in Figure 4.18, phosphorus loadings on a per acre basis are larger for subwatersheds located closer to the reservoir.

4.6.4.4 Phosphorus: Mulhockaway Build Out

The simulation of the Mulhockaway Creek study area under build out land conditions predicts an annual phosphorus load of approximately 5,780 pounds, a reduction of 470 pounds (8%) from existing conditions. The reduction results from the conversion of agricultural land to large lot residential and urban land uses. The model results for phosphorus from build out land use conditions are presented in Figure 4.19. Subwatershed 214, which has the largest phosphorus loading rate for both existing and build out conditions, experiences an increase of over 30%. The urban land use in subwatershed 214 nearly triples from existing to build out conditions through the loss of forest, agricultural and mining land uses.

Phosphorus is a pollutant of concern for the Mulhockaway Creek study area. Although the simulated total phosphorus load from the study area decreases for the build out scenario, the increased phosphorus load from individual drainage areas may result in instances of eutrophication in the waterways draining to the Spruce Run reservoir. Stormwater management and land use planning actions should be targeted at subwatersheds where predicted phosphorus loadings increase.

4.6.5 Nitrogen

Like phosphorus, nitrogen contributes to eutrophication and algal blooms, decreased photosynthesis, and decreased DO. Typical sources of nitrogen loading in stormwater runoff are farm animal wastes, fertilizers and domestic sewage. Agricultural land uses and residential septic systems contribute much of the nitrogen to streams.

Nitrogen was not identified as a pollutant of concern for these waterbodies and observed total nitrogen concentrations were not trending upwards⁶. Thus, total nitrogen does not pose a significant threat to the health of the watershed at this time.

4.6.5.1 Nitrogen: Spruce Run Existing Conditions

The Spruce Run study area under existing land use conditions produces an annual nitrogen load of approximately 20 tons. As shown in Figure 4.21, subwatersheds 101, 102, 103 and 106 contribute the highest nitrogen loadings on a per acre basis. Although these subwatersheds are small in area, 101, 102 and 103 are adjacent to the Spruce Run reservoir and supply about 20 percent of the Spruce Run study area load to the reservoir.

4.6.5.2 Nitrogen: Spruce Run Build Out

Under build out land use conditions, the estimated the annual nitrogen load for the Spruce Run study area is 17 tons, a reduction of 15% across the study area. As shown in Figure 4.22, subwatersheds 101, 102, 103 and 105 experience increases in annual

⁶ Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

nitrogen loading rates, while the remaining subwatersheds experience decreases. The subwatersheds closest to the reservoir exhibit the highest nitrogen loading rates. These areas experience reductions of forested areas and increases in urban and large lot residential land uses.

4.6.5.3 Nitrogen: Mulhockaway Existing Conditions

The simulation of the Mulhockaway Creek study area under existing land use conditions indicates an annual nitrogen load of approximately 24 tons, ½ pound more than the Spruce Run study area on a per acre basis. As Figure 4.23 shows, the subwatersheds within the Mulhockaway Creek study area with the largest total nitrogen loading rates are those closest to the Spruce Run Reservoir. The water quality data available at USGS gage 01396660 do not reflect the pollutant loads in runoff from these areas; thus, their impacts on nitrogen concentrations in the reservoir cannot be fully assessed. Additional water quality sampling is required to determine if near-reservoir non-point nitrogen sources pose a threat to the reservoir, streams, or local water bodies.

4.6.5.4 Nitrogen: Mulhockaway Build Out

The simulation of the Mulhockaway Creek study area with build out land use conditions predicts an annual nitrogen load of 23 tons, about a 2% reduction. The subwatershed nitrogen loading rates are shown in Figure 4.24. Subwatershed 214 experiences the highest percent increase in loading rate, approximately 44%. Although subwatershed 214 experiences a small decrease in agriculture (the largest contributor of nitrogen) and a modest decrease in forested areas, the increases in runoff volume and urban land uses more than offset the reduction in nitrogen load. The build out scenario decreases nitrogen loads by over 20% in four subwatersheds (205, 211, 213 and 212), where large amounts agricultural lands are converted to large lot residential land use. While the overall trend of nitrogen loading was a slight decrease (2%), 10 of the 16 subwatersheds experience increases in nitrogen loading rates of 0.2% to 44%. Although nitrogen was not identified as a surface water quality problem for Mulhockaway Creek⁷, ammonia, a component of total nitrogen was. Stormwater management practices to control nitrogen loadings would help to protect the health of the watershed.

4.6.6 Lead

Lead poses a serious adverse health hazard to humans and wildlife. Some common sources of lead are from the scraping and painting of bridges and overpasses, and automobile related lead (batteries, tire wear, additives) found on roadways and parking lots. Stormwater runoff from urban areas carries lead to receiving waters and into the aquatic food chain. Once in the food chain, lead has the potential to bio-accumulate, or increase in concentration when consumed by bacteria and benthic organisms.

⁷ Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

4.6.6.1 Lead: Spruce Run Existing Conditions

Water quality data from gage USGS 01396588 shows that lead concentrations in the Spruce Run generally do not exceed the NJ Drinking Water Standard of 15 ug/L or the NJ Surface Water Quality Human Health Criteria for Freshwaters of 5 ug/L. One reading, out of 10 in data collected from 1991 through 1997, exceeded the 5 ug/L threshold with a concentration of 9 ug/L.

Under existing land use conditions the annual lead load from the Spruce Run study area is approximately 450 pounds. As Figure 4.26 shows, subwatershed 103 (over 13% urban) contributes the highest amount of lead annually on a per acre basis, and runoff pollutant concentrations from this subwatershed are not reflected in the water quality data from the USGS gage. Subwatershed 110 contributes almost 40% of the total lead load, approximately 178 pounds a year.

4.6.6.2 Lead: Spruce Run Build Out

For lead, the annual loading increased for all subwatersheds under the build out scenario. The simulation of build out conditions predicts that the overall lead load increases approximately 32% to 596 pounds per year. The average annual loading rates are presented in Figure 4.27. Subwatersheds 101, 103 and 105 more than doubled their average annual load, with increases of 105%, 122%, and 151%, respectively. Forested and pasture-agricultural land uses provide less than one-quarter the lead load than urban and residential land uses. Since lead has previously exceeded the NJ Surface Water Quality Human Health Criteria of 5 ug/L in the Spruce Run, these increases may cause exceedances of both drinking water and freshwater criteria in the study area.

4.6.6.3 Lead: Mulhockaway Existing Conditions

Lead is not a pollutant concern for the Mulhockaway Creek⁸. However, water quality records from USGS gage 01396660 indicate that lead concentrations have exceeded the surface water quality criterion. Additional surface water quality monitoring may be useful to better understand lead loads in the watershed.

The Mulhockaway Creek study area under existing land use conditions produces an annual lead load of approximately 517 pounds. As Figure 4.28 shows, subwatersheds 203, 206, and 214 have the largest lead loading rates (greater than 0.1 pounds/acre). The subwatershed responsible for the largest portion of the total annual load is 208, almost 20%.

4.6.6.4 Lead: Mulhockaway Build Out

Build out conditions for the Mulhockaway Creek study area produce an increased average annual lead load for all but one subwatershed, 211, which experiences a reduction in urban land use. The total load of lead increases approximately 32% to 682 pounds. As Figure 4.29 shows, subwatersheds 214 and 215 more than double their

⁸ Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

average annual loadings, with increases of 105% and 129%, respectively. Increases in non-point source lead load may create a water quality concern for the study area. Lead concentrations in the Mulhockaway Creek have exceeded surface water quality standards, so increases in lead loads may cause exceedances of both drinking water and freshwater criteria in the study area.

4.6.7 Copper

Copper is an important trace nutrient that can be bio-accumulated, and thus, a health threat. Elevated concentrations of copper can create toxic health hazards if accumulated in the food chain and increase long-term ecosystem stress. The primary anthropogenic sources of copper are anti-fouling paints on boat hulls and abrasion of copper pipes and brass fittings.

4.6.7.1 Copper: Spruce Run Existing Conditions

Copper is not a pollutant of concern for the study area. Although one sample in the late 1990s exceeded surface water quality standards, the one exceedance was insufficient evidence for listing⁹. The copper load from the Spruce Run study area with existing land uses is approximately 106 pounds. As figure 4.31 shows, the distribution of copper loading on a per acre basis is relatively uniform throughout the study area (~0.007 to ~0.009 lbs/acre). Subwatersheds closest to the reservoir contribute some of the larger loads on a per acre basis, but they do not contribute a significant portion of the total annual copper load.

4.6.7.2 Copper: Spruce Run Build Out

Build out conditions of the Spruce Run study area produce a 14% increase in average annual copper loadings of over existing conditions to 121 pounds. Copper loads increase as land is converted from other land uses to urban and residential land uses. As Figure 4.32 shows, the majority of the subwatersheds experience increased copper loading rates, the largest being 103 and 105 with increases of 144% and 161%, respectively. Both 103 and 105 nearly triple their urban land uses. The potential increase in the copper load may lead to further violations of surface water quality standards.

4.6.7.3 Copper: Mulhockaway Existing Conditions

Copper has not been identified as a pollutant of concern within the Mulhockaway Creek study area. Water quality data for Mulhockaway Creek shows that copper concentrations in the creek are relatively low. Existing water quality data indicate that copper has not posed a threat to the health of the Mulhockaway Creek watershed.

The existing conditions for the Mulhockaway Creek study area produce a total copper load of 117 pounds. As indicated in Figure 4.33, the subwatersheds that contribute the highest annual loadings of copper on a per acre basis are clustered around the Spruce

⁹ Surface Water Quality and Pollutant Loadings, A Technical Report for the Raritan Basin Watershed Management Project. August 2001. NJWSA

Run Reservoir. Copper, however, does not appear to pose a threat to the Mulhockaway Creek study area under existing conditions.

4.6.7.4 Copper: Mulhockaway Build Out

The simulation of build out conditions for the Mulhockaway Creek study area indicates that the total copper loading is 143 pounds per year, an increase of almost 22% over existing conditions. Subwatersheds 214 and 215 experience the greatest percent increase in annual loadings, 98% and 125%, respectively. Subwatershed 214 triples and 215 doubles their urban land uses under build out. While observed copper concentrations have not exceeded water quality standards, increases in the load may pose a threat to water quality in the study area.

4.6.8 Zinc

Zinc is the most commonly found toxic metal in the mid-Atlantic region¹⁰. The primary sources of zinc are the weathering and abrasion of galvanized iron and steel. Both agricultural and urban land uses can be major sources of zinc.

4.6.8.1 Zinc: Spruce Run Existing Conditions

Under existing land use conditions, the annual zinc load in the Spruce Run study area is approximately 2,390 pounds. In the Spruce Run watershed, zinc was not identified as a pollutant of concern. Water quality data indicate that zinc concentrations are well below the NJ Drinking Water Standard of 5,000 ug/L. At this time, zinc does not pose a major threat to the health of the watershed.

4.6.8.2 Zinc: Spruce Run Build Out

The simulation of the Spruce Run study area for build out conditions estimates an increased in the annual zinc load to 2,480 pounds, a 4% increase for the study area. Subwatershed 105 experiences the greatest increase, 124%. In subwatershed 105, forested area (0.07 mg/l zinc) is almost halved and urban use (0.16 mg/l zinc) is tripled. Since concentrations have not exceeded water quality standards in the past and the increase in total load is minor (4%), zinc should not become a threat to the water quality status of the Spruce Run.

4.6.8.3 Zinc: Mulhockaway Existing Conditions

The annual zinc load is approximately 2,660 pounds for the Mulhockaway Creek study area with existing land use conditions. Water quality data for gage 01396660 shows that zinc concentrations within the Mulhockaway Creek are well below drinking water quality standards. Zinc is not a pollutant of concern within the study area.

4.6.8.4 Zinc: Mulhockaway Build Out

Under build out land use conditions, the zinc load for the Mulhockaway Creek study area increases by 9% to 2,890 pounds. The largest subwatershed increases, 59% and

¹⁰ Chester County, Pennsylvania. Water Resources Compendium.

54%, were predicted for subwatersheds 214 and 215, respectively. Even with these increases, zinc does not appear to be a significant threat to water quality within the study area since the current water quality data is well below standards.

4.6.9 Runoff Volume

The volume of runoff discharged to a receiving water can adversely affect downstream conditions. Increased urbanization and impervious surface cover results in escalated runoff volumes and heightened peak flows. These conditions can destroy natural habitats, erode stream banks, increase sedimentation of lake and river beds and lead to serious and frequent flooding. Areas contributing high volumes of runoff are typically indicators of watershed problems. High runoff volumes generally mean reduced groundwater infiltration, which can impact the groundwater table, aquifer levels and result in reduced baseflow to streams.

4.6.9.1 Runoff: Spruce Run Existing Conditions

Figure 4.41 shows the simulated average annual runoff volumes for the Spruce Run study area under existing land use conditions. The runoff volume is represented as a depth (in inches per year) for comparison of runoff volumes generated from different size subwatersheds. The total annual runoff volume across the entire study area is 8.5 inches per year. Figure 4.43 displays the simulated average annual runoff volume for land uses other than water or wetlands (see discussion in Section 2.). The runoff volumes from water and wetlands were discounted so that the changes in runoff volumes generated from the other land use types in both existing and build out conditions would be evident (wetland and water runoff does not change between scenarios, muting the effect of land use changes). The average annual runoff volume across the non-water land uses is 4.5 inches per year.

4.6.9.2 Runoff: Spruce Run Build Out

Average annual runoff volumes across the entire study area will increase approximately 7% from existing to build out conditions, to 9.1 inches per year. The annual runoff volume when water and wetlands are not considered is 5.2 inches per year. The percent change for the non-water land uses is approximately 17%, 0.7 inches or 232 million gallons. This magnitude of increased runoff volume may result in stream erosion, additional sediment loading, habitat destruction and flooding. The results of the build out condition simulations are shown in Figures 4.42 and 4.44.

4.6.9.3 Runoff: Mulhockaway Existing Conditions

As shown in Figure 4.45, the largest stormwater runoff volumes relative to size within the study area appear are generated by the subwatersheds surrounding the Spruce Run Reservoir, particularly subwatersheds 218 and 217. These watersheds have large amounts of open water (the reservoir) and do not accurately reflect overland stormwater runoff volumes. The runoff depth over the entire study area was found to be 9.4 inches per year when volumes from water and wetland land uses were included in the calculations.

Figure 4.47 provides a more accurate depiction of the stormwater runoff volumes within the study area. In this figure, wetland and water land uses are not included in the runoff analysis. The depth when runoff from water and wetlands was not considered is 5.4 inches per year. As expected, subwatersheds with the highest percentage of urban land use contributed a large portion of the total annual runoff volume. Subwatersheds 203, 217, and 206 are responsible for the greatest annual runoff volumes on a per acre basis. The percentage of urban land use within subwatersheds 203 and 206 are greater than 30%, the highest of the subwatersheds in the study area.

4.6.9.4 Runoff: Mulhockaway Build Out

Average annual runoff flow volumes for the Mulhockaway study area are simulated to increase approximately 8% between existing and build out conditions to 10.1 inches per year. The annual runoff when water and wetlands are not considered is 6.2 inches per year. The percent change over the non-water land uses is approximately 16%, 0.8 inches or 254 million gallons. This increase in runoff volume could result in stream erosion, additional sediment loading, habitat destruction and flooding. The results of the build out conditions are shown in Figures 4.46 and 4.48

Figure 4.1

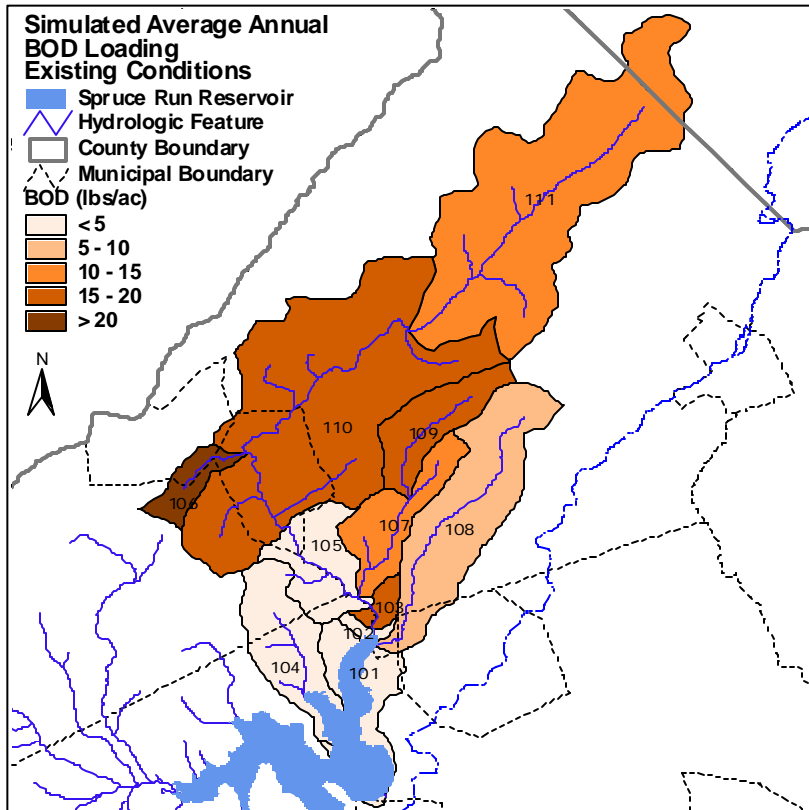


Figure 4.2

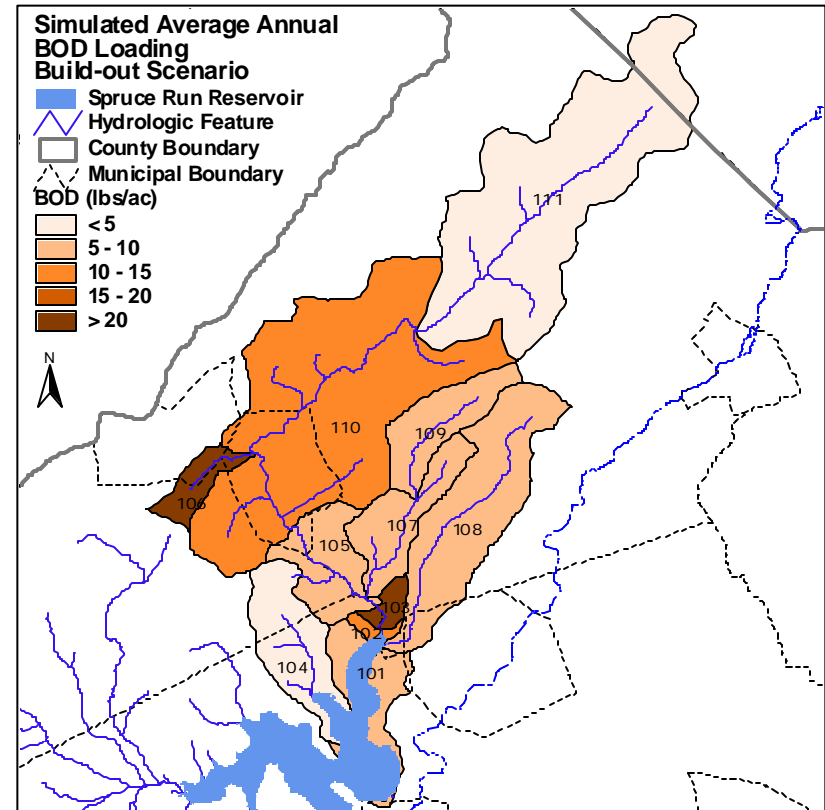


Figure 4.3

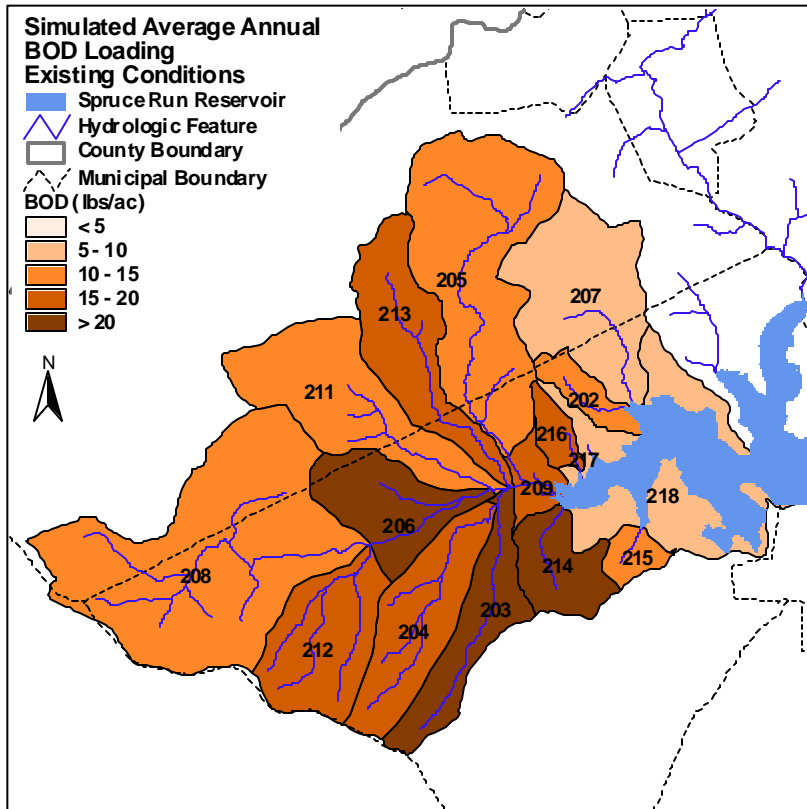


Figure 4.4

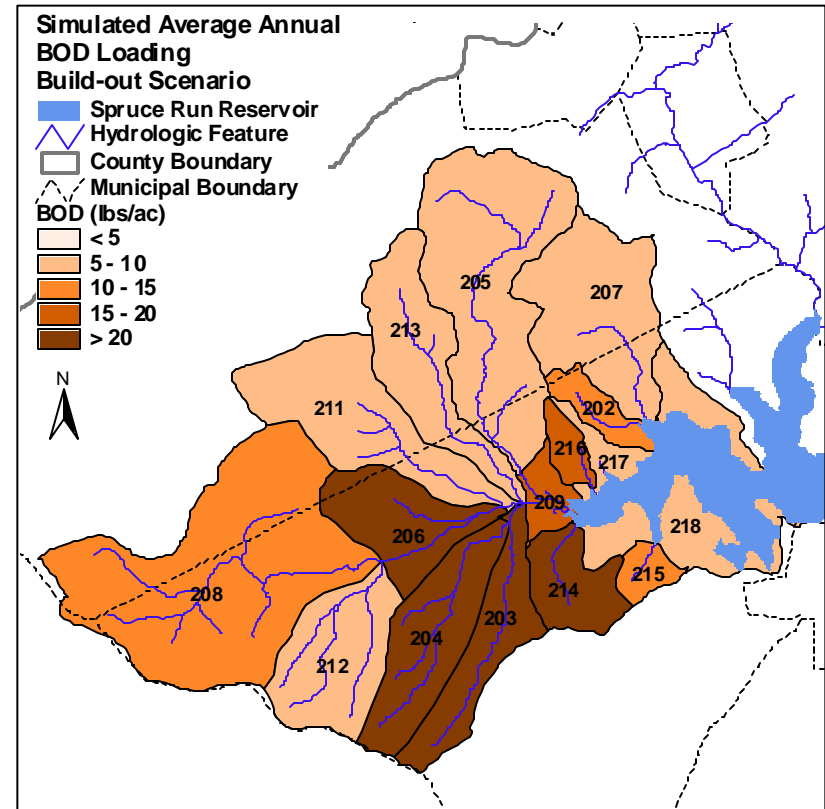


Figure 4.5

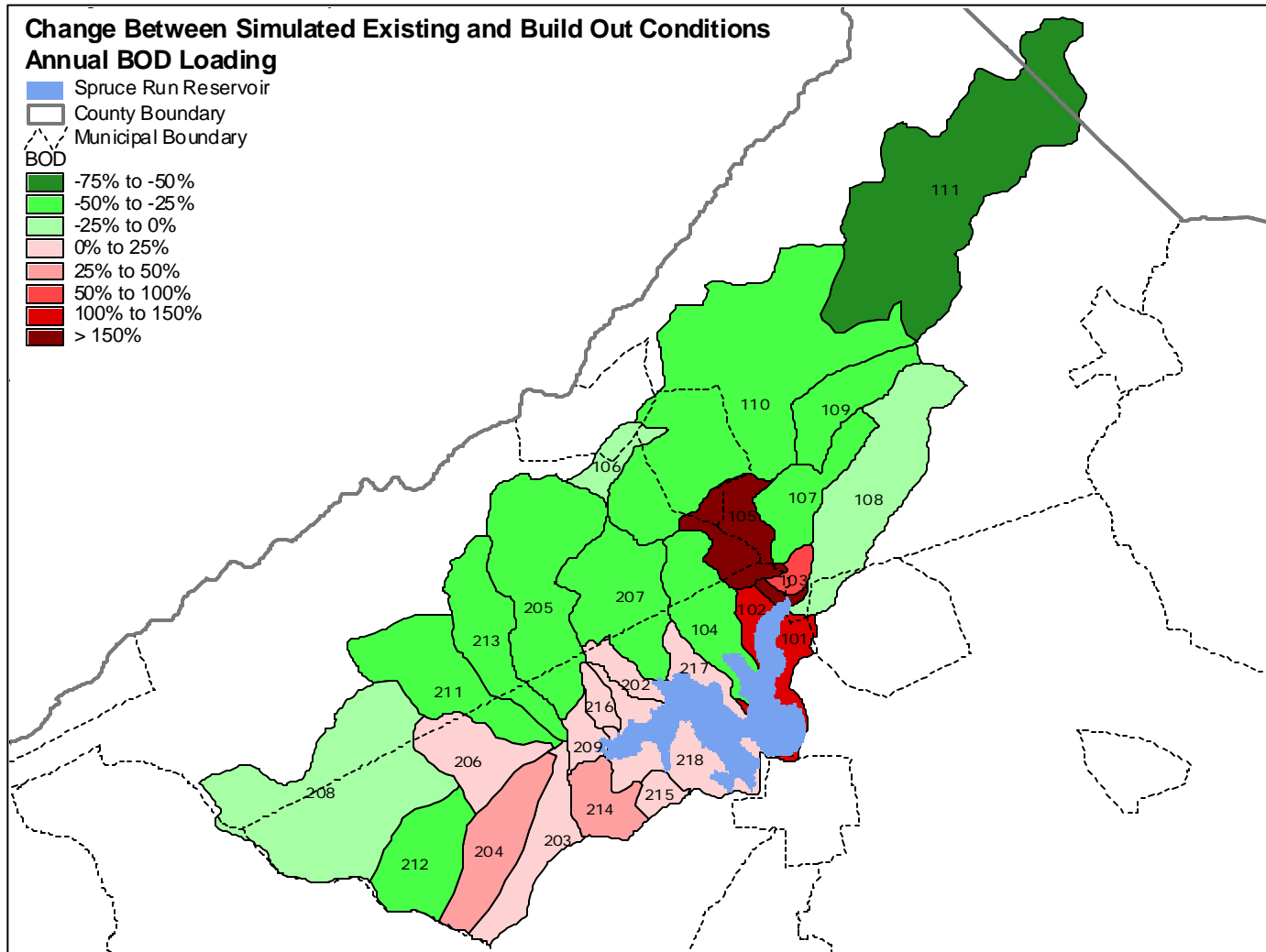


Figure 4.6

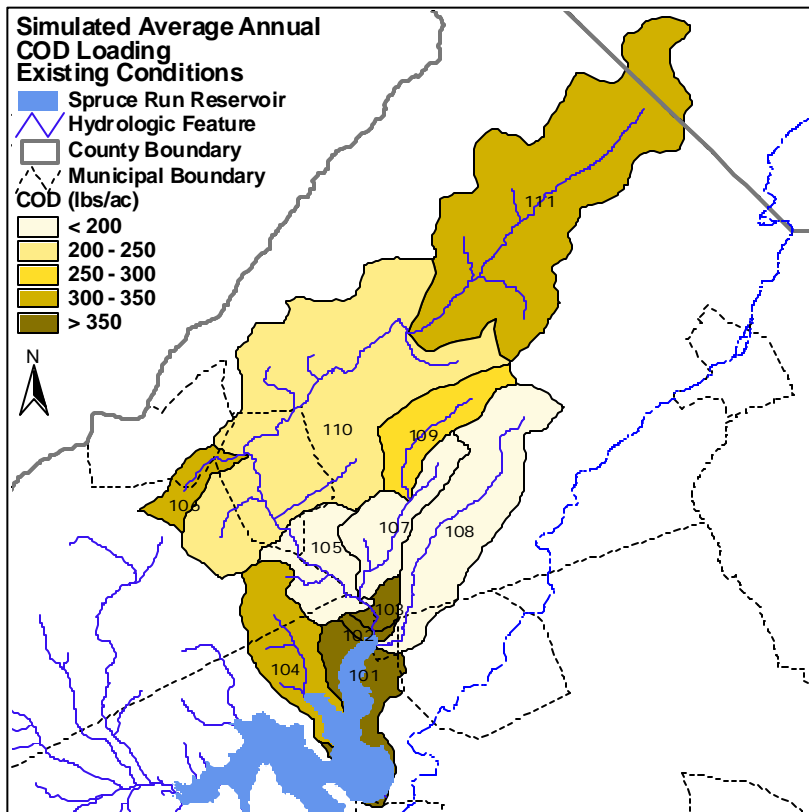


Figure 4.7

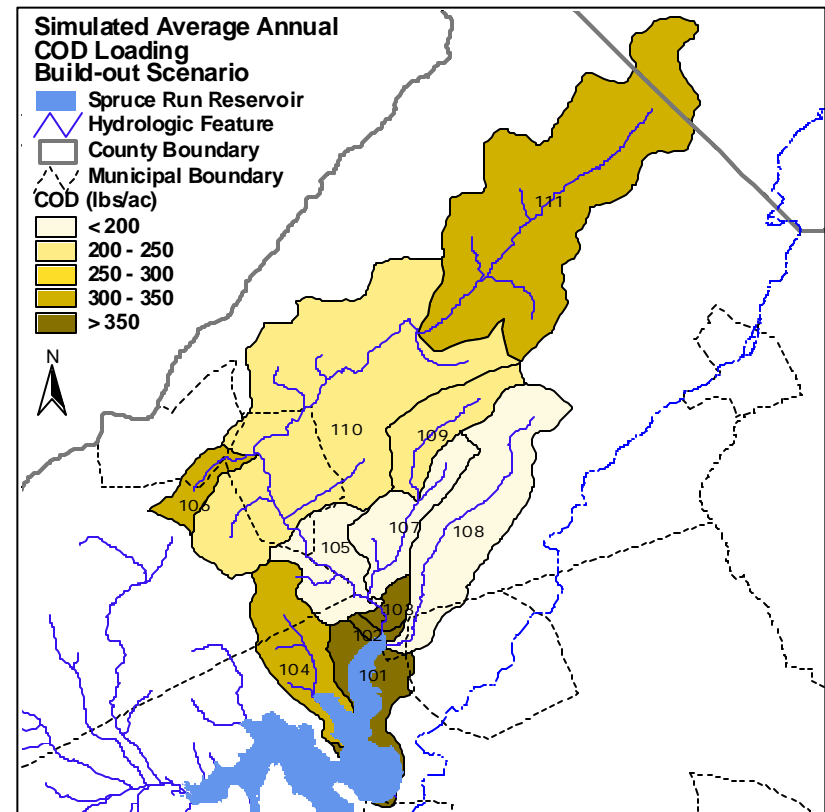


Figure 4.8

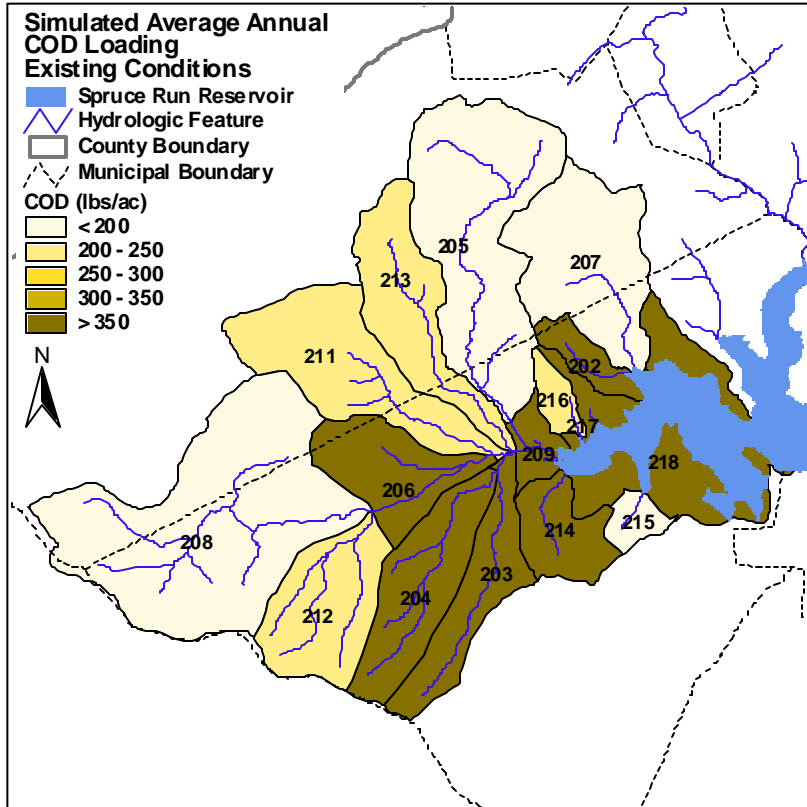


Figure 4.9

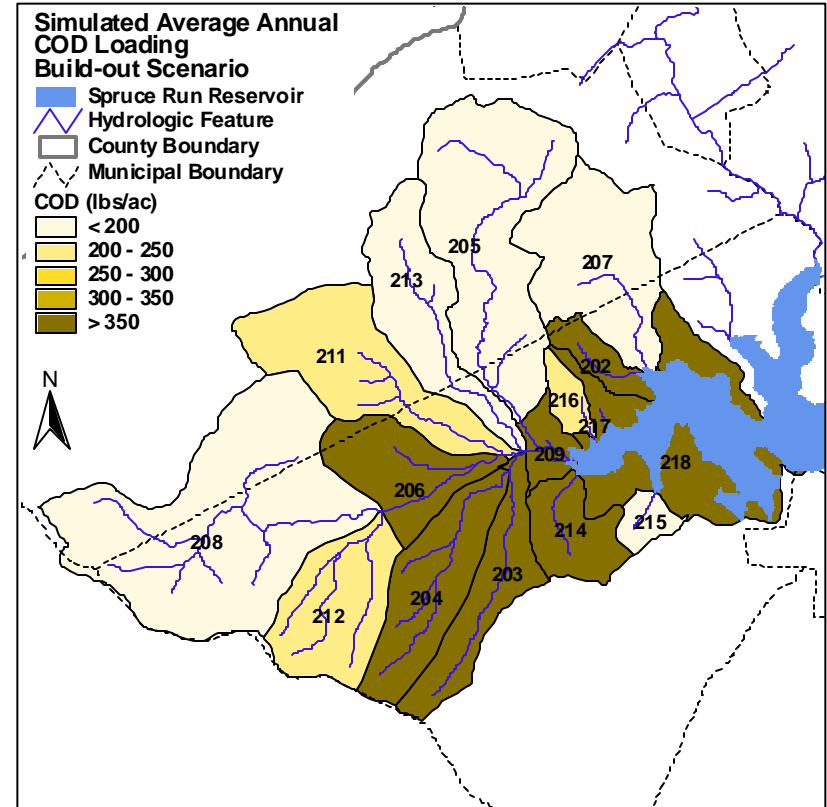


Figure 4.10

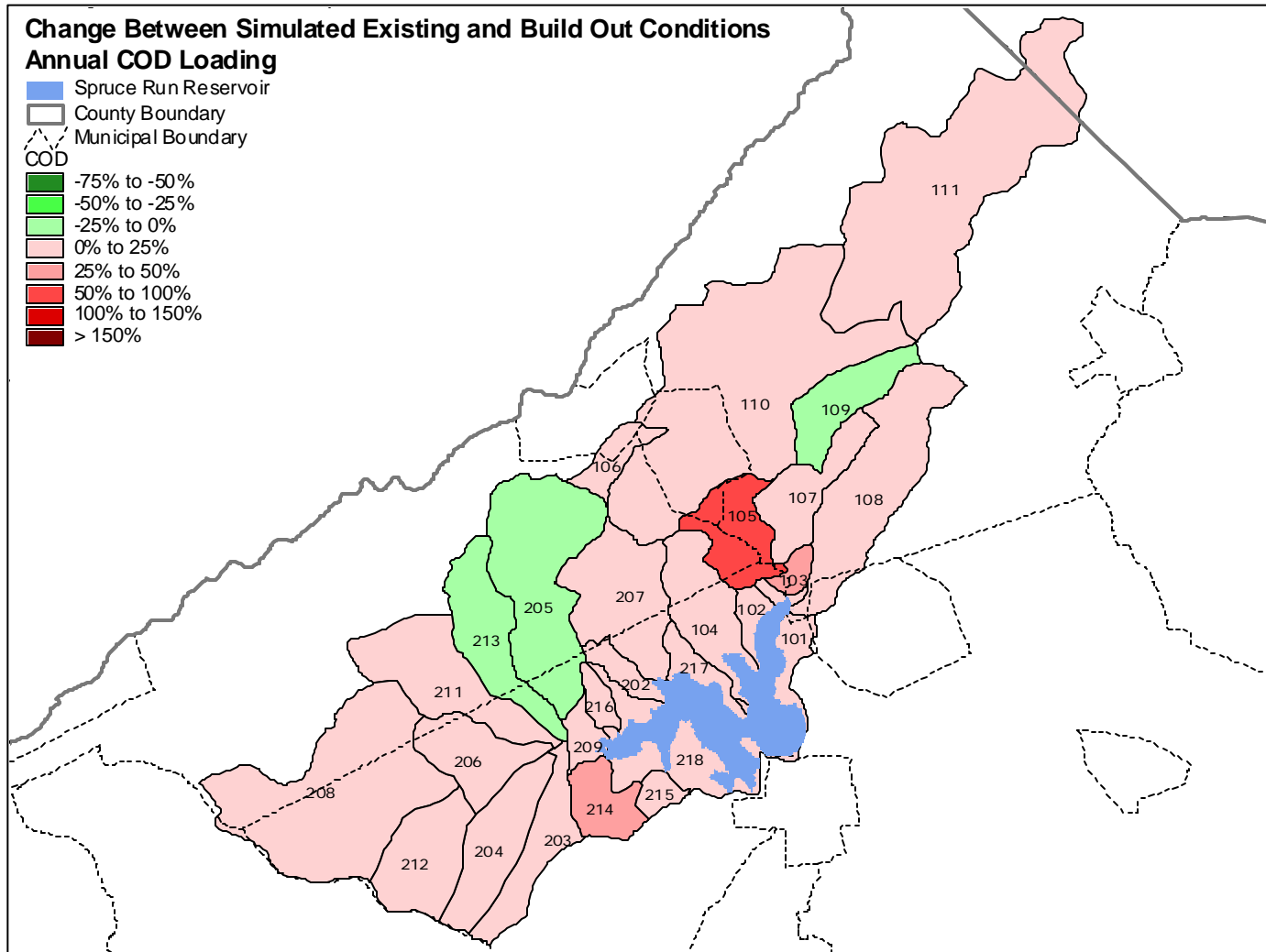


Figure 4.11

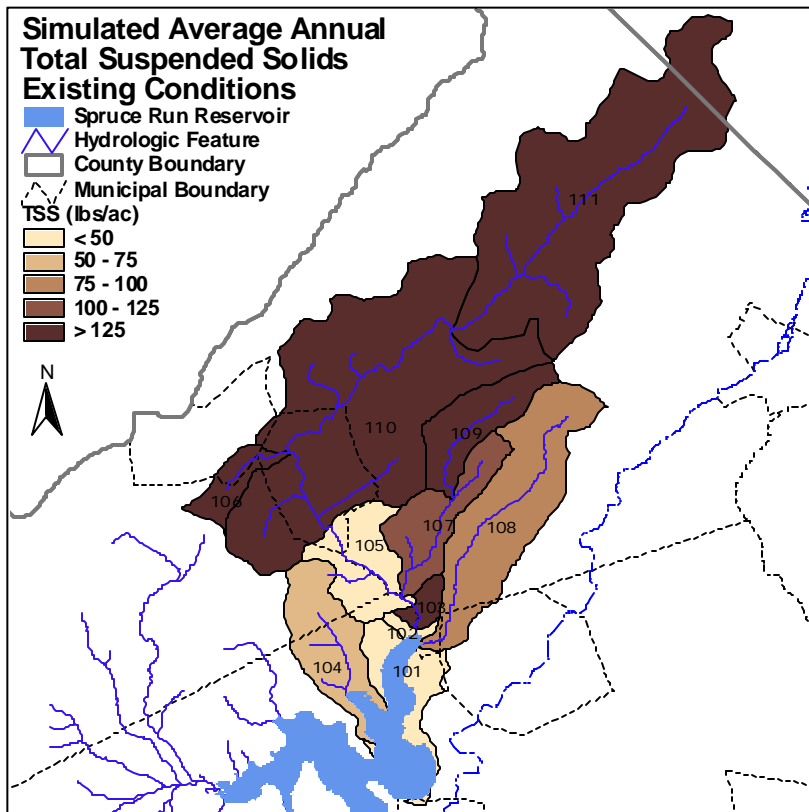


Figure 4.12

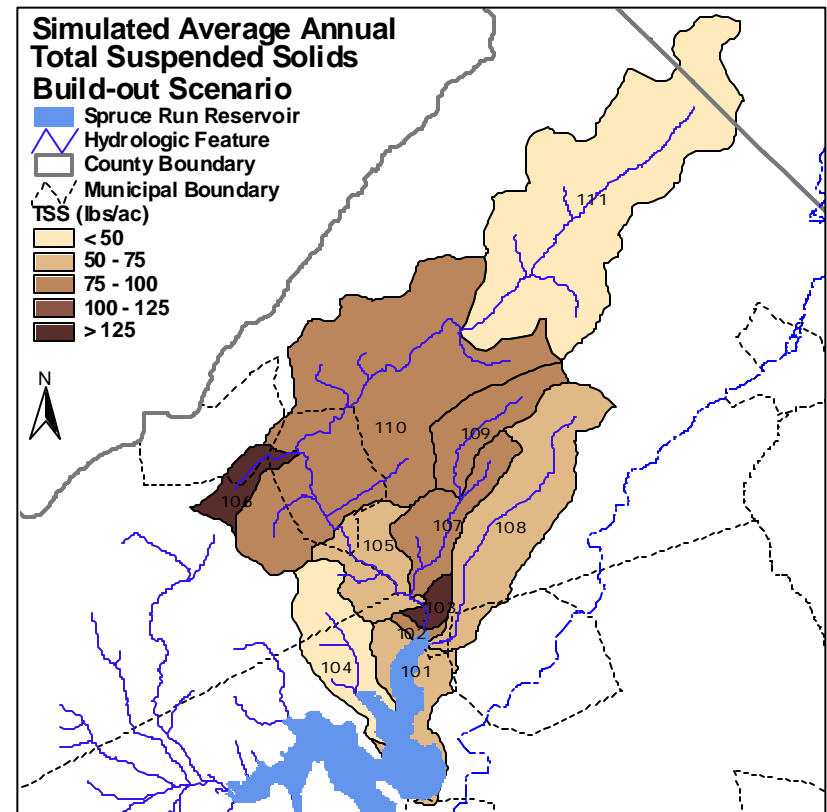


Figure 4.13

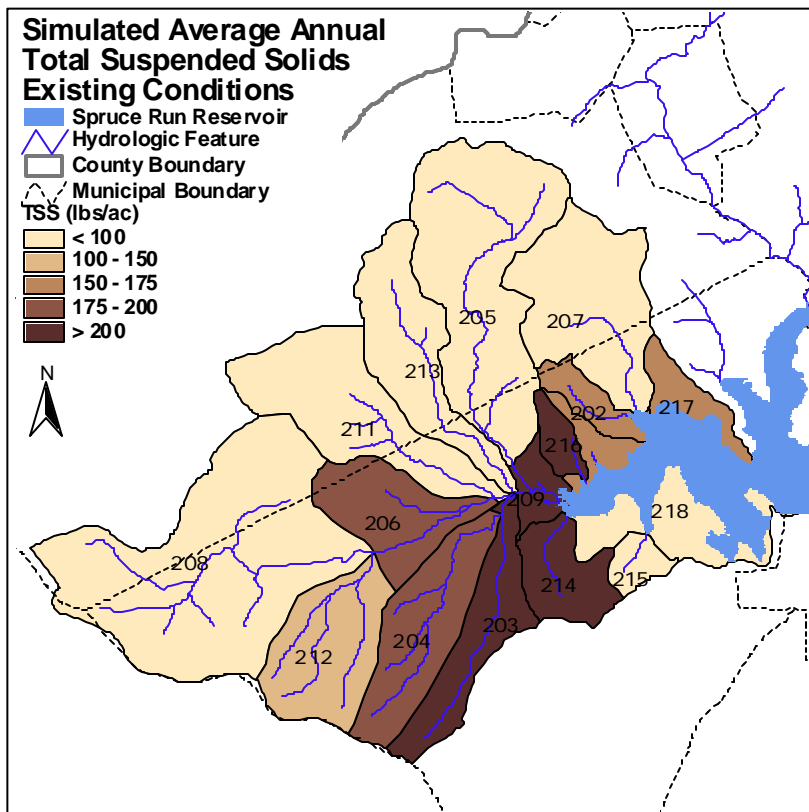


Figure 4.14

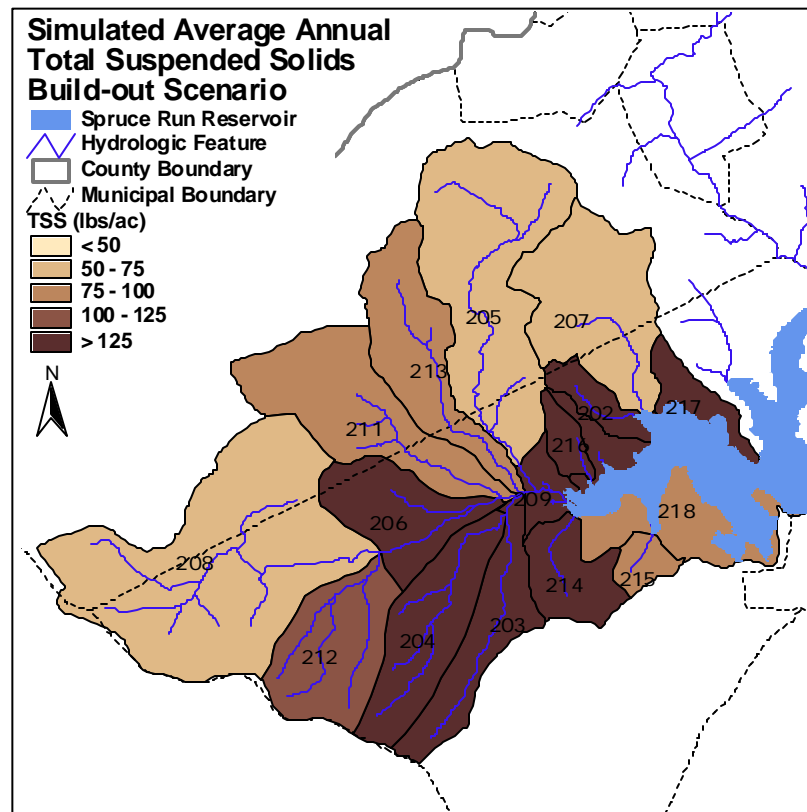


Figure 4.15

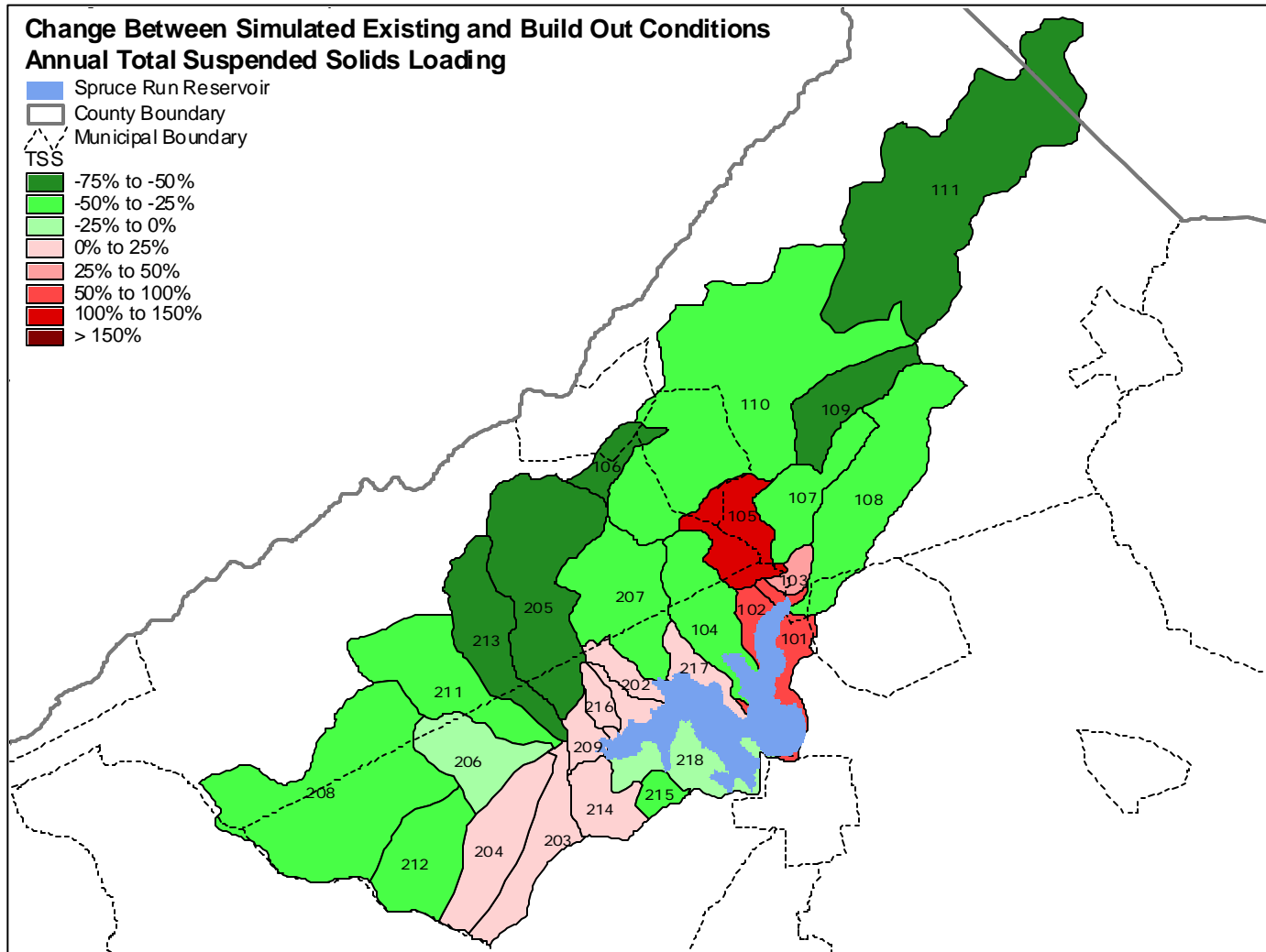


Figure 4.16

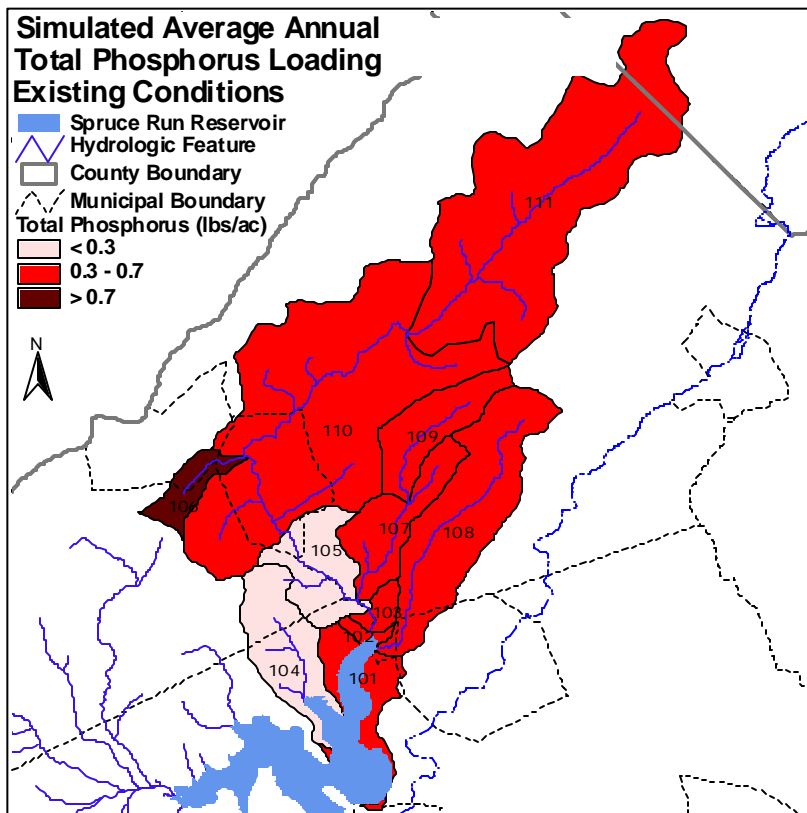


Figure 4.17

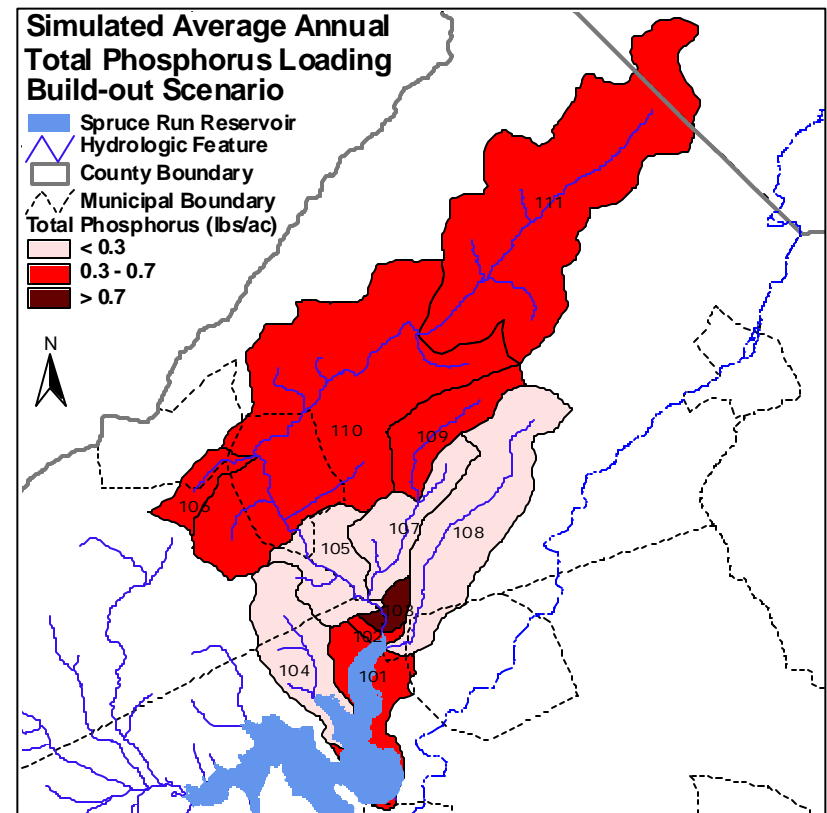


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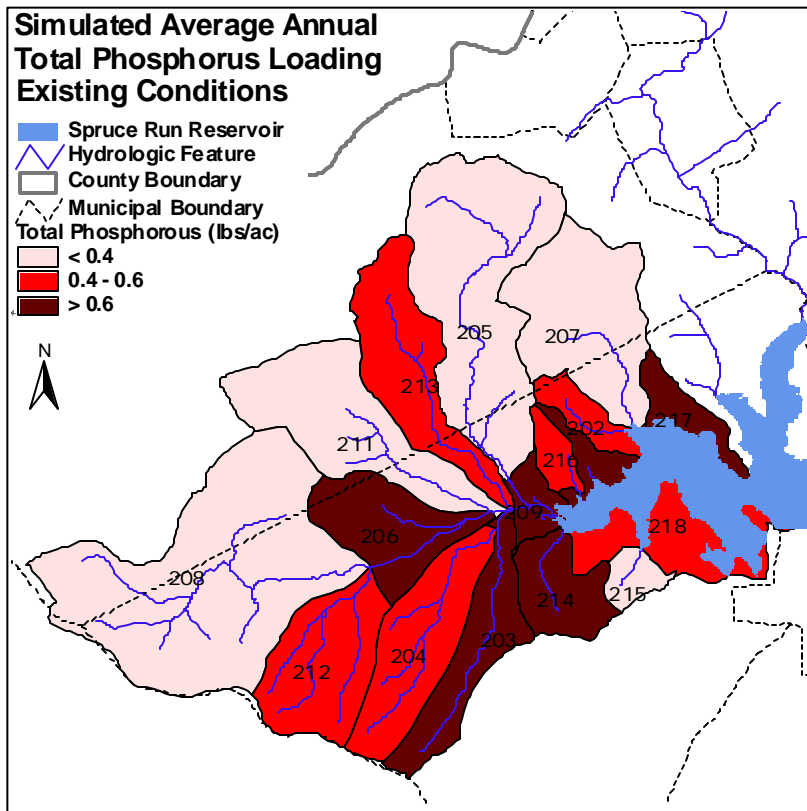


Figure 4.19

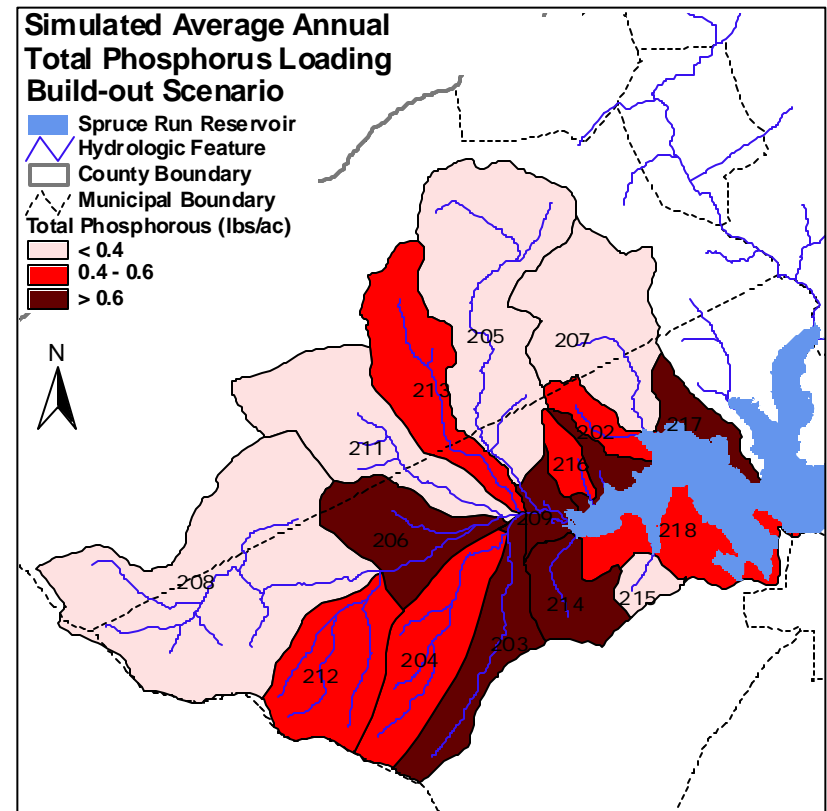


Figure 4.20

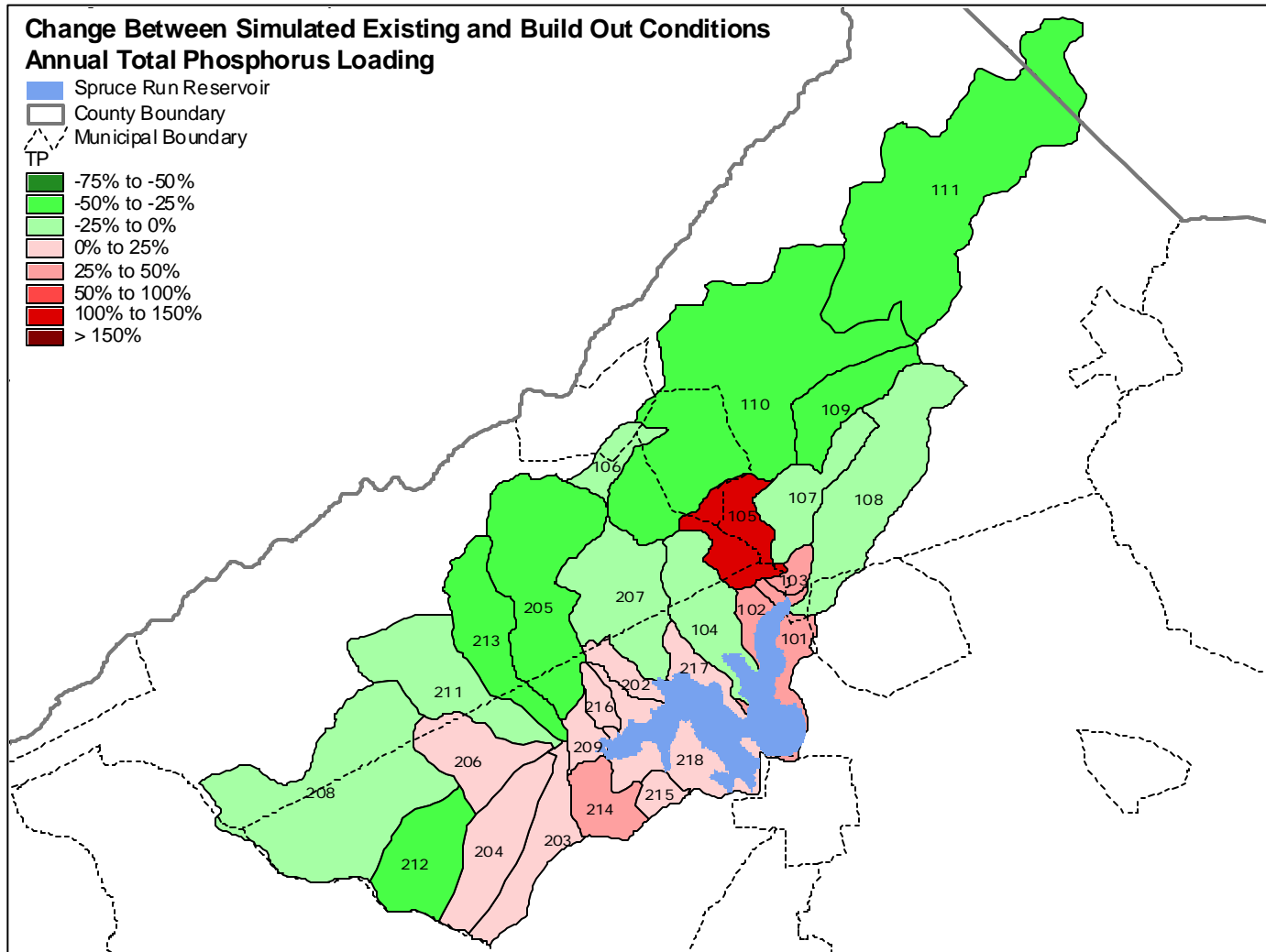


Figure 4.21

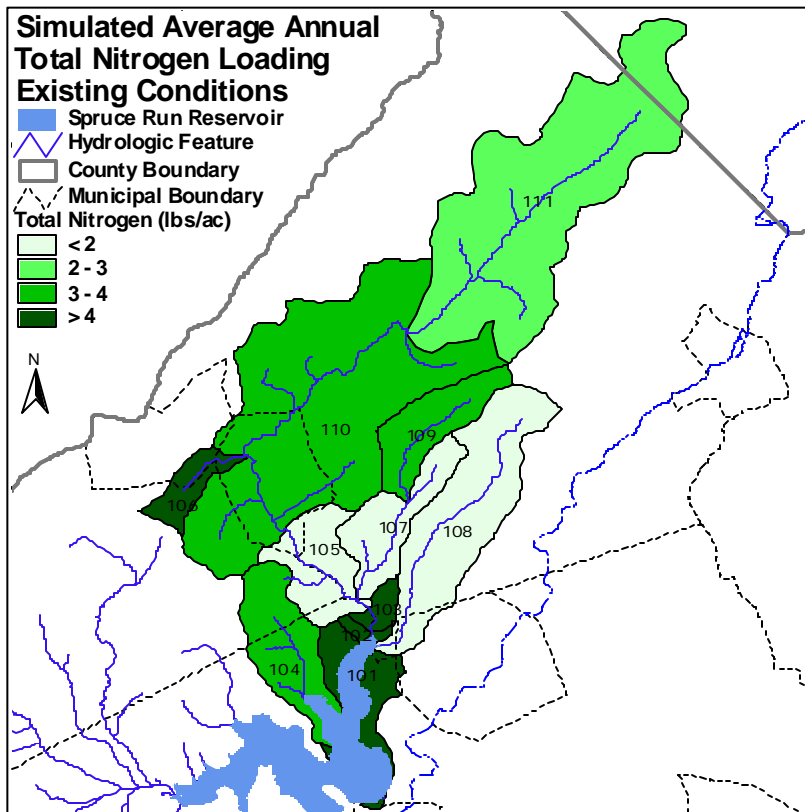


Figure 4.22

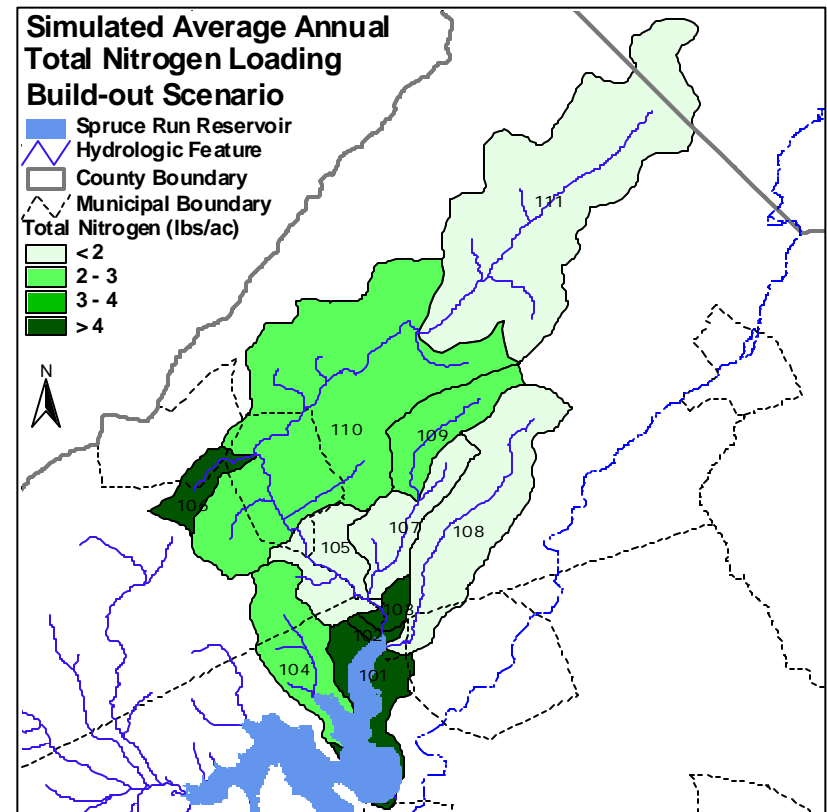


Figure 4.23

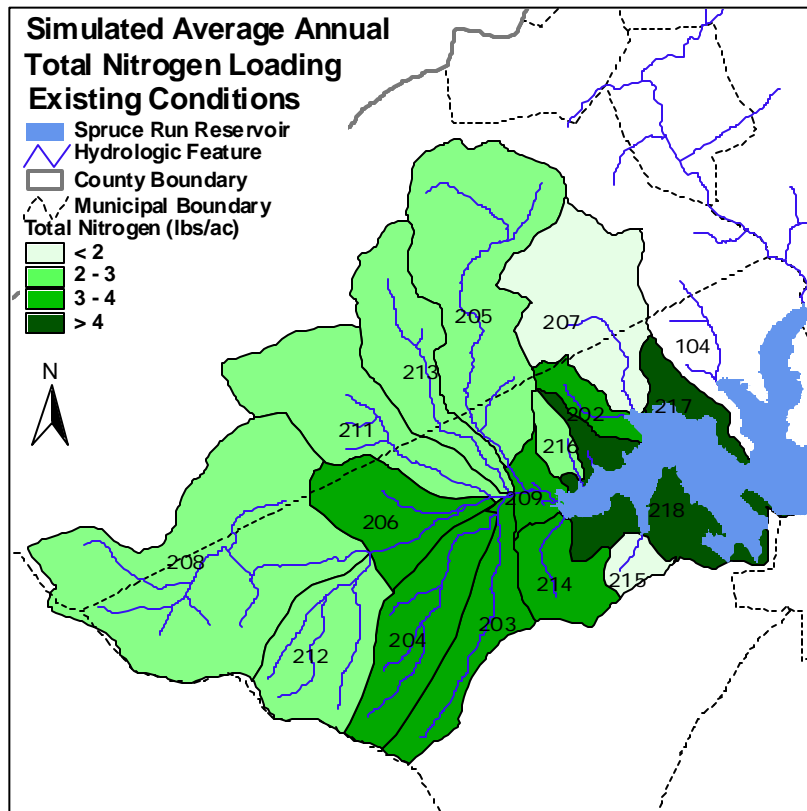


Figure 4.24

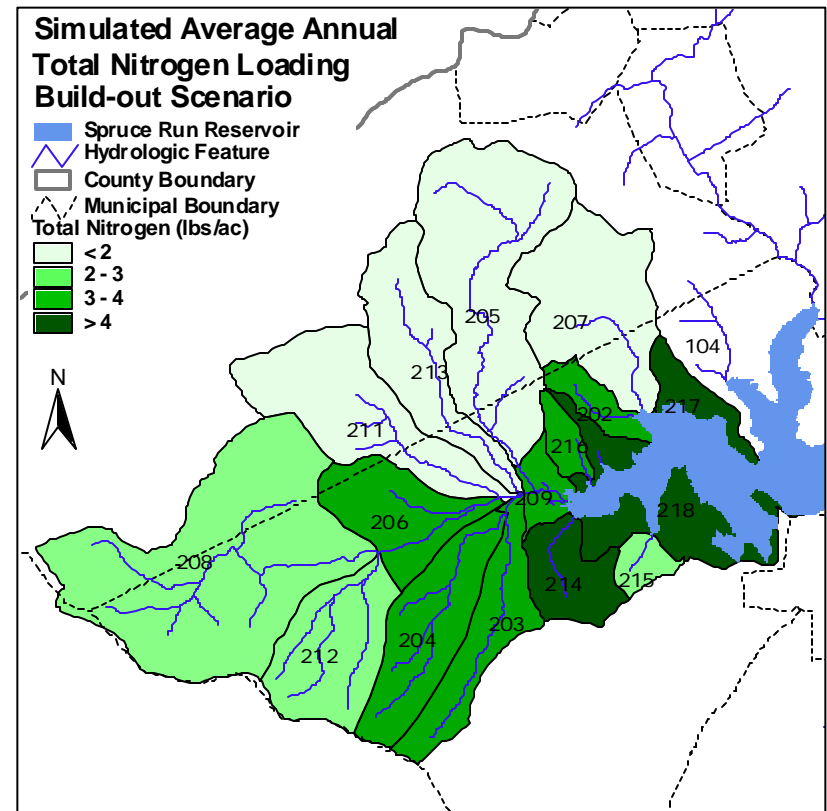


Figure 4.25

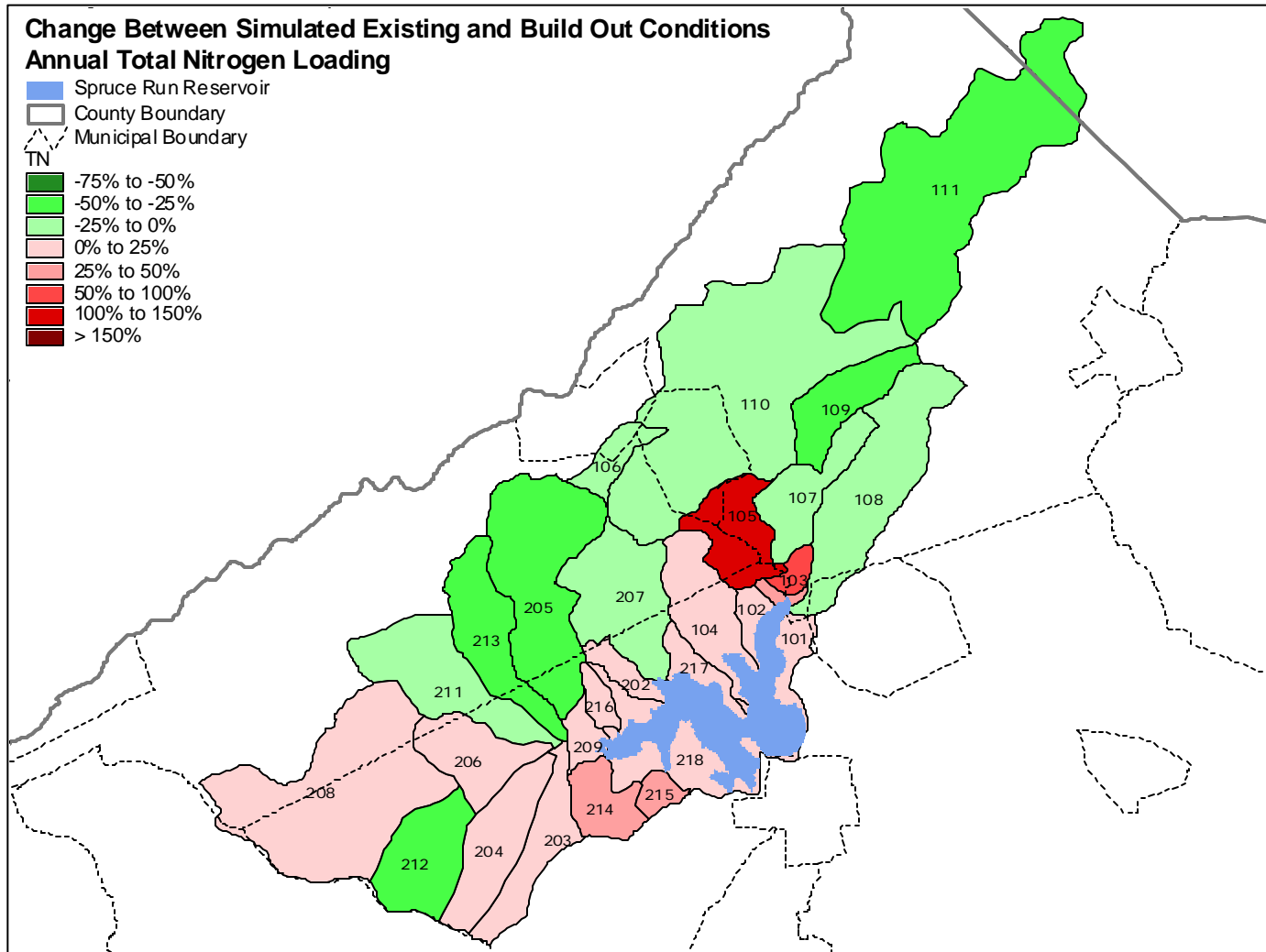


Figure 4.26

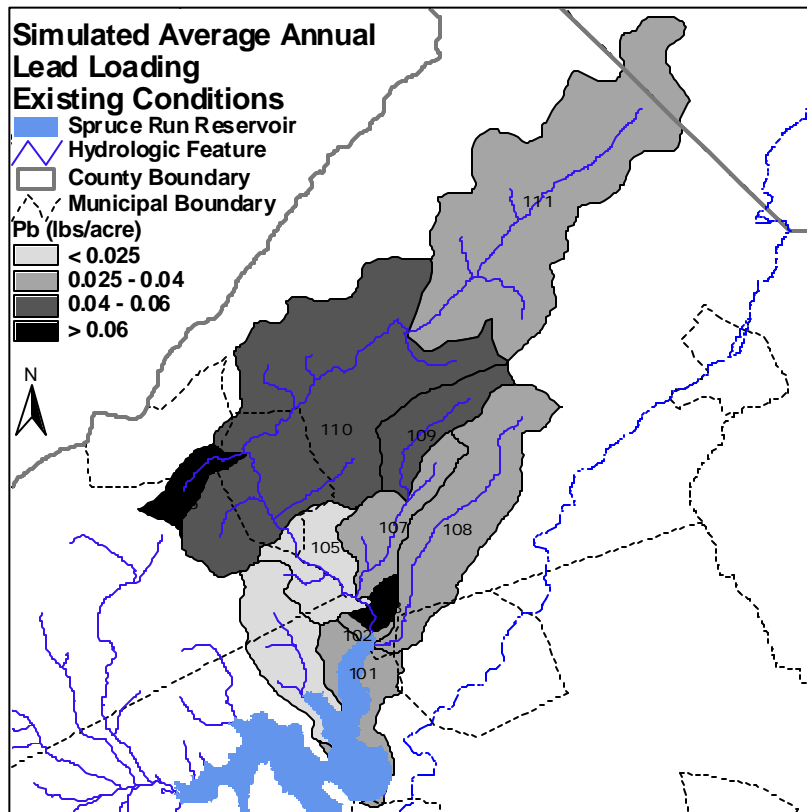


Figure 4.27

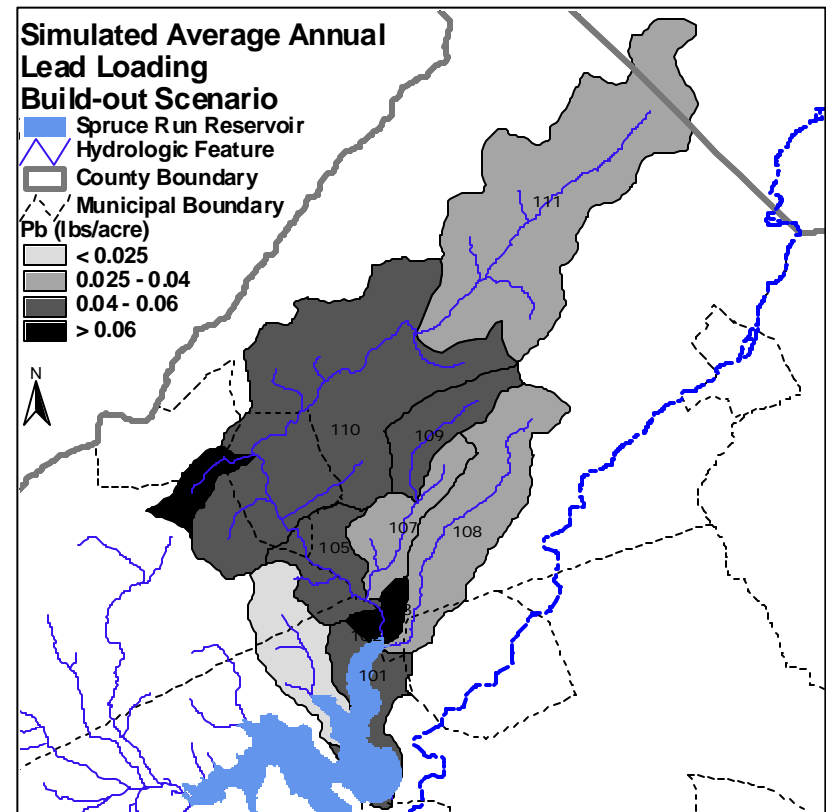


Figure 4.28

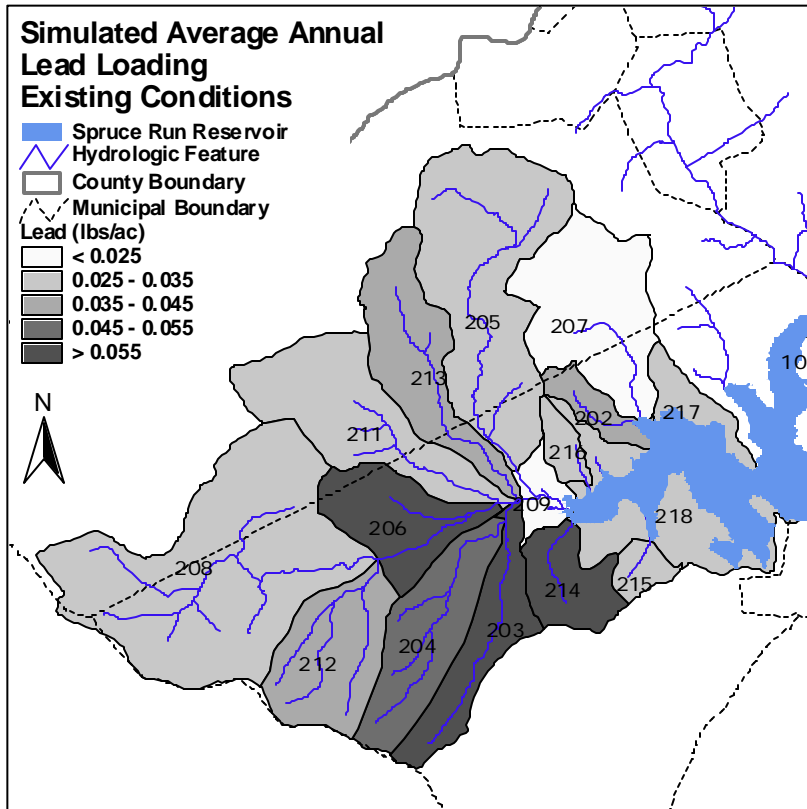


Figure 4.29

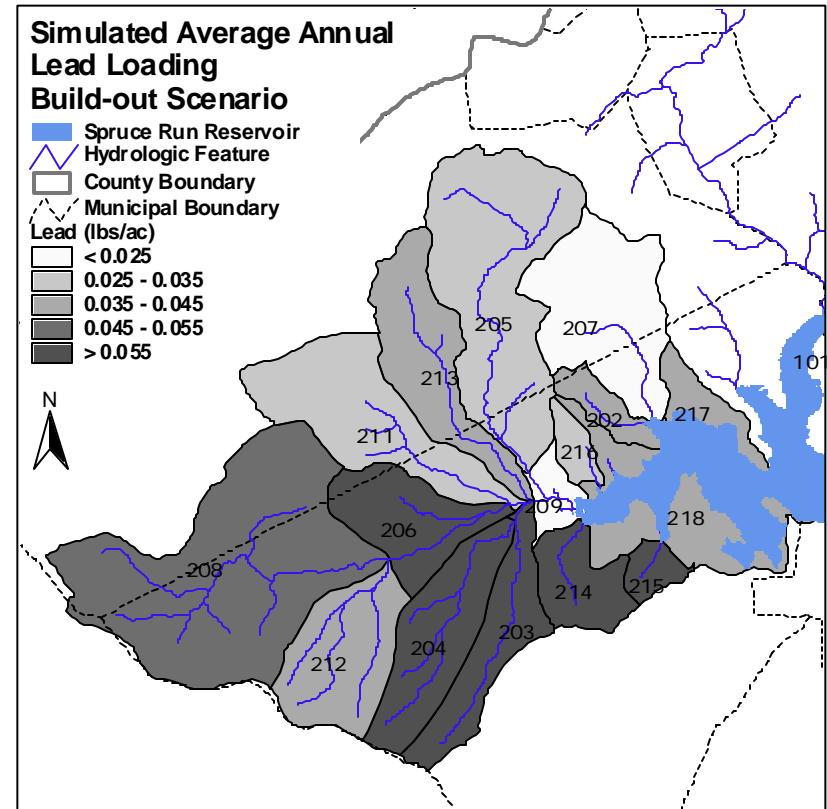


Figure 4.30

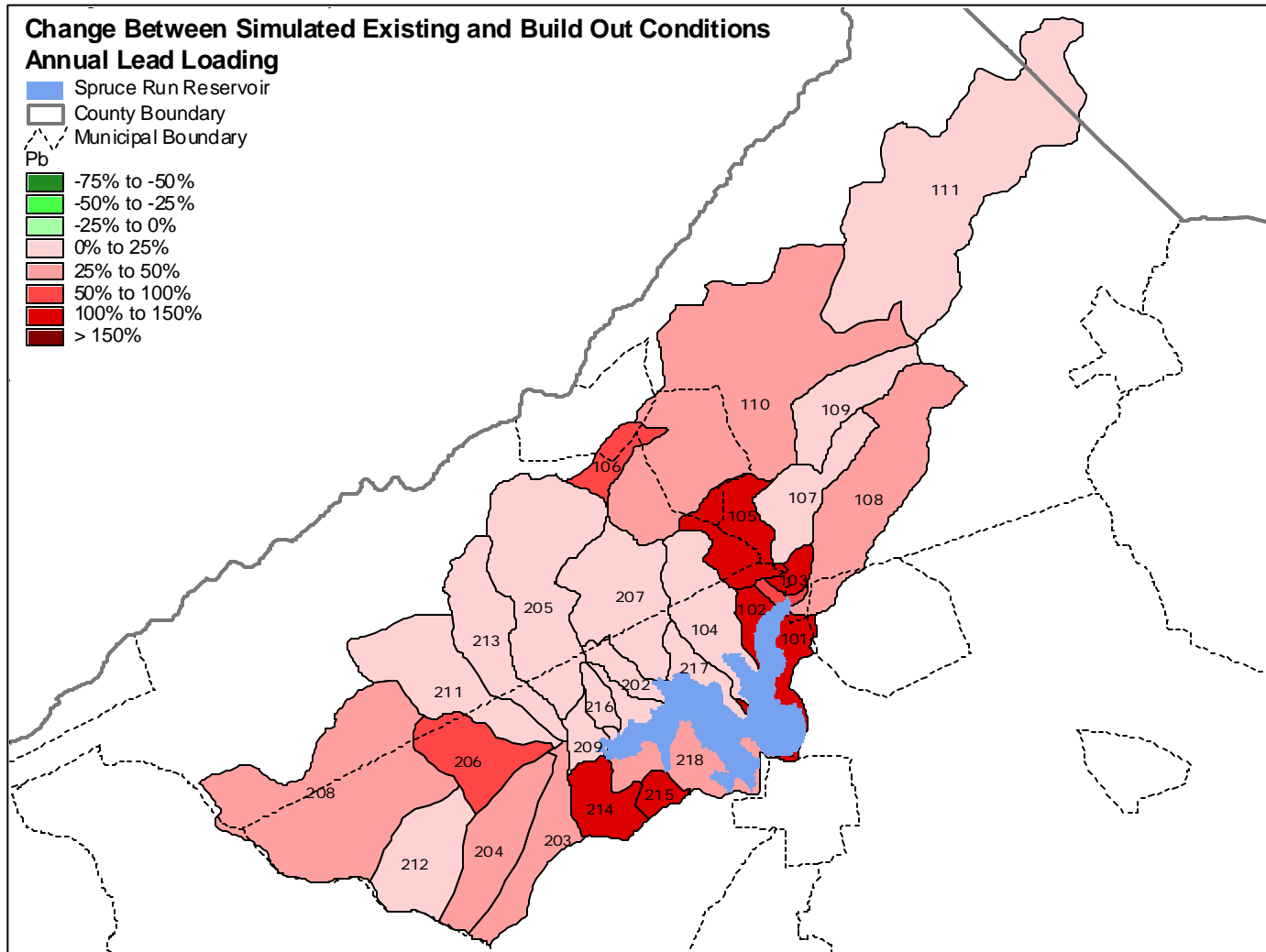


Figure 4.31

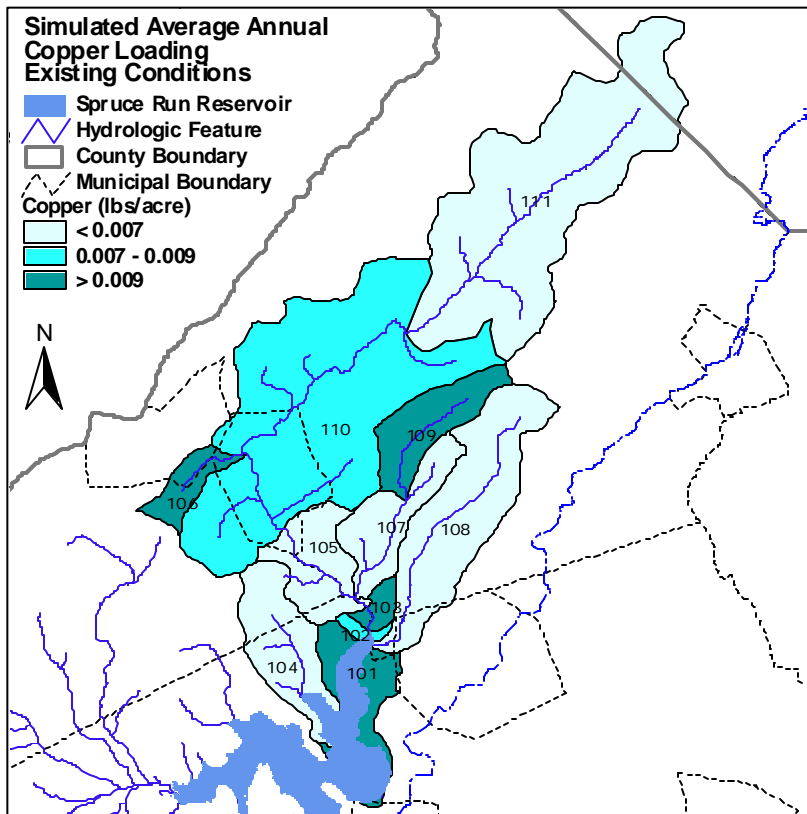


Figure 4.32

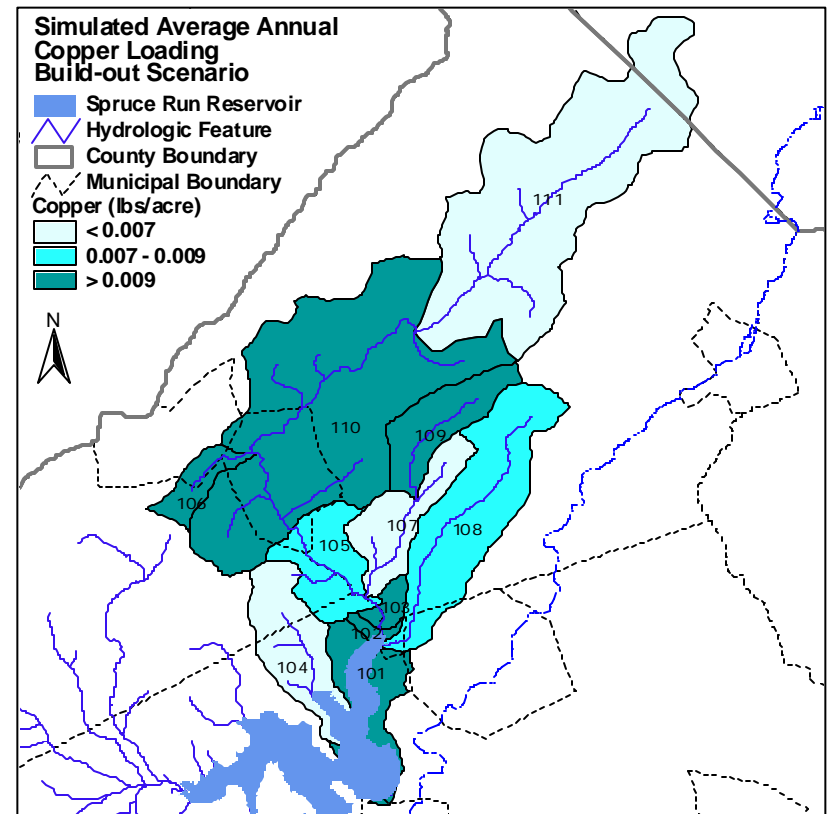


Figure 4.33

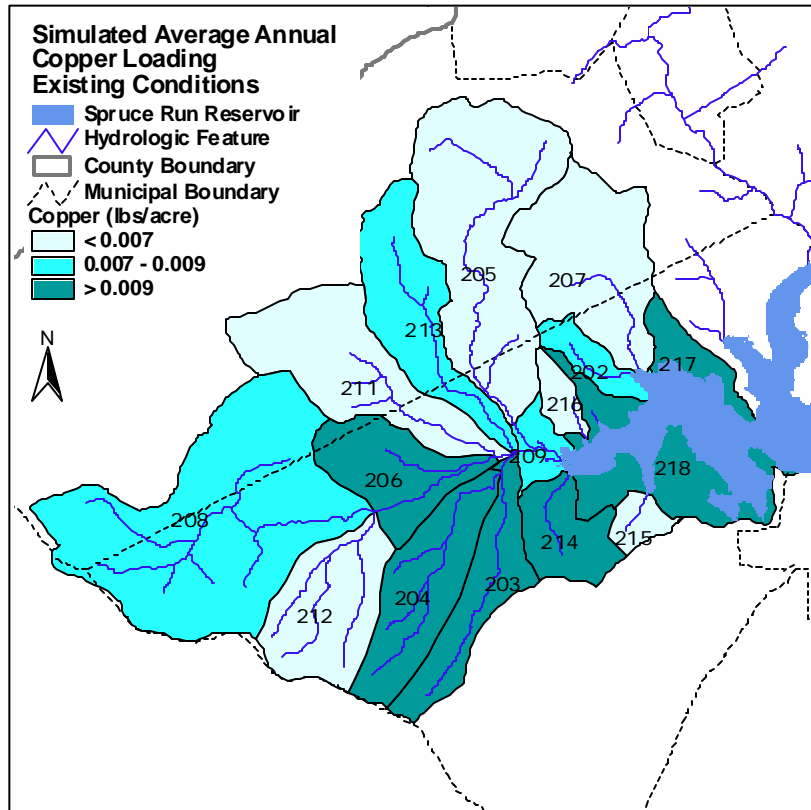


Figure 4.34

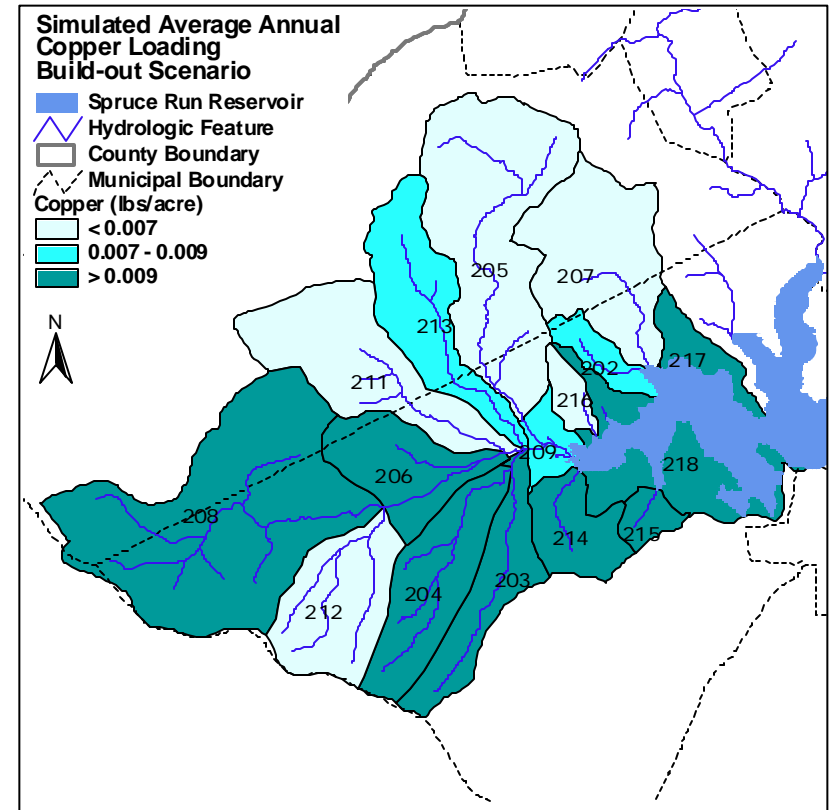


Figure 4.35

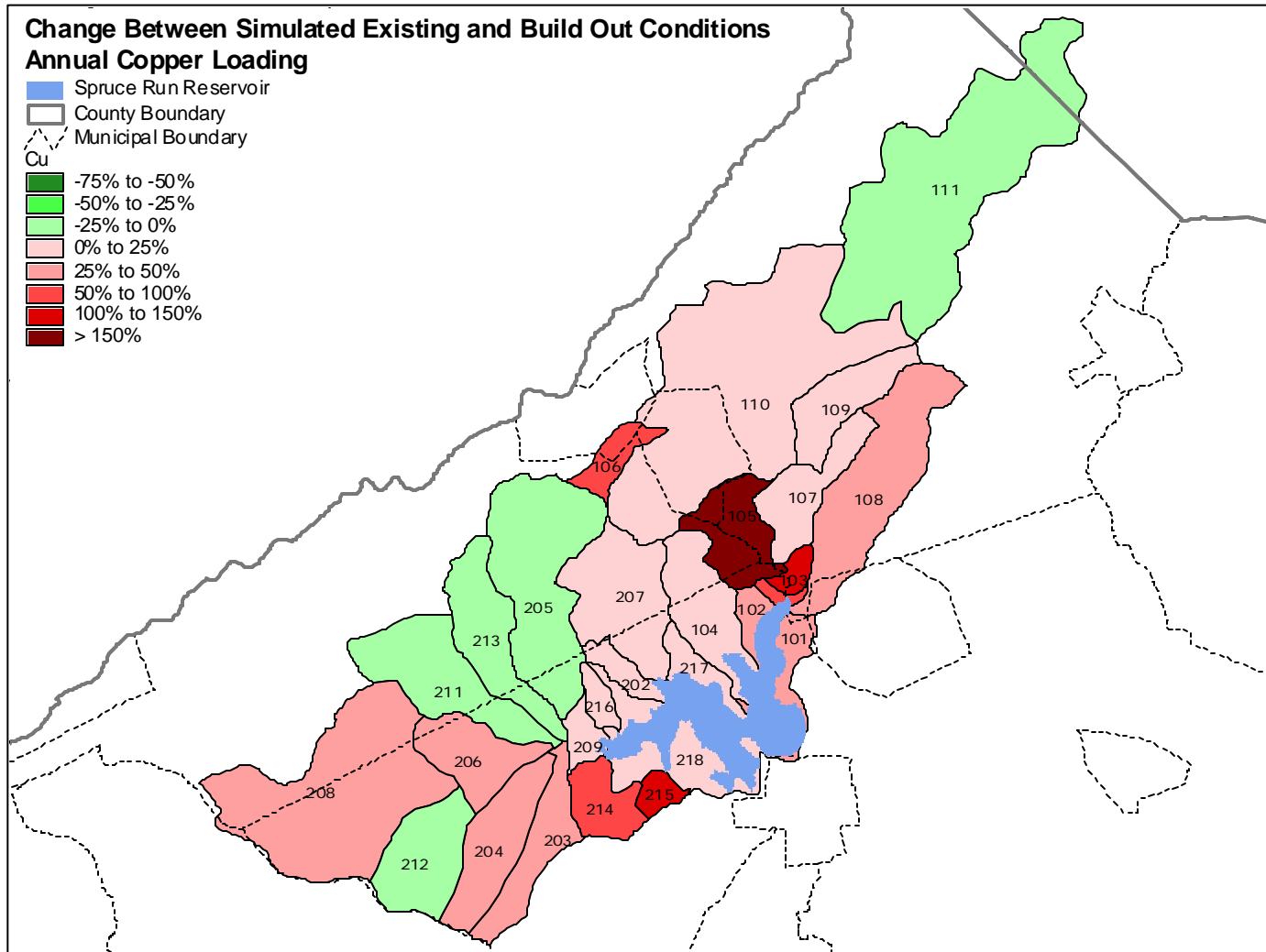


Figure 4.36

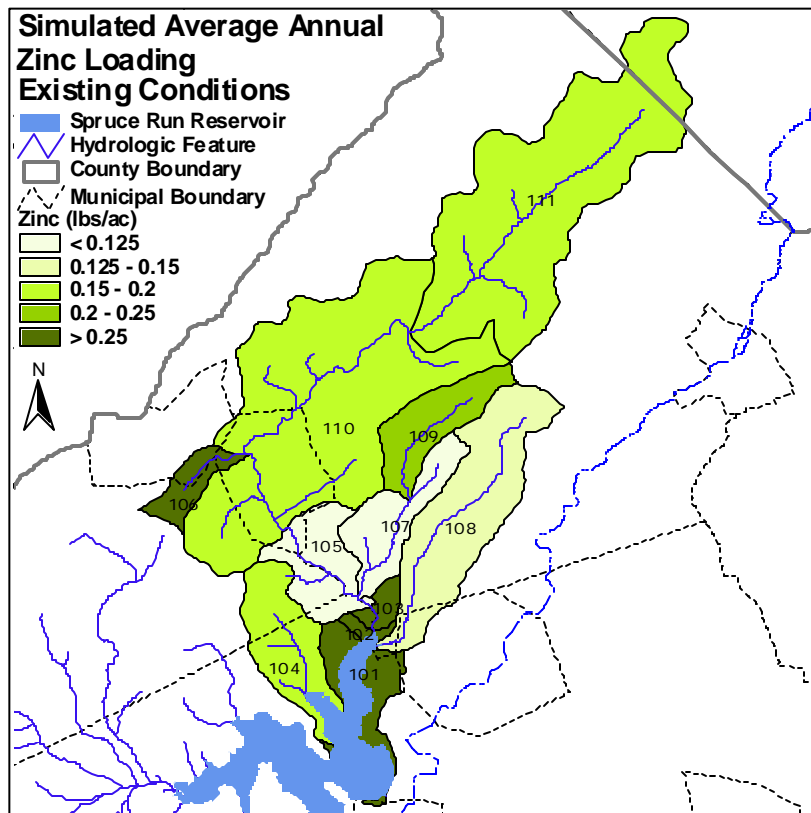


Figure 4.37

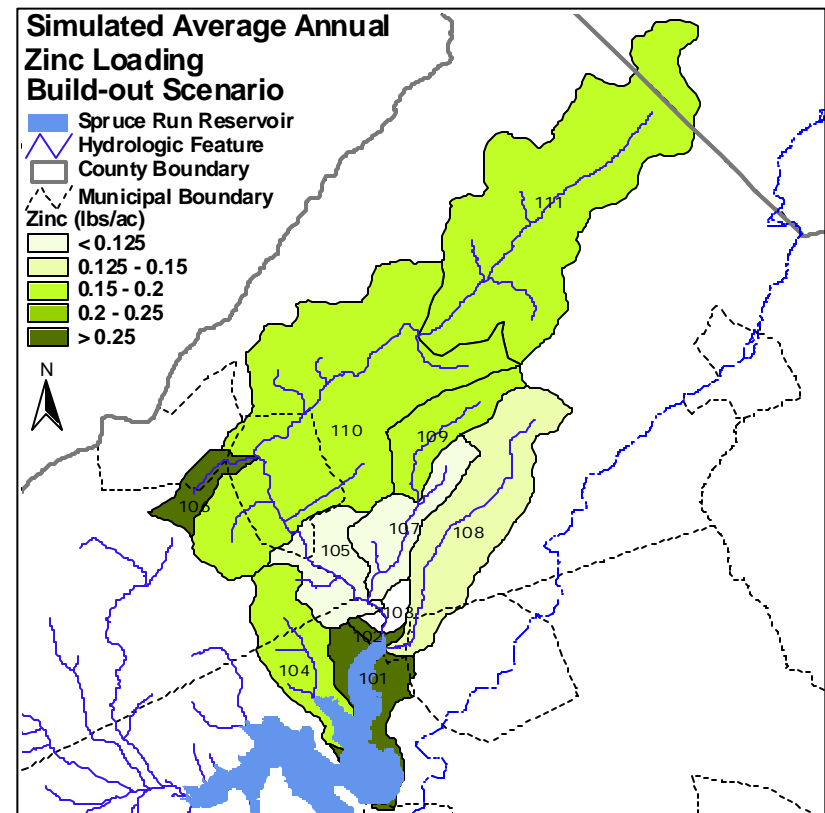


Figure 4.38

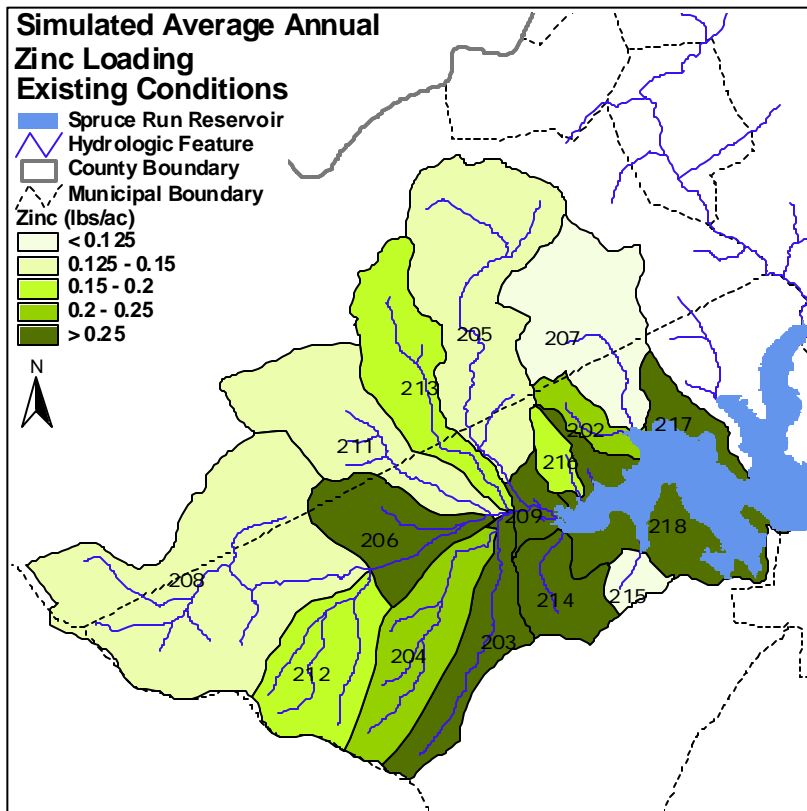


Figure 4.39

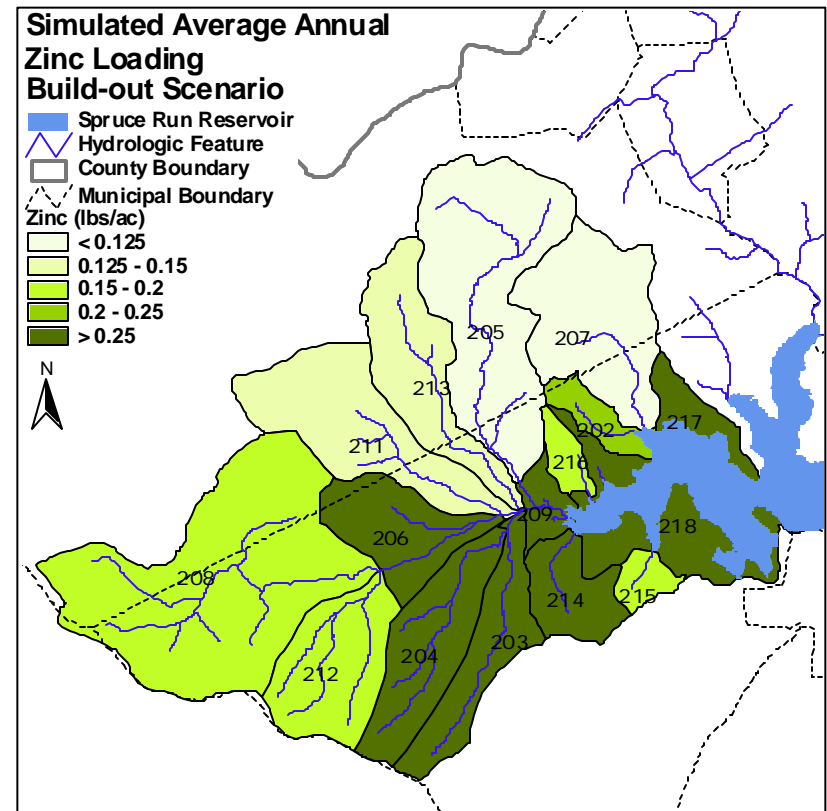


Figure 4.40

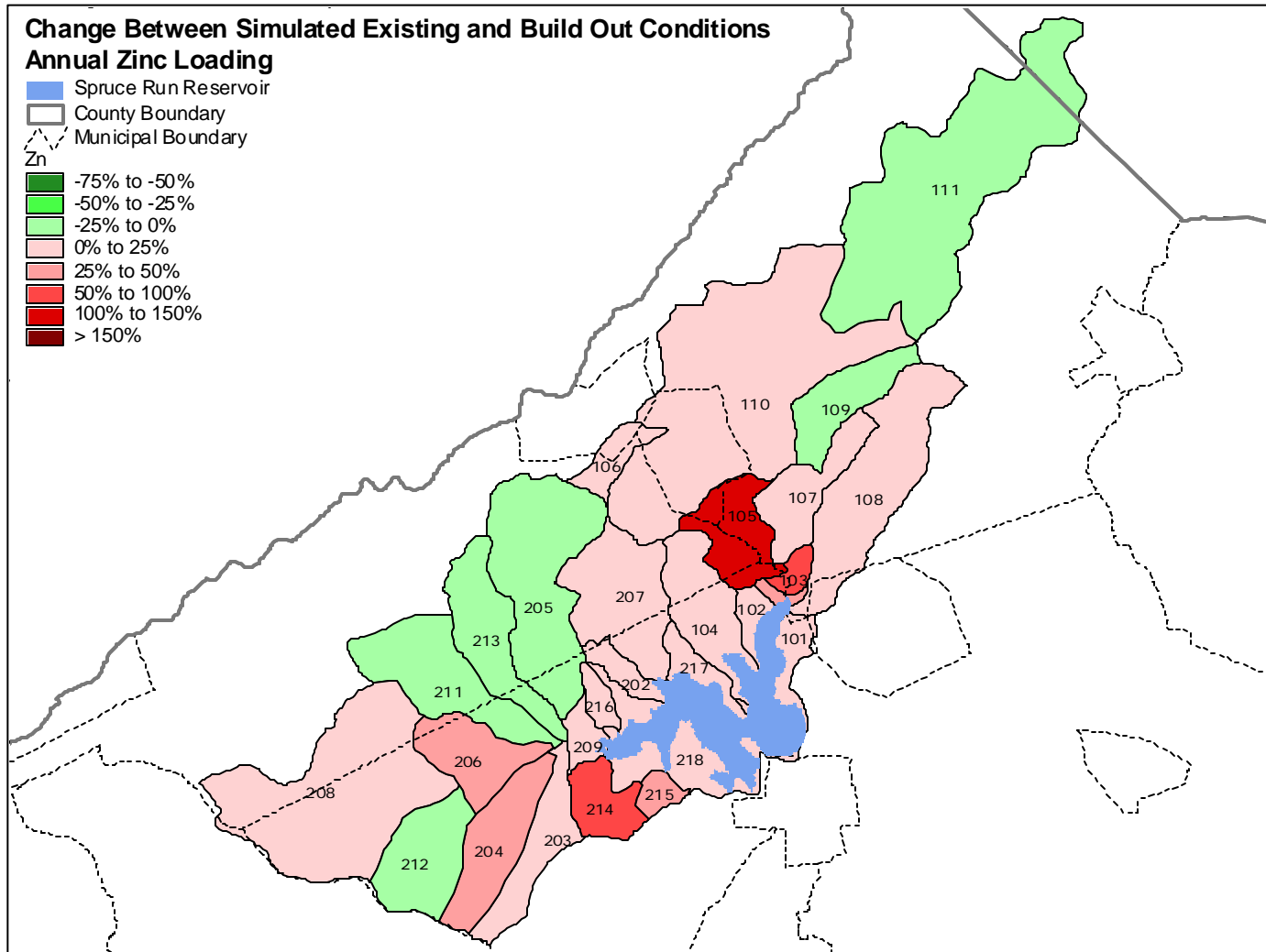


Figure 4.41

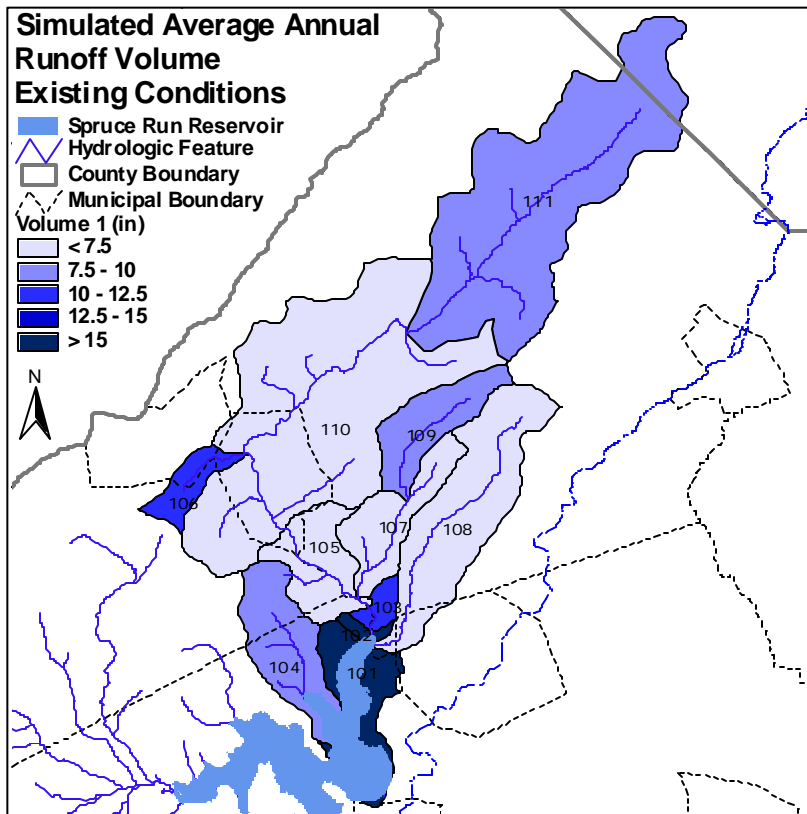


Figure 4.42

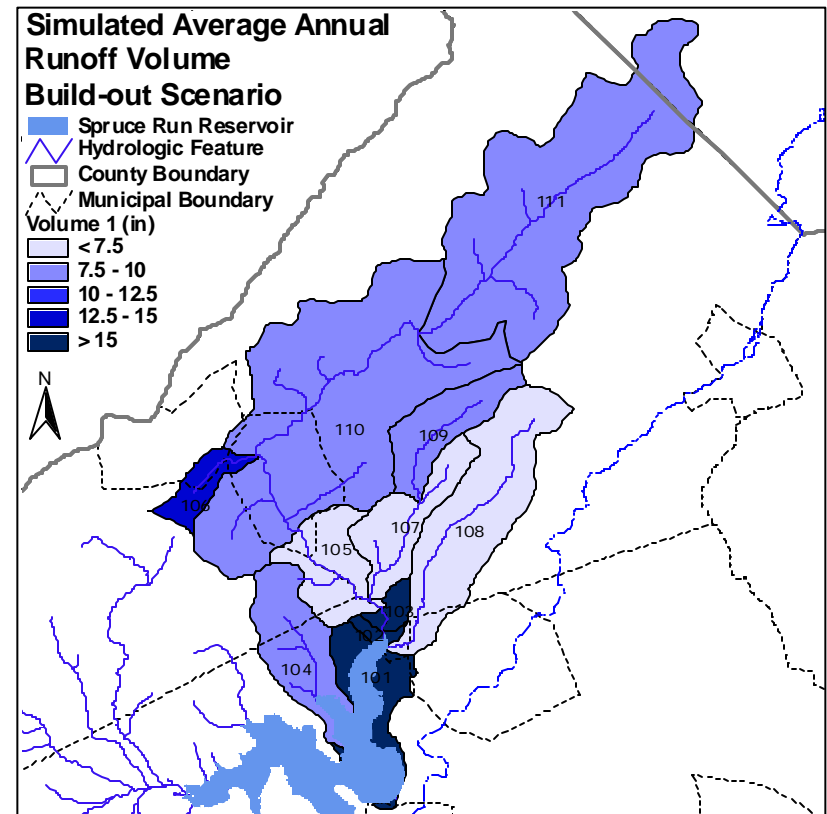


Figure 4.43

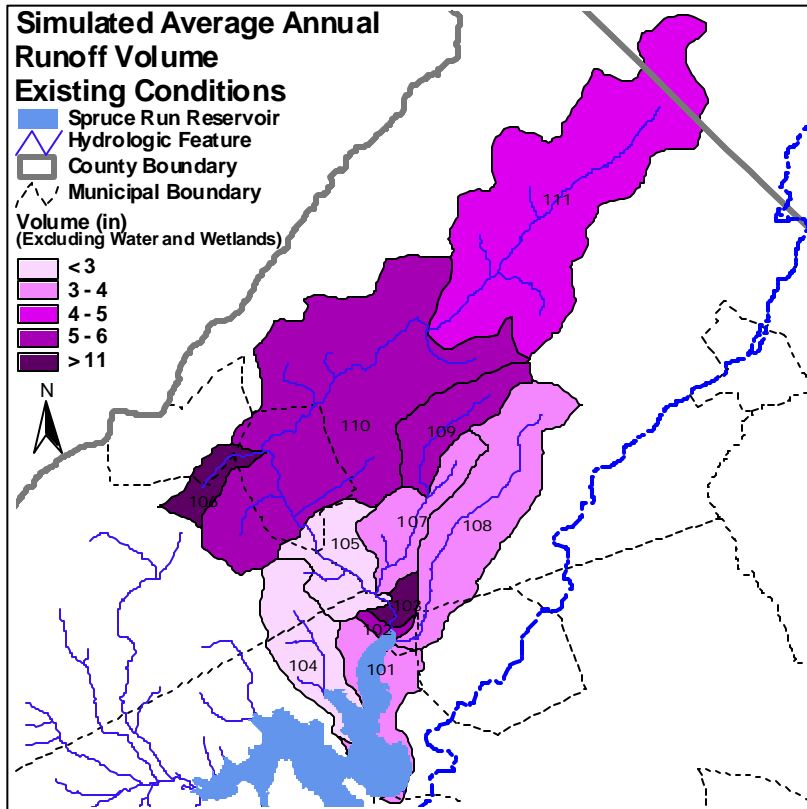


Figure 4.44

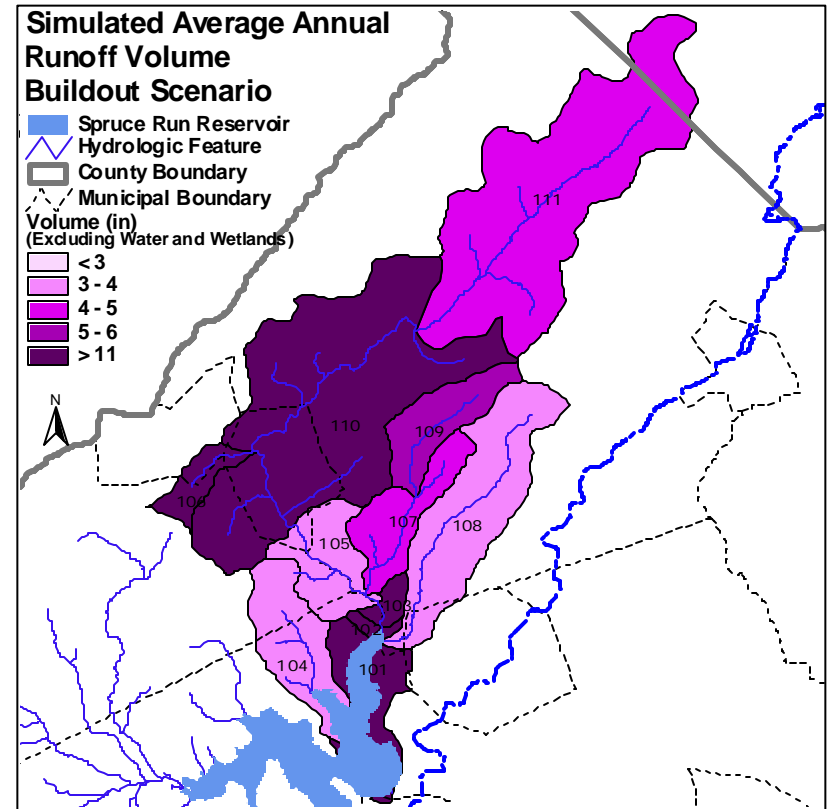


Figure 4.45

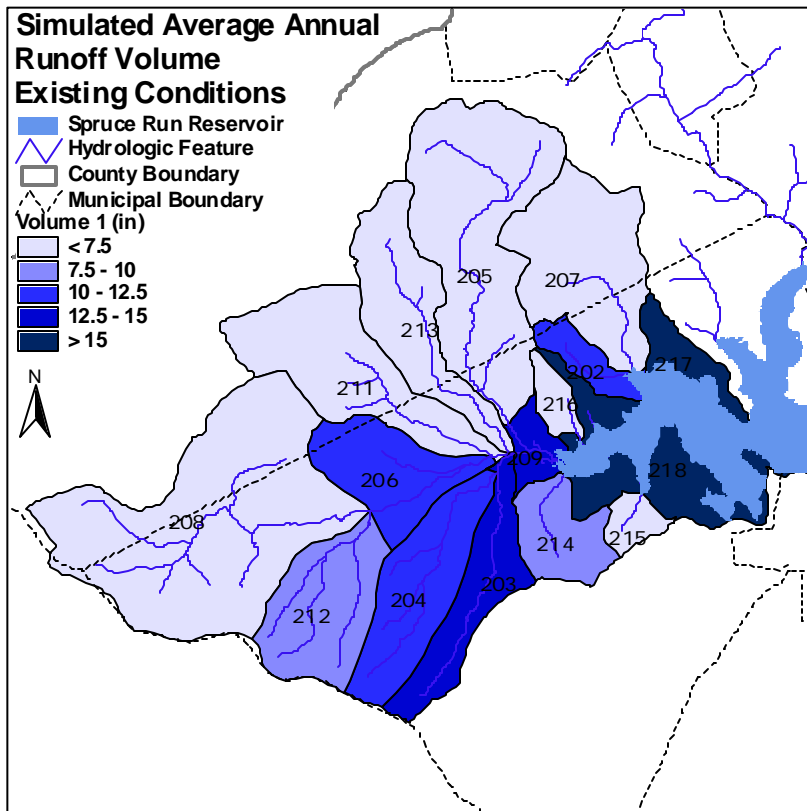


Figure 4.46

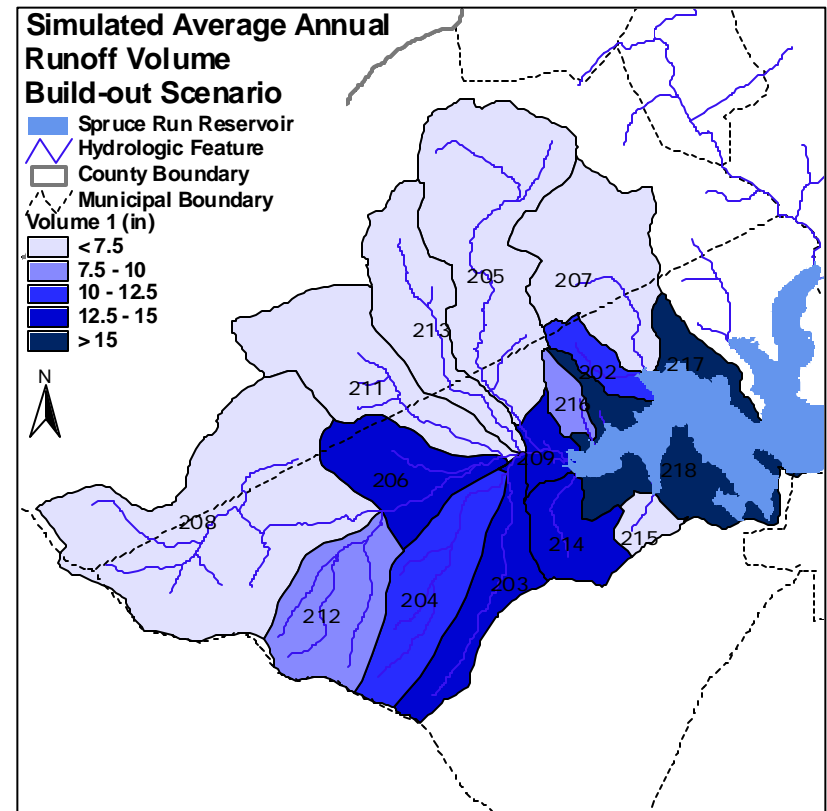


Figure 4.47

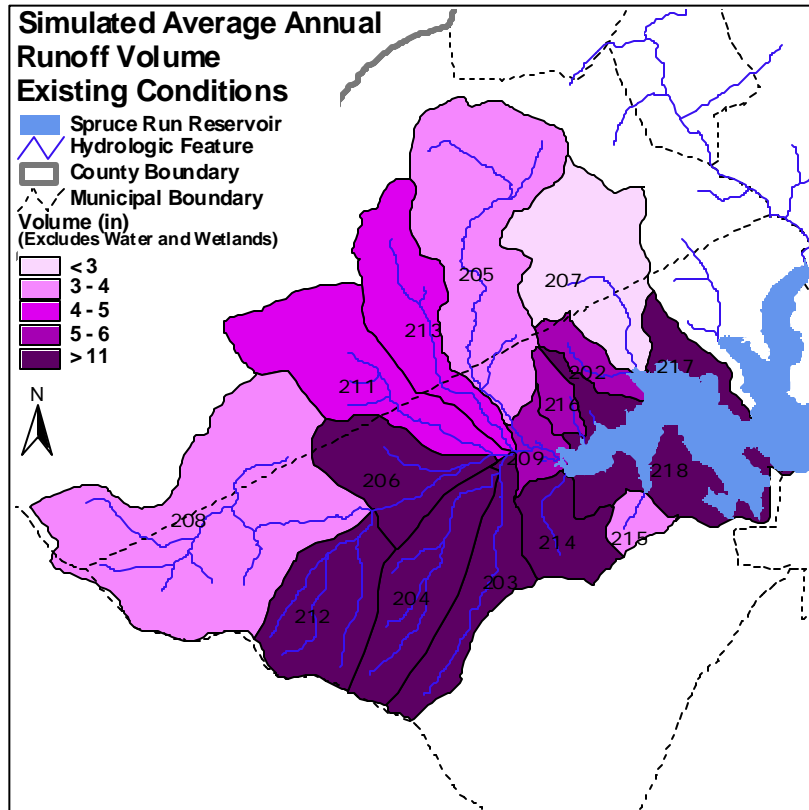


Figure 4.48

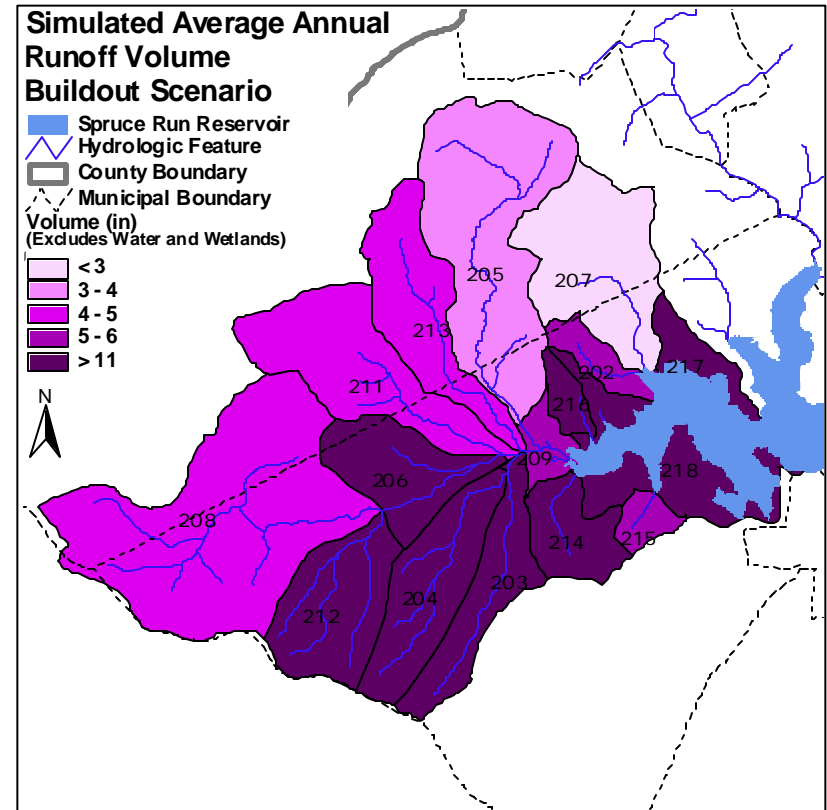


Figure 4.49

