5. Causes and Sources of Pollution

5.1. Land Use Change

As discussed previously, like many other parts of New Jersey, the Neshanic River Watershed has experienced dramatic land use changes during the last two decades, notably decreases in wetlands, forest and agricultural lands. The percentage of the urban land in the watershed increased from 17 percent in 1986 to 25 percent in 1995, 31 percent in 2002 and 35 percent in 2007. These increases were accompanied by notable decreases in agricultural land. Agricultural lands in the watershed decreased from 51 percent in 1986 to 43 percent in 1995, 36 percent in 2002 and 35 percent in 2007. Forest areas increased from 1986 to 1995, but have been decreasing since 1995. The wetlands have been in constant decline.

The trends in land use changes in the watershed are expected to continue as land development occurs in the rural landscape. Ballesteros (2008) developed a sophisticated land use change model for Hunterdon County where the watershed is located. The model integrates advanced machine-learning algorithms, such as cellular automata and decision trees. Although agricultural lands will continue to decrease and urban lands increase, the pace of change will be slower due to the extensive farmland and open space preservation programs and implementation of various land use planning and ordinances in local municipalities (Ballesteros, 2008).

5.2. Hydrological Alteration

Land use changes significantly alter watershed hydrology and have direct impacts on both water quality and quantity. As urban land increases at the expense of agricultural and forest lands, impervious surfaces, such as rooftops, driveways, additional roads, and parking lots, increase, which decreases infiltration and groundwater recharge and increases surface runoff. Urban and suburban developments also bring additional roads and stormwater infrastructure, such as drainage pipes and ditches that are designed to quickly disperse stormwater from individual properties. For the same reason, tile drainage and swale infrastructure are also constructed in agricultural lands. In general, urban development and intensive agricultural operations create flashier streams in the watershed. The impacts of intensive land uses and development can be characterized in terms of drainage density, which measures the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin and is an indicator of how well or how poorly a watershed is drained by stream channels. The calculated drainage density in the Neshanic River Watershed is 2.02 miles if the water is drained through streams and 7.05 miles if the water is drained by both streams and roads. The latter are shown in Figure 5.1. Streams and roads act as drainage pathways for water. The drainage density could be even higher when incorporating the impacts of stormwater and runoff infrastructure, such as tile drainage, swales, drainage pipes and ditches that direct runoff to streams. Drainage density affects the shape of the hydrograph of a river during a rain storm. Rivers that have a high drainage density will often have a flashier hydrograph with a steep falling limb, and therefore, greater flood risk. Figure 5.2 shows the hydrograph observed at the USGS Neshanic River at Reaville Gage Station for a 0.03-inch storm on December 7, 2008, a 0.53-inch storm on December 10, 2008, a 1.91-inch storm on December 11, 2008 and a 0.67-inch storm on December 12, 2008. The streamflow went from less than 100 cubic feet per second (cfs) several hours after the December 11 storm to a peak of 3,000 cfs. The spike hydrograph implies the flash flooding in the watershed as evidenced by the photos in Figure 5.3 below.

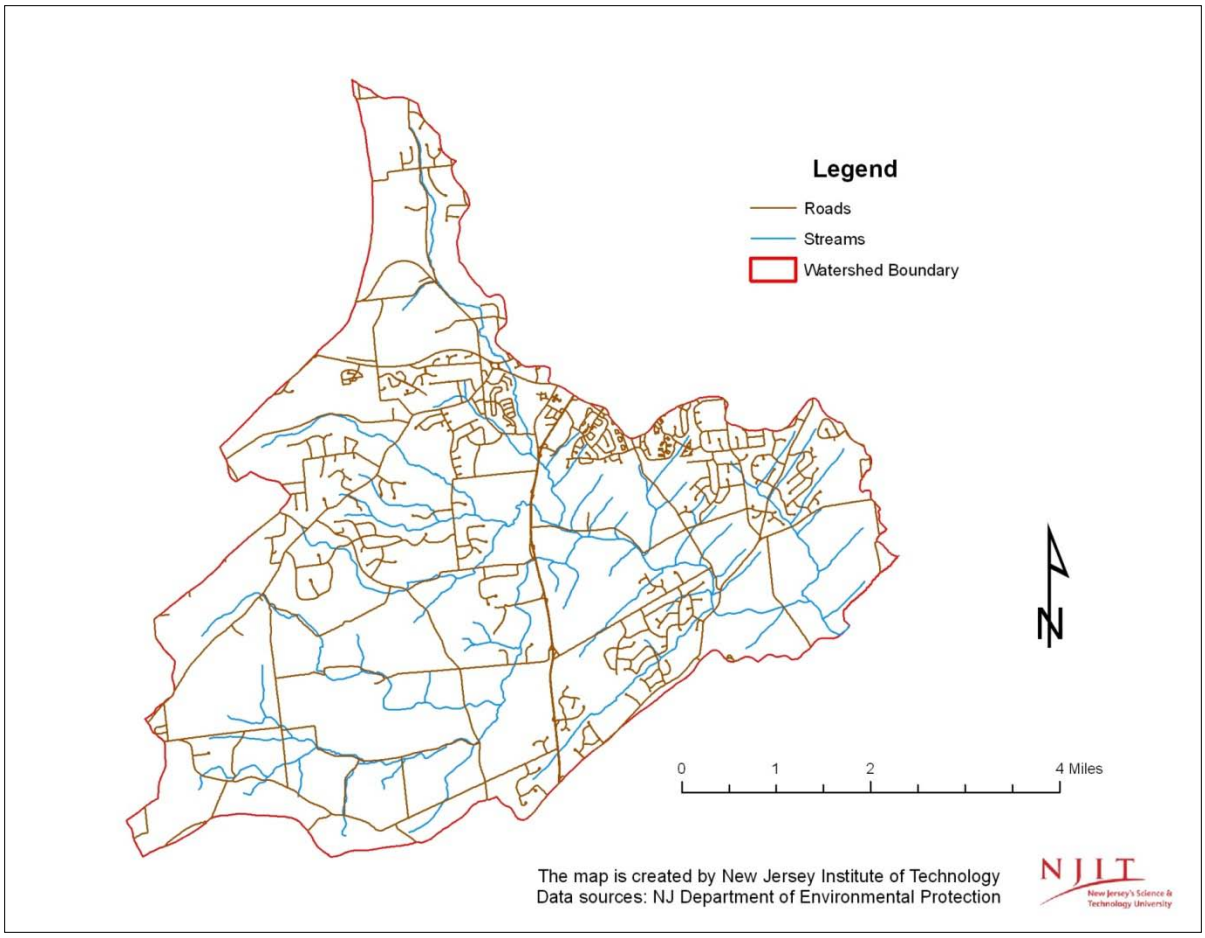


Figure 5.1: Distribution of streams and roads in the Neshanic River Watershed

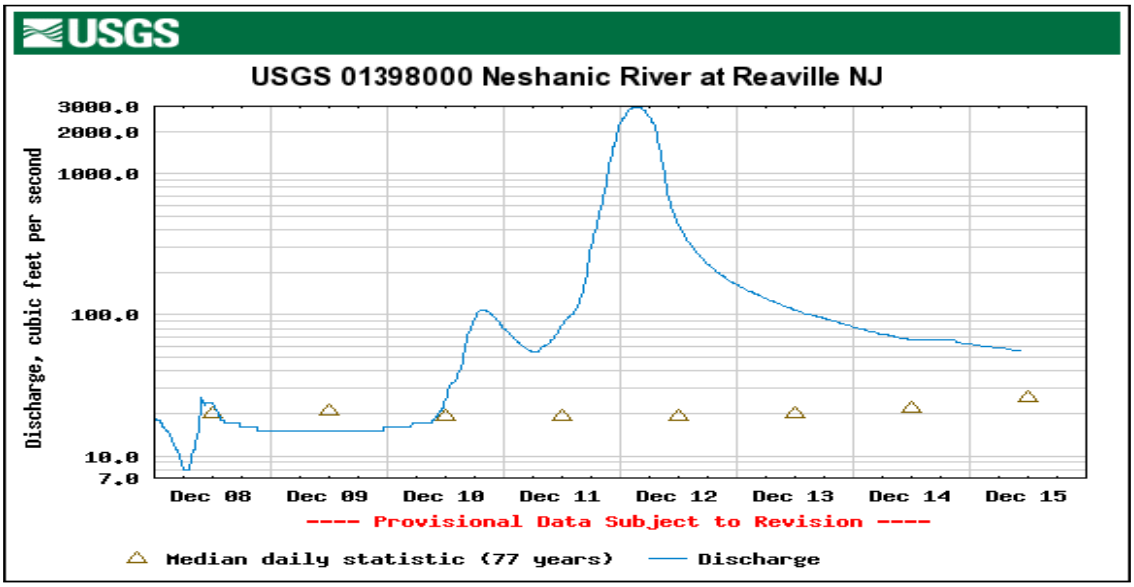


Figure 5.2: Hydrograph at the USGS Reaville station in the Neshanic River Watershed

Figure 5.3: Flooded Hampton Corners Road after a spring storm

Hydrological alteration is attributed to not only the quantitative changes in land uses as discussed above, but also where various land use changes take place in the watershed. In the Neshanic River Watershed, many intensive land use activities have taken place in critical environmental areas in the watershed, such as hydric soils, HSAs and riparian areas. A major concern in the watershed is that agriculture and urban development occur in hydric soils. According to the 2007 NJDEP land use/cover data, agriculture occurs on 202 acres and urban development occurs on 237 acres of hydric soils. The agricultural and urban use acreage accounts for more than half of the total hydric soil acreage in the watershed. A very similar observation can be made for HSAs in the watershed as discussed above. Figure 5.4 shows the acreages of different land uses in HSAs in 2007. In 2002, HSAs contained 714 acres of agricultural land and 743 acres of urban land, which accounts for 54 percent of the HSAs. Agricultural lands were decreased slightly to 677.3 acres, but urban land rose to 848.7 acres in 2007. More than half (57 percent) of the HSAs in the watershed were in agricultural and urban land uses in 2007.

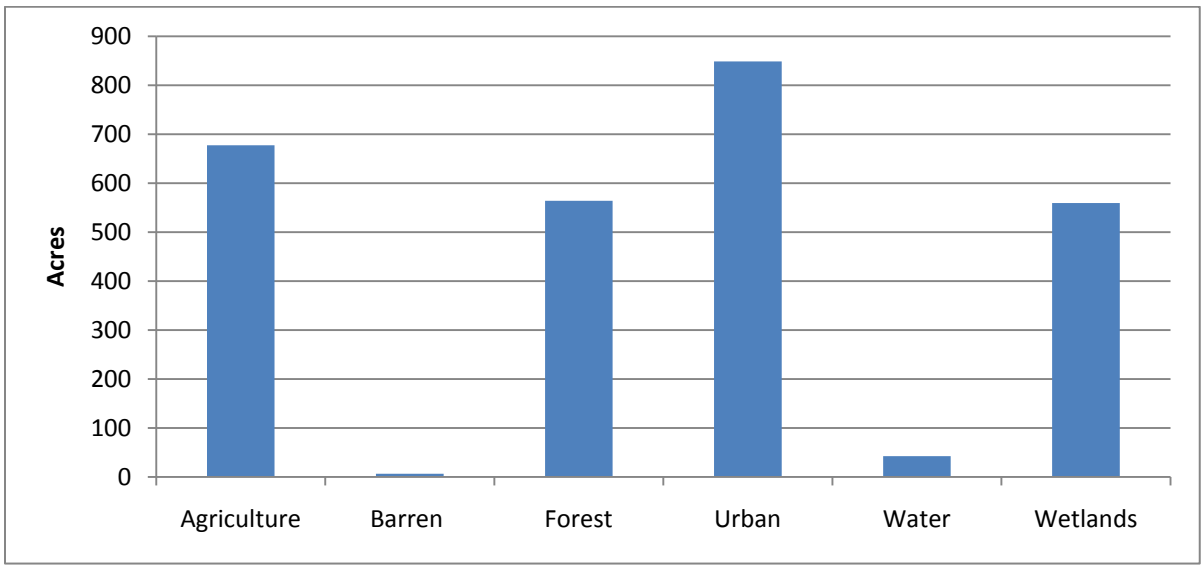


Figure 5.4: Land uses in HSAs in the Neshanic River Watershed, 2007

Land use changes during the past decades have disrupted riparian areas of the watershed. In particular, riparian areas of the watershed have been increasingly used for urban development. Figure 5.5 presents the land uses in riparian areas of the Neshanic River Watershed in 1986, 1995, 2002 and 2007. In 1986, riparian areas were primarily used for agriculture, wetlands and forest; only about 500 acres of riparian areas were in urban uses. Urban uses of riparian areas have increased substantially in the last two decades; the increases were 282 acres during 1986-1995, 294 acres during 1995-2002 and 151 acres during 2002-2007. Increases in urban lands that occurred during the last two decades were accompanied by losses in agriculture and wetlands in riparian areas. Losses in agricultural lands in riparian areas amounted to 309 acres, 256 acres and 55 acres during the periods 1986-1995, 1995-2002 and 2002-2007, respectively. Although poorly managed agricultural areas could contribute to water quality degradation in the watershed, converting pervious agricultural lands to urban land with more impervious surfaces changes watershed hydrology and contributes to both frequent flooding and water quality degradation.

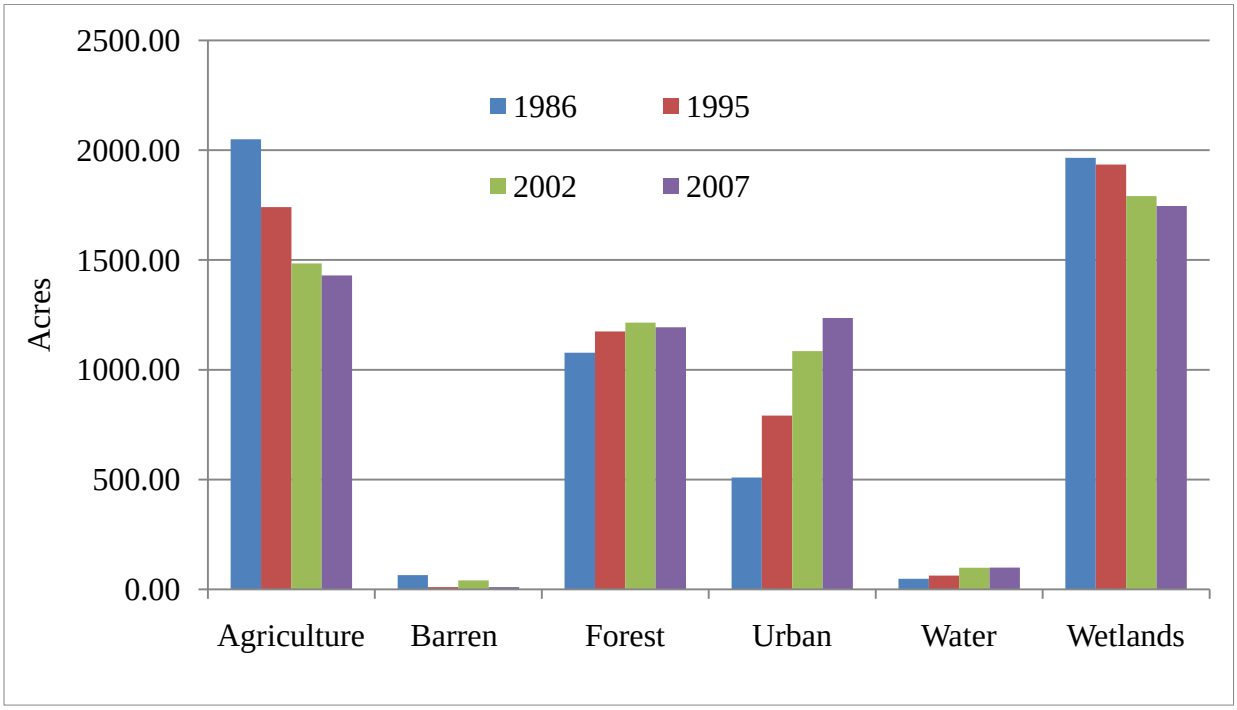


Figure 5.5: Land uses in riparian areas of the Neshanic River Watershed, 1986, 1995, 2002 and 2007

Wetland losses and agriculture and urban development in hydric soils and riparian areas usually destroy natural pathways for water drainage and reduce the storage capacity for runoff; the latter leads to higher runoff quantity and velocity reaching streams. The latter increases the occurrence of flash flooding and stream sedimentation that is discussed in detail later. Additionally, the loss of wetlands reduces water treatment of runoff before it reaches the streams.

5.3. **Surface Water Quality**

5.3.1. Designated Uses and Impairments

The NJDEP (2010a) designated the Neshanic River and its tributaries as FW2-NT. "FW2" refers to freshwater bodies that are used for primary and secondary contact recreation; industrial and agricultural water supply; maintenance, migration, and propagation of natural and established biota; public potable water supply after conventional filtration treatment and disinfection; and any other reasonable uses. "NT" means those freshwaters may support other fish species, but are not suitable for trout production or trout maintenance due to their physical, chemical, or biological characteristics.

According to the designated use FW2-NT, the following surface water quality standards are applicable to the Neshanic River and its tributaries following NJAC 7:9B, as amended on January 4, 2010 (42 N.J.R. 68a):

- *E. coli* shall not exceed a geometric mean of 126 counts per 100 milliliter (mL) or a single sample maximum of 235 counts per 100 mL;
- Fecal coliform shall not exceed a geometric average of 200 counts per 100 mL, nor shall more than 10 percent of the total samples taken during any 30-day period exceed 400 counts per 100 mL;
- Dissolved oxygen (DO) shall not be less than 5.0 mg/L for its 24 hour average, but not less than 4.0 mg/L at any time;
- pH shall be between 6.5 and 8.5;
- TP as shall not exceed 0.1 mg/L;
- TSS shall be less than 40 mg/L;
- Temperatures shall not exceed a daily maximum of 31 degrees Celsius or rolling seven-day average of the daily maximum of 28 degrees Celsius, unless due to natural conditions; and
- Nitrate shall be below 10 mg/L.

In accordance with Section 305(b) of the Clean Water Act, New Jersey has authority to address overall water quality of the State's waters and identify impaired waterbodies through the development of a document referred to as the *Integrated List of Waterbodies*. The list details the presence and level of impairment for each monitored waterbody. It is recommended that this list be a guideline for water quality management actions that address the cause of impairment.

Based upon numerous monitoring sources, including the NJDEP Ambient Biomonitoring Network (AMNET), the NJDEP/ USGS water quality monitoring network and the Metal Recon Program, the Neshanic River and its branches are impaired for aquatic life, phosphorus, TSS and copper and are listed on Sublist 5 of the New Jersey 2004 Integrated Water Quality Monitoring and Assessment Report (NJDEP, 2004b). Sublist 5 of the 2004 Integrated List contains the waterbodies that are impaired or threatened for one or more designated uses by a pollutant(s) and require a TMDL (NJDEP, 2004b). According to the 2006 Integrated List, which uses a HUC-14 based water quality impairment listing methodology, the Neshanic River and its tributaries (HUC14 02030105030010, 02030105030020, 02030105030030, 02030105030040, and 02030105030060) are impaired for DO, arsenic and phosphorus, and listed on Sublist 5 for aquatic life and drinking water supply and Sublist 4 for primary contact recreation impairments (NJDEP, 2006). Sublist 5 of the 2006 Integrated List contains the waterbodies that are impaired

or threatened for one or more designated uses by a pollutant(s) and require a TMDL. Sublist 4 contains the waterbodies that are impaired or threatened for their designated uses, however development of a TMDL is not required (NJDEP, 2006).According to the most recent listing (i.e., the 2008 Integrated List), the Neshanic River and its tributaries are impaired for DO, pH, arsenic and phosphorus and listed on Sublist 5 for aquatic life, drinking water and industrial water and Sublist 4 for recreation impairments (NJDEP, 2009a). According to NJDEP (2009a), both Sublist 4 and Sublist 5 list waterbodies where the designated use attainment is threatened and/or a waterbody is impaired, however, a TMDL is not required for the waterbodies listed under Sublist 4, but for the waterbodies listed under Sublist 5. A nutrient TMDL is being developed by NJDEP for the entire Raritan Basin. Like many waterbodies in New Jersey, the Neshanic River and its tributaries are also contaminated by pathogens. A TMDL for fecal coliform was adopted for the Neshanic River in 2003 that requires 87 percent reductions in fecal coliform from medium/high density residential, low density/rural residential, commercial, industrial, mixed urban/other urban, forest, and agricultural lands (NJDEP, 2003).

5.3.2. Monitoring Stations

The NJDEP assessed the impairment status of the Neshanic River and its tributaries based on the surface water quality monitoring at the USGS Reaville Gage Station near the stream-road crossing between the Reaville Road and the main Neshanic River noted as N1 as well as AMNET monitoring at four biological monitoring stations AN0330, AN0331, AN0332 and AN0333 represented by FN1, SN1, TN3 and N1 in Figure 5.6, respectively.

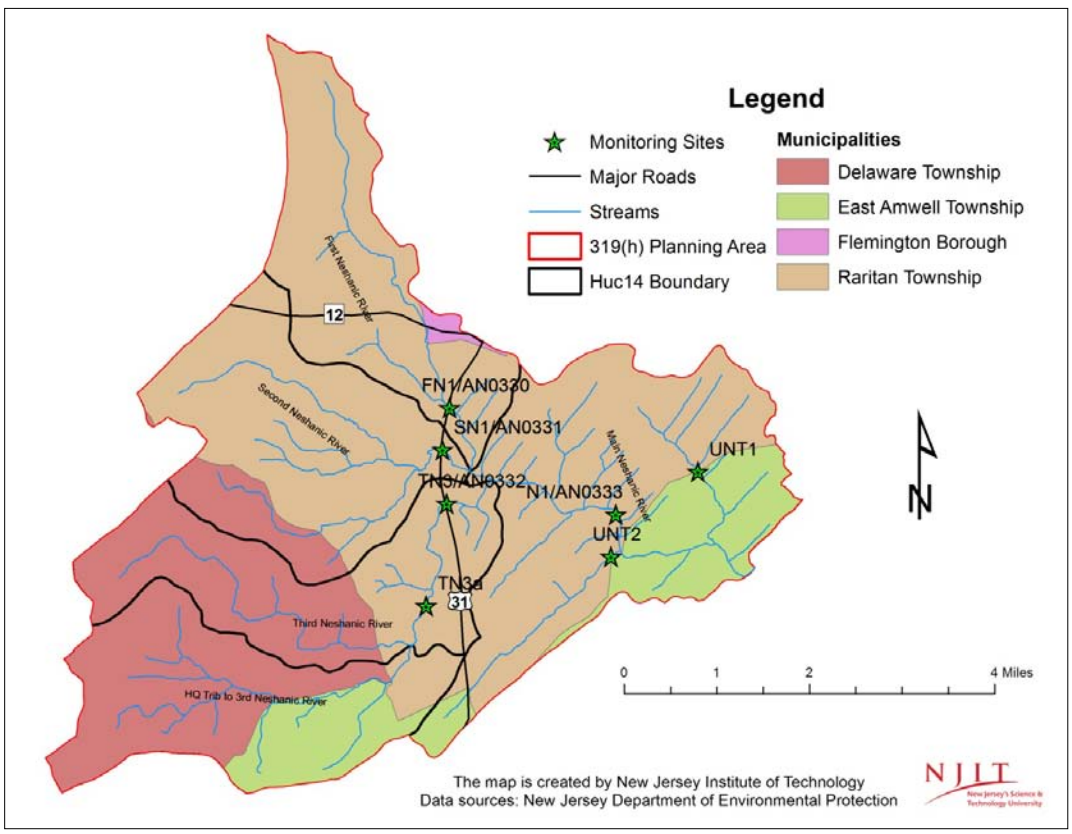


Figure 5.6: Location of the seven monitoring stations in the Neshanic River Watershed

In order to understand the causes and sources of water pollution in the watershed, surface water quality monitoring was expanded to include seven monitoring stations in the watershed. Additional water quality monitoring stations include FN1, SN1, TN3, TN3a, UNT1 and UNT2. Biological monitoring was continued at all four biological monitoring stations.

Station FN1, First Neshanic River at the Route 202 crossing, was selected to characterize the First Neshanic River (HUC 02030105030010), a major tributary to the Neshanic River, upstream from the confluence with the Neshanic River. Station SN1, Second Neshanic River at the Route 202 crossing, was selected to characterize the Second Neshanic River (HUC 02030105030020), a major tributary to the Neshanic River, upstream from the confluence with the Neshanic River. Station TN3a, Third Neshanic River at the Everitts Road bridge crossing, was selected to characterize both the southern and northern branches of the Third Neshanic River, a major tributary that drains areas having substantial agricultural land. Station TN3, third Neshanic River at the Route 202 crossing, was selected to characterize the Third Neshanic River, a major tributary to the Neshanic River, upstream from the confluence with the Neshanic River. Station TN3 is located further downstream from the confluence of the northern and southern branch of the Third Neshanic River. Both TN3 and TN3a were selected to characterize HUCs 02030105030030-40. Station N1, Neshanic River main stem at the Everitts Road and Reaville Road, was selected to characterize the main stem of the Neshanic River downstream from the confluence and drainage from the First, Second, and Third Neshanic Rivers. This site was selected to also characterize portion of HUC 02030105030060. Station UNT1, the unnamed tributary at the Route 514 crossing, was selected to help identify if loadings are coming from areas within this subwatershed that are suspected of having failing septic systems. Station UNT2, the unnamed tributary at Old Mill Court and Hunterdon Pointe Boulevard crossing, was selected to help characterize the loadings from suburban/urban areas within this subwatershed.

Figure 5.7: USGS Reaville gage station (N1)

5.3.3. Summary of Water Quality Data

The USGS began monitoring the water quality at station N1 in the late 1970s. The earlier monitoring efforts focused on nutrients in water, including ammonia-N (NH_3-N), nitrate-N (NO_3-N), nitrite-N (NO_2-N), organic N, TN, phosphorus, and orthophosphate. Monitoring is usually conducted 3 to 5 times a year with some interruption. Water quality monitoring at station N1 was later expanded to include TSS and fecal coliform. The historical USGS/NJDEP water quality monitoring data at station N1 was used by NJDEP to evaluate the impairment status compared to the designated uses for the Neshanic streams and develop integrated water quality reports that recommended the development of TMDLs and this watershed restoration plan as discussed in Section 5.3.1.

In order to assess the water quality conditions in different parts of the watershed, this project conducted additional surface water quality and physical conditions monitoring under both dry and wet weather conditions at all seven monitoring stations. Both historical monitoring data and the additional monitoring results are used to assess the pollutant load reductions required to meet the water quality standards for the designated uses. Dry weather monitoring included biweekly surface water sampling and additional bacteriology sampling during June-November 2007. Biweekly (twice a month) surface water samples were collected from June to November 2007, which resulted in 12 sampling events. Water samples were tested for ammonia-N, nitrate-N, nitrite-N, total Kjeldahl nitrogen, TP, dissolved orthophosphate phosphorus, TSS, fecal coliform, *E. coli*. pH, temperature, DO, stream width, stream depth and stream velocity were measured onsite during sampling. During June, July and August 2007, three additional water samples per month (i.e., 9 events) were collected for testing fecal coliform and *E. coli*, resulting in five bacteria samples per month for June, July and August 2007. Three wet weather monitoring events were conducted between June and November 2008. A series of water samples were collected during the course of a storm event; only three samples at the beginning, middle and end of the storm event were tested for TP, dissolved orthophosphate phosphorus, TSS and *E. coli*, the primary pollutant. Due to safety concerns, no physical parameters of water were measured during the wet weather sampling.

Biological monitoring was conducted at four of the seven monitoring stations in the watershed: FN1, SN1, TN3 and N1. Biological samples were taken once in early summer 2007 for analysis of benthic macroinvertebrate survey. A habitat assessment was performed during each biological sampling event. The physical parameters, such as pH, temperature, DO, stream width, stream depth and stream velocity, were also measured during the sampling.

5.3.4. Surface Water Quality

Table 5.1 gives the basic statistics of the water quality results of the biweekly and additional bacteria sampling during the dry weather condition and the percentage of samples that were in violation of the surface water quality standards or exceeded the surface water quality criteria (SWQC) in the monitoring stations. The average pH at all seven sites exceeded 6.5, the minimum requirement, and occasional violations of the pH criterion were observed throughout the watershed. There was only a single violation of the DO criterion at sites UNT2, UNT1 and SN1. A high percentage of the samples collected throughout the Neshanic River Watershed exceeded both the current bacteria criterion for *E. coli* and the former criterion for fecal coliform. The TP criterion was also exceeded often. Only a single violation of the TSS criterion was observed at UNT2. In regard to the wet weather sampling, 98 percent of the samples collected throughout the watershed exceeded SWQC for *E. coli*, and 84 percent of the samples collected exceeded the criterion for TP. Persistent and continual violations of the TSS criterion were not observed during the wet weather sampling events. The NJDEP's Integrated Water Quality Monitoring and Assessment Methods indicate that if the frequency of water quality results exceed the water quality criteria twice within a five-year period, then the waterway's quality may be compromised (NJDEP, 2009).

Table 5.1: Basic statistics of water quality monitoring results in the Neshanic River Watershed

Monitoring Station	SWQC	Count	Minimum	Maximum	Mean	% of Violating SWQC
UNT2	**pH** minimum 6.5 (SU)	12	6.21	7.25	6.75	8 (1/12)
UNT1		12	6.12	6.88	6.62	25 (3/12)
N1		13	6.11	7.50	6.79	25 (3/12)
TN3a		12	5.74	7.31	6.82	17 (2/12)
TN3		12	5.69	8.35	6.91	25 (3/12)
SN1		13	6.16	7.67	6.85	23 (3/12)
FN1		13	5.56	7.75	6.82	8 (1/12)
UNT2	**Dissolved Oxygen** Not less than 4 (mg/L) at any time	12	3.63	11.93	7.26	8 (1/12)
UNT1		12	3.82	10.70	6.05	8 (1/12)
N1		13	4.23	12.22	6.99	0
TN3a		12	5.26	12.62	8.14	0
TN3		11	5.11	12.01	7.90	0
SN1		13	3.24	11.42	7.15	8 (1/12)
FN1		13	4.62	10.95	7.02	0
UNT2	***E. coli*** Single sample maximum of 235 (counts/100 ml)	21	5	76,000	855	86 (18/21)
UNT1		21	5	32,000	390	57 (12/21)
N1		21	50	26,000	429	62 (13/21)
TN3a		21	60	6,200	544	71 (15/21)
TN3		21	80	4,000	397	71 (15/21)
SN1		21	20	38,000	468	71 (15/21)
FN1		21	10	46,000	678	81 (17/21)
UNT2	**Fecal Coliform** No more than 10% of the total samples taken during any 30-day period can exceed 400 (counts / 100 ml)	21	40	44,000	1,065	67 (14/21)
UNT1		21	10	24,000	401	57 (12/21)
N1		21	40	18,000	402	38 (8/21)
TN3a		21	40	8,200	543	52 (11/21)
TN3		21	68	12,000	613	52 (11/21)
SN1		21	2	12,000	539	48 (10/21)
FN1		21	2	23,000	733	71 (15/21)
UNT2	**Total Phosphorus** 0.1mg/L in any stream	12	0.03	0.29	0.11	25 (3/12)
UNT1		12	0.03	0.27	0.12	58 (7/12)
N1		12	0.03	0.19	0.10	33 (4/12)
TN3a		12	0.05	0.13	0.09	33 (4/12)
TN3		12	0.04	0.15	0.10	42 (5/12)
SN1		12	0.05	0.28	0.11	58 (7/12)
FN1		12	0.04	0.37	0.14	58 (7/12)
UNT2	**Total Suspended Solids** 40.0 (mg/L)	12	0.25	110	13.40	8 (1/12)
UNT1		12	0.25	35.00	6.23	0
N1		12	0.25	8.00	2.52	0
TN3a		12	0.25	13.00	4.81	0
TN3		12	0.25	21.00	5.15	0
SN1		12	0.25	14.00	3.38	0
FN1		12	0.50	36.00	7.00	0

The water quality in the Neshanic River Watershed is clearly compromised given the continual and persistent violations of the SWQC for bacteria and TP, and the occasional violation of the minimum pH. These results are consistent with the assessment presented in the *Integrated List of Waterbodies* by NJDEP (2009a). However, the water quality monitoring shows that TSS, even during wet weather events, and DO do not appear to be a problem for the Neshanic River Watershed, which is not consistent with the assessment presented in the *Integrated List of Waterbodies* by NJDEP (2009a). Additional assessments are needed to further evaluate the impairment status of the Neshanic River and its tributaries.

5.3.5. Microbial Source Tracking

Microbial source tracking is the concept of applying microbiological, genotypic (molecular), phenotypic (biochemical) and chemical methods to identify the origin of fecal pollution (Scott et al., 2002; USEPA, 2005). The microbial source tracking techniques were applied as a supplemental tool to identify the causes and sources of pathogen contamination in the Neshanic River Watershed. Samples were collected in sterile bottles at the seven monitoring locations as part of the wet weather surface water sampling and held at 4˚C until processing. For each ½ inch wet weather event, three samples were collected (A, B, and C) between the onset of the storm and the time when the flow reached the pre-storm level. The protocol used for the Neshanic River Watershed samples is a modification of the procedure found in the DNeasy Tissue Handbook (Qiagen, Inc., 2004); it measures the number of bacteroides present. After extraction, all DNA samples were quantified by spectroscopy (Beckman DU 640) at 260 and 280 ηm and then diluted in sterile water to a concentration of 1 µg/mL. The diluted DNA was used as the template for quantitative, real-time polymerase chain reactions (PCRs) to measure the number of bacteroides present. Three sets of PCR primers (targets) were used to quantify bacteroides from human sources (HuBac), bovine sources of bacteroides (BoBac) and other sources of bacteroides (OtherBac) (e.g., wildlife, birds, horses, domestic animals, etc.).

The microbial source tracking results show that Monitoring Stations UNT2, UNT1, N1, FN1 and TN3a have a higher incidence of human bacteroides than at SN1 and TN3. For the first wet weather event, human bacteroides were detected at N1 in the second set of samples. By the time the third sample was collected, no bacteroides were detected; they were most likely flushed from the system. For the second wet weather event, human bacteroides were detected in the first set of samples from UNT2 and N1, but none were detected in the second or third set of samples collected at these locations. Human bacteroides were detected at FN1 and TN3a in the second set of samples, but by the third set of samples, human bacteroides were not detected and were most likely flushed from the system. For the third wet weather event, human bacteroides were detected at UNT2, TN3a and FN1 in the first set of samples, at UNT2 and N1 in the second set of samples and at UNT2 and UNT1 in the third set of samples.

Bovine bacteroides were not detected in any of the samples collected and analyzed. This is most likely due to the sampling locations not being in close proximity to bovine sources. In studies conducted in Salem and Cumberland Counties, New Jersey, bovine bacteroides were not detected much beyond 1,000 feet downstream from bovine sources, possibly due to the effect of settling, die-off and/or predation of the bovine *Bacteroides* within 1,000 feet of the source. Not surprisingly, other sources of bacteroides were detected at all the sampling locations during each wet weather event. Possible other sources of bacteroides include wildlife, birds, horses, domestic

animals, etc. Although these data illustrate the highly variable nature of water quality measures, these data are useful for determining the potential sources and extent of fecal contamination within the watershed.

5.3.6. Biological Monitoring and Results

Biological monitoring in the Neshanic River Watershed was conducted in the same manner as AMNET administered by the NJDEP. It used a modified version of the USEPA Rapid Bioassessment Protocol II (NJDEP, 2004). Biological monitoring assesses both the impairment status of streams by measuring the presence of benthic macroinvertebrate communities in streams and the habitat conditions for supporting the benthic macroinvertebrate communities in streams by evaluating the physical and biological habitat attributes.

The NJDEP (2004) developed a scale of biological integrity referred to as the New Jersey Impairment Score (NJIS) to classify the impairment status of a monitoring site. NJIS is based on several measurements on the benthic macroinvertebrate communities including taxa richness, EPT (Ephemeroptera, Plecoptera, Trichoptera) index, percent EPT, percent contribution of the dominant family and the family biotic index. NJIS ranges from 0 to 36. Monitoring sites with total NJIS scores ranging from 24 to 30 are considered as non-impaired sites, from 9 to 21 as moderately impaired sites, and from 0 to 6 as severely impaired sites. A non-impaired site generally has a benthic community comparable to other high quality “reference” streams within the region characterized by maximum taxa richness, balanced taxa groups and a good representation of intolerant individuals. A moderately impaired site is characterized by reduced macroinvertebrate taxa richness; in particular, the EPT taxa. Changes in taxa composition result in reduced community balance and intolerant taxa become absent. A severely impaired site is one in which the benthic community is significantly different from that of the reference streams, where the macroinvertebrates are dominated by a few taxa which are often very abundant, and tolerant taxa are typically the only taxa present.

The habitat assessment is designed to provide an estimate of habitat quality based upon qualitative estimates of selected habitat attributes. The assessment involves evaluating instream substrate, channel morphology, bank structural features, and riparian vegetation based on numerical scoring of ten habitat attributes (i.e., epifaunal substrate/available cover, embeddedness, velocity/depth regime, sediment deposition, channel flow status, channel alteration, channel sinuosity, bank stability, vegetative protection, and riparian vegetative zone width). Each parameter is scored and summed to produce a total score which is assigned a habitat quality category of optimal, sub-optimal, marginal or poor. Sites with optimal/excellent habitat conditions have total scores ranging from 160 to 200, sites with suboptimal/good habitat conditions have total scores ranging from 110 to 159, sites with marginal/fair habitat conditions have total scores ranging from 60 to 109 and sites with poor habitat conditions have total scores less than 60. The findings from the habitat assessment are used to interpret survey results and identify obvious constraints on the attainable biological potential (NJDEP, 2004).

The NJDEP Bureau of Biological & Freshwater Monitoring maintains four AMNET monitoring locations in the Neshanic River Watershed (i.e., stations AN0330, AN0331, AN0332 and AN0333). Station AN0330 is the same as Monitoring Station FN1, Station AN0331 as SN1, Station AN0332 as TN3 and Station AN0333 as N1 in the above the Neshanic River Watershed monitoring station map. All four stations were sampled in 1994, 1999 and 2004 by NJDEP

(1995; 2000; and 2008a) and in 2007 by the project team. Table 5.2 summarizes the AMNET monitoring results at these sites in the four rounds of assessments. In 1994, 1999, and 2004, Station AN0330 (FN1) was classified as being moderately impaired and its habitat conditions were found to be sub-optimal in 1999 and 2004. In the 2007 assessment, biological condition remained moderately impaired, but habitat conditions were degraded from sub-optimal to marginal conditions. Station AN0331 (SN1) was assessed as being non-impaired in 1994, but was degraded to moderately impaired in 1999 and non-impaired in 2004. Habitat conditions in 1999 and 2004 were found to be sub-optimal. Like Station AN0331, Station AN0332 (TN3) was found to be non-impaired in 1994, moderately impaired in 1999 and non-impaired in 2004. Habitat conditions for the site were found to be sub-optimal in both 1999 and 2004. The 2007 assessment indicated that the stream impairment status remained at non-impaired and the habitat condition remained as sub-optimal at both AN0331 (SN1) and AN0332 (TN3). Station AN0333 (N1) was assessed as being moderately impaired in 1994, 1999 and 2004. Its habitat conditions were found to be sub-optimal in 1999 and 2004. The 2007 assessment indicated that the impairment status at site AN0333 (N1) was downgraded to a non-impaired status and the habitat condition remained as sub-optimal. In summary, the Neshanic River continued to support a non-impaired to moderately impaired benthic macroinvertebrate community.

Table 5.2: AMNET monitoring results in the Neshanic River Watershed, 1994, 1999, 2004 and 2007

AMNET Station		AN0330 (FN1)	AN0331 (SN1)	AN0332 (TN3)	AN0333 (N1)
1994	Impairment Status (Score)	moderately impaired (15)	non-impaired (27)	non-impaired (24)	moderately impaired (18)
1999	Impairment Status (Score)	moderately impaired (12)	moderately impaired (21)	moderately impaired (21)	moderately impaired (12)
	Habitat Status (Score)	sub-optimal (138)	sub-optimal (148)	sub-optimal (149)	sub-optimal (133)
2004	Impairment Status (Score)	moderately impaired (12)	non-impaired (27)	non- impaired (30)	moderately impaired (21)
	Habitat Status (Score)	sub-optimal (142)	sub-optimal (137)	sub-optimal (129)	sub-optimal (130)
2007	Impairment Status (Score)	moderately impaired (15)	non-impaired (24)	non-impaired (24)	non-impaired (24)
	Habitat Status (Score)	Marginal (105)	sub-optimal (144)	sub-optimal (149)	sub-optimal (127)

5.4. **Point Sources**

According to regulations in the United States, point sources generally include municipal wastewater (sewage), industrial wastewater discharges, municipal separate storm sewer systems and industrial stormwater discharges (Public Law 100-4. 1987). These facilities are required to obtain National Pollution Discharge Elimination System permits or state/local permits. According to NJDEP's permitted point source surface discharges database, there are only two permitted industrial point sources that discharge treated petroleum products cleanup wastewater to the Neshanic River streams during certain periods of time. First is Exxon Company, USA (NJPDESID: NJ0000892) that is located just outside of the Neshanic River Watershed in Raritan Township at latitude 40° 30' 10.2" and longitude 74° 51' 14.5" and discharged treated

groundwater to the First Neshanic River via storm sewer before 2000. Second is Suburban Sunoco Inc. (NJPDESID: NJG0136034), located just inside of the watershed boundary in East Amwell Township, at latitude 40° 26' 29.7" and longitude 74° 51' 26.5"; that source discharged treated groundwater to the Neshanic River via an unnamed tributary and storm sewer during 2001-2006. Exxon Company no longer holds the active permit. Suburban Sunoco Inc. has an active permit, but no longer discharges treated groundwater into Neshanic River streams according to the latest record inquiry from NJDEP. Therefore, there are no point sources considered in the Plan.

5.5. **Nonpoint Sources**

Nonpoint sources (NPS) is comprised of diffuse sources of water pollutants originating from the landscape. Although the exact location of the pollution may not be easily identified due to its diffuse nature, it is well recognized that agriculture and urban development are major sources of nonpoint source pollutants. Agriculture has been identified as a leading source of water pollution in the U.S. by USEPA (1994). Agricultural sources are responsible for many pollutants, such as sediment, nutrients, pesticides, pathogens, and organic enrichment. Agriculture here refers to irrigated and non-irrigated crop production, confined animal feeding operations, grassland and rangeland. Table 5.3 lists the potential pollutants generated by different agricultural activities.

Table 5.3: Agricultural activities and potential related pollutants (Krivak, 1978)

	Crop Production		Animal Production	
Pollutant	Irrigated	Non-irrigated	Confined	Pastured/Grazing
Sediment	o	x	o	x
Nutrients	o	o	x	o
Salts	x	-	o	-
Organics	o	o	x	o
Pesticides	o	o	-	-
Pathogens	-	-	o	o

Note: x indicates a principal problem, o indicates a secondary problem and - indicates a minor problem, if any.

Urban development has taken a new form in the last several decades called urban sprawl, characterized by low density residential development. Nonpoint source pollutants associated with urban development are sediments, nutrients and pathogens originating from site development, sewer and wastewater, and fertilizer and pesticides that are used for greening the lawns. Prime examples of urban development are exurbanization (i.e., residential developments in large lots in rural settings) (Nelson, 1992; Davis et al., 1994) and the development of hobby farms associated with exurbanization. The examples of hobby farms include horse and other animal farms, orchard and small cash crop farms, which blurs the traditional distinction between agricultural and urban NPS.

Wildlife such as deer, raccoons and geese are another source of pollutants. The wastes deposited by wildlife contain nutrients and pathogens, which are all potential water pollutants. The protective regulations on deer, such as the limitations placed on deer hunting, greatly contribute to deer population growth. The well-maintained lawns in low density residential areas, commercial and industrial complexes and recreational facilities, such as golf courses creates the perfect habitat for the Canada goose.

Although the contribution of individual sources may be small, the cumulative effect of nonpoint sources is large. Because all the pollutants generated by agriculture, urban development and wildlife are accumulated in land surface, the natural hydrological processes, such as runoff and percolation during a storm event, will eventually transport these pollutants into nearby streams and groundwater causing water pollution.

The transport of pollutants from the source to streams (receptors) is not a simple and straightforward process. It is affected by weather and natural resource conditions, such as topography, soils and land uses during the pathway. Under certain ideal weather and natural resource conditions, the risk of transporting pollutants from sources to receptors could be limited. However, the human interactions with nature tend to increase such risk. As discussed previously, land use activities in the watershed have caused significant hydrological alteration and in some ways accelerated the extent and the speed of pollutant transport from sources to streams.

The following sources of pollutants, including sediment, nutrients and pathogens in the Neshanic River Watershed, were identified and assessed: (1) crop and hay production; (2) livestock production; (3) wildlife; and (4) urban land use. In crop production, the impacts of tillage and fertilizer (both synthetic fertilizer and animal manure) on water quality are considered. Impacts of grazing and direct access to streams are considered for livestock production. Impacts of urban land uses include fertilizer applications on lawns and failing OSDS in low density and rural residential areas. These sources are described below in detail and their impacts and relative contribution to the water quality problems in the watershed were assessed using the SWAT biophysical simulation model. SWAT simulates the transport process for pollutants from the sources to receptors given the weather and natural resource conditions in the watershed. The SWAT model utilizes 2002 NJDEP land use/cover data, NJDEP 10-meter DEM and streams data and the SSURGO soil survey database maintained by NRCS.

5.5.1. Crop and Hay Production

The Neshanic River Watershed had the highest percentage of agricultural lands among all watersheds in the Raritan River Basin. According to the NJDEP land use/cover, about 36.4 percent of the watershed (7,221 acres) was in agricultural lands during 2002. This included the following subcategories with their 4-digit classification codes in parenthesis: cropland and pastureland (2100); confined feeding operations (2300); orchard/vineyard/nursery/horticultural areas (2200); and other agriculture (2400). The 2002 agricultural land class did not include agricultural wetlands (modified) (2140) and former agricultural wetlands (2150), which were counted as wetlands, but were frequently in agricultural uses. Including both agricultural wetlands (modified) and former agricultural wetlands in agricultural lands increases total agricultural lands to 7,726 acres or 39 percent of the watershed in 2002.

The NJDEP land use/cover classification system does not distinguish the agricultural types (i.e., specific crops and types of animals) within cropland and pastureland (2100), the dominant class of agricultural lands. In order to understand the water quality impacts of agriculture in the watershed, the detailed pattern of agricultural land use has to be identified. Agricultural land use surveys were conducted in 2007 and 2008. Using maps and aerial photographs, an agricultural specialist and volunteers were able to identify the specific crops and types of animals in fields. In cases where the data were difficult to collect due to limited access, best educated guesses were made. The agricultural land use survey data were combined with the 2002 NJDEP land use data to estimate detailed agricultural land use patterns in the watershed. The final estimate of agricultural lands in the watershed is about 8,074 acres, of which 58 percent (i.e., 4,662 acres) is for row-crop production, such as corn, soybean, wheat and rye. There are about 2,420 acres of hay fields (i.e., 30 percent of agricultural lands) that produce timothy and other types of hay to support livestock operations in the watershed and the neighboring communities. Also, there are 892 acres of pasture that are used for livestock grazing. The remaining 100 acres are in orchards and nurseries.

In addition to the spatial pattern of agricultural land uses, crop or plant-specific information on tillage, fertilizer, pesticide applications, and harvest, and animal grazing schedules are required to run the SWAT model. Such information was collected through interviews with several individual farmers in or near the watershed and then generalized to represent the conditions in the watershed. The latter were then discussed and finalized through several meetings with agricultural specialists in RC&D, NJDA and HCSCD and the resource conservationists from NRCS who have worked in the region. The choices of farming practices depend on farmers' experiences and specific resource conditions, which makes data collection on farming practices difficult. The information used in the SWAT model does not capture details of farming practices, but does reflect the general farming conditions in the watershed. Specific farming operations and their schedules are in the SWAT modeling report.

Given the large area of the watershed in agricultural land uses, the management of row crops, hay and other agriculture has significant implications for water quality and quantity in the watershed. On the negative side, agricultural operations could be sources of sediments that can be carried into stream. In addition, agricultural fertilizers and pesticides not used by the crops and plants could be carried by runoff into streams. On the positive side, all agricultural lands have pervious surfaces, which allow water to infiltrate into the ground during a storm event, which reduces surface runoff.

5.5.2. Livestock Production

Livestock in the watershed include horses, cattle, sheep, goats and many other small animals. There are no large-scale confined animal feeding operations in the watershed. Small-scale livestock operations can have significant impacts on water quality in the watershed. Nutrients, fecal coliform and *E. coli* in manure could end up in the streams because of improper manure management and manure applications in row-crop and hay production. In addition, livestock grazing in pastures could cause water quality degradation via soil erosion and sediment transport to streams. Animal access to streams could further expose the streams to water quality degradation.

Accurately counting the type and number of livestock in the watershed is very difficult. To estimate the impacts of livestock production on water quality in the watershed, this project primarily focused on the impacts of large livestock (i.e., horses, beef cattle and dairy cows) on water quality because they generate much more manure than other animals. The total number of cattle and horses was estimated using the animal density in Hunterdon County obtained from the 2007 Agricultural Census published by the National Agricultural Statistics Service (NASS) and the total agricultural area of the watershed. The project further assumes that cattle and horses are annually active and evenly distributed among the pasture land in the watershed. Manure production, in terms of nutrient and pathogen loads in the Neshanic River Watershed, was estimated based on the total number of cattle and horses and manure production, fecal coliform content and loading rates of cattle and horses determined from the daily manure production and fecal coliform amounts for typical livestock estimated by ASAE (2003). There is no established measurement for *E. coli* in animal manure. *E. coli* content of animal manure was assumed to be 62.5 percent of fecal coliform for those livestock animals (IDNR, 2006). Additional information on the nutrient loads from manure is based on the percentages of nutrient content in dry manure given in various fertilizer databases.

5.5.3. Wildlife

Wildlife in the Neshanic River Watershed include, but are not limited to deer, raccoons, rodents, geese and ducks. There is no wildlife inventory for the watershed. Deer and geese are considered the dominant wildlife in the watershed because of their pervasive presence. White-tailed deer are found throughout New Jersey except in the most urbanized areas of the state. The estimated annual deer population during 1984 and 2006 ranged from 120,000 to 200,000 (i.e., a density of 13.7 to 22.9 deer per mi^2) (NJDEP, 2008b). The total number of deer in the watershed is estimated assuming a deer density of 20 deer per mi^2. The total number of deer is estimated to be 620 in the watershed.

Canada geese have a clear preference for tender, mowed and fertilized turf grass, although they also feed heavily on small grains, such as corn and soybeans, during the fall and winter. They prefer to feed in large open areas with few obstructions that give the birds a 360-degree view of potential predators. Giant Canada geese differ from seasonally migrating interior Canada geese. The NJDEP Division of Fish and Wildlife conducts a breeding population survey each spring when only resident species are present because the migrating geese have already traveled to northern breeding grounds. The population of “resident” Canada geese in New Jersey was estimated at approximately 98,000 or 11.2 per mi^2 (NJDEP, 2010b). Suburban development leads to an increase in lawns, recreational fields and other grassy areas that are suitable habitat for Canada geese. As suburban development continues in the watershed, the population of resident geese is expected to increase. Considering the seasonally migrated interior Canada geese during winter and the hatching and growing of young residential Canada geese during spring and summer, the annual average goose density in the watershed is assumed to be twice the number of resident geese–about 22 geese per mi^2.

The numbers of and amount of manure produced by animals are used to estimate the nitrogen, phosphorus, fecal coliform and *E. coli* loads to streams from wildlife. Manure production for deer and goose come from the TMDL study in the Salt Creek watershed in Cook County, Illinois (WHPA, 2004). Daily fecal coliform loading rates of deer and goose come from

the TMDL for Pathogens in Beeds Lake Franklin County, Iowa (IDNR, 2006). Nutrient loads are based on the percentages of nutrient content in dry manure. Since various fertilizer databases do not reflect wildlife animals, such as deer and geese, it is assumed that the dry manure from deer and geese have the same percentages of nutrient content as from goats and ducks, respectively.

5.5.4. Urban Land Uses

Urban land uses in the Neshanic River Watershed include high, medium, low density and rural residential areas, commercial, industrial, recreational, transportation and other urban land uses. The acreages in various urban land use types are given in Table 5.4. The rural residential area is the dominant urban land use and comprised almost 64 percent of all urban uses.

Table 5.4: Areas and percentages of urban land uses in the Neshanic River Watershed, 2002

NJDEP Classification	Land Use Type	Area (Acres)	Percentage (%)
1110	Residential, High Density Or Multiple Dwelling	96.18	1.58
1120	Residential, Single Unit, Medium Density	216.70	3.56
1130	Residential, Single Unit, Low Density	382.04	6.27
1140	Residential, Rural, Single Unit	3,897.06	63.96
1200	Commercial/Services	290.34	4.76
1300	Industrial	78.24	1.28
1400	Transportation/Communication/Utilities	16.77	0.28
1410	Major Roadway	43.34	0.71
1462	Upland Rights-Of-Way Developed	12.99	0.21
1463	Upland Rights-Of-Way Undeveloped	90.45	1.48
1499	Stormwater Basin	93.05	1.53
1700	Other Urban Or Built-Up Land	452.20	7.42
1710	Cemetery	14.52	0.24
1800	Recreational Land	375.57	6.16
1804	Athletic Fields (Schools)	33.99	0.56
Total	All urban land uses	6,093.42	100.00

Runoff from urban areas is a potential source of nutrients and pathogens for streams and rivers. Fertilizers applied to lawns can be carried into streams by stormwater during a storm event. Since many residents in the watershed use OSDSs to treat wastewater, failing wastewater treatment systems in the watershed could contribute nutrients and pathogens to the streams, which is discussed in detail in the next section. Since the watershed has experienced rapid urbanization during the last two decades, another water pollution source is improper management of sediment and runoff during the land development and construction periods. Many regulatory measures and ordinances are utilized to deal with the control of sedimentation and runoff during construction. Additional nutrients and bacteria sources from urban lands include pet feces, urban wildlife, sanitary sewer cross-connections and deficient solid waste collection.

To assess the water quality impacts of urban land uses in the watershed using SWAT, those land uses in Table 5.4 were regrouped into eight different land use types embedded in SWAT model based on the similarity of hydrological responses: high (1110), medium (1120), medium/low residential (1130), low density residential (1140), commercial/industrial (1200 and 1300), institutional (1800 and 1804) transportation uses (1400, 1410, 1462, and 1463), and other urban areas (1499, 1700 and 1710). Each of the 8 urban land use types was further distinguished into pervious (e.g., lawns) and impervious (e.g., built-up areas) areas to capture different hydrological processes and water quality impacts in those areas. A set of linear regression equations developed by the USGS (Driver and Tasker, 1988) were used to estimate storm runoff volumes and sediment and nutrients loads from impervious sections. Lawns are assumed to be in pervious sections. Fertilizer application rates on lawns were estimated based on information provided by local landscaping companies.

5.5.5. Onsite Disposal Systems (OSDSs) for Wastewater Treatment

Household OSDSs for wastewater treatment have the potential to release nutrient and bacteria to streams due to system failures caused by improper maintenance, malfunctions and/or close proximity to streams. Although most households in the watershed rely on OSDSs for sewer and waste water treatment, there is no inventory of those systems and their operational status in the watershed. Many residents do not know that their wastes are treated by OSDS; they assume all sewer and waste waters are transported by regular municipal sewer systems and processed by municipal waste water treatment facilities. According to the 2007 NJDEP land use data, the watershed contains 2,696 households located in the low density and rural residential areas. Of those households, 1,508 are in SSAs delineated by NJDEP and 1,188 are in the non-SSAs. Assuming one-fifth of the households in SSAs and all households in non-SSAs rely on OSDSs, about 1,490 households are likely have septic systems.

No study clearly estimates how many OSDSs fail or do not properly function in the watershed. Generally, septic system failures occur in older homes. Improper maintenance also increases the failure rate of septic systems. Virginia Department of Environmental Quality (2002) estimated the failing rate of septic systems based on their construction dates. Failing rates were estimated to be 40, 20, and 5 percent for systems built before 1970, during 1970-1989, and after 1989, respectively. Several studies found that 30 percent of all septic systems were either failing or not functioning at all. Based on the construction ages of housing units in the 2000 Census and the failure rates discussed above, the general failure rate for septic systems in Hunterdon County is assumed to be 26.5 percent. Because 10 years have passed since the 2000 Census, a 30 percent failure rate was assumed for failing OSDSs in the watershed, which results in 447 failing OSDSs in the Neshanic River Watershed. Only failing OSDSs close to the streams are likely to directly impact water quality. Of the 447 potentially failing OSDSs, 164 OSDSs are located within the 656 foot (200 meter) buffer zone of the streams and are assumed to have direct impacts on water quality. Nutrient and pathogen loads from failing OSDSs were estimated based on the following assumptions: (1) average number of persons served by each system is 2.8; (2) septic system effluent discharge rate of 70 gallons per person per day; and (3) concentrations in septic tank effluents were 40 mg/l TN, 12 mg/l TP, 1×10^6 cfu per 100mL fecal coliform, and 6.3×10^5 cfu per 100mL *E. coli*. These assumptions come from Indiana's Salt Creek *E. coli* TMDL study (WHPA, 2004).

5.5.6. Source Area Assessment Based on Water Quality Monitoring Data

As discussed previously, the source areas of pollutants of concern were assessed based on water quality data for seven monitoring stations in the watershed. Monitoring sites are shown in Figure 5.8. Each of the monitoring stations represents the outlet of a subwatershed in the Neshanic River Watershed. To identify which subwatersheds contribute the most pollution to the Neshanic River, data from the monitoring stations were used to determine the annual pollutant load and the annual pollutant loading rate for the seven subwatersheds. [1] The subwatersheds were then ranked by their annual pollutant load.

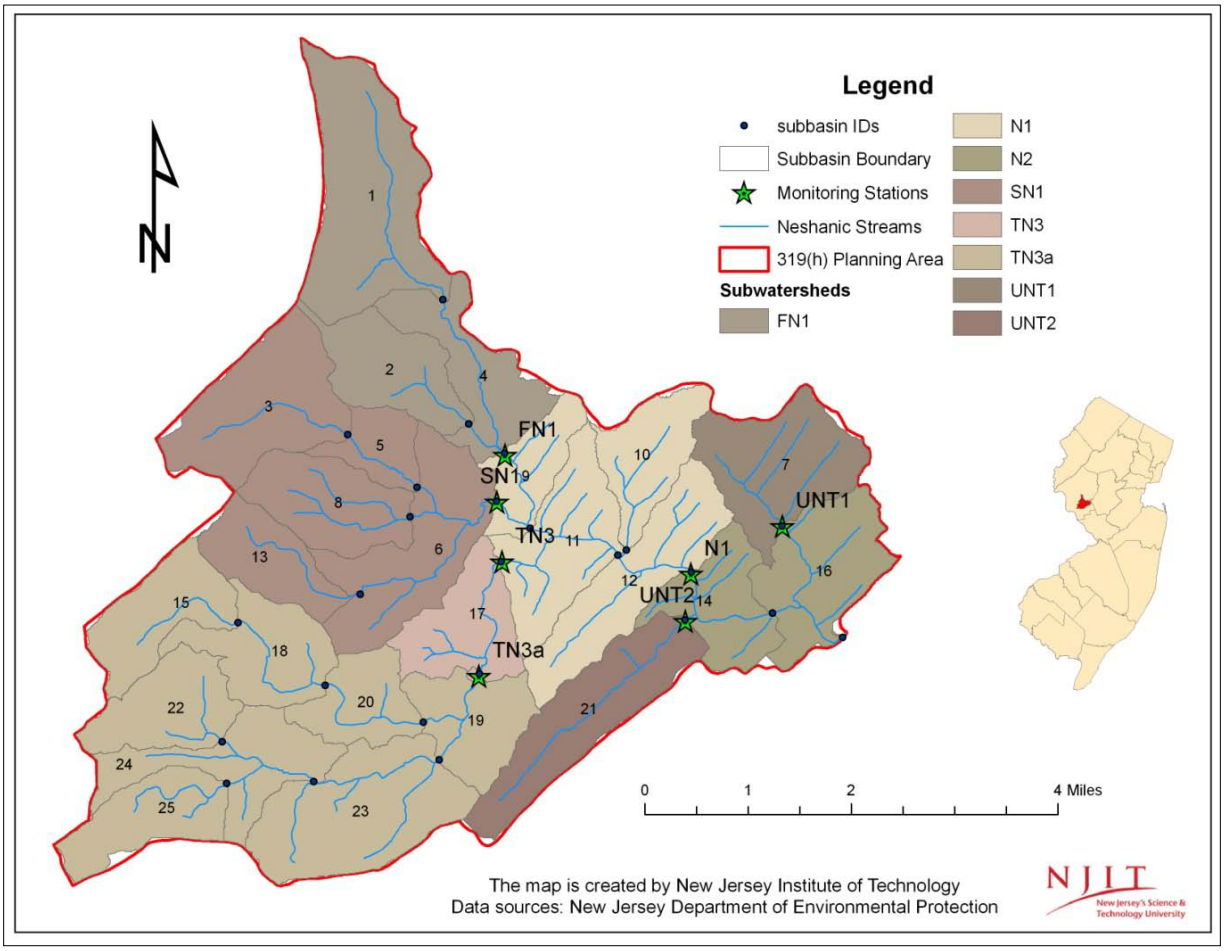


Figure 5.8: Water quality monitoring stations in the Neshanic River Watershed

The two primary pollutants of concern in the watershed are TP and fecal coliform; the latter is an indicator of pathogen contamination. Flow and pollutant concentrations were used to calculate the load for each sampling event at each monitoring station. Annual total load for each subwatershed was determined by averaging the daily loads and multiplying the average daily load by 365 days. Annual load of TP is measured in pounds per year. Annual load of fecal coliform is measured in colonies per year. Since each subwatershed has a different size, the

[1] For streams that have multiple sampling locations, the load measured at the upstream station was subtracted from the load measured at the downstream station to determine the pollutant load contributed by the watershed located between the two sampling stations.

annual loads were then normalized by dividing them by the number of acres in the subwatershed. This resulted in a TP loading rate in pounds per acre per year and a fecal coliform loading rate in colonies per acre per year.

Subwatersheds were ranked from highest to lowest according to the normalized pollutant loading rate. The resulting ranking is given in Table 5.5. For TP, subwatershed N1 ranked the highest, followed by subwatershed TN3. Subwatershed FN1 ranked the lowest in terms of TP loading. Subwatershed N1 also ranked the highest for fecal coliform, followed by subwatershed UNT2. Subwatershed TN3 ranked the lowest in terms of the fecal coliform loading. These rankings can be used to prioritize the implementation of stormwater and agricultural BMPs in the watershed.

Table 5.5: Ranking of the subwatersheds by normalized annual pollutant loads

Subwatershed	FN1	SN1	TN3	TN3a	UNT1	UNT2	N1
Drainage area (ac)	2,897.15	3,817.72	659.43	5,828.73	956.43	997.3	2,581.23
Total Phosphorus							
Annual Load (lbs/yr)	154.79	364.47	186.11	385.17	74.80	104.68	1159.59
Annual Load Rate (lbs/ac/yr)	0.05	0.10	0.28	0.07	0.08	0.10	0.45
Ranking	7	4	2	6	5	3	1
Fecal Coliform							
Annual Load (colonies/yr)	2.23E+13	2.56E+13	2.42E+12	4.51E+13	4.56E+12	2.89E+13	1.94E+14
Annual Load Rate (colonies/ac/yr)	7.70E+09	6.71E+09	3.67E+09	7.74E+09	4.77E+09	2.90E+10	7.52E+10
Ranking	4	5	7	3	6	2	1

5.5.7. Source Area Assessment Based on SWAT Modeling

The SWAT model gives a more comprehensive assessment of the source areas of water pollutant loads at a much more detailed level than the subwatershed ranking described in the section above. It was used to quantify the pollutant loads originating in each source area and to assess the extent to which various BMPs reduce pollutant loads in the watershed. Application of the SWAT model involved delineating 25 subbasins in the Neshanic River Watershed as shown in Figure 5.8. Subbasins were further divided into 625 HRUs based on land use, soil type and topography so that each HRU has a unique combination of land use, soil type and slope.

Table 5.6 presents the source contribution of average annual loads for TN and TP in the watershed. It appears that TN and TP loads to the streams originate primarily from the agricultural land sources in the watershed, which includes row crops and other agriculture. Row crops, such as corn, soybeans, wheat and rye, account for about 64 percent of the TN load and about 44 percent of the TP load. Other agricultural production, including hay and pasture, accounts for about 12 percent of the TN load and about 17 percent of the TP load. Lawn care fertilizers in urban lands contribute about 11 percent of the TN load and about 17 percent of the TP loads and are the second largest land source of the TN and TP loads to the streams. The other

minor land sources include forest and wetlands, which discharge nitrogen and phosphorus into the environment that eventually ends up in the streams.

In addition to the land sources discussed above, there are several other sources of nutrient loads to streams, including livestock access to streams, failing OSDSs and streams themselves. Livestock access to streams results in the deposition of animal manure in streams. The nutrients in the wastewater from failing OSDSs may also end up in the streams. Stream contribution is much more complicated than livestock and failing OSDSs. Nutrients may be detached from the eroded sediments from streambanks and resurfaced sediments from the bottom of the streams. In addition, biological processes related to algae growth can significantly affect the TN and TP in streams. The algae activities in the stream may absorb or contribute TN and TP to streams. Results of the SWAT model indicate that algae activities in Neshanic streams generally absorb TN and TP. As shown in Table 5.6, streams are a minor source of nutrient loads, contributing only 1.77 percent of the annual load of TN and only 5.01 percent of the annual loads of TP. Nutrient loads from livestock access to streams and falling OSDS systems are generally minor.

Table 5.6: Average annual loads of TN and TP in the Neshanic River Watershed

Sources	Total Nitrogen (TN)			Total Phosphorus (TP)		
	Average Load (lbs/ac/yr)	Total Load (lbs/yr)	Source Contribution (%)	Average Load (lbs/ac/yr)	Total Load (lbs/yr)	Source Contribution (%)
Urban	3.84	24,461	10.68	0.55	3,504	28.53
Row crop	33.92	146,976	64.15	1.24	5,351	43.62
Other agriculture	8.19	27,962	12.20	0.61	2,068	16.86
Forest	2.73	11,292	4.93	0.07	301	2.45
Wetland	10.85	13,468	5.88	0.13	165	1.34
Total Land Contribution		224,159	97.84		11,389	92.83
Livestock access to streams		111	0.05		31	0.25
Failing OSDS systems		784	0.34		235	1.92
Streams		4052	1.77		614	5.01
Total		229,106	100.00		12,269	100.00

Human and animal wastes are sources of pathogens in the Neshanic streams. Table 5.7 presents the approximate source contribution of average annual loads of fecal coliform and *E. coli*. Livestock access to streams and falling OSDS systems contribute significant amounts of pathogens to the streams. Failing OSDS systems are the largest source for pathogens and contribute almost half of the pathogenic loads to the Neshanic River streams. The second largest source of pathogens is manure applied to row crops, which accounts for about 31 percent of the annual pathogenic load to the Neshanic River streams. Livestock access to streams contributes about 19 percent of the annual pathogenic loads in the watershed, which makes it the third largest source of pathogens. Livestock grazing on pastures contributes about 2 percent of the pathogenic load. Another minor source of pathogens is wildlife, including geese and deer.

Table 5.7: Average annual loads of fecal coliform and *E. coli* in the Neshanic River Watershed

Sources	Fecal Coliform		*E. Coli*	
	Load (cfu/yr)	Contribution (%)	Load (cfu/yr)	Contribution (%)
Failing OSDS	7.20E+13	45.94	4.54E+13	46.09
Livestock access to streams	2.96E+13	18.90	1.85E+13	18.81
Manure application	4.91E+13	31.34	3.08E+13	31.25
Livestock grazing	3.85E+12	2.45	2.41E+12	2.45
Wildlife	2.15E+12	1.37	1.37E+12	1.40
Total	1.57E+14	100.00	9.84E+13	100.00

Table 5.8: Average annual loads for nutrients and pathogens by subbasin and ranks of subbasins based on average annual loads

Sub-basin	Area (acres)	Drainage area (acres)	Total Nitrogen		Total Phosphorus		Fecal Coliform		*E. Coli*	
			Load (lbs/ac)	R*	Load (lbs/ac)	R*	Load (cfu)	R*	Load (cfu)	R*
1	1480.2	1480.2	4.93	23	0.27	25	1.8E+14	18	1.1E+14	18
2	689.4	689.4	7.27	17	0.60	15	1.6E+14	19	1E+14	19
3	1082.3	1082.3	5.23	22	0.36	24	3E+14	13	1.9E+14	13
4	726.5	2891.1	7.14	18	0.64	13	1.4E+14	20	9E+13	20
5	333.6	1413.4	8.00	16	0.54	18	8.3E+13	21	5.2E+13	21
6	1109.5	3830.1	10.15	12	0.56	17	1.8E+14	17	1.1E+14	17
7	956.3	956.3	6.00	21	0.61	14	3.4E+14	12	2.1E+14	12
8	738.8	738.8	8.46	15	0.46	20	2E+14	16	1.2E+14	16
9	434.9	7141.3	27.32	2	0.94	2	4.2E+16	3	2.6E+16	3
10	580.7	580.7	6.28	19	0.68	12	2.4E+15	7	1.5E+15	7
11	879.7	14529.8	12.06	10	0.72	11	7.4E+14	10	4.6E+14	10
12	958.8	16061.8	13.36	9	0.85	6	2.4E+16	5	1.5E+16	5
13	556.0	556.0	4.89	24	0.45	21	5.9E+14	11	3.7E+14	11
14	622.7	17668.0	9.68	13	0.58	16	7.4E+13	22	4.6E+13	22
15	664.7	664.7	6.28	20	0.43	22	5.2E+13	23	3.2E+13	23
16	879.7	19521.3	17.19	5	1.00	1	2.8E+15	6	1.7E+15	6
17	652.4	6498.9	14.39	8	0.90	5	2.9E+16	4	1.8E+16	4
18	709.2	1373.9	39.59	1	0.75	7	1.3E+17	1	8.2E+16	1
19	625.2	5831.7	15.29	7	0.74	9	4.4E+13	25	2.7E+13	25
20	511.5	1885.4	15.99	6	0.91	4	2.1E+15	8	1.3E+15	8
21	995.8	995.8	4.50	25	0.42	23	2.7E+14	15	1.7E+14	15
22	654.8	654.8	9.06	14	0.52	19	4.7E+13	24	3E+13	24
23	1272.6	3335.9	11.66	11	0.73	10	1.1E+15	9	7E+14	9
24	775.9	2053.4	20.72	4	0.74	8	2.9E+14	14	1.8E+14	14
25	622.7	622.7	26.63	3	0.93	3	8.3E+16	2	5.2E+16	2
Total	19513.9	19521.3	11.74		0.63		3.2E+17		2E+17	

Note: R* indicates the rank for subbasins.

Table 5.8 presents the average annual loads and ranks for both nutrients and pathogens by the 25 subbasins in the watershed. Average annual load for a subbasin includes loads from all sources in that subbasin for the specific pollutants. Since the nutrients are primarily from land sources, subbasins are ranked by the average annual load per acre. For TN, subbasin 18 generates the most TN load per acre to streams, followed by subbasins 9, 25 and 24. Subbasin 21 generates the smallest TN load per acre. Subbasin 16 generates the largest TP load per acre and is assigned the highest rank based on the average TP load, followed by subbasins 9, 25 and 20. Subbasin 1 generates the least TP load per acre to the stream. Since pathogenic sources are site specific, such as where failing OSDSs are located, the livestock is present and the manure is applied, it is more reasonable to rank subbasins based on total annual pathogenic loads from the subbasins. Since fecal coliform and *E. coli* are closely related, subbasin rankings for both pathogens are the same. Subbasin 18 generates the largest pathogenic load and is the highest ranked subbasin for pathogenic loads, followed by subbasins 25, 9 and 17. Subbasin 19 generates the smallest pathogenic load to the streams in the watershed.

5.6. **Soil Erosion and Sedimentation**

Soil erosion and sedimentation are two different but interrelated processes and concepts. Soil erosion is the process of weathering and transport of soil particles in the environment. Sedimentation occurs when eroded soil particles are deposited and transported to nearby land and streams. The primary causes of soil erosion and sedimentation are ice, water and wind. Both soil erosion and sedimentation are natural processes, but are often accelerated by intensive land use activities, such as agriculture, road construction and urban development. For example, urban development increases runoff and drainage density, which results in flashy streamflow as discussed previously. The energy embedded in flashy streamflow not only causes flash flooding, but also erodes streambanks, which delivers substantial amounts of sediment to streams. A notable example of soil erosion is in the Walnut Brook, where a streambank stabilization project was conducted in 2009 under this 319 grant contract.

From a water quality perspective, sediment entering the streams is a concern because the sediment in water, measured as TSS, is an important water quality indicator. Many other water pollutants, such as nutrients, pesticides and pathogens, are also attached to sediments. Potential sources of the TSS are land, streambank, and deposited sediment in the bottom of streams. This project used several methods to quantify soil erosion and sedimentation in the Neshanic River Watershed, which are briefly summarized below.

5.6.1. Soil Erodibility

Soil erodibility measures the soil erosion potential of a specific site. Soil erosion not only results in less productive soil, but also is linked to many water quality problems, such as sediment loads and nutrients and pesticides attached to the soil particles transported to streams. In this project, the NRCS soil erodibility index (EI) was used to approximate soil erodibility. EI provides the numerical expression of the potential for a soil to erode that considers the physical and chemical properties of the soil and the climatic conditions where it is located. The higher the index, the more susceptible the soil is to erosion. EI equals the potential erodibility for the soil (RKLS) divided by the soil loss tolerance value (T) following Wischmeier and Smith (1978):

$$EI = \frac{RKLS}{T}, \qquad (1)$$

where R measures rainfall and runoff intensity, K is soil erodibility that indicates the susceptibility of the soil to water erosion, L is slope length and S is slope steepness. T is the soil loss tolerance factor defined as the maximum amount of soil erosion that can occur without degrading the quality of a soil as a medium for plant growth. EI is usually estimated for each soil type and used to define the highly erodible lands mapping units in NRCS soil surveys. Soils with an EI greater than 8 are considered to be highly erodible (NRCS, 2008). EI was estimated for each 10-m grid in the watershed.

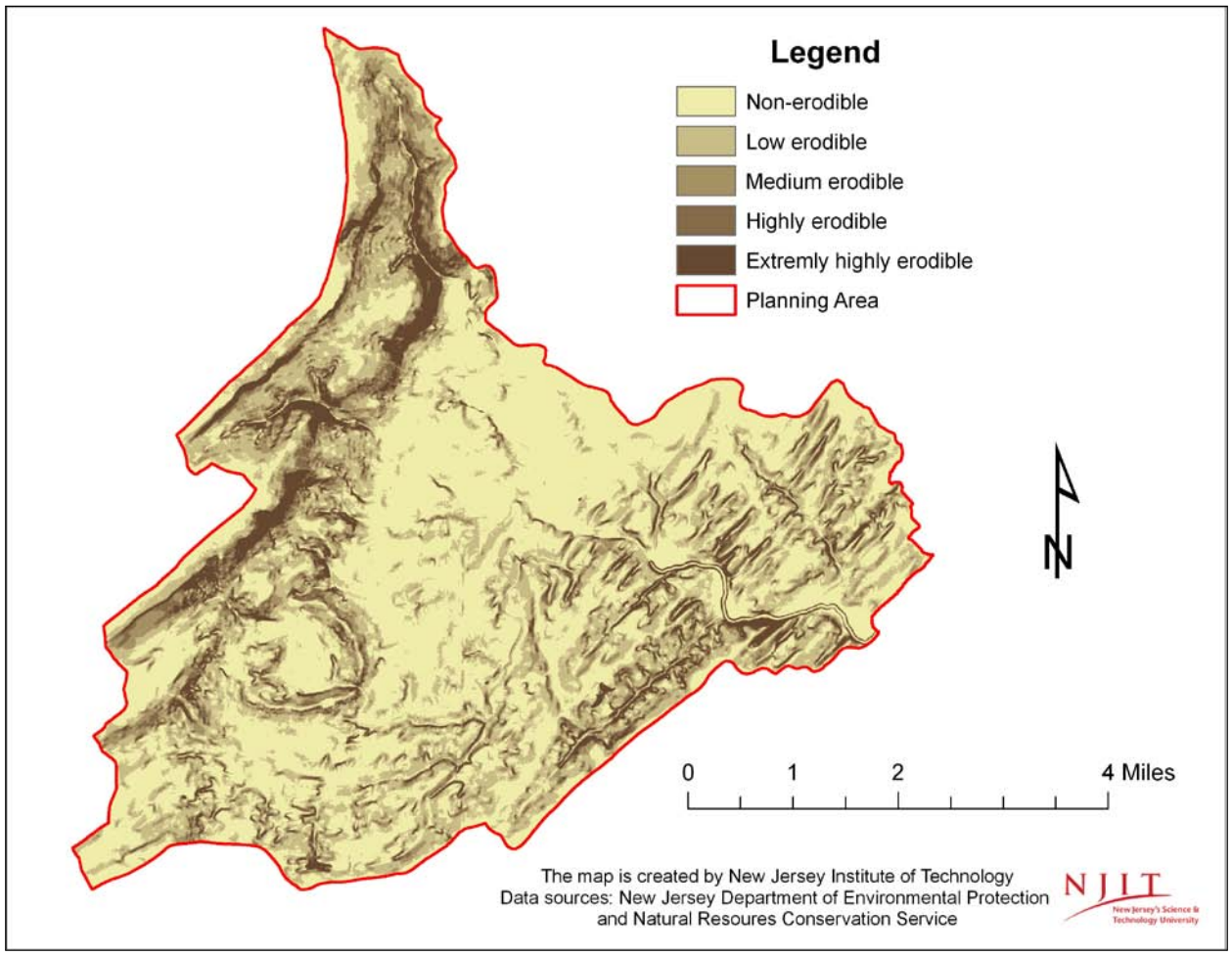


Figure 5.9: Location of soil erodibility classes in the Neshanic River Watershed

Soil erodibility was grouped into five classes based on the estimated EI values. Grids with EI values less than or equal to 2 were considered to be non-erodible. The low erodibility class includes grids with EI values between 2 and 5 and the medium erodibility class grids with EI values ranging from 5 to 8. Two high soil erodibility classes are defined: grids with EI values between 8 and 12 are considered to be highly erodible and grids with EI values greater than 12 are considered to have extremely high erodibility. The non-erodible, low erodibility and medium erodibility classes comprise about 48, 28 and 11 percent of the watershed, respectively. About 6 and 7 percent of the watershed are in the highly and extremely high erodibility classes,

respectively. Figure 5.9 shows the location of the five different soil erodibility classes in the watershed. The highly erodible lands tend to be located in the upper part of the watershed along the northwestern ridge of the watershed as well as the lower portion of the watershed where the terrain is steep. Agricultural lands in the watershed are primarily in the non-erodible, low or medium erodibility class (54, 29 or 10 percent, respectively). Only about 5 and 3 percent of the agricultural lands are in the high and extremely high erodibility classes, respectively. In general, the soil erodibility assessment indicates that 87 percent of the watershed has soils in the non-erodible, low erodible or medium erodible classes.

5.6.2. Geomorphic Evaluation of Streams

While soil erodibility assesses soil erosion potential of land, the geomorphic evaluation examines the processes of bank erosion and channel sedimentation, meander evolution, sediment budgets and connectivity as a means of understanding how water and sediment are related to channel form and function. The Rosgen Stream Classification System and Schumm's 1984 Channel Evolution Model (CEM) were used to assess the streams in the Neshanic River Watershed. Based on the simplified Rosgen analysis, several typical stream types were identified within the watershed as shown in Table 5.9.

Table 5.9: Rosgen analysis for Neshanic River subwatersheds

	Sampling Stations						
	FN1	SN1	TN3	TN3a	N1	UNT1	UNT2
Single Threaded Channels	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Entrenchment Ratio	Moderate	Slight	Slight	Entrenched	Slight	Slight	Slight
Width/Depth Ratio	<12	<12	>12	<12	<12	<12	<12
Sinuosity	1.2	2	1.3	1.64	1.16	1.15	1.15
Stream Type	B	E	C	G	C	E	E
Slope	0.014	0.008	0.00125	0.004	0.0022	0.001	0.00675
Channel Material	Clay/Silt	Clay/Silt	Clay/Silt	Clay/Silt	Silt/Clay	Clay/Silt	Clay/Silt
Stream Classification	B6c	E6	C6	G6c	C6	E6	E6

Type B is a moderately entrenched, moderate gradient, riffle dominated channel with frequently spaced pools. This stream type has a very stable plan and profile with stable banks. Type C is a low-gradient, meandering stream containing point-bars, riffle/pools and alluvial channels within a broad, well-defined floodplain. This type of stream has a fairly stable plan and profile. Type E is a low-gradient, meandering riffle/pool stream with a low width/depth ratio and little deposition; it is very efficient and stable. Type E streams have a high meander width ratio. Type G is an entrenched "gully" step/pool stream with low width/depth ratio on moderate gradients. This type of stream is unstable with grade control problems and high bank erosion rates (Rosgen, 1994).

Although stream types B, C and E are stable, streams could undergo morphological changes due to various alterations in the watershed, such as increases in urbanization or changing farming practices. A stream can start as Type C, a very stable system, but can change to Type G with downcutting and then change to Type F through widening, ultimately changing back to Type C, a stable condition with a connected floodplain and terracing. These evolutions are predominately caused by changes in land use in the upper watershed.

Schumm et al. (1984) developed a five-stage CEM to describe the systematic response of a channel to base level lowering, encompassing conditions that range from disequilibrium to a new state of dynamic equilibrium. The CEM illustrates how a stable channel (Stage I) can become unstable through incision (Stage II) and widening (Stage III) and then gradually aggrading (Stage IV) and becoming stable again (Stage V). CEM was applied to 15 locations in the watershed to evaluate the stages that the channels are experiencing during the channel evolution process. Figure 5.10 shows the 15 locations where CEM was applied and the stages of the reaches at those locations.

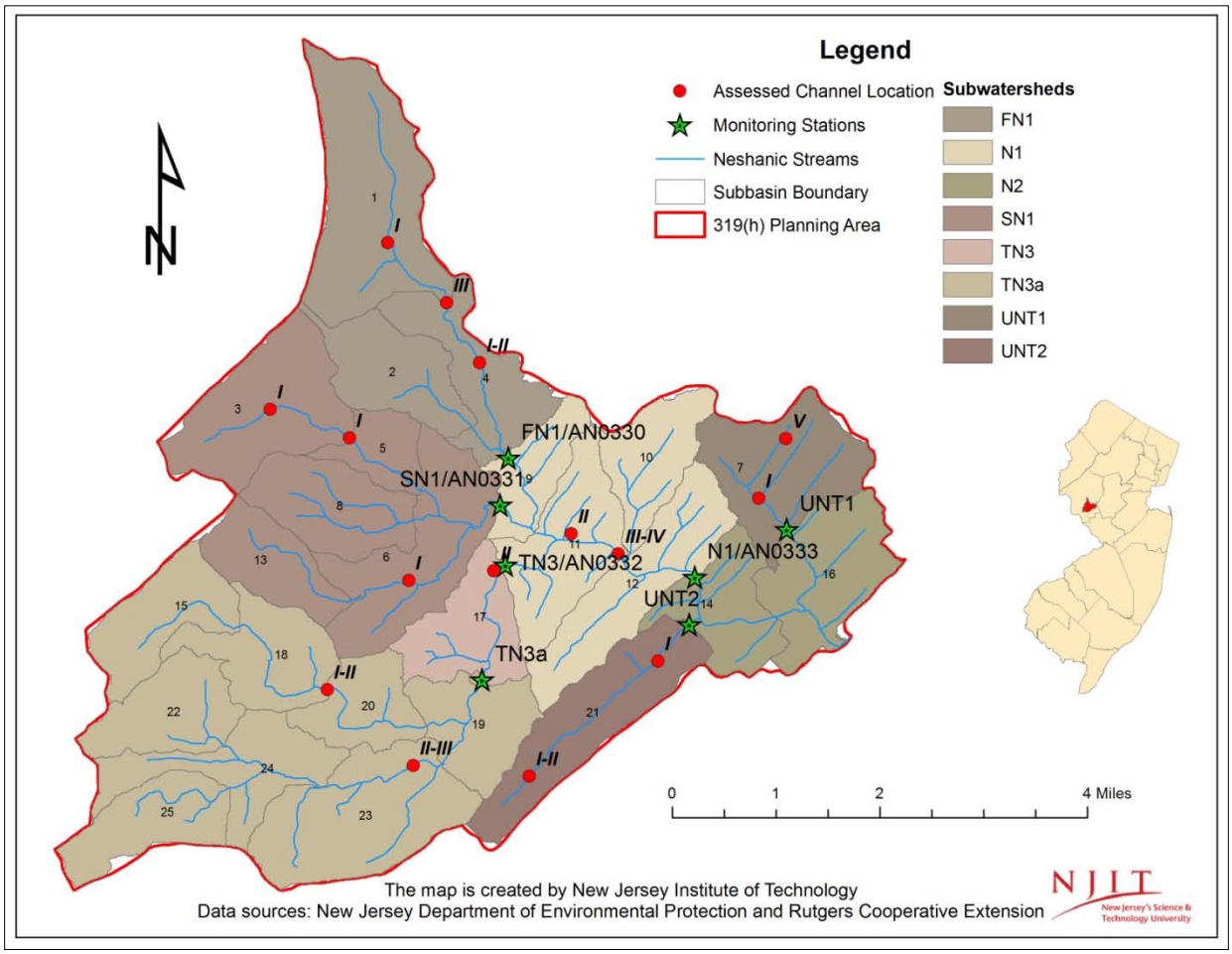


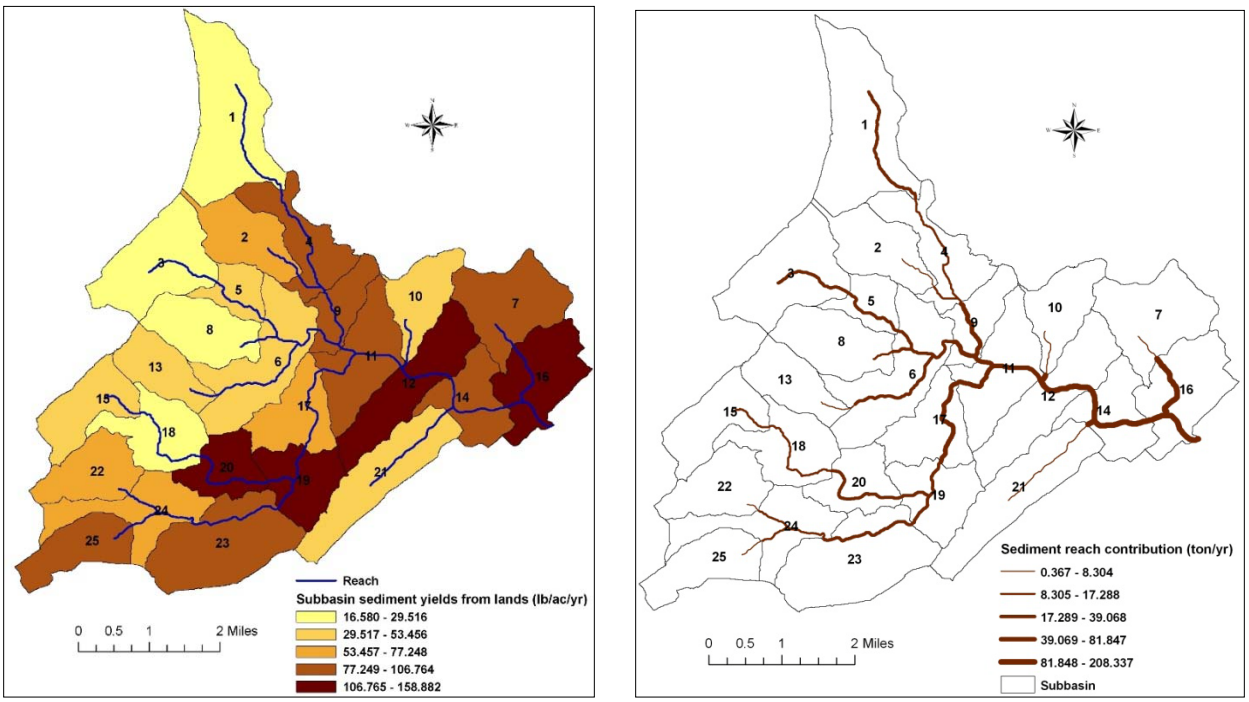
Figure 5.10: Channel stages assessed at fifteen locations in the Neshanic River Watershed

The assessment indicates that streams in the watershed are experiencing dramatic changes. Among the 15 reaches that were assessed, five reaches were assigned Stage I, three were in the transition from Stage I to II, two were in Stage II, one was in the transition from Stage II to III, one was in Stage III, one was in the transition from Stage III to IV and one was in Stage V. The

changes in the channel stages are closely associated with suburbanization in the watershed. The stage number of reaches generally tends to be higher as the percentage of agricultural land in the drainage area increases and lower as the percentage of forest land increases with a few of exceptions. Reaches classified in Stage II or III are unstable and can contribute significant amounts of sediment to the streams. Streams in Stage II or III are most likely suffering from higher peak stormwater flows resulting from land use changes in the upper watershed. In most cases, the downcutting and widening seen in Stages II and III can be linked to increases in impervious cover that are directly connected to the stream, resulting in very flashy hydrology.

5.6.3. Source Contributions to Sediment Based on Watershed Modeling

The soil erodibility and Rosgen analyses and the CEM provide qualitatively assessments of soil erosion and sedimentation potential from land and reaches. In contrast, the SWAT model integrates the topography, land use, soil, streams and weather data in the watershed to provide quantitative measures of where and how much sediment is generated in the watershed. Based on current land use and weather conditions in the watershed from 1997 to 2008, the average annual sediment yield is 1,715 tons. Reaches are the primary sediment source and contribute 1,021 tons of sediment per year, which accounts for 60 percent of the total annual sediment load. The remaining 40 percent of annual sediment load, roughly 694 tons, comes from various land uses in the watershed. Of the various land uses in the watershed, row-crop agriculture is the largest land source of sediment, accounting for about 57 percent of the sediment load, followed by urban land (28 percent) and other agricultural lands, such as pasture and hay (15 percent).



A. from land sources B. from reach sources

Figure 5.11: Sources and yields of sediment in the Neshanic River Watershed

Figure 5.11 illustrates subbasin sediment yields from land in panel A and from reaches in panel B. It is not surprising that lands with more row-crop production generate higher sediment yields, and are primarily located in the lower part of the watershed along both sides of the First Neshanic River, the Third Neshanic River and the main branch of the Neshanic River. Sediment contribution from reaches increases as the stream order increases. Reaches encompassing first-order streams contribute less sediment than higher order streams, such as the main branch of the Neshanic River. Streambank soil erosion is the primary source of sediments in lower-order reaches. In addition to streambank soil erosion, the sediment deposited in the bottom of streams is a potentially important source of sediment for the higher order reaches. High streamflow with greater velocity could resurface those sediments, especially during the larger storm events.

5.7. **Stream Visual Assessment Protocol (SVAP)**

The SVAP was developed by USDA NRCS to assess the health of streams, identify pollutant sources and determine potential management measures to control pollutant sources based on visual inspection of the physical and biological characteristics of instream and riparian environments of assessed stream reaches. The SVAP assessment is based on a three-page worksheet modified for New Jersey by the RCE Water Resource Program. The SVAP assesses a set of 15 stream condition indicators and assigns each indicator a numerical score relative to reference conditions. Specific indicators include channel condition, hydrologic alteration, riparian zone, bank stability, water appearance, nutrient enrichment, barriers to fish movement, instream fish cover, pools, insect/invertebrate habitat, canopy cover, manure presence, riffle embeddedness and macroinvertebrates observed, if applicable. This project did not assess macroinvertebrates. Indicators are scored on a scale of 1 to 10, with 1 being the worst and 10 being the best score for an indicator. The indicator scores at each stream reach are averaged to obtain an overall rating for that reach. A score of less than 6.0 is considered “poor”, a score of 6.0 to 7.49 is considered “fair”, and a score above 7.5 is considered “good.” This numerical assessment is complemented by photographs and drawings of the stream reach, as well as notes on visual observations for items such as dumping, manure, runoff or outfall pipes, etc.

All stream-road crossings in the project area were evaluated and about 60 stream reaches at the crossings were identified as potential candidates for SVAP. It was decided that the SVAP would be performed on 42 stream reaches which was done by project team members and volunteers during the period July-October, 2007. Of the 42 sites assessed, 18 scored “poor,” 13 scored “fair” and 11 scored “good,” as shown in Figure 5.12. Of the five HUC-14 subwatersheds in the project area: HQ Tributary recorded three fair and four poor sites; the Third Neshanic River had three good, two fair and five poor sites; the Second Neshanic River had five good and one fair sites; the First Neshanic River had one good, three fair and three poor sites; and the Main Neshanic River had one good, four fair and six poor sites. Compared to the poor and fair sites, good sites had higher ratings for riparian zones, bank stability, channel condition, pools, in-stream fish cover, canopy cover and invertebrate habitat. Many of the “poor” sites have a stream bed of sand/silt/mud or gravel, while the “fair” and “good” sites have a stream bed of gravel/cobble/boulder. The “poor” sites often scored much lower on pools, channel condition, in-stream fish cover, canopy cover, and invertebrate habitat than the “good” sites.

Observations common to many of the sites include erosion, dry stream and low flow in summer, occasional dumping, exposed drainage pipes and overgrowing invasive plants.

Improving riparian zones and bank stability at the poor and fair sites will, over time, lead to better ratings for many of the other indicators observed in the SVAP assessment. Possible recommended remedies include riparian plantings, added or expanded riparian buffers, streambank stabilization, reconnection to flood plain and removal of invasive plants.

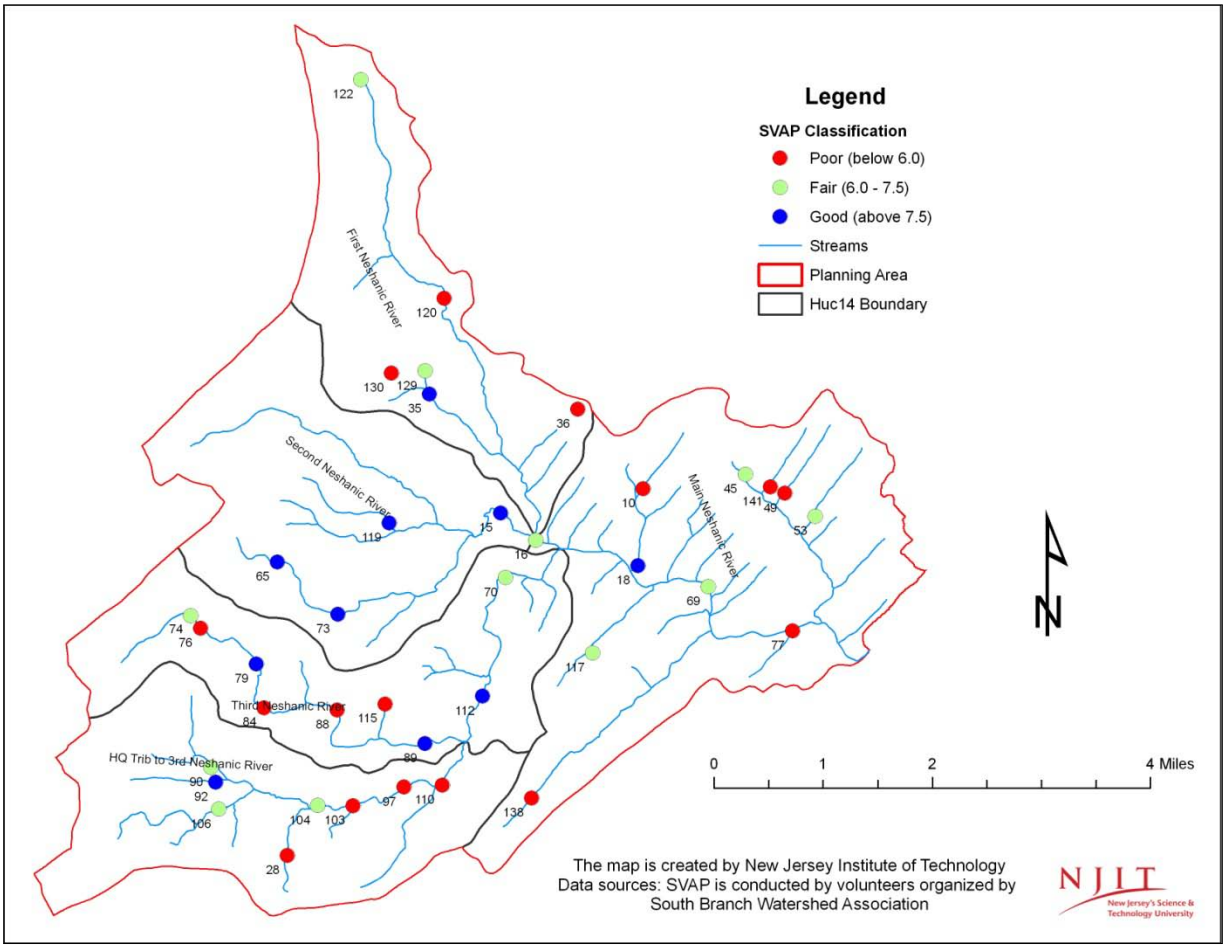


Figure 5.12: SVAP location and assessment results in the Neshanic River Watershed

5.8. **Water Quantity**

A water quantity concern in the watershed is the increasing occurrence of low/no streamflow during the late summer. Streamflow is the result of a range of climatic and hydrological processes, including precipitation, surface runoff, lateral flow and groundwater recharge and discharge. Since streamflow in late summer is primarily from base flow, low/no streamflow in the late summer may indicate a decline of the base flow contribution to the streamflow.

To better understand the base flow contribution to streamflow, the streamflow is separated into runoff and base flow through three passes by applying a digital filter program (Arnold and Allen, 1999). Each pass produces a pair of time series of daily base flow and runoff. The actual average base flow contribution is generally between the first and second pass averages. The mean fractions of base flows were filtered from the observed streamflow at the USGS Reaville

Gage Station during each decade from 1930 to 2008. The actual base flow contribution was 31-47 percent in the 1930s, 34 -51 percent in the 1960s and 30-46 percent since the 1970s; the lowest percentage of 28-44 percent was reached in the 1990s after which it increased to 30-45 percent in the 2000s. Temporal variability in base flow contribution may reflect increasing conversion of agricultural lands to urban lands. Historical data analysis indicates the low/no streamflow may result from both the seasonal variation and the general decline in base flow caused by the land use changes in the watershed.

Table 5.10: Average annual water yields of subbasins, 1997-2008

Subbasin	Area (acres)	Water yield[a] (inches per year)	Ranking	Surface runoff (%)	Lateral flow (%)	Groundwater discharge (%)
1	1,480.16	21.15	17	67.01	1.89	31.09
2	689.42	21.92	11	70.44	2.65	26.92
3	1,082.32	20.81	21	73.31	0.64	26.05
4	726.49	24.01	1	76.02	0.61	23.37
5	333.59	22.53	7	69.46	0.34	30.2
6	1,109.50	21.74	12	66.49	0.31	33.2
7	956.30	19.91	25	62.01	1.15	36.83
8	738.85	20.70	23	61.16	1.28	37.56
9	434.91	23.98	2	75.48	0.16	24.36
10	580.70	21.03	19	65.31	0.65	34.04
11	879.70	23.58	3	75.3	0.6	24.11
12	958.77	22.28	8	71.58	0.86	27.56
13	555.99	20.71	22	59.09	2.86	38.05
14	622.71	21.19	16	66.9	1.43	31.68
15	664.71	20.92	20	66.6	1.37	32.03
16	879.70	21.69	13	69.23	0.8	29.97
17	652.36	22.93	4	73.84	0.42	25.73
18	709.19	21.11	18	65.84	0.62	33.54
19	625.18	22.55	6	73.56	0.65	25.78
20	511.51	22.67	5	72.88	0.35	26.77
21	995.84	19.96	24	57.62	1.53	40.85
22	654.83	22.23	9	65.37	1.58	33.05
23	1,272.59	22.09	10	71.19	0.71	28.11
24	775.91	21.67	14	70.24	0.29	29.47
25	622.71	21.60	15	66.16	1.68	32.15
Watershed	19,513.91	21.69		68.54	1.02	30.44

a. Water yield is defined as the net amount of water that leaves the subbasin and contributes to streamflow in the main channel (reach).

The SWAT model was used to simulate average annual water yields exported from subbasin outlets during the simulation period 1997-2008. As reported in Table 5.10, average annual water yield exported from the watershed outlet is 21.69 inches per year, of which about 69, 30 and 1 percent are attributed to surface runoff, groundwater and lateral flow, respectively. There are notable spatial variations in water yields. Annual water yields of subbasins range from 20 inches per year to 24 inches per year. Surface runoff is the most important component, contributing 58 to 76 percent of water yield and groundwater is the second most important component, contributing to 23 to 41 percent of water yield. The contributions from lateral flow are small amounting to less than 3 percent of water yield. Such spatial variation in water yield is attributed to the heterogeneous land uses in the watershed.

To better understand the impacts of land uses on water yields, Table 5.11 summarizes the SWAT-simulated annual total and average water yields for different land uses in the watershed for the period 1997-2008. Residential-low density, corn, soybean, timothy, forest-deciduous, and wetlands-forested lands, which each cover areas greater than 1,100 acres, generate water yields of more than 10^8 ft^3 per year. Water yields are lower for land uses covering smaller areas, ranging from 7.119E+06 to 7.535E+07 ft^3 per year. The impacts of land use on water yields were also evaluated by the annual average water yields (i.e., total water yield for a land use divided by the total area of that land use) and rankings of land uses by annual average water yields as shown in Table 5.11.

Table 5.11: Total and annual average water yields by land use, 1997-2008

Land use	Area (acres)	Total water yield (ft^3 per year)	Average water yield (inches)	Ranking
Residential-High Density	92.27	1.03E+07	30.676	3
Residential-Medium Density	190.97	1.79E+07	25.866	6
Residential-Med/Low Density	336.45	2.92E+07	23.903	10
Residential-Low Density	4,899.21	3.15E+08	17.724	19
Commercial/Industrial	256.73	3.05E+07	32.730	2
Institutional	451.27	4.92E+07	30.027	4
Transportation	149.05	1.98E+07	36.516	1
Corn-soybean Rotation	328.95	2.83E+07	23.734	11
Corn	1,834.41	1.60E+08	24.055	9
Soybean	1,847.59	1.65E+08	24.665	8
Rye	321.96	2.10E+07	17.928	18
Hay	748.80	5.18E+07	19.052	17
Timothy	1,671.27	1.19E+08	19.591	16
Pasture	892.46	7.54E+07	23.259	12
Orchard	99.93	7.12E+06	19.626	15
Forest-Deciduous	3,047.60	2.48E+08	22.439	13
Forest-Evergreen	179.55	1.33E+07	20.391	14
Forest-Mixed	902.41	5.76E+07	17.59	20
Wetlands-Forested	1,101.95	1.02E+08	25.37	7
Wetlands-Mixed	139.72	1.39E+07	27.419	5

High-density urban land uses (including transportation, commercial, institutional and high and medium density residential uses), wetlands and row crops (corn and soybeans) generate much higher water yields than other types of land uses. Although all land uses generate high water yields, the mechanism by which water yield is generated can vary with land use. Water yields for urban and row crop land uses come primarily from surface runoff, whereas groundwater discharge is the primary source of water yield from wetlands. The SWAT simulation results clearly indicate that human activities, including both urban development and row-crop production, are major contributors to water yields in the watershed.

5.9. **Discussion**

The water quality monitoring and watershed modeling results presented above clearly establish cause and effect relationships between upland land use activities and downstream water quality. It appears that intensive land use activities, such as urban development and agriculture, have altered watershed hydrology and degraded water quality in the Neshanic River Watershed. Although the assessments are extensive, they are still insufficient relative to the increasing demand for detailed site-specific information. Due to the diffuse nature of nonpoint source water pollution, it is cost prohibitive to monitor water quality in each stream segment and land use in each parcel in the watershed. Certain simplifying assumptions need to be made in modeling the impacts of land use changes on water quality. A watershed model is not an exact representation of real world conditions, but rather a simplified representation of those conditions that is designed to capture the aggregate impacts of land use changes and management practices on watershed hydrology and water quality. The limitations and assumptions of a watershed model do not invalidate model results and model-based conclusions regarding the sources and causes of water pollution in the watershed. Despite its limitations and assumptions, the models utilize rigorous protocols for collecting, processing and analyzing data and results. Furthermore, the similar models have been used in other watersheds in the U.S. and other parts of the world. However, results and conclusions need to be applied and interpreted with caution; they are not intended to be valid for each and every individual parcel in the watershed. Different methods and models and more detailed monitoring and data are required to make site-specific assessments.