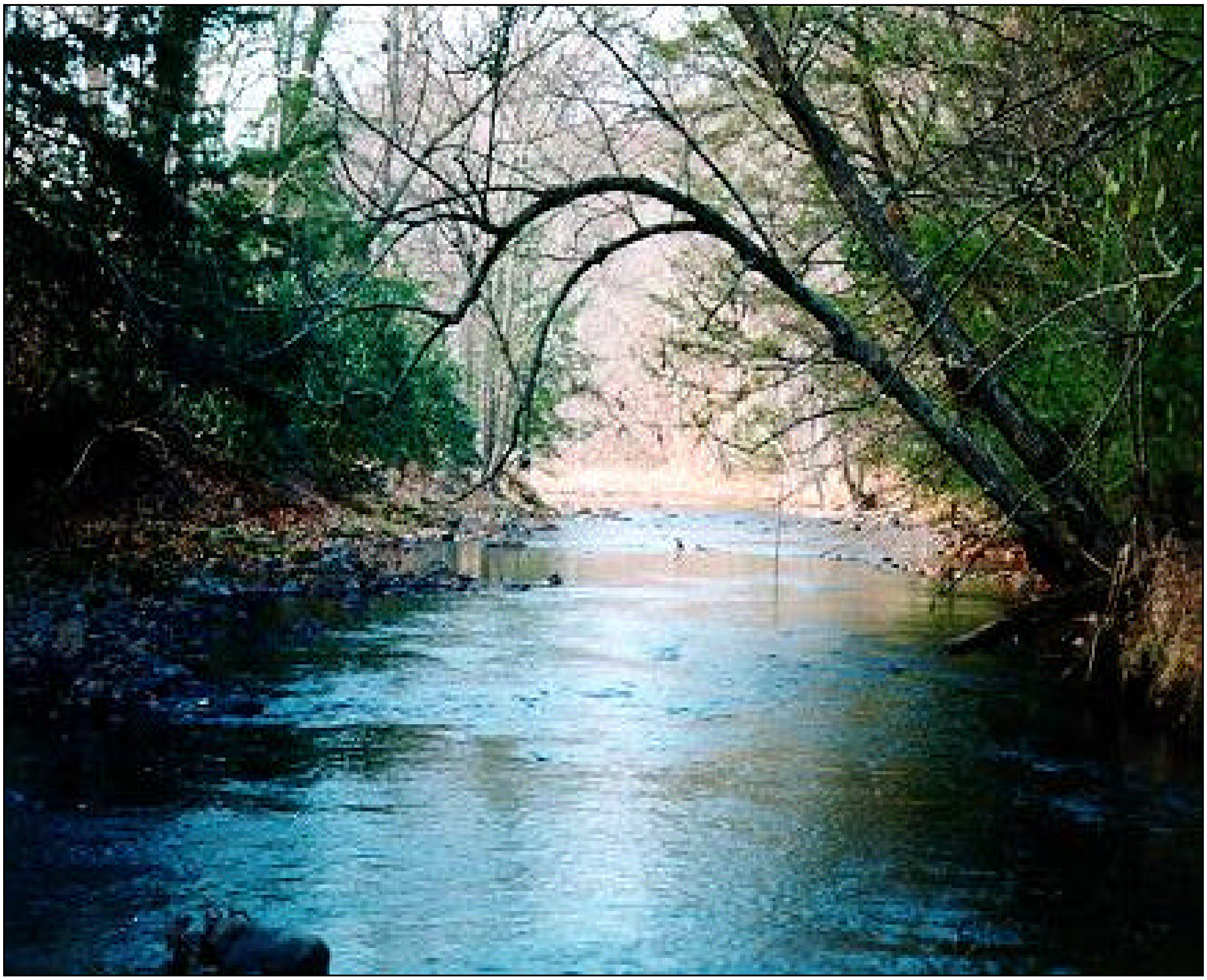
HIGH FLOW MANAGEMENT OBJECTIVES
FOR
NEW JERSEY NON-COASTAL WATERS

A Study of the Delaware, Saddle, Whippany, and Musconetcong Rivers and Flat Brook



Delaware River Basin Commission
West Trenton, NJ

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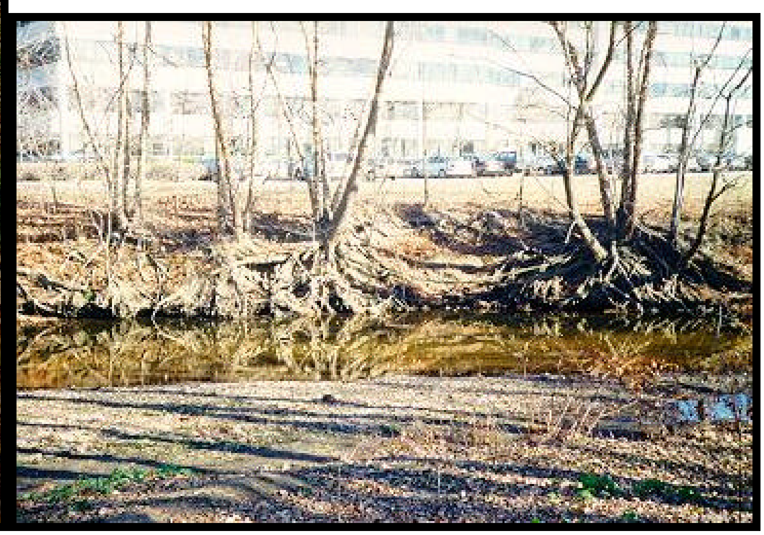
Cover Photo: Flat Brook in Delaware Water Gap National Recreation Area, NJ.

Whippany River at Morristown

Musconetcong at Riegelsville

Musconetcong at Bloomsbury



Saddle River at Fair Lawn

Acknowledgements

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Copies of this report are available from the Delaware River Basin Commission, PO Box 7360, West Trenton, NJ, 08628. Tel. 609-883-9500 ext. 205. An Adobe .pdf version is available via DRBC's web site at http://www.drbc.net

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Musconetcong River field workers (clockwise from top left): Doug Jerolmack surveys at a cross-section; Pamela V'Combe takes notes by a scoured stream bank; Judith Strong records measurements at a cross section; and Ms. V'Combe measures channel characteristics next to a leaning tree.

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I. PROBLEM STATEMENT

One important source of nonpoint pollutants in New Jersey is the runoff associated with stormwater and snowmelt. Stormwater runoff can introduce a variety of pollutants into streams and rivers during times of high flows. These pollutants include roadway deicing salts, lawn and farm fertilizers, pesticides, animal wastes, oil and grease, heavy metals, and a variety of other potential contaminants.

Urbanization compounds the nonpoint source pollution problem associated with stormwater runoff. Increase of the amount of impervious surfaces in a watershed, provision of storm sewers and detention basins, and other landscape modifications increase runoff and, thus, stream flow. These changes impact the stream's channel, riparian, and habitat characteristics and compound the impact of runoff pollutants.

Water quality managers need sensible and realistic water quality and watershed-based surface-water goals to guide planning, monitoring, priority setting, regulation, mitigation, restoration, and other activities. Traditionally, watershed management goals and standards have been oriented to base flow conditions as represented by minimum average seven consecutive day, ten-year return frequency low-flow condition. Low flow derived standards and criteria are not necessarily relevant for managing and controlling high-flow, storm-runoff problems.

II. PURPOSE OF STUDY

The purposes of this study were to use existing, available flow and water quality data plus field observations from non-coastal New Jersey watersheds to:

A. Evaluate the nature of water quality, habitat, and stream channel changes due to stormwater runoff and nonpoint source pollutants;

B. Examine and develop various flow and nonpoint source watershed assessment methods;

C. Determine which methods can be used to develop nonpoint source or stormwater related goals and objectives; and,

D. Develop, if possible, numeric and non-numeric goals and objectives for these watersheds.

III. STUDY WATERSHEDS

In order to assess impacts and develop potential goals and standards, five watersheds were selected for study. These were:

A. Delaware River above Montague: This 3,480 mi^2 watershed, draining portions of three states, was selected for its size and its relatively pristine water quality;

B. Flat Brook at Flatbrookville (64 mi^2) was selected as the reference watershed against which all other watersheds are measured;

C. Musconetcong River was subjected to detailed study at four locations instead of a single location as per the other watersheds. These locations were, in upstream to downstream order: (a) Lockwood (60.1 mi^2); (b) Beattystown (90.3 mi^2); (c) Bloomsbury (141 mi^2); and (d) Riegelsville (156 mi^2). The watershed has some urbanization, but is largely rural, particularly in its downstream reaches.

D. Whippany River (29.4 mi^2), a tributary to the Passaic River, is impacted by the City of Morristown and Interstate 287; and

E. Saddle River at Lodi (54.6 mi^2), also a tributary to the Passaic River, is the most developed watershed. It also includes areas within New York State.

The Flat Brook, Musconetcong, Whippany, and Saddle Rivers were selected because they represent differing degrees of urbanization ranging from largely undeveloped (Flat Brook) to developed (Saddle River). The selection of locations was highly influenced by available stream flow (USGS gage) and water quality data. In addition, the Musconetcong, Whippany, and Saddle River Watersheds represent a specific physiographic region in New Jersey, the Piedmont.

The Delaware River was analyzed in order to have a comparison between a large watershed and relatively small ones that range in size from 29.4 to 156 mi^2. While it might be assumed that smaller streams behave or respond differently to pollutant runoff/high flow events than a large river, this assumption needs to be verified in order to determine the transferability of the methods to other New Jersey waterways.

Table 1 describes USGS data available at each location. Figure 1 locates watershed and study locations.

Table 1: Data Availability at USGS Water-Quality and Streamflow Stations.

Station ID	Station Name	Data type: id: instantaneous discharge cd: continuous discharge c: chemical; m: microbial	Drainage Area (mi^2)	Period of WQ Record in USGS main data base
01455801	**Musconetcong River** at Lockwood	id, c, m	60.1	1976-91
01456200	" at Beattystown	id, c, m	90.3	1976-
01457000	" near Bloomsbury	cd, c, m	141	1963-80, 91-
01457400	" at Riegelsville	id, c, m	156	1976-
01391500	**Saddle River** at Lodi	cd, c, m	54.6	1962-
01381500	**Whippany River** at Morristown	cd, c, m	29.4	1923-24, 1926,1962-
01440000	**Flat Brook** at Flatbrookville	cd, c, m	64.0	1923-24, 1956-57, 1959-80, 1992-
01438500	**Delaware River** at Montague	cd, c, m	3,480	1956-73, 1976-78, 1991-

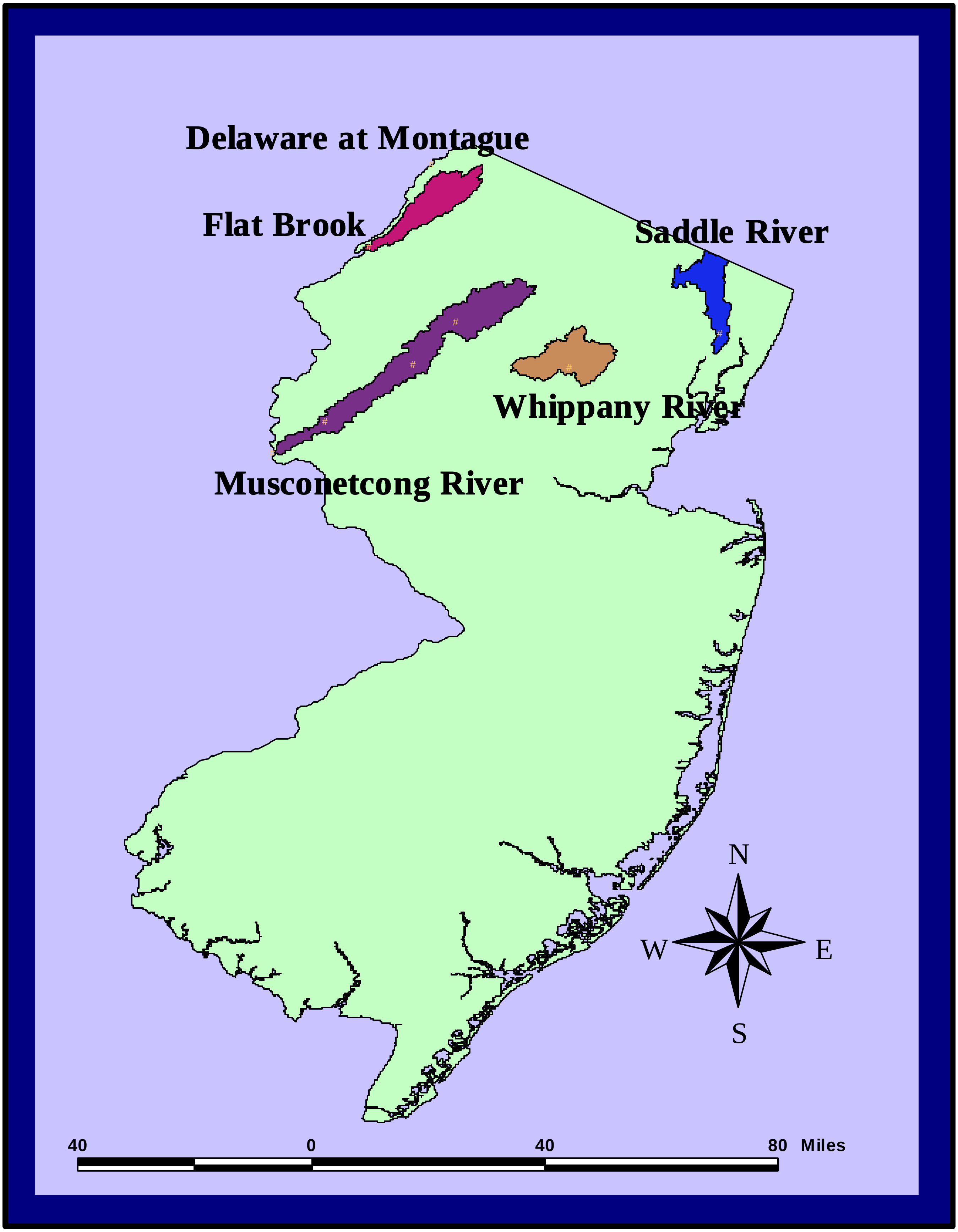


Figure 1. Location of New Jersey High-Flow Study Watersheds and USGS Stream Gages.

IV. LITERATURE REVIEW

Stormwater runoff and nonpoint source pollution have been known problems for many decades. Polluted stormwater runoff from the Lehigh River Watershed, for example, periodically shut down the Trenton, NJ, water filtration plant in the early 1900's. Erosion and sediment problems throughout the U.S. led to the establishment of watershed associations, county conservation districts, the U.S. Soil Conservation Service, and re-forestation programs in the 1920's and 1930's.

Increased focus on nonpoint source/stormwater problems has occurred in recent decades due to three factors: (1) the gradual correction of the massive wastewater point-source discharge problem in the U.S.; (2) the acceleration in suburban and commercial development and the attendant contributions to runoff and pollution; and (3) a general increase in awareness of the impacts of nonpoint source pollutants and stormwater runoff on water quality and stream channel stability. Federal legislation (e.g., the Clean Water Act, the Coastal Zone Management Act, and others) has made nonpoint source abatement a paramount priority. As a result, New Jersey is formulating strategies to address nonpoint source and stormwater impacts (NJDEP, 1999).

Nonpoint source impacts are largely derived from human activities. Nonpoint loads enter the aquatic system from overland runoff, from highway and street stormwater drainage systems, from stormwater detention systems, and from ground water infiltrating a stream. Nutrients such as phosphorus, nitrogen, various organic compounds, heavy metals, salts, bacteria and many other forms of pollutants enter streams from nonpoint sources. Once in the stream, nonpoint source pollutants cause problems such as nuisance plant growth, diurnal fluctuations in dissolved oxygen and pH, loss of aquatic life, and public health threats to recreation.

The nature of the problem in New Jersey is detailed in several studies. In these studies, the impairment of macroinvertebrate populations and the presence of trace metals and organic contaminants in sediments were related to the degree of urbanization versus forested land uses (Kennen, 1999; Stackelberg, 1997; O'Brien, 1997). Two study watersheds, the Whippany and the Saddle River, appear on New Jersey's 303(d) list as water quality limited (NJ DEP, 1998) and are considered moderately and severely impaired for aquatic life uses respectively. Point sources may also contribute to these problems.

The other component of the nonpoint source problem occurs when excessive water runs off from the impervious area within a watershed. This excessive runoff increases the number of annual bankfull events, i.e., incipient flood-stage events that most shape and maintain the stream channel (Rosgen, 1996). The increase in bankfull flow events reshapes the channel, causing erosion problems. The re-shaped channel, increased flood frequency, and accelerated erosion rates create more stream instability problems.

The resultant instability (Rosgen, 1998) aggravates erosion problems, i.e., stream bank erosion, stream bottom scouring, and sediment deposition derived from the bank erosion creates new impacts yet further downstream. These impacts smother aquatic habitats, a reduce stream aesthetics, and further diminish the stream's capacity to properly transport water and sediment.

Depending upon local geological and soil characteristics, erosion and sediment deposition problems cause stream channels either to widen, which increases pressure on banks, or to scour and become incised or down-cut. Typically, unstable urban streams are, thus, either overly wide and shallow, or set down into their landscapes and commonly have vertical, or near vertical, raw stream banks. Stable streams lie atop the landscape and typically possess well-vegetated banks held in place not by exposed soil, but by dense roots.

Numerous studies have shown that nonpoint/stormwater impacts are correlated with the amount of impervious land area within a given watershed. Impervious areas are paved, hardened, or compacted surfaces such as roads, parking lots, driveways, roof areas, and some lawns and fields where soil compaction prevents precipitation from infiltrating into the soil. Schueler (1994), Arnold and Gibbons (1996), and U.S.EPA (1997a) present summaries of many of these studies. Schueler's (1994) pivotal article on imperviousness summarized 18 studies documenting impacts on aquatic biological communities at imperviousness levels ranging from ten to 20 percent. Recent studies in Wisconsin (Wisconsin Outdoors, 1998) indicated that stream quality impacts were evident in Wisconsin streams with eight to 12 percent imperviousness.

Schueler 1994 cites the following major impacts from increasing imperviousness:

- Increases in stream cross-sectional area by widening, down-cutting or both (with resulting erosion and sedimentation problems);

- Losses of in-stream habitat structure due to loss of pool/riffle sequences, loss of overhead cover due to bank loss, reduction of wetted perimeter area, increased stream temperatures, and others;

- Increased pollutant loadings due to wash off from impervious areas including oil, pesticides, heavy metals, road salt, and other toxicants;

- Increased pollution concentrations due to lowered base flows due to less infiltration of precipitation.

An ironic aspect of imperviousness is that it promotes construction of flood control measures and other actions that, history proves, further aggravate channel instability problems. For example, Hollis (1975) found that the magnitude of small floods may be increased ten or more times depending upon the degree of urbanization, and floods of a 100 year return interval may be doubled in size by 30 percent imperviousness in the watershed. Straightening and hardening of the stream channel is typically conducted for flood control and related erosion control purposes by adding stone, concrete and other structural elements to the stream bank or bottom. This often exacerbates stream instability and related problems by artificially hardening the banks and bottom (reducing resistance), building oversized channel dimensions (causing aggradation and higher flood peaks), and removing natural meander and slope patterns (natural buffers of stream energy). In high flow, the resultant increase in stream velocity, stage, and energy is transferred downstream, causing tremendous damage that is traditionally mitigated by yet more flood control measures costing billions of dollars.

V. STUDY APPROACH

A. Water Quality and Stream Flow Analyses

The analyses of water quality and stream flow data were performed by the U.S. Geological Survey. Available water quality and stream flow data from October 1, 1980 through September 30, 1997 were analyzed for each study location. Data were retrieved for 28 water-quality characteristics. Flow data included both fifteen-minute streamflow data for six of these sites (those with continuous streamflow records) and unit-value records where available.

Unit-value streamflow data for three days prior to and after each water quality sampling date at each site were plotted to determine if the sampling occurred during a storm event. Streamflow during each water sampling was subsequently categorized as occurring 1) during base flow (more than three days before or after a storm), 2) within three days before a storm, 3) during rising streamflow, 4) during peak streamflow of a storm, 5) during falling streamflow, or 6) within three days after a storm.

A data set reflecting high flow runoff events was created for the period of record water years 1982 to 1997. Statistical analyses of concentrations (mg/l) and yields (lbs./day/sq.mi.) of selected water-quality constituents were grouped into different flow categories. Ultimately, water-quality concentrations (eight constituents) and yields (six constituents) were grouped into three different flow categories then plotted. The three flowgrouping categories included: 1) base flow and storm flow; 2) before a storm, during a storm, and after a storm; and 3) during low flow, during medium flow, during high flow (based on the 75 and 25 percent flow-duration values for each station).

The following statistical analyses were performed to determine the difference between and among concentrations and yields of eight water-quality characteristics during selected flows at eight sites:

a. The Tukey test was used to determine at which stations the concentrations and yields of each water-quality characteristic were different during 1) base flow and storm flow; 2) before, during, and after a storm; and 3) low, medium, and high flows.

b. The Kruskal-Wallis test was used to determine whether differences exist between median values of concentrations and yields in samples collected during: 1) base flow and storm flow; 2) before, during, and after a storm; and 3) low, medium, and high flows at each site for each water-quality constituent.

Sufficient data existed for analyses of five water-quality constituents, including total nitrogen, nitrate plus nitrite, total phosphorus, total suspended solids, and chlorides. Abbreviated results are presented beginning on page 16. A more detailed presentation of the U.S. Geological Survey analyses and methods is presented in a companion report entitled *Comparisons of Water Quality During Different Hydrologic Conditions in Five Rivers of Northern New Jersey, Water Years 1982-97* (Kariouk, 2000).

B. Assessment of Channel Characteristics

A second phase of the study involved field assessments of the physical and habitat characteristics of the stream channel at each site. Due to scale of the site, the Delaware River at Montague was not subjected to channel characteristic assessment during this phase of the study.

While nonpoint source runoff and stormwater flow events are transient, their impact on the physical and biological characteristics of a stream may be measurable long afterwards. Measures of habitat structure and stream geomorphology provide information that should, in theory, correlate with one or more water quality and/or stream /flow relationships.

The following methods were used to evaluate habitat, channel and related stream characteristics:

Habitat assessment employed two methods, the modified EPA Rapid Bioassessment Habitat Protocols (RBP) (US EPA, 1997b) and Fish Habitat Rating System (FHR) developed by the Wisconsin Department of Natural Resources (Simonson et al., 1994). Both are qualitative to semi-quantitative methods that assess the physical habitat utilized by their target aquatic organisms. Although each method is normally employed in conjunction with detailed biological sampling, this study only conducted field-level qualitative analyses of the macroinvertebrate organisms at each site. Scores were assigned based on presence or absence of particular indicator taxa. The Musconetcong River at Riegelsville was not sampled due to winter safety considerations.

The RBP Habitat method for high gradient streams considers ten parameters in its evaluation. These are:

- available substrate cover;
- gravel, cobble, and boulder embeddedness;
- velocity/depth regime;
- sediment deposition;
- channel flow status;
- degree of channel alteration;
- frequency of riffles or bends;
- bank stability;
- vegetative bank protection; and
- width of the riparian zone.

The FHR (method for streams greater than ten meters wide) employed five parameters:

- bank stability;
- maximum thalweg depth;
- riffle to riffle or bend to bend ratio;
- percent rocky substrate; and
- cover for fish.

In both cases, each parameter received a score based upon whether it was rated optimal (excellent), sub-optimal (good), marginal (fair), or poor. The scores for each parameter were tallied to derive an overall rating of the site.

The Pfankuch Channel Stability Evaluation method used in this study is described in Pfankuch (1975) with modifications from Rosgen (1996). The Pfankuch rating system analyzes the condition of the stream banks and channel to determine overall channel stability. The rating system employs 15 parameters and variable scoring for each parameter:

- stream bank slope gradient (< 30% is excellent, > 60% is considered poor);
- presence or absence of mass wasting (slumping of the banks is a sign of instability);
- debris jam potential (a stream that moves organic debris is here considered stable - this may be debated, though the scoring system was not changed for this study);
- the degree of stream bank vegetative protection (densely vegetated banks are rated stable);
- channel capacity to handle peak flows (overbank flows, if common, are signs of instability);
- bank rock content (large substrate along lower bank is sign of stability);
- flow obstructions (signs of instability include frequent new obstructions; cross-cutting of channel; and sufficient sediment deposition to cause channel migration);
- degree of bank cutting (eroded, high raw banks indicate instability);
- deposition (enlargement of point bars and creation of mid-channel bars composed mainly of fine sediment indicates channel instability);
- angularity of stream bottom rocks (sharp edges and corners, rough plane surfaces indicate stability);
- brightness of stream bottom rocks (stable channel contains > 35% dull or stained rocks);
- consolidation of bottom deposits (tightly packed rocks indicate stability, these are hard to move);
- distribution of bottom particle sizes (stable materials should comprise over 80% of bottom particles);
- scouring and deposition (stable if < 5% of the bottom affected by scour or deposition); and
- aquatic vegetation (presence and abundance of moss, algae, and submerged plants indicates stability).

The Pfankuch rating system yields numeric scores with low scores being better than high scores. The Rosgen modification converts these numeric scores to “good, fair, or poor” according to stream type using the Rosgen Stream Classification System (Rosgen & Silvey, 1998). The Rosgen Stream Classification System is a method of categorizing streams according to various fluvial geomorphic criteria. The Rosgen adjustment to the Pfankuch rating system accounts for differences in each stream type's vulnerability to instability.

A **bottom substrate assessment** examines the relationship of the sand, silt, gravel, cobble, and boulders that make up a stream's bottom. This relationship is an important indicator of what is going on in a watershed and how habitat might be altered. In order to assess bottom substrate, the study employed the Wolman pebble count procedure (Wolman, 1954; Kondolf, 1997). This method involves random sampling of various points along a stream cross-section at regular intervals from bankfull flow line to bankfull flow line. Stream rocks, sand, and silt are measured along their 'B' axis and the results recorded as to one of 16 size classifications.

When at least 100 measurements have been made, the sub-totals are computed and a cumulative distribution curve is plotted on log paper. The D_{50} size, which corresponds to the 50^{th} percentile, determines whether the stream is gravel-dominated, sand dominated, etc. Other information is obtained by denoting the distribution of other sizes. For example, a binomial distribution of sand and gravel might suggest that the streambed is being subjected to sedimentation.

One recent study, Schnackenberg and MacDonald (1998) used the Pfankuch rating system and the Wolman pebble count in headwater streams in Colorado. The researchers found that the former yielded strong differences between disturbed and undisturbed streams. The pebble count technique was also found to be able to detect differences although observer variability and other factors were found to affect sensitivity.

Using the data derived from the pebble count procedures, **percent sand/silt** was calculated. Particles of 2 mm or less in size constitute "fines". The increase in fines between gravel and other rock bed materials (i.e., embeddedness) has profound negative impact on aquatic life (Beschta and Platts 1986). Other stream functions such as sediment transport are also impacted deleteriously. Erosion and runoff are the major contributors of fine sediments to the stream system.

Bank angles and other visual indicators on stream banks are also indicators of problems in the watershed. Stream bank morphology reflects effects of both degradation (scouring and erosion) and aggradation (sedimentation). One classification system, Simon's channel evolution model (Simon 1989), attempts to use various visible indicators to show whether a stream is pre-modified, has constructed banks or is suffering from, or re-stabilizing from, degradation or aggradation.

While use of Simon's model was limited in this study, Simon's indicators were measured or observed in the field. These included numerous bank angle measurements plus observations concerning the presence or absence of convex and concave bank shapes, the relationship of the flow line to top of bank, vertical faces, large bank scallops, retreating banks, failure blocks, and others.

Visual indicators also include a **qualitative sample of macroinvertebrates**. In the absence of chemical pollution, stable streams should possess a rich, diverse, abundant, and pollution-intolerant assemblage of aquatic invertebrates. Channel instability, whether manifested in aggradation or degradation, severely impacts the macroinvertebrate community. Samples were collected on the day that the site was assessed for its habitat characteristics. The visual assessment consisted of the collection of a composite kick net sample proportionally representative of habitat types within a study reach, preservation of the sample, and subsequent examination of indicator taxa. Macroinvertebrates were rated on a scale of zero to ten based upon five criteria which were given up to two points each. The criteria were based upon a field-level assessment system developed by the New York State Department of Environmental Conservation (Bode et al. 1996) and adapted by DRBC for this study into a field-level numeric scoring system for cold water streams, including:

1. Presence/absence of Stoneflies (Plecoptera). Scoring is judged by richness and abundance of these extremely pollution-intolerant insects.
   Scoring: 0 = not present. 1 = present but not rich or abundant. 2 = rich and abundant.

2. Presence/absence of Mayflies (Ephemeroptera). The sample should be rich (more than three taxa), and composed of mostly clean-water forms.
   Scoring: 0 = rare, tolerants only. 1 = up to 3 taxa, mostly tolerant. 2 = rich and abundant.

3. Presence/absence of Beetle larvae (Coleoptera), which tend to be pollution-intolerant.
   Scoring: 0 = not present. 1 = rare. 2 = abundant Psephenidae & Elmidae at minimum.

4. Presence and abundance of Caddisflies (Trichoptera), which should be less abundant than the mayflies and composed of mostly clean-water taxa.
   Scoring: 0 = rare, tolerant. 1 = present, more abundant than mayflies. 2 = rich, abundant, intolerant.

5. Worms (Oligochaeta) and red chironomid midges should not be present.
   Scoring: 0 = present, no stoneflies. 1 = present, stoneflies present. 2 = none present.

It should be noted that most analyses of all of the above-listed indicators represent an averaging of data sets obtained at each site.

C. Assessment of Watershed Urbanization

Nonpoint source pollution, stormwater runoff, and the impacts on water quality, stream morphology, hydrology, and habitats are functions of activity in the watershed - especially mankind's. In this element of the study, numerous methods were employed to assess characteristics of a watershed that might directly or indirectly serve to measure human activity intensity in each watershed.

The **Basin Development Factor (BDF)** was developed by the US Geological Survey (Sauer et al., 1983) to measure of stormwater conveyance efficiency within a watershed as part of a peak flow estimation method for ungaged waterways near urban areas. The Basin Development Factor is obtained by conducting a watershed windshield survey using relevant maps.

The method divides a watershed into thirds and scores the presence (score of 1) or absence (score of 0) of four parameters in each third. The four parameters used to develop the BDF value are: channel improvements, channel linings, storm drains, and curbs and gutters. Scores for a watershed can therefore range from zero to 12, where zero represents an undeveloped drainage system and 12 represents a fully developed drainage system that generates maximum peak flows during runoff events.

As discussed previously, **percent imperviousness** is a parameter that has been suggested as a unifying benchmark for assessing urban watershed runoff, and might be useful for evaluating flow, water quality, and other relationships. Imperviousness represents the integration of almost all the factors affecting the magnitude of nonpoint source-stormwater impacts.

Percent imperviousness was determined by traveling throughout each watershed with an up-to-date county road map (Hagstrom, 1999) and physically observing and recording land uses. Using various descriptive criteria for different land uses from Table 6.2 of Center for Watershed Protection (1998), individual land use areas were colored directly on the road maps. Land use categories assigned a special color in the assessment were: open space (forest, agriculture, urban parks, water/wetlands), low, medium, and high-density development, multi-family, and industrial/commercial. Values used to estimate percent imperviousness are presented in Table 2.

TABLE 2: Assumed values used to calculate percent watershed imperviousness.

Land Use Category	Dwelling Units Density	% imperviousness/acre
Open space: Forest, Agriculture, Parkland etc.	Very Low	2
Low Density	1 or less per acre	12
Medium Density	2 to 4 per acre	40
High Density	5 to 7 per acre	60
Industrial and Commercial	N/A	90
Multifamily	Greater than 20 per acre	Not used

(Values from Table 6.2 of the *Rapid Watershed Planning Handbook* (Center for Watershed Protection, 1998))

After the field survey, the area occupied by each color was determined in each watershed. This was converted to percent imperviousness for each land use category using literature values found in Center for Watershed Protection (1998). The sum of the impervious area for all the watershed land use categories divided by the total watershed area yielded the individual watershed percent imperviousness. Due to the lack of development in the Flat Brook Watershed, a percent imperviousness of two percent was assigned without further analyses.

The third method for assessing land use impact was **the number of road crossings** in each watershed. Schnackenberg and MacDonald (1998) in their studies of headwater streams in Colorado forests found that the amount of fine particles found in stream bottoms was correlated more strongly with the number of road crossings than with equivalent clear cut areas. Although the study's watersheds are totally different from those studied by Schnackenberg and MacDonald, it was decided to test the number of road crossings as a possible indicator, or surrogate, of the degree of urbanization.

VI. RESULTS

A. Water Quality Characteristics

As mentioned previously, a full discussion of the water quality and flow analyses is presented in the companion report prepared for this study (Kariouk 2000), which should be consulted to learn about the derivation and limitations of the data discussed below.

In this report, the trends observed are discussed for their relevance to other study parameters and overall study objectives. The following section discusses and summarizes water quality data as concentration (mg/l) and loadings (lbs./day) and for base flow and stormwater conditions.

1. Total Nitrogen (TN)

Total nitrogen concentrations (Figure 2) suggest that stormwater-related sources of total nitrogen are not as important as base flow contributions. At every location, base flow TN concentrations were higher than stormwater concentrations. It appears that the high flow (more water) dilutes the total nitrogen that is observed during lower flows.

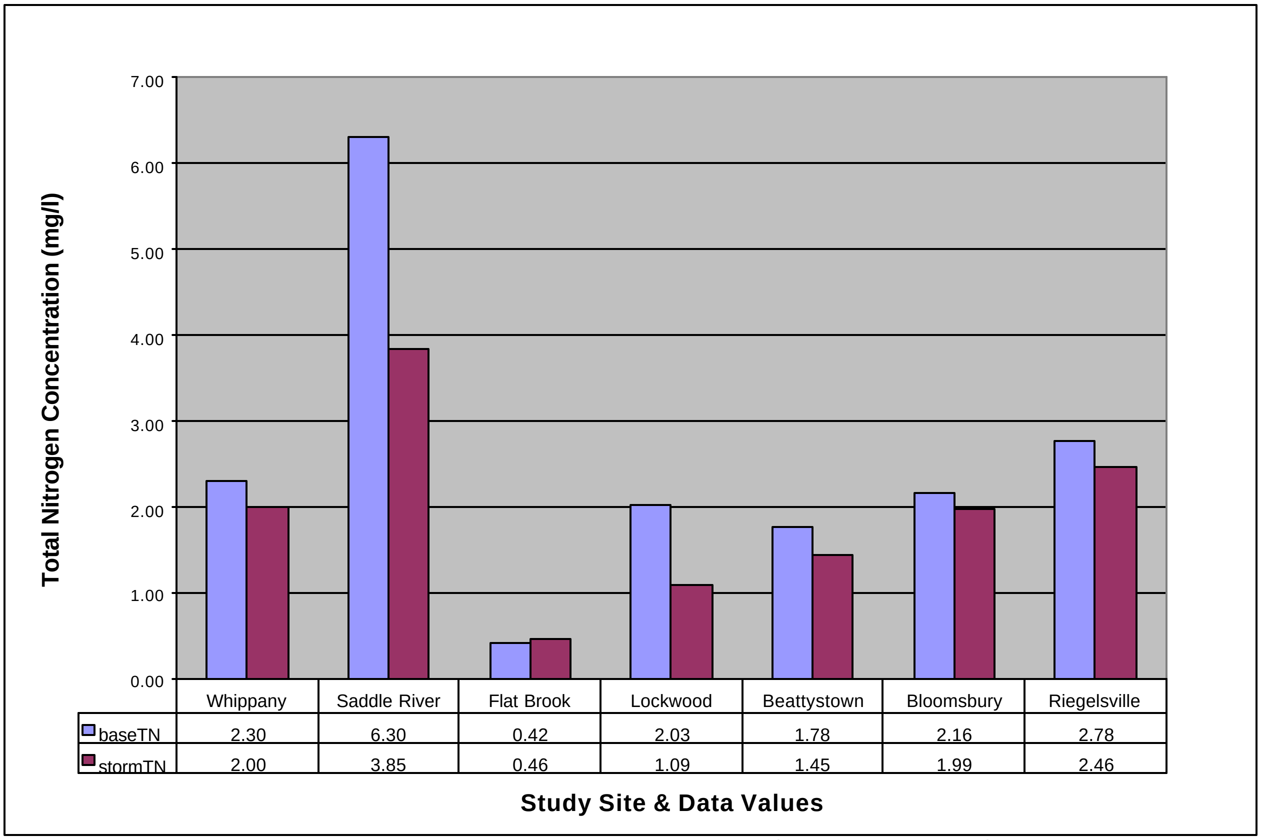


Figure 2. Total Nitrogen Concentrations under Baseflow and Stormflow Conditions.

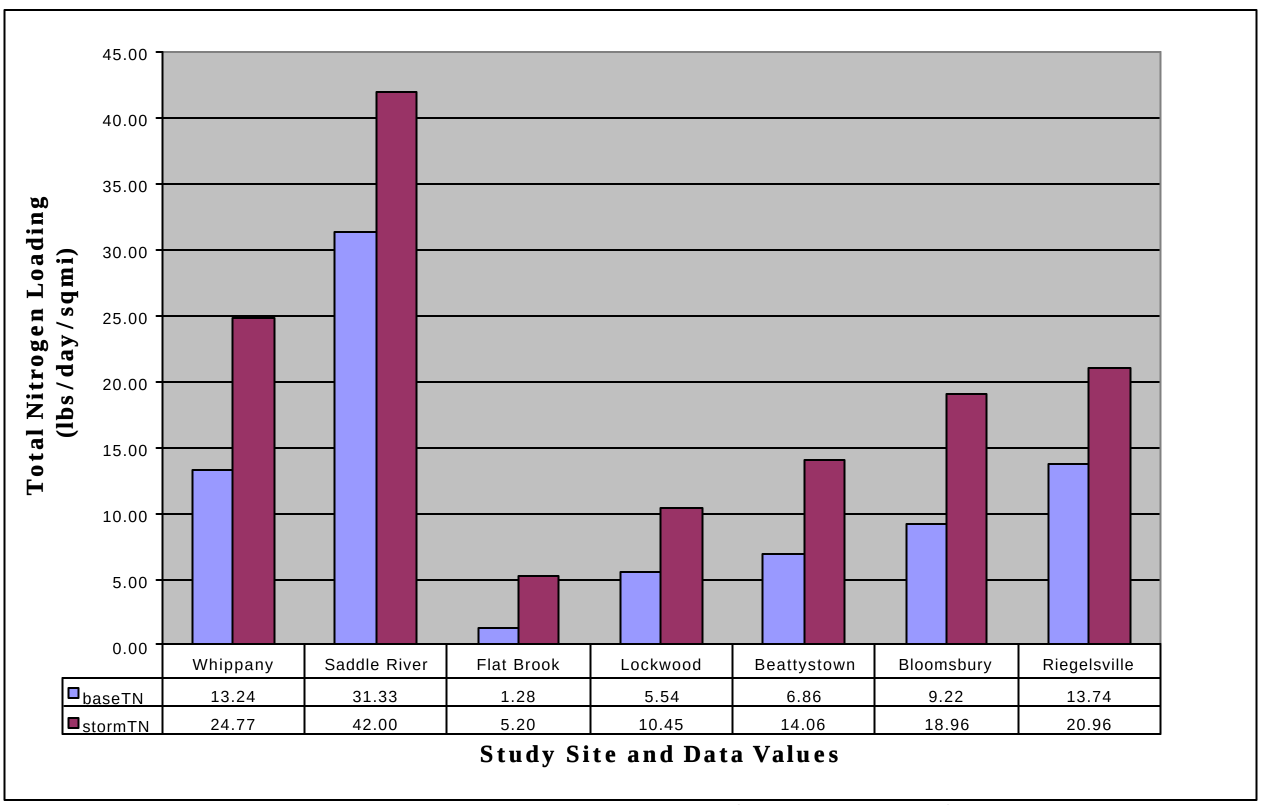


Figure 3. Total Nitrogen Loadings under Baseflow and Stormflow Conditions.

Looking at total nitrogen from a yield or loading basis (Figure 3), it is readily apparent that the loading of total nitrogen is greater during high flow runoff events than during low flow. These data could represent a higher amount of nitrogen in the system – an amount that is still, however, not enough to overcome the dilutive effect of higher water levels.

Loading is a function of water as well as pollutant concentration[1]. It was observed that an increase in the amount of water flow increased loading irrespective of pollutant additions. In this situation, the fact that concentrations are lower during stormwater events is much more significant than the higher loadings observed.

Total nitrogen on both a concentration and loading basis shows the same pattern. The most urban watershed, the Saddle River, has the highest TN concentrations and loadings. These may, in fact, represent the contributions of one or more wastewater treatment plants. As might be expected, the reference watershed, Flat Brook, has the lowest concentrations and loadings. In this watershed, base flow and stormwater concentrations are essentially equal.

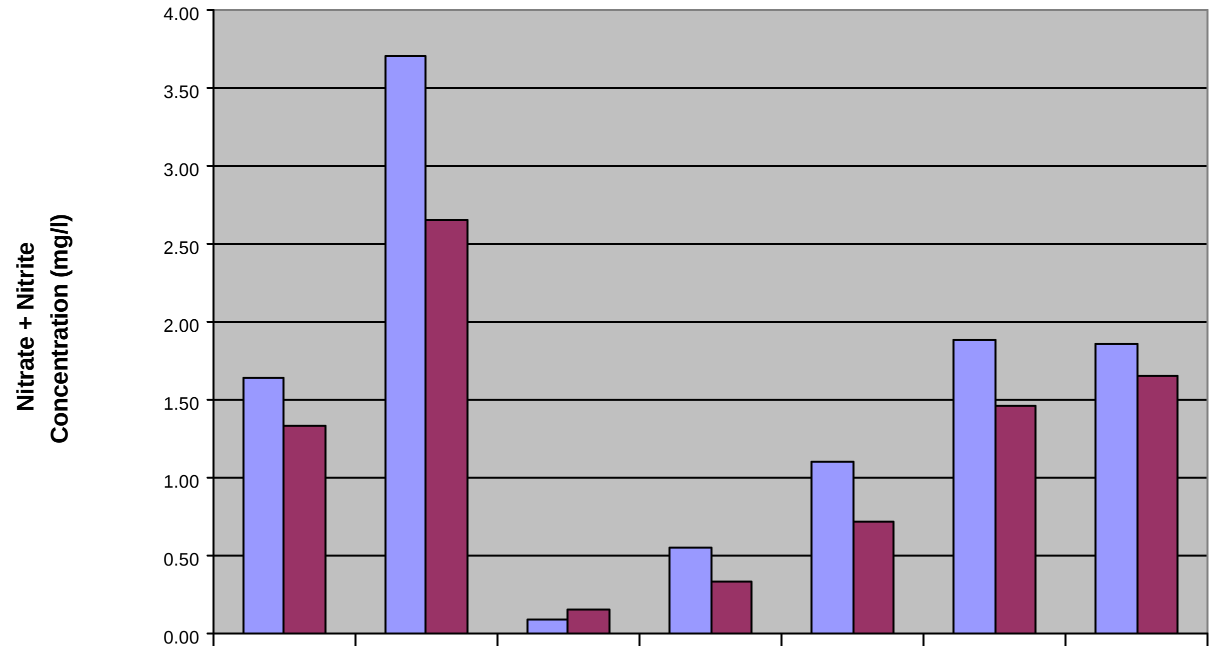
The Musconetcong locations are interesting. Lockwood reflects the most urban portion of the watershed and concentrations decline between there and Beattystown, the latter downstream of a significant urban area. After that location, however, nitrogen concentrations show an increasing, cumulative total nitrogen pattern – even though the watershed becomes increasingly rural. Rural nonpoint source pollutants, thus, may dominate the water quality picture for this reach of the Musconetcong Watershed. The data, however, suggest that these pollutant sources are not delivered by runoff. A ground water delivery system may be dominant, especially in view of the karst geology of the area.

2. Nitrate plus Nitrite Nitrogen

Two components of total nitrogen are nitrate and nitrite, commonly measured as one value. In the study streams, nitrate plus nitrite concentrations and loadings generally follow the same pattern discussed previously for total nitrogen (Figures 4 and 5). Of particular note are the high values at Saddle River, the exceptionally low values at Flat Brook, and the increasing values from upstream to downstream in the Musconetcong as previously noted.

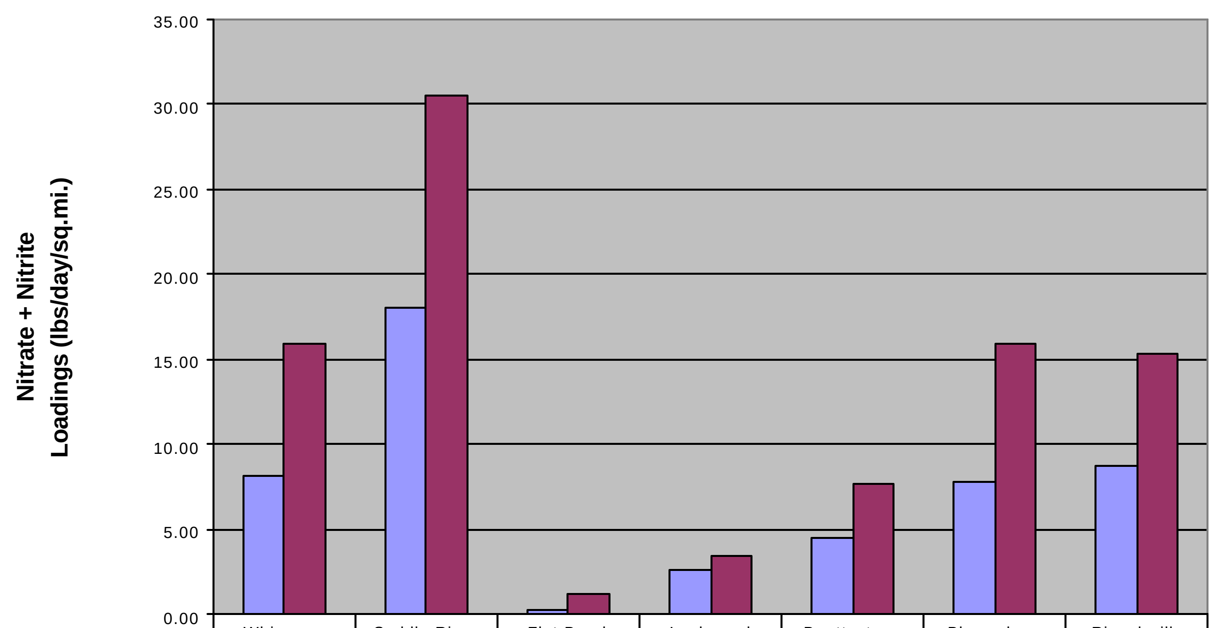
Two exceptions are evident. Nitrate plus nitrite base flow loads for Saddle River are somewhat of an anomaly when compared with the concentration data. The other exception is a much more significant increase in nitrate plus nitrite concentrations in the lower reaches of the Musconetcong than that observed for total nitrogen. This increase undoubtedly reflects agricultural sources, especially fertilizer. Loading data suggest that nitrate plus nitrite runoff becomes significant upstream of Bloomsbury.

[1] Pollutant concentration multiplied by flow multiplied by a unit conversion factor = pounds/day



	Whippany	Saddle River	Flat Brook	Lockwood	Beattystown	Bloomsbury	Riegelsville
baseNO2/3	1.64	3.70	0.09	0.55	1.10	1.89	1.86
stormNO2/3	1.34	2.66	0.16	0.34	0.72	1.46	1.65

Figure 4. Nitrate plus Nitrite Concentrations under Baseflow vs. Stormflow Conditions.



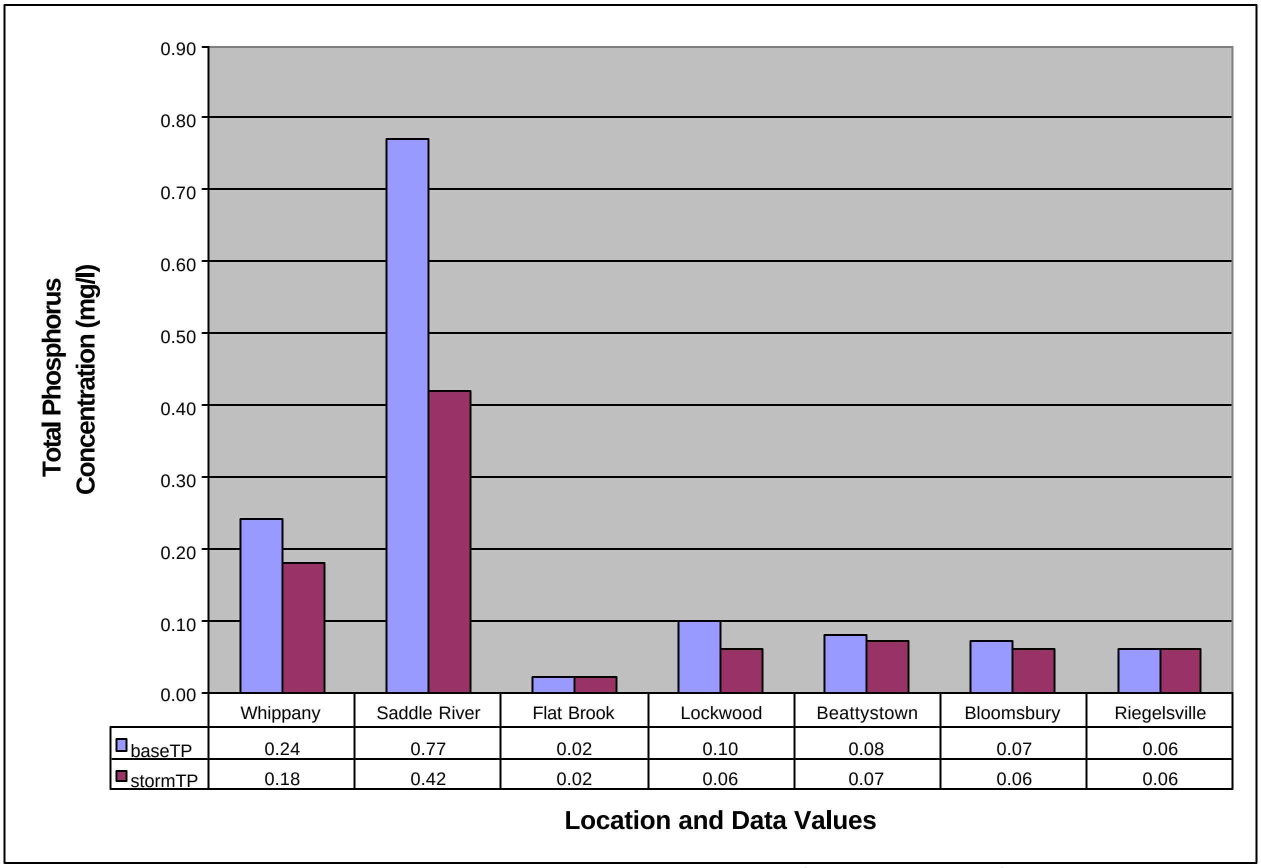
	Whippany	Saddle River	Flat Brook	Lockwood	Beattystown	Bloomsbury	Riegelsville
base NO2/3	8.20	18.00	0.26	2.60	4.50	7.76	8.71
stormNO2/3	15.88	30.51	1.20	3.41	7.74	15.90	15.28

Figure 5. Nitrate plus Nitrite Loadings under Baseflow vs. Stormflow Conditions.

3. Total Phosphorus

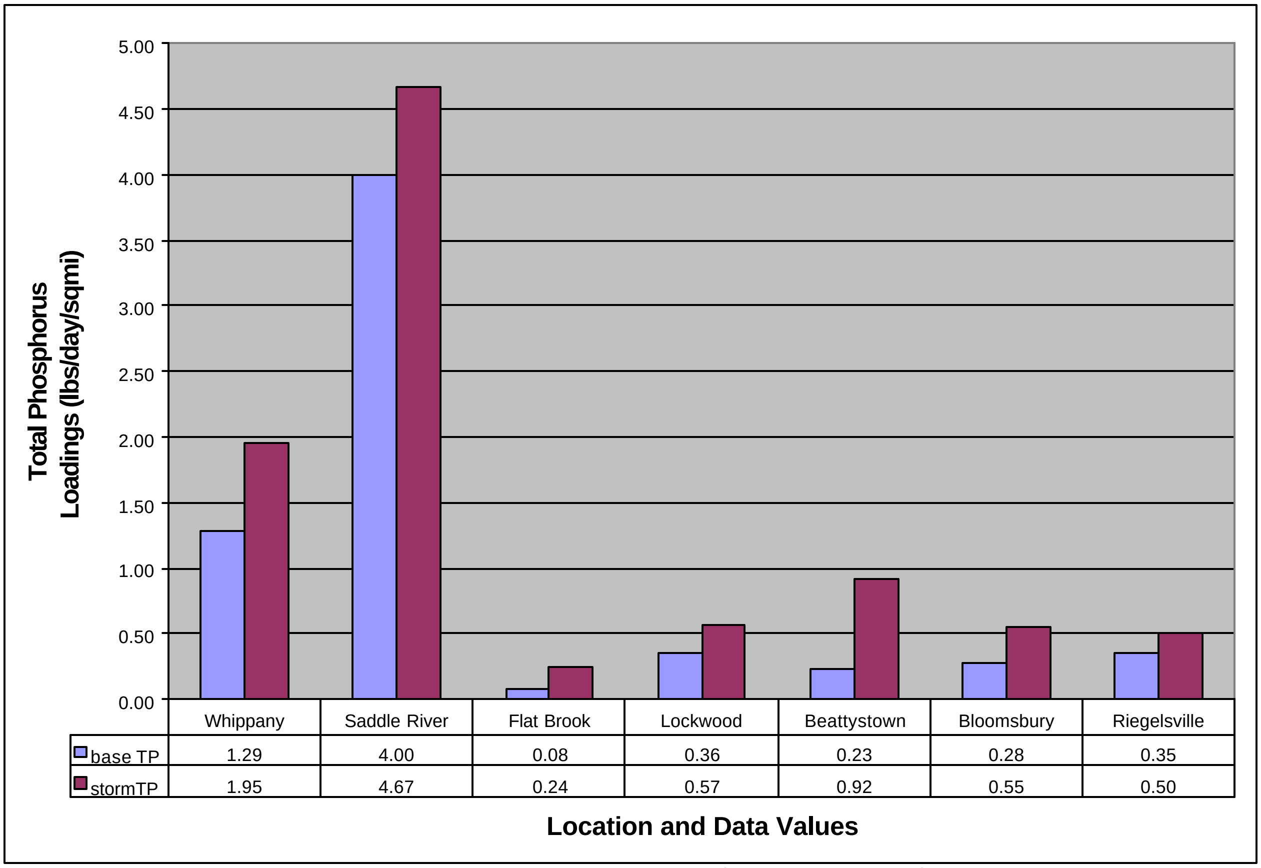
Data for total phosphorus (Figures 6 and 7) show high values for the Whippany River, even higher values for the Saddle River, and exceptionally low values at Flat Brook. In addition, base flow concentrations are higher than stormwater concentrations. These patterns were also seen for nitrogen parameters.

Unlike nitrogen, however, total phosphorus in the Musconetcong shows no major increases from upstream to downstream with the exception of a minor loading increase at Bloomsbury. Even this increase is not reflected in the concentration data.



	Whippany	Saddle River	Flat Brook	Lockwood	Beattystown	Bloomsbury	Riegelsville
baseTP	0.24	0.77	0.02	0.10	0.08	0.07	0.06
stormTP	0.18	0.42	0.02	0.06	0.07	0.06	0.06

Figure 6. Total Phosphorus Concentration (mg/l), Baseflow vs. Stormflow Conditions.



	Whippany	Saddle River	Flat Brook	Lockwood	Beattystown	Bloomsbury	Riegelsville
base TP	1.29	4.00	0.08	0.36	0.23	0.28	0.35
stormTP	1.95	4.67	0.24	0.57	0.92	0.55	0.50

Figure 7. Total Phosphorus Loadings, Baseflow vs. Stormflow Conditions.

4. Total Suspended Solids (TSS)

The available, useful data for total suspended solids (Figures 8 and 9) are limited in comparison with other parameters, thus limiting conclusions. The TSS data indicate that high stormwater loadings are generated in the Whippany Watershed and the lower portion of the Musconetcong River, especially at Riegelsville. Data were more limited for the Saddle River and other study watersheds. Based on visual observations, discussed later, the Saddle River carries immense TSS loadings during high flow, though Figure 9 data were insufficient to verify this observation.

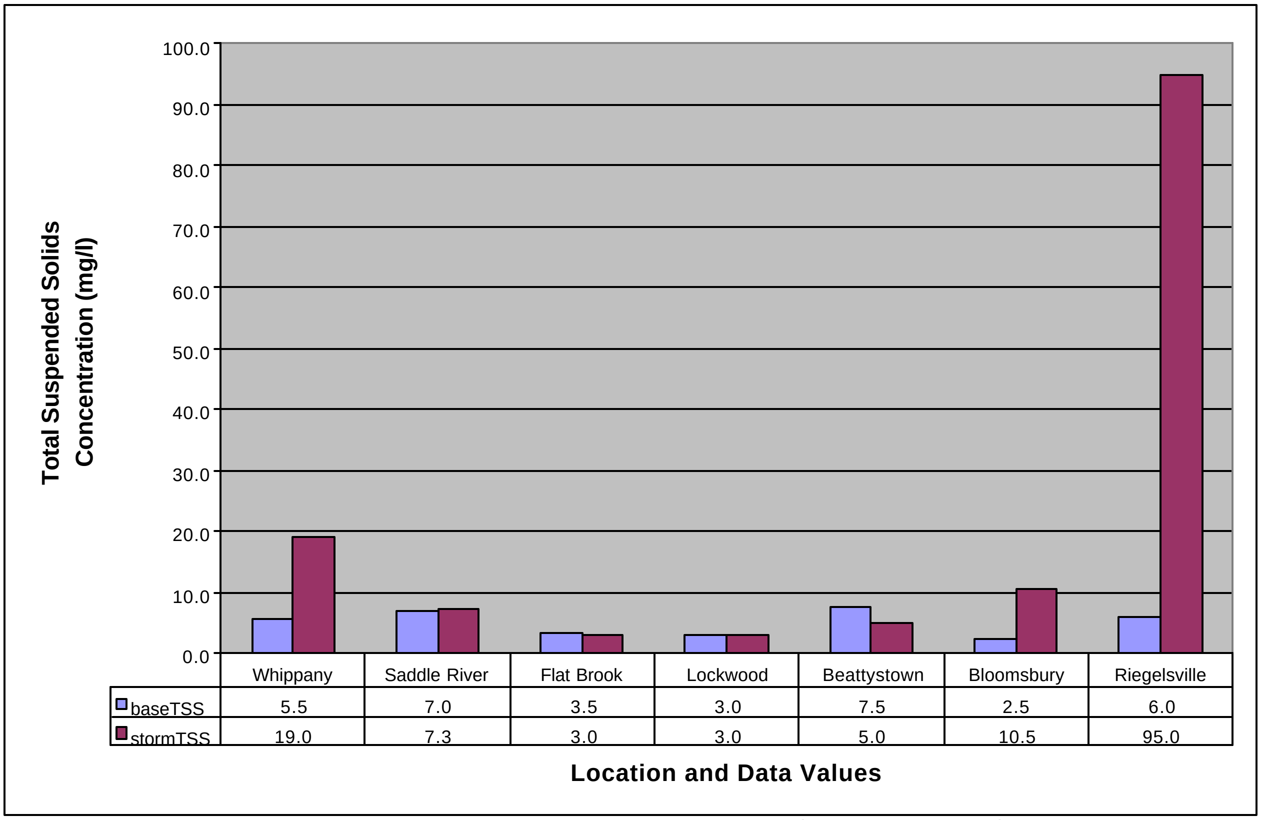


Figure 8. Total Suspended Solids Concentrations, Baseflow vs. Stormflow Conditions.

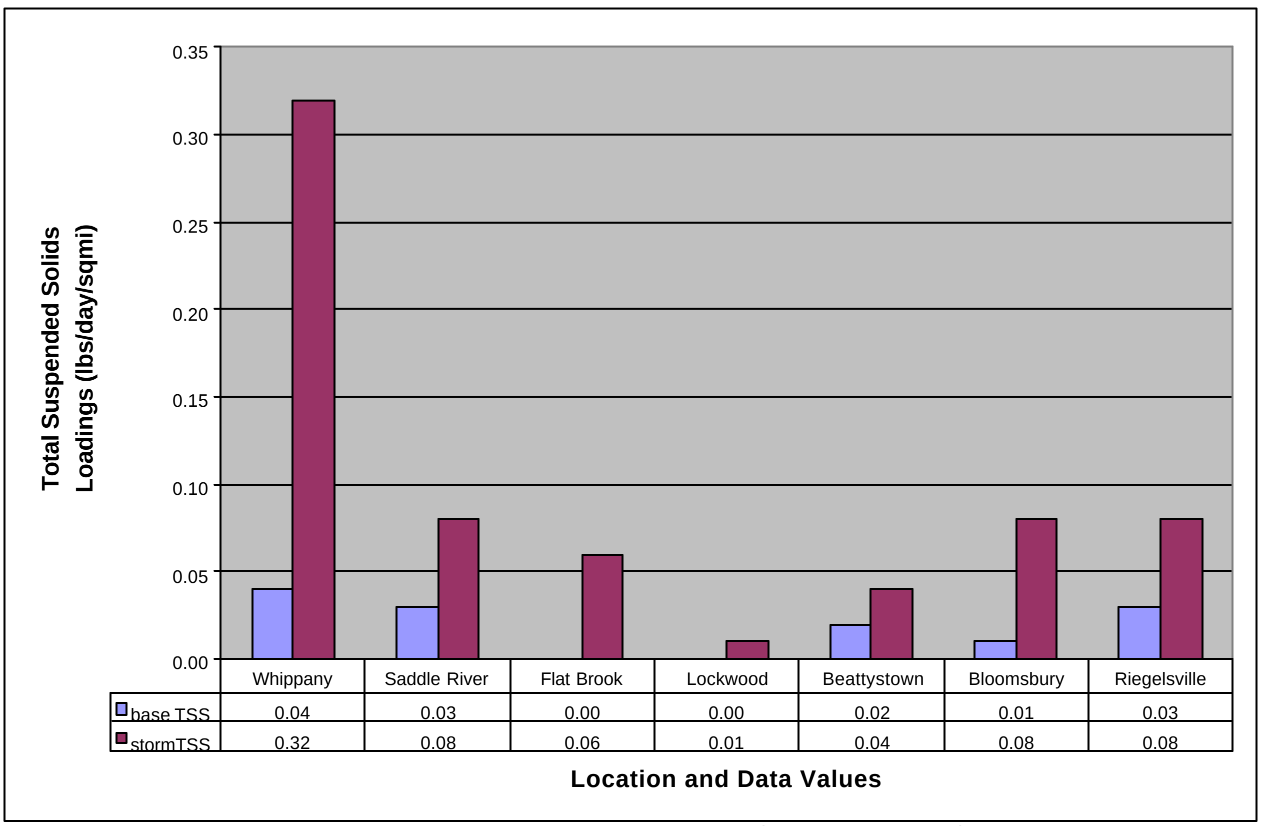


Figure 9. Total Suspended Solids Loadings, Baseflow vs. Stormflow Conditions.

5. Chlorides

Chlorides are an indicator of human activity and wastes. Human waste effluents (wastewater treatment plants, septic tanks, etc.) and salts used on roadways are two sources of chloride contamination in streams, either directly or via ground water. Data for chlorides (Figures 10 and 11) show high values for the Whippany River, even higher values for the Saddle River, and exceptionally low values at Flat Brook. This pattern was seen elsewhere, particularly with total nitrogen. However, unlike total nitrogen, chloride concentrations decrease from upstream to downstream in the Musconetcong River. The Musconetcong River pattern may reflect the unusual complex of highways that converge upstream of the Lockwood site at Netcong, NJ. Interstate 80 and interchanges, U.S. Route 206, U.S. Route 46, and numerous secondary roads intersect here. From the Musconetcong chloride concentration patterns, one could speculate that chlorides entering the system upstream of Lockwood could influence concentrations in the river to below Beattystown during low flow and all the way to Riegelsville during high flow.

It is likely that the Whippany and Saddle Rivers reflect a level of chlorides associated with human activity including road salt usage that is typical of urban and suburban development. The Flat Brook Watershed contains few inhabitants and few roadway miles subject to winter salting.

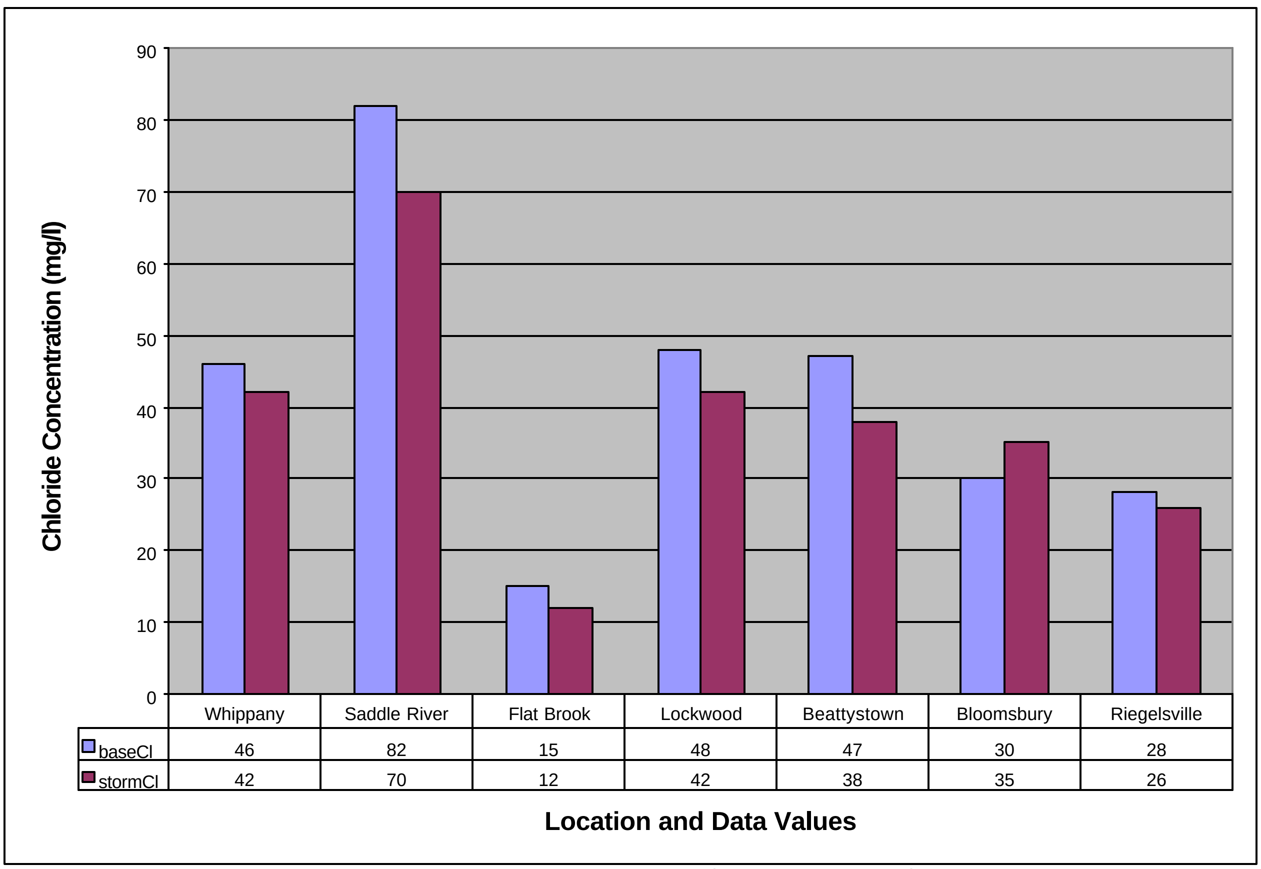


Figure 10. Chloride Concentrations, Baseflow vs. Stormflow Conditions.

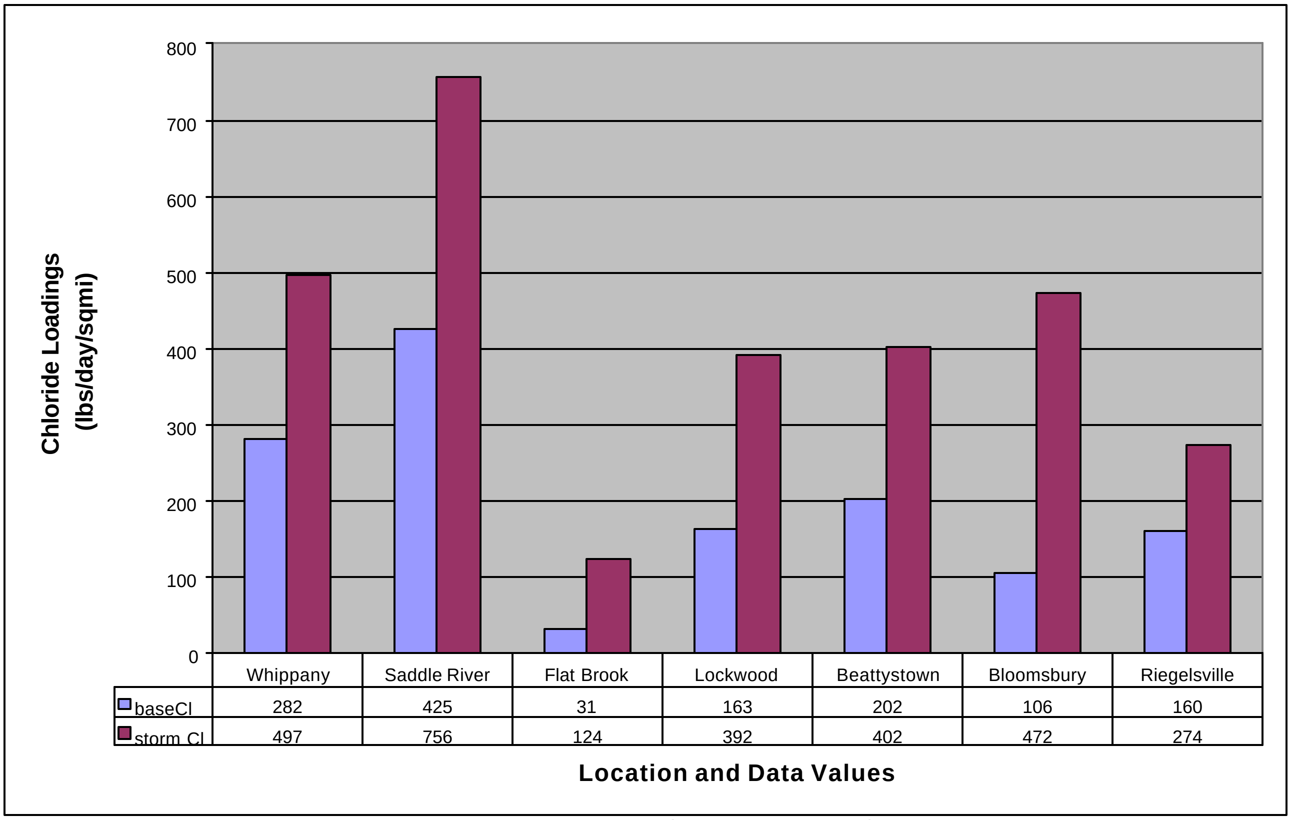


Figure 11. Chloride Loadings, Baseflow vs. Stormflow Conditions.

6. Flat Brook versus Delaware River Water Quality

Flat Brook was selected as a study watershed because it could likely serve as the reference stream against which the other study streams would be compared. The Delaware River, on the other hand, was selected for study in order to compare a large river with the study streams. Although the Delaware River Watershed above Montague is largely rural with some small towns, it was never anticipated that the Delaware would be a reference stream. Table 3 presents comparisons of Flat Brook and Delaware River water quality under both base flow and high flow conditions. The comparisons indicate a remarkable similarity between the two water bodies for all parameters. This level of water quality may represent a non-degraded condition, a regional best-expected reference condition, or a regional water quality management goal.

	Base Flow		Storm Flow	
	Flat Brook	Delaware River	Flat Brook	Delaware River
Total N	0.42	0.71	0.46	0.67
NO3/2	0.09	0.37	0.16	0.36
Total P	0.02	0.03	0.02	0.03
TSS	3.5	1.0	3.0	3.0
Chlorides	15.0	8.8	12.0	8.6

Table 3. Water quality comparison at base flow and storm flow conditions, Flat Brook vs. Delaware River at Montague, NJ. Concentration units are mg/l.

B. Site Observations and Physical/Biological Assessments.

1. Description of Sites and Visual Indicators

a. The Delaware River at Montague was not assessed for channel characteristics. The site has been the subject of a wide variety of studies and routine monitoring by the DRBC/NPS Scenic Rivers Monitoring Program, operated by the Delaware River Basin Commission and National Park Service. A bathing beach is active on the Pennsylvania side of the river and natural conditions are evidenced on the New Jersey side. The former has been the subject of some contouring while the latter is protected by a substantive outcrop of bedrock that extends into the river itself.

b. The Flat Brook sampling site was located in an undeveloped area several hundred feet upstream of the USGS gage in order to avoid potential impacts from an adjacent road. Although the site represents relatively pristine conditions, some bank and channel conditions reflect impacts from a nearby abandoned road, bridge, farm, and pasture, plus more intense agriculture prior to land acquisition for creation of the Delaware Water Gap National Recreation Area in the 1960s.

Visual indicators observed at Flat Brook include some basal erosion on banks and a few leaning trees. Neither appeared to be unnatural. Positive indicators included banks well-vegetated to the flow line.

c. The Musconetcong River at Lockwood is downstream from the most urban section of the watershed – the area surrounding Lake Hopatcong, Lake Musconetcong, Cranberry Lake, Lake Mohawk and several smaller ones. Lake Hopatcong and Lake Musconetcong are formed by dams on the main stem of the Musconetcong River. The influence of these lakes on channel stability, or instability, is not known. The Lockwood site is immediately downstream from a relatively new road bridge serving the International Trade Center. Upstream of this bridge about 300 yards is an older, abandoned road bridge. The river section between the two bridges is braided (multiple channels). Presence of mature vegetation on the island sections suggests that channel problems, which created the braiding pattern, occurred many years ago.

The Lockwood site evidenced some bank scalloping on the outside bend due to large trees that were lost to the river. Some undercutting of existing tree root masses was also evident. Positive indicators predominated, however, including the extension of vegetation to the stream flow line which itself was fairly high with respect to the height of the bank.

d. The Musconetcong River at Beattystown was a problem site and no work was done on it except for pebble counts. The site was highly modified by an old mill, raceway, and millponds, adjacent highways and backyards, and fish habitat "enhancement" structures. A suitable access site between Beattystown and a location downstream of Hackettstown was not found. Favorable visual indicators at Beattystown included the absence of both stream incision and bank erosion. Some braiding was evident as the result of the mill.

e. The Musconetcong River at Bloomsbury had the most variability of any study site. It is believed that a combination of local and watershed conditions were contributing to this variability.

Unfavorable local conditions included poorly-functioning in-stream fish habitat structures built by local fishing clubs (particularly those upstream of the Limekiln Road Bridge) that were obviously contributing to the sediment load at the site. The structures were creating sediment deposition sites mid-stream, while contributing to bank erosion problems by directing flow toward the riverbanks. Downstream, a large landowner was possibly creating bank erosion problems by mowing vegetation on the riverbank and riparian area. Observed aggradation of the channel due to severe sediment deposition indicates erosion problems upstream of this site.

Negative visual indicators included vertical banks, large bank scallops, leaning or absent trees, concave banks, raw banks, excessive basal erosion, evidence of mass wasting, channel incision, possible erosional piping holes, and a general lack of a thalweg (main channel). These conditions were generally located downstream of the Limekiln Road bridge along the northern (right) bank.

f. The Musconetcong River at Riegelsville study reach is located upstream of the River Road bridge. It is a worrisome site because it suggests major watershed changes that are possibly recent. The site displays excessive sediment deposition that directs high flow laterally, eroding the stream banks. This indicates that the streambed elevation is rising. Of special concern are the number of older trees (estimated 70 to 80 years old) that are leaning or have fallen since the study was initiated. Other negative observations include sediment deposits burying the base of trees, scallops, high and relatively raw banks, and the filling of pools (evidenced by a rope swing hanging over shallows). The site is probably impacted by its watershed as well as from a braided section immediately upstream of the site. There is also a localized area showing massive bank erosion from overland flow down the bank from a farm's hillside. The braided section, possibly old, is likely related to a former water diversion canal (suspected but unconfirmed) for the abandoned paper mill in Riegelsville, New Jersey. A canal is evident in aerial photos.

g. The Whippany River site is located in undeveloped parkland believed to be owned by the City of Morristown. The site is adjacent to the property occupied by the city's wastewater treatment facility and an industrial railway. Interstate 287 bounds the property as well and the river enters the site via a two-barrel bridge under the interstate (one-barrel is clogged with sediment - a common observation throughout New Jersey).

While the site shows evidence of its upstream urban area, the riparian zone is extensively wooded, and the stream has a natural appearance in its pool and riffle patterns, sinuosity patterns, gravel bar development, and lack of incisement. Visual evidence suggests that one large leaning, partially undercut tree at the site is no longer threatened with toppling – a sign of healing after historical channel instability which might have been caused by I-287 construction.

Negative visual indicators include leaning trees, raw banks, basal undercutting, and urban debris. The reach upstream of the study section has been extensively rip-rapped. Just above the study reach, the left bank is composed entirely of a wall of gabions for about 40 yards. Within the study section (left bank), bank angles and clay deposits in one area suggests a man-made bank, which is evidence of past channelization.

h. The Saddle River at Lodi and Fairlawn are complex river sites. Initially, data were collected from the reach immediately downstream from the gage in Lodi. It was discovered, however, that this site was not representative of upstream conditions. Work was, therefore, shifted several miles upstream to Otto C. Pehle Park in Fairlawn.

A comparison of municipal boundaries with the existing stream course (USGS maps, for example) indicates that the Saddle River has been extensively straightened. Older maps suggest that it formerly had much greater sinuosity. Bank angles and clay indicated extensive man-made banks throughout the study reach, albeit not everywhere. The man-made banks are not readily apparent due to vegetation that has grown since their construction. A flood control project was constructed in the 1960's (Steve Neiswand, U.S. Geological Survey, personal communication), but other channel modifications may have been constructed long ago, possibly pre-World War II. At the Fairlawn site, negative visual indicators included extreme sediment deposition, raw vertical banks, and some leaning trees.

The Lodi site, further downstream at the Lakewood Cemetery, appears to be much more stable than the Fairlawn location. The channel in this reach might show the original stream sinuosity and slope pattern, but this is speculative. Odors coming off the stream during the date of sampling were highly suggestive of chemical pollution. Bottom substrate is relatively clean, a surprising finding in view of the massive sediment deposited in upstream reaches. It could be speculated that the dam at the USGS gage or some geological condition provides some protection, as heavy sediment deposition was again observed further downstream. A comparison of bottom substrate between Lodi and Fairlawn is presented later.

i. All sites were re-visited following the September 16, 1999 flooding caused by Tropical Storm Floyd. Each study site was visited to assess changes that might have occurred since data were collected. At all but the Saddle River Fairlawn site, floodwaters barely topped banks, spilling onto the flood plain. At the Fairlawn site, however, flooding was much more severe, damaging homes. Post-storm observations suggest that one or more feet of additional fine sediment was deposited by the flood into the already sediment-laden channel. It is theorized that the extreme sediment deposits reduced the stream channel capacity, sending flood peak levels higher than normal. The cause of such heavy deposition could be stream slope problems resulting from channel alterations. A low-sloped stream gradient was constructed, causing low velocity areas in the stream. This created a situation where the stream was unable to carry its normal sediment load, which clogged the channel and elevated the flood peak to destructive levels. The deposits were probably mobile during high flow, as there were no signs of stability of bottom materials, such as vegetation or macroinvertebrate colonization. This reach appears to receive a continuous supply of fine sediment.

2. Habitat Assessment

The results of the modified EPA Rapid Bioassessment Protocols and (Wisconsin) Fish Habitat Rating System appear in Table 4. Higher values are more desirable than lower values. RBP Habitat scores are based on a scale of 0-200, and the FHR scores are based on a 0-100 scale. Results in Table 4 are displayed as percentages so that direct comparisons may be made between the two methods. The values obtained from the two habitat evaluation methods are shown with percent watershed impervious area.

Table 4. Habitat Assessment Scores (Two Methods)

Location	EPA RBP%	RBPverbal	Wisconsin FHR%	FHRverbal	% Impervious
Whippany	64.5%	suboptimal	61.0%	good	23
Saddle River	49.0%	marginal	36.0%	fair	29
Flat Brook	90.0%	optimal	80.0%	excellent	2
Lockwood	79.5%	suboptimal	90.0%	excellent	8.5
Bloomsbury	56.2%	marginal	60.0%	good	5.6

Not Assessed: Delaware River at Montague, and the Musconetcong River at Beattystown and Riegelsville.

With one exception, a direct correlation between "good" habitat and imperviousness above or below ten percent is evident. The exception is the Musconetcong River at Bloomsbury. This location has habitat value similar to the Whippany River. Habitat assessment data for Riegelsville were not obtained due to safety considerations in high-flow conditions at the site.

3. Macroinvertebrate Assessment

The results of the field-level macroinvertebrate assessment are presented in Table 5. The best sites, as indicated by higher total scores, were the Flat Brook and the Musconetcong River at Lockwood. These sites were represented by balanced, rich, and abundant populations of pollution-intolerant macroinvertebrates. Even though some pollution-tolerant worms and red chironomids were present in all samples, they were not abundant or dominant in any of the high scoring stream reaches.

The Whippany River (sampled in multiple habitats just upstream of the Morristown Sewage Treatment Facility discharge) and the Musconetcong River at Bloomsbury scored as good, and were roughly equivalent regarding habitat heterogeneity and sediment deposition. The macroinvertebrate habitat looked great in some areas of each study reach, yet didn't possess the expected abundance or richness of pollution-intolerant taxa. Other areas of both study reaches (generally pools and runs) contained cobble and gravel that was smothered by fine sediment deposition, and were essentially lifeless. Further and more detailed assessment of these sites may reveal the extent of man-made impact upon the macroinvertebrate assemblage.

The Saddle River reach at Fairlawn contained fairly frequent riffle segments, which should be abundant in macroinvertebrates. The poor score was based on a 20-kick composite sample, with eight taken from riffle areas, three from runs or glides, and nine from extremely sediment-laden pool areas (over two feet of loose, coarse sand in some areas, enough to make wading treacherous). Examination of the samples revealed very few organisms (20 total). Twenty kick samples should have produced hundreds or even thousands of organisms. Even though mayflies and caddisflies were found, the samples were so sparse that it may not be valid to assign any score at all. Sampling took place about two months after Tropical Storm Floyd, and habitat availability ranged from plentiful and heterogeneous in the upstream end to abysmally homogeneous and choked by fine sediment in the downstream two-thirds of the reach.

Table 5. Macroinvertebrate Field Assessment Scores

Criterion	Flat Brook	Whippany River	Saddle River	Musconetcong at Lockwood	Musconetcong at Bloomsbury
Stoneflies	2	1	0	2	1
Mayflies	2	2	1	2	2
Caddisflies	2	2	1	1	1
Beetles	2	1	0	2	1
Worms/Red Midges	1	1	1	1	1
Total Score	9	7	3	8	6

Not Assessed: Delaware River at Montague, Musconetcong River at Beattystown and Riegelsville

4. Pfankuch Channel Stability Evaluation

The results of the Pfankuch assessment are shown on Table 6. Lower values are more desirable than higher values. The Pfankuch values are compared with percent imperviousness. The resultant pattern is similar to that exhibited by habitat assessment. The same factor apparently affects both habitat and channel stability. As suggested by the percent imperviousness data, this factor is likely the degree of urbanization.

Table 6. Pfankuch Channel Stability vs. Percent Imperviousness

Location	Pfankuch	Verbal	% Imperv.
Whippany	115	poor	23.0
Saddle River	117	poor	29.0
Flat Brook	61	excellent	2.0
Lockwood	69	excellent	8.5
Bloomsbury	90	good	5.6
Riegelsville	99	fair	5.3

Data for the lower reach of the Musconetcong River, e.g., Bloomsbury and Riegelsville suggest that something other than degree of urbanization might be affecting channel stability. The channel problem could be responsible for the observed habitat degradation.

5. Bank Angles

Bank angle is another parameter tested as an indicator of channel problems. Table 7 presents median bank angle measurements for each location. Because of man-made banks at one location (Saddle River) and bank angles showing possible historical modifications at the reference location (Flat Brook), information derived from bank angles is relatively inconclusive. A possible increase in bank angles from upstream to downstream in the Musconetcong River could be inferred except that data from Beattystown was not obtained for reasons discussed previously. It may be that the use of bank angles as a channel stability indicator is precluded by urbanization. Streams may not be left undisturbed long enough to undergo natural channel evolution. Artificial uniformity of bank angles measured along a stream may reveal channelized reaches that are otherwise hard to identify, such as those possessing mature vegetation.

Table 7. Bank Angles

Location	Bank Angle
Whippany	51.2
Saddle River	45.0
Flat Brook	38.0
Lockwood	33.0
Bloomsbury	42.0
Riegelsville	51.2

6. Bottom Substrate Assessment

The importance of bottom substrate size and heterogeneity as a habitat condition cannot be overly stressed. Fish and macroinvertebrates are very sensitive to bottom substrate conditions, especially when fines smother important gravel and rock interstitial areas. Table 8 presents data on the percent sand and silt (particles two millimeters or less in size).

Table 8. Percent Sand/Silt Indicator

Location	%sand/silt
Whippany	30
Saddle River	74
Flat Brook	14
Lockwood	27
Beattystown	12
Bloomsbury	27
Riegelsville	19

One significant aspect of the percent sand/silt data is the 74 percent value obtained at the Saddle River locations. Huge deposits of sand/silt exist in the streambed. It is uncertain whether the sand supply in the Saddle River is "natural" or derived from anthropogenic sources (see discussion below).

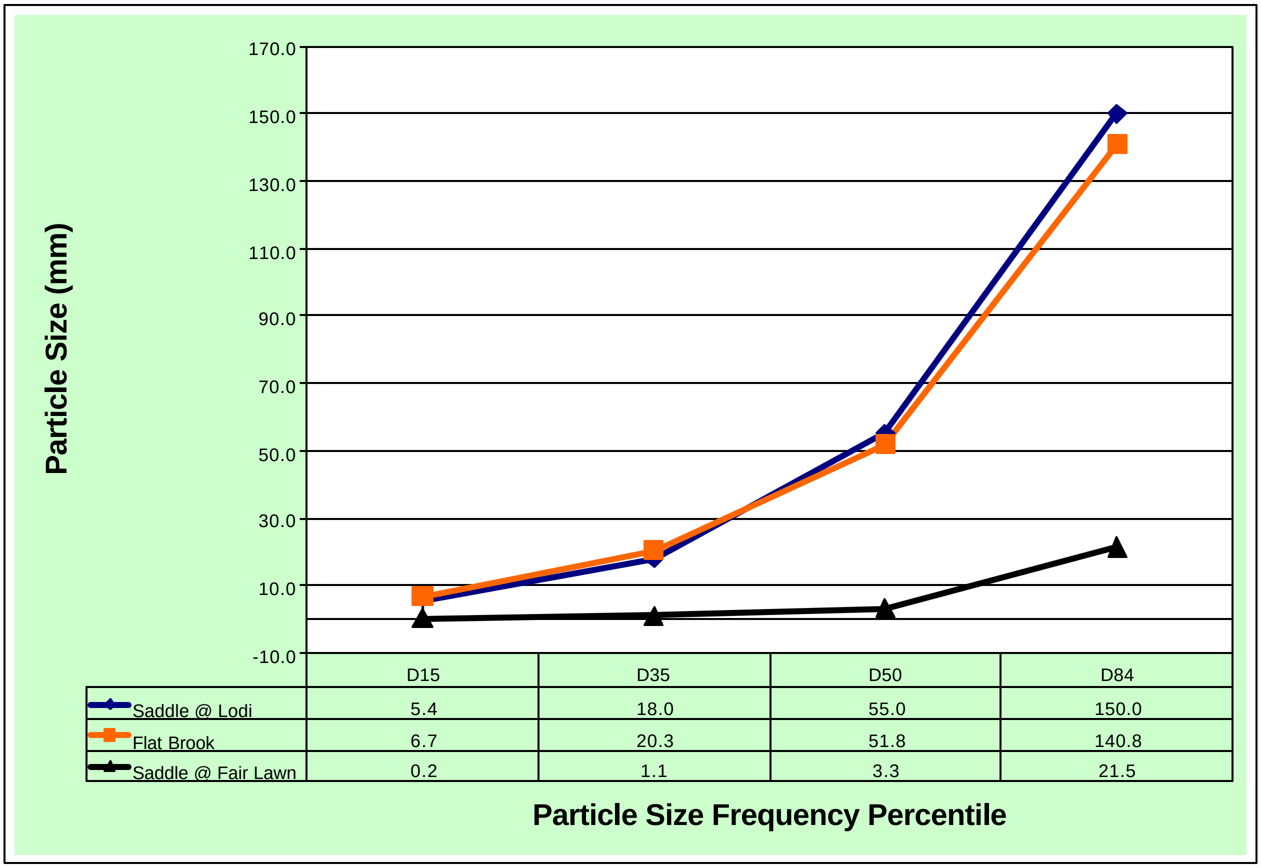
Particle size distribution at each location is shown in Table 9. The D_{16}, D_{35}, D_{50}, and D_{84} designations refer to the particle size representing the 16^{th}, 35^{th}, 50^{th}, and 84^{th} percentile on a particle size-distribution frequency graph. Flat Brook, the reference location, has the highest range in particle distribution, while Saddle River has the lowest as indicated by the spread between the D_{16} and D_{84} values for each location. Flat Brook also has the highest D_{16} and D_{84} values, making it the "cleanest" bottom with the most habitat structure.

Table 9. Wolman Pebble Count, Particle Sizes (mm)

Location	D16	D35	D50	D84
Whippany	0.63	6.40	21.20	68.20
Saddle River	0.19	1.13	3.30	21.50
Flat Brook	6.70	20.30	51.80	140.80
Lockwood	0.21	19.00	54.70	123.70
Beattystown	5.50	38.00	25.10	82.70
Bloomsbury	0.35	11.50	25.10	82.70
Riegelsville	1.00	9.80	22.00	78.00

Unlike the Saddle River Fairlawn location with its large deposits of sediment, pebble count data collected immediately downstream from the Saddle River Lodi stream gage are suggestive of a natural condition. In fact, bottom substrate data for the Saddle River at the Lodi site is a similar to that seen in the Flat Brook, the reference stream. In this reach, the percentage of sand and silt is 11 percent; reasonably comparable to the 14 percent observed at Flat Brook.

Figure 12 compares bottom substrate data distribution from the Saddle River at Lodi (test site), the Saddle River at Fair Lawn (test site highly impacted by fine sediment deposition) and the Flat Brook (reference site). The Lodi and Flat Brook results are nearly identical, showing ideal particle size distribution, as opposed to the Fair Lawn site where 74 percent of all particles were sand or silt.



	D15	D35	D50	D84
Saddle @ Lodi	5.4	18.0	55.0	150.0
Flat Brook	6.7	20.3	51.8	140.8
Saddle @ Fair Lawn	0.2	1.1	3.3	21.5

Figure 12. Comparison of particle size distributions sampled from the Saddle River at Lodi, NJ; Saddle River at Fair Lawn, NJ; and the Flat Brook reference reach.

C. Watershed Urbanization

Three methods for measuring the degree of urbanization were employed and compared: (1) Basin Development Factor (BDF); (2) percent imperviousness; and (3) the number of road crossings per square mile. These results are shown in Table 10.

Of the three measures, the number of road crossings is the most precisely measured since these are easily counted on a USGS or other map. As indicated in Table 10, however, the number of road crossings fails to distinguish between differing degrees of urbanization, for example, between Saddle River and Flat Brook. Flat Brook has numerous little-used road crossings that inflate the significance of road crossings as a measurement of development. Conversely, in an urban area more intensely developed than the Saddle River, the burying of streams as part of a storm sewer network may result in an under count of road crossings.

The two remaining methods appear to successfully measure urbanization, capturing the increasingly rural character of the Musconetcong from its headwaters to mouth. Of these two methods, percent imperviousness is perhaps the most relevant, although the Basin Development Factor measures factors such as storm drains and gutters that are not accounted for in percent imperviousness.

Table 10. Development Factor, Impervious Surface, Road Crossings			
Location	**BDF**	**% Imperv.**	**Road Xings**
Whippany	7	23.0	2.00
Saddle River	8	29.0	2.10
Flat Brook	0	2.0	0.91
Lockwood	5	8.5	0.57
Beattystown	4	7.5	0.74
Bloomsbury	3	5.6	0.99
Riegelsville	2	5.3	1.00

VII. CONCLUSIONS

A. It was not possible to develop high flow - specific water quality criteria because concentrations of pollutants during high flow were generally equal to, or less than, concentrations observed during low flow. Based on this conclusion, a single set of criteria covering both low and high flows might be feasible – at least for some parameters. This does not mean that the level of effort required for mitigation of high versus low flow pollution sources is equal. If these findings hold true, the potential for pollutant trading between high and low flow sources would be implied, though not necessarily feasible, such as when water quality standards are exceeded under both high and low flow conditions.

B. The above conclusions are tempered by the fact that the data used in this study were not collected for high flow nonpoint source assessment. There is some doubt that peak pollutant concentrations and loads were sufficiently captured, as the number of samples grabbed at peak flow was relatively sparse. However, since high flow events are transient in comparison to low flow periods, peaking considerations may not be relevant.

C. Major differences between high flow and low flow water quality were observed to be a function of the degree of urban, suburban, and rural land uses. When the Saddle River is compared even to the Whippany River, the need for pollution abatement is clear. The level of impact observed at the Whippany and one or more Musconetcong locations may represent a threshold of acceptability.

D. Percent imperviousness, as an indicator of the degree of urbanization and as an indicator of potential aquatic life impairment, appears to have been verified by this study. Clearly, differences were seen between watersheds that had greater than 20 percent imperviousness and watersheds that had less than ten percent. Watersheds between ten and 20 percent imperviousness were not examined in this study.

E. Reducing the impact of stormwater and nonpoint pollutant sources by focusing directly on mitigation of impervious area impacts in a watershed, via applicable best management practices, might be the key to a successful watershed management effort.

F. The method used to estimate percent imperviousness allowed the study planners to calculate the Basin Development Factor while simultaneously making other important observations. The value of transversing an entire watershed, rather than conducting studies from maps and photos, was apparent. While possibly less precise than more sophisticated methods, the method employed was quick, with accuracy derived from actual observations of land use. A 30 square mile watershed (or watershed portion) can be covered in one day with a driver and recorder. Percent imperviousness was calculated in the office in two to four hours for the typical watershed.

G. The Delaware River at Montague and Flat Brook proved to be similar in water quality and excellent representatives of best-expected or reference water quality conditions. The level of water quality represented by these streams could be used as regional goals for both pollution abatement and non-degradation purposes in other watersheds in the non-coastal part of the state.

H. The water in high flow runoff may be more important than the extra pollutants carried by it. Field observations indicate that important sources of sediment and solids are in-stream sources: stream channel erosion, bed scouring, and the resuspension of sediment during high flow.

I. Although bacterial data were insufficient for low versus high-flow analyses, a link is known to exist between bacterial concentrations and total suspended solids in high flows. Since total suspended solids and fecal bacteria are the cited as the leading nonpoint source parameters causing stream impairment, it would be reasonable to believe that a good portion of the nonpoint source pollution problem is derived in-situ in the stream channel rather than from adjacent land uses.

J. Habitat structures built by fishing clubs (and others unknown) in the Musconetcong River appear to add to the erosion and sediment deposition problems seen in the river. These structures, V-shaped rock weirs pointing downstream, divert water toward the stream banks, thus causing bank erosion. Because of the lateral water diversion, a "dead" or very slowly flowing area is created directly below the point of the V. This dead spot creates an area of sediment deposition. This sediment is undoubtedly resuspended during high flows. Pointing the V upstream would eliminate both problems while providing the desired "scour hole" habitat for fish.

K. Observations from the lower reaches of the Musconetcong Watershed (Bloomsbury and Riegelsville) suggest that upper watershed changes may be causing downstream channel and habitat degradation. Problems from the upper portion of the watershed have been observed to first manifest themselves in the furthest downstream portion of the river, with further degradation progressing from downstream to upstream. Loss of trees at Riegelsville, the lack of a definitive thalweg and homogeneous habitat at Bloomsbury, and other negative indicators warrant investigation for this reason.

L. Chloride and nitrogen nonpoint source pollution is significant in the Musconetcong Watershed, and warrants further investigation. The former is possibly road salt derived and the latter may be agriculturally-derived.

M. Wolman pebble counts, bank angle measurements, Pfankuch channel stability index calculations, and other visual indicator records are recommended for routine monitoring. These methods provide information about the damages caused by the water and sediment components of high flow runoff.

N. The virtually identical water quality between the Delaware River and Flat Brook suggests that river size is not a variable in setting chemical water quality objectives. A large river could be a reference stream for a smaller one and vice versa.

O. While outside the purview of the study objectives, there is a general belief that both the Whippany and Saddle Rivers could be enhanced and/or restored through the use of natural channel design techniques (Rosgen, 1996) and other river and habitat restoration methods. This restoration would address sediment and other nonpoint source problems as well.

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