Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan

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EXECUTIVE SUMMARY

The Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan was compiled from various components of the overall program, integrating results from numerous reports. Information was obtained through historical references and in-field physical, chemical, biological, and visual watershed assessments.

Background

Since its inception in 2005, the Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan Program has produced several supporting documents which together provide a comprehensive assessment of the physical, chemical, and biological aspects of the streams, in addition to an overall assessment of municipal actions and policies that are currently in place to protect these water resources. The New Jersey Water Supply Authority (NJWSA), in cooperation with the Natural Resources Conservation Service (NRCS), developed the Plan with funding support through in-kind services and a 319(h) grant from the New Jersey Department of Environmental Protection.

The Lockatong and Wickecheoke creeks flow into the Delaware and Raritan Canal that supplies water to water purveyors that serve approximately 1.5 million people in central New Jersey. Since 1997, several of the purveyors reported increased concentrations of total suspended solids and total organic carbon in the raw water during and immediately following precipitation events. Since the combined area of these watersheds comprise approximately 60 percent of the total drainage to the Canal, downstream of the Delaware River inflow, these watersheds could be sources for large contributions of the contaminant loading.

The watershed assessments revealed the major water quality and quantity problem as stormwater runoff. Although there was only 2 percent impervious cover (2002 NJDEP Land-Use Land-Cover GIS data) from anthropogenic activities, the destabilization effects to the stream channel represented conditions of much greater imperviousness, possibly 15 percent, or more. Naturally occurring shallow soil depths atop bedrock, with only secondary porosity, produce short-duration runoff hydrographs stemming from limited water storage in the soils. The “flashy” runoff can impart greater scour velocities and flow levels with only minimal increases in impervious land covers. Limited water storage in shallow soils also reduces the potential for ground water recharge for use as a potable water supply and the source of stream baseflow.

Program Goal

The goal of this program is to focus efforts for the restoration and protection of the watersheds toward natural conditions, to the extent feasible, for protection of the water supply, threatened and endangered species, aquatic ecology, natural aesthetics, and to support the primary goal of the Lower Delaware Wild and Scenic Rivers Protection Plan: “Maintain existing water quality in the Delaware River and its tributaries from measurably degrading, and improve it where practical.”

Program Objectives

- Develop a watershed restoration and protection plan for both watersheds to address water quality issues such that the requirements of existing TMDLs can be met through plan implementation, incorporating the nine elements of a management plan (listed in **Appendix A**) as required by the US Environmental Protection Agency and the New Jersey Department of Environmental Protection.
- Protect the Delaware and Raritan Canal drinking water supply through reduction of sediment, nutrient, and bacterial pollution, and increase ground water recharge.
- Develop partnerships to facilitate the watershed restoration and protection plan.

Critical Issue

Visual, chemical, physical, and biological assessments of the watersheds have highlighted a critical need to reduce stormwater runoff and the associated pollutant loadings, whereby increasing ground water recharge and stream baseflow.

Critical Elements Identified For Watershed Restoration and Protection

The following list prioritizes primary sources of runoff flow and water quality contamination that were identified during the project. A rainfall event of 1.25 inches was used for the estimates.

Stormwater Runoff Flow:

1) Roadways (approximately 120,000 gallons/mile);
2) Active and inactive farms (semi-impervious conditions from fragipans and plow pans produces approximately 9,500 gallons/acre);
3) Private and public lawns, and athletic fields (semi-impervious conditions from soil compaction produces approximately 9,500 gallons/acre); and
4) Driveways and rooftops (approximately 80 gallons/100 ft^2).

Stormwater Runoff Contamination (Note: 0.0055 pound of TP load for each pound of TSS load in stream water and sediments, referencing NJWSA report):

1) Stream-channel erosion from increased flows (approximately 12,000 tons TSS/year, referencing NRCS report);
2) Roadways and roadside drainage (approximately 4,700 tons TSS/year, referencing NRCS report);
3) Agricultural fields (approximately 1,870 tons TSS/year, referencing NJSW BMP Manual)
4) Improper management of agricultural and domestic animal wastes (loads specific to animal type and site conditions);
5) Wildlife excrement (loads specific to type of animal and site conditions); and
6) All -terrain vehicles (ATV) (loads specific to activity level and site conditions).

Another critical element that was identified during the study was an imbalance in water use and water supply from ground-water wells. Increase of impervious land cover has increased runoff flow and erosion potential while decreasing aquifer recharge. Impervious cover, combined with increasing water uses from an expanding population and services, has continued to stress the limited ground water supply that also reduces surface water (i.e., wetlands, stream baseflow, ponds) during dry summertime conditions. Baseflows were measured in both streams during the project, showing loss or zero inflow from many sections of the watersheds, as presented in the monitoring report: ***Lockatong and Wickecheoke Creeks Water Quality and Flow Monitoring Project – 2006 through 2007*** (NJWSA, 2008).

Recommended Remediation Strategies

Five of the proposed remediation strategies have watershed-wide applications, and ten of the proposed projects are site-specific applications. More detail of these projects is presented in **Appendix B**. The major emphasis of the remediation strategies is to retain stormwater runoff and loadings by retrofits of roadside and driveway drainage; subsoiling active agricultural fields, together with microtopographic modifications to inactive farm fields; initiating or enhancing education for students, homeowners, businesses, and farmers regarding fertilizers, proper management techniques for runoff and pollutant control, and protection of the stream corridor. Effective watershed protection requires expedient implementation of the recommendations, with inter-municipal coordination and long-term commitments from each municipality. Watershed-wide strategies should readily produce enhancements to the flow regime and water quality throughout the watersheds. Site-specific strategies should provide localized remediation for sources of stormwater runoff and the associated contaminants, although universal application and management of these techniques would provide a more effective program.

The following illustrates possible remediation techniques for major sources of contamination and stream-channel destabilization.

1. Increased impervious, or semi-impervious surfaces from roadways, driveways, roofs, swimming pools, lawns (compaction from mowing and uses), recreational open spaces, parking lots, and agricultural fields (compaction from plowing, plow-pan, and fragipans).

    - Remediation:

        i. Require a selected frequency for subsoiling and simultaneous blending of organic material on active crop-farming fields, and initial subsoiling and microtopographic modifications to inactive farm fields, prior to any preservation activities;

        ii. Emphasize, through public education (flyers, Community-Day displays and brochures, and supplements to school curriculums and programs) optional techniques for retaining stormwater on both private and public lawn areas; and

        iii. Initiate a well-testing ordinance to ensure an adequate water supply from new and expanding water uses (see sample ordinance in ***An Assessment of Municipal Plans, Policies and Regulations***

Effecting Water Quality in the Lockatong and Wickecheoke Watersheds, NJWSA, 2008).

2. Directing stormwater from lawns and agricultural fields directly into stream channels or roadside drainage ravines.

    - Remediation:

        i. Disconnect stormwater conveyance paths and retain major portions of runoff volume on private and public lawns using rain barrels (where applicable), rain gardens, curb-cuts or elimination of driveway curbs, bioretention systems, and pervious subsurface storage. Include this information as part of a Municipal Stormwater Management Plan; and

        ii. Education, via a targeted agricultural assistance program by the Hunterdon County SCD (Integrated Crop Management Services) coordinated with specific conservation options for stream corridor and stormwater controls by the NJRC&DC River-Friendly Farms program.

3. Roadside drainage-channel destabilization and associated erosion from inadequate designs and maintenance techniques.

    - Remediation:

        i. Provide annual, or biannual, training for DPW Managers and municipal road crews, including the training time as part of the required DPW continuing education units; and

        ii. Emphasize options for the design and maintenance of roadway drainage for retaining stormwater runoff volume and minimizing shear velocity. Minimize annual drainage ditch maintenance-dredging, incorporating this practice only when necessary.

4. Natural surface and ground water interconnectivity in fractured bedrock, providing inflows and outflows along the stream channel and at dispersed sites throughout the watersheds, enhancing the potential for inter-transfer of pollutants and simultaneous flow losses between the water systems.

    - Remediation:

        i. Develop a hydrogeologic map of dry- and wet-season aquifer levels and flow paths, identifying local recharge areas and potential contamination sources; and

        ii. Install continuous water-level monitors to develop an existing reference condition for determining long-term variations to aquifer level and supply, to ensure a continued supply for potable and aquatic-ecology functions, to provide scientific information for planning and zoning functions, and as an indicator of drought conditions for initiating water conservation measures.

5. Stream contamination emanating from stormwater runoff of development sites and other major land-disturbance activities.

    - Remediation:

        i. Development of site-specific water quality and flow targets, at designated sites along the stream, to determine "existing" water quality and "measureable change" in support of the antidegradation rules for C1 streams. A method similar to the flow-integrated technique known as FIRE (Flow-Integrated Reduction of Exceedences) that NJDEP has developed to determine reductions of total phosphorus for TMDLs could be implemented. More information on this technique is presented in the "Applicable Antidegradation Criteria" section of the ***Lockatong and Wickecheoke Creek Water quality and Flow Monitoring Project 2006 through 2007*** report (NJWSA, 2008). Applications for projects with large volumes/areas of land disturbance must provide scientific evidence that water quality at the closest downstream target site will not be measureably degraded;

        ii. Require, through amendments to the NJ Department of Agriculture's Sediment and Erosion Control Act and/or municipal policy, a shorter duration and smaller area of soil disturbance during any land moving activity;

        iii. Require filter bags for pumped seepage-water during bridge construction to remove sediment prior to discharge of this water into the stream; and

        iv. Promote land-preservation with assistance from land-acquisition organizations such as New Jersey Green Acres, Hunterdon Land Trust Alliance, New Jersey Conservation Foundation, and the New Jersey Water Supply Authority.

6. Permitted discharges with inconsistent compliance

    - Remediation:

        i. Invite representatives of discharger(s) to present quarterly updates of compliance at Township meetings; and

        ii. Notification of regulatory authorities, if necessary.

7. Intense channel and streambank erosion from an increased flow regime, deer trails and grazing, ATV traffic, and direct egress to the channel by livestock.

    - Remediation:

        i. Streambank-stabilization through revegetation of the riparian zone, where necessary, combined with the runoff retention techniques previously described. Nearly all of the stream segments that were identified for revegetation in the ***Lockatong Creek Stream Visual Assessment Results and Restoration Plan*** and the ***Wickecheoke Creek Stream Visual Assessment Results and Restoration Plan*** are located on private property, requiring authorization for entry from the landowner(s). This remediation should be implemented after reductions in stormwater runoff flow have been achieved to ensure long-term channel stability;

        ii. Deer deterrents include fencing, planting deer-resistant vegetation, commercial deer repellents, increased harvesting, and regulatory management (i.e., no feeding, harvesting incentives, etc.). Dogs, bordered by "invisible fence" technology, are a proven deterrent. For agricultural facilities, EQIP and other Farm Bill assistance programs could be sources of funding;

        iii. Restricting ATV traffic from riparian areas could include signage along known ATV trails, municipal ordinance, education of ATV operators through required training for license/certification, and/or the formation of local patrols with enforcement contact information for residents wanting to report incidents; and

        iv. Restricting livestock access to the stream channel by fencing and vegetation; and providing other means of animal drinking water. EQIP and other Farm Bill assistance programs could be funding sources.

8. Over-application of lawn and crop fertilizers and pesticides, unmanaged livestock and domestic animal wastes, and malfunctioning or failed septic systems.

    - Remediation:

        i. Initiate an Integrated Crop Management (ICM) Services program for agricultural operations, and promote certification as a River-Friendly Farm. Both of these options are detailed in **Appendix B**; and

        ii. Distribute educational materials and request presentations from Rutger University's Cooperative Extension Service, Hunterdon County Health Department, and the South Branch Watershed Association (Raritan River), regarding proper lawn care, pet waste management, and septic-system care. Rutgers and the HCSCD can be contacted to test soils for available nutrients and to provide information on pesticides. The latest Wastewater Management Rules should be utilized for adopting a septic-system management ordinance/utility (see sample ordinance in ***An Assessment of Municipal Plans, Policies and Regulations Effecting Water Quality in the Lockatong and Wickecheoke Watersheds***, NJWSA, 2008).

9. Narrowing or elimination of natural vegetative buffers along riparian corridors.

    - Remediation:

        A riparian corridor-protection and/or wildlife-feeding restriction ordinance(s) could be adopted (see sample ordinances in ***An Assessment of Municipal Plans, Policies and Regulations Effecting Water Quality in the Lockatong and Wickecheoke Watersheds***, NJWSA, 2008). Fencing is an option to ban wildlife and livestock egress in agricultural or larger residential areas. NJDEP could present information on an annual basis to municipal officials and residents.

10. Abundance of geese inhabiting waterways.

    - Remediation:

        i. Maintaining vegetative buffers around ponds and lakes could be required as part of a riparian corridor-protection ordinance. A municipal ordinance for restricting wildlife feeding could be adopted (see sample ordinance in ***An Assessment of Municipal Plans, Policies and Regulations Effecting Water Quality in the Lockatong and Wickecheoke Watersheds***, NJWSA, 2008). Dogs, bordered by physical or "invisible fence" technology, are a proven deterrent; and

        ii. Addling eggs could be an alternative, with assistance from the NJ Division of Fish, Game, and Wildlife. Scare tactics, using sounds, dogs, or other physical options would also be an alternative.

Implementation of remediation projects, prioritized as above, would fulfill TMDL load-reduction requirements for total phosphorus and coliform bacteria, while reducing stormwater runoff flow and increasing infiltration for ground water recharge and stream baseflow. Sediment and bacteria loadings should be reduced proportionately with the total phosphorus load reduction and the reduction to stormwater runoff. See **Appendix B** for more detailed information on remediation strategies. **Table 1** summarizes the proposed remediation projects and their estimated cost.

Table 1. Proposed stormwater remediation projects.

Project	Project Location	Estimated Cost
Preservation/Conservation-Land Stormwater Control	Initially – Delaware and Kingwood Townships	$564,000
Agricultural Runoff Remediation	Franklin Township	$991,000 - $1,231,000
Roadside Drainage Design/Retrofit Training	Delaware, Kingwood, Raritan, and Franklin Townships	$47,000
Road-Drainage Retrofit, Section of Pine Hill Road	Delaware Township	$1,274,000
Road-Drainage Retrofit, Section of Route 579	Franklin Township	$101,000
Road-Drainage Retrofit, Section of Goose Island Road	Raritan Township	$118,000
Road-Drainage Retrofit, Barbertown-Point Breeze Road	Kingwood Township	$72,000
Targeted Agricultural Assistance Program	Delaware, Kingwood, Raritan, and Franklin Townships	$226,000
Update Stormwater BMP Manual For Soils and Bedrock Conditions in Hunterdon County	Delaware, Kingwood, Raritan, and Franklin Townships	$33,000
Hydrogeologic Study of Copper, Lockatong, and Wickecheoke Watersheds	Delaware, Kingwood, Raritan, and Franklin Townships	$168,000
River-Friendly Farms Certification Program	Delaware, Kingwood, Raritan, and Franklin Townships	$74,000
Bioretention Applications – Recreational Areas and Private/Public Lawns	Initially - Kingwood Township	$164,000 – $298,000
Delaware Township Municipal-Garage Retrofit	Delaware Township	$265,000
Vehicle Maintenance and Storage Facility Retrofit	Delaware Township	$112,000
Sergeantsville Firehouse Parking-Lot and Municipal Park Retrofits	Delaware Township	$117,000

Continuing Efforts

Program partners, including Delaware, Kingwood, Franklin, and Raritan Townships; NJWSA; NRCS; USGS; Hunterdon County Health Department and SCD; NJDEP; NJCF; D&R Canal Commission; NJRC&DC; and residents and businesses in the watersheds continue to prioritize remediation projects for the next round of 319(h) funding from the NJDEP. Following acceptance by NJDEP of the Restoration and Protection Plan, current and future proposals for remediation projects should have enhanced opportunity for funding. It is anticipated that fiscal year 2010 or 2011 will provide the first opportunity for submitting implementation-project proposals. The list of Proposed Implementation Projects in Appendix B is not intended as a comprehensive list of projects, but rather an evolving list, based on available information and municipal priorities. Additional projects are anticipated to be proposed as more information, and non-public site accessibility, becomes available.

INTRODUCTION

The Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan is intended to be used to guide municipal and inter-governmental efforts to ensure long-term protection of these watersheds that provide source water, via the Delaware and Raritan Canal System, for the water supply of approximately 1.5 million New Jersey residents. The watersheds are situated in Hunterdon County, New Jersey and provide approximately 60 percent of the direct drainage to the Delaware and Raritan Canal, downstream of the intake from the Delaware River. The Canal conveys water to purveyors: NJ American (Elizabethtown) Water Company, Middlesex Water Company, the Townships of East Brunswick and North Brunswick, and the City of New Brunswick. The raw water is treated for potable water uses. Since 1997, several of the purveyors reported increased concentrations of total suspended solids and total organic carbon in the raw water during, and immediately following, precipitation events. The solids and carbon require increased chemical doses for treatment that increases the residual sludge to be removed, subsequently increasing the cost of water treatment. Debris (wood and other floatables) removal from the Canal, downstream of the Lockatong and Wickecheoke Creek confluences, occurs several times each year (Buss and Shepherd, 2007). Combined average annual volumes of sediment removal at the Wickecheoke inflow and the Prallsville Lock, from October 1998 through July 2007 (Shepherd, 2007), were approximately 750 cubic yards, or 1,013 tons (1.35 tons per cubic yard, NRCS, 2007). Cost of this work was roughly estimated at more than $200,000 per year (NRCS, 2007). A study in 1987 by EBASCO Services Incorporated estimated annual costs for sediment dredging in the Canal from the Delaware River inlet at Bulls Island to the "Navagation" Canal at Trenton. Including equipment, labor, materials, stockpiling, and administrative costs, the estimated total annual cost was $317,050. The study estimated an average sediment load of 5,226 tons from 26 small tributaries, and 3,300 and 3,600 tons from Lockatong and Wickecheoke Creeks, respectively.

Municipalities within these watersheds are Kingwood, Franklin, Delaware, and Raritan Townships, three of which are listed as Tier B, with Raritan Township listed as Tier A for the NJPDES Municipal Stormwater Regulation Program. The New Jersey State Development and Redevelopment Plan classifies all of the municipal lands within the watersheds as "Areas for Conservation," either Planning Area 4B (Rural Planning Area) or 5 (Environmentally Sensitive Planning Area). **Figure 1** is a map of the project area.

This effort was partially funded by a New Jersey Department of Environmental Protection (NJDEP) 319(h) grant (contract RP05-082); and supplemented by funding and in-kind services of the New Jersey Water Supply Authority (NJWSA); and through contractual and in-kind services of the Natural Resources Conservation Service (NRCS), US Department of Agriculture.

Figure 1. Study area - monitoring sites and sub-watershed areas. See **Table 2** for site descriptions.

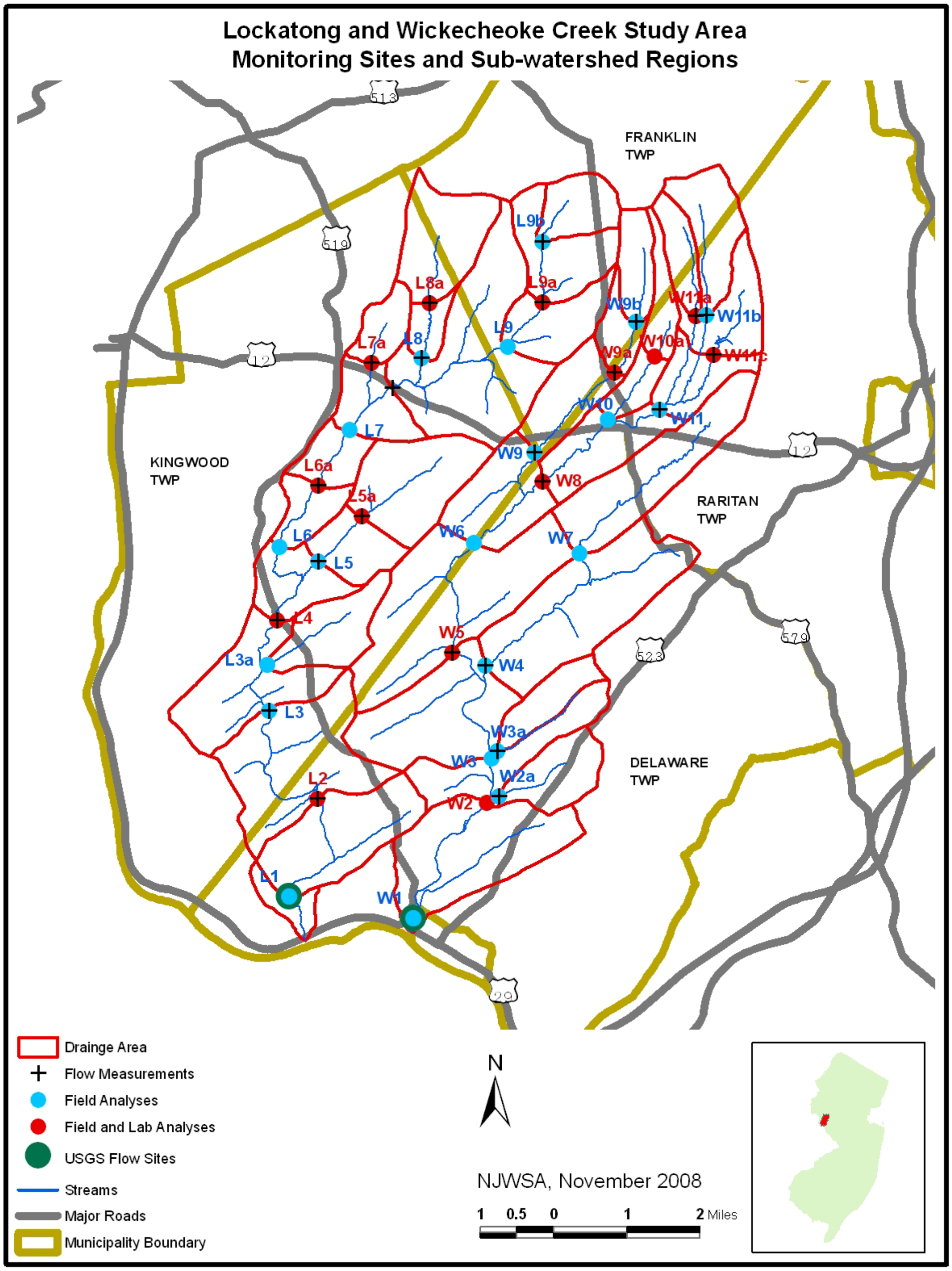


Table 2. Descriptions of monitoring sites.

Lockatong Creek Site Code	Location Description	Wickecheoke Creek Site Code	Location Description
L1	Mainstem at Raven Rock-Rosemont Road bridge	**W1**	Mainstem at State Route 29 bridge
L2	Mainstem at Strimples Mill Road bridge	**W2**	Mainstem, approximately 2/3 mile downstream of W3 (covered bridge), 200 feet downstream of W2a (Rose Brook)
L3	Mainstem at Milltown Road bridge	**W2a**	Rose Brook tributary at Lower Creek Road culvert
L3a	Tributary, at Brook Road bridge	**W3**	Mainstem at Rosemont-Sergeantsville Road bridge (covered bridge)
L4	Mainstem at County Route 519 bridge	**W3a**	Cold Run tributary at Pine Hill Road culvert
L5	Muddy Run tributary at Muddy Run Road bridge	**W4**	Plum Brook tributary at Pine Hill Road bridge
L5F	Muddy Run tributary at Barbertown-Point Breeze Road bridge	**W5**	Mainstem at Old Mill Road bridge
L5a	Muddy Run tributary at Union Road bridge	**W6**	Mainstem at Locktown Road bridge
L6	Mainstem at Barbertown-Point Breeze Road bridge	**W7**	Plum Brook tributary at Locktown-Flemington Road culvert
L6a	Mainstem at Thatcher Road bridge	**W8**	Mainstem at Whiskey Lane bridge
L7	Mainstem at Union Road bridge	**W9**	Tributary at Whiskey Lane bridge
Rt 12	Mainstem at County Route 12 bridge	**W9a**	Tributary at Goose Island Road culvert
L7a	Tributary at Lower Oak Grove Road culvert	**W9b**	Tributary at Oak Grove Road culvert
L8	Tributary at Lower Oak Grove Road culvert	**W10**	Tributary at Old Croton Road culvert
L8a	Tributary at Oak Grove Road culvert	**W10a**	Tributary at Goose Island Road culvert
L9	Tributary at Pittstown Road culvert, south channel	**W11**	Mainstem at Rake Road bridge
L9a	Tributary at Oak Grove Road culvert	**W11a**	Tributary at Oak Grove Road culvert
L9b	Tributary at Old Franklin School Road culvert	**W11b**	Tributary at Oak Grove Road culvert
		W11c	Tributary at Decker Road culvert

All program segments and reports were reviewed by the Project Committee members (listed in the Acknowledgements section). In addition to the Management Plan, several support projects were performed concurrently and the following reports are the products of those efforts:

- Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan – Watershed-Based Implementation Projects (with proposed implementation projects)
- 319(h) Grant Proposal: Watershed Restoration and Protection Plan for the Lockatong and Wickecheoke Creek Watersheds
- Lockatong and Wickecheoke Creeks Water Quality and Flow Monitoring Project – 2006 through 2007;
    - Work/Quality Assurance Project Plan, Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Project;
    - Lockatong Creek Stream Visual Assessment Results and Restoration Plan;
    - Wickecheoke Creek Stream Visual Assessment Results and Restoration Plan;
- Characterization and Assessment of the Lockatong and Wickecheoke Creek Watersheds;
- An Assessment of Municipal Plans, Policies and Regulations Effecting Water Quality in the Lockatong and Wickecheoke Watersheds; and
- A Non-Point Source Pollutant Loading Build-Out Analysis in the Lockatong and Wickecheoke Creek Watersheds
- NRCS Report – Lockatong and Wickecheoke Creek Watersheds Sediment and Phosphorus Source Report.

This report integrates the results and recommendations from all of the supplemental projects, in addition to supporting stream channel and water quality protection goals from the Lower Delaware Management Plan (http://www.nps.gov/phso/sp/p07new3.htm), to provide implementation strategies for long-term protection of the water quality and quantity in the Lockatong and Wickecheoke Creek watersheds. Critical issues, regarding sources/effects of water quality and flow-regime degradation are presented in the "Critical Elements Identified For Watershed Restoration and Protection" section of the Executive Summary. A flow-chart illustrating the "Interrelationships of Watershed Reports" and digital copies of all reports (on CD) are included in **Appendix F**.

Sources and Effects of Water Quality and Quantity Changes

The following source/effect relationships were determined to be the most critical for restoring and protecting stream flow and water quality.

Sources of Increased Runoff Flow and Elevated Loads of Sediment and Nutrients include:

- Increasing impervious surfaces, and semi-impervious surfaces, (i.e., roadways, driveways, roofs, swimming pools, lawns, recreational fields, parking lots, etc) with direct flow connections to the waterways (greatly reduces ground water recharge);
- Directing stormwater from private and public lawns, athletic fields, and impervious surfaces directly to stream channels or to roadside drainage ravines;

- Creation of stormwater erosion from deer trails and grazing, and from all-terrain vehicle (ATV) traffic into and through stream channels;
- Over-application of lawn and crop fertilizers;
- Improper disposal/management of wastes from livestock and domestic animals;
- Malfunctioning septic systems;
- Over-abundance of geese on constructed and natural ponds;
- Narrowing, or elimination of natural vegetative buffers along stream channels; and
- Land-disturbance and development activities stripping large areas of vegetation for prolonged time periods, conveying sediment, nutrients, and other contaminants into adjacent waterways.

Effects of Increased Runoff Flow and Pollutant Loads include:

- Increased upland and in-stream erosion potential;
- Stream-channel destabilization;
- Wider and shallower stream channels, susceptible to increased water temperature from exposure to the sun;
- Nutrient-enrichment supporting abundant growth of aquatic plants, causing extreme variability in daily pH and dissolved oxygen levels;
- Loss of ground water recharge, decreasing water supply, stream baseflows, and wetland, pond, and lake levels;
- Loss of habitat for both aquatic and terrestrial organisms, including threatened and endangered species, and trout;
- Turbid (cloudy) water;
- Elevated levels of bacteria and pathogens; and
- Ultimate loss of potable water supply (quantity and quality).

WATERSHED CHARACTERISTICS

Both watersheds have been classified as Category One (C1) streams. These waters receive a higher form of state protection for water quality that prohibits any measurable change in the existing water quality. The draft 2004 Integrated Listings, which is a summary of water quality levels exceeding the Surface Water Quality Standards in stream segments throughout the state, show violations of total phosphorus, fecal coliform bacteria, and water temperature for the Lockatong and Wickecheoke Creeks. Macroinvertebrates, or the combination of aquatic insects, worms, mollusks, and crustaceans, were also listed as degraded at a site in the Wickecheoke Creek. During May and July 2005, the New Jersey Department of Environmental Protection (NJDEP) developed a TMDL for fecal coliform for the Wickecheoke watershed, and a total phosphorus TMDL for each watershed, respectively. Both TMDLs were approved by the Environmental Protection Agency (EPA) in September 2005.

The drainage areas of the Lockatong and Wickecheoke Watersheds are 23.3 and 26.6 square miles, respectively. Watershed areas are defined by the US Geological Survey

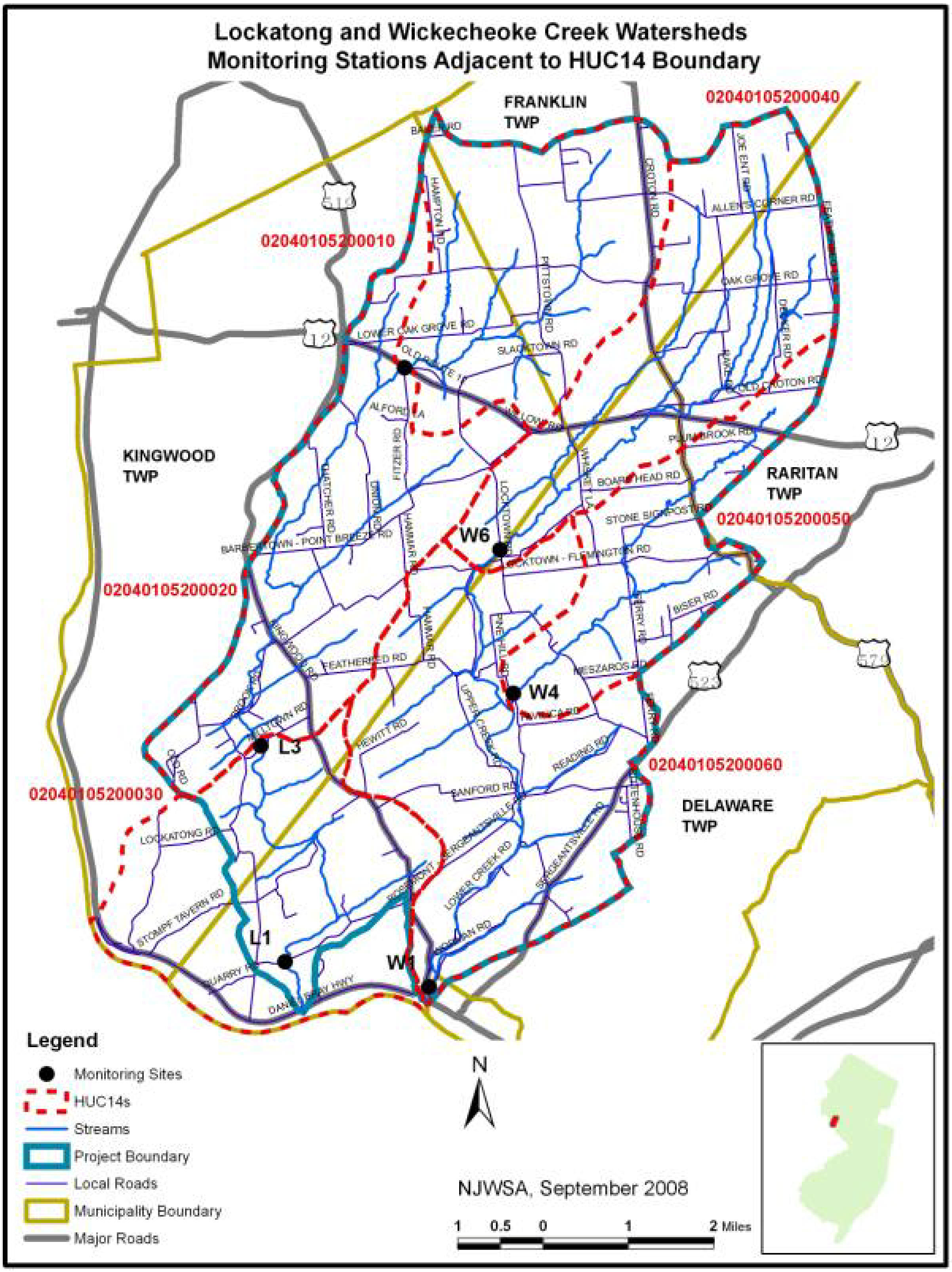
(USGS), using a numerical coding known as a Hydrologic Unit Code (HUC). The watershed sizes become smaller as the number of digits in the HUC code becomes larger. The Lockatong and Wickecheoke watersheds are each composed of three HUC14 (14 digit) drainage areas: 02040105200010 (above Rt 12), 02040105200020 (Milltown to Rt 12), and 02040105200030 (below Milltown, includes Upper Delaware River) for the Lockatong; and 02040105200040 (above Locktown), 02040105200050 (Plum Brook), and 02040105200060 (below Locktown) for the Wickecheoke. Areas of each HUC 14 are illustrated in **Figure 2**. The actual drainage area of two of the watersheds differs from the HUC 14s since some of the area within the HUC 14s, near the mouth of the streams, includes drainage outside of these watersheds.

The Lockatong and Wickecheoke Creek Watersheds are characterized by a mostly rural landscape, consisting primarily of agriculture, forest, and wetlands. Much of the soil is classified as either hydric or as having a seasonal high water table within two feet of the land surface. Except for two sections of the Wickecheoke watershed (Village of Rosemont and a small portion of Delaware Township), the potable water supply is obtained from private on-site wells. Sewage is treated on-site, via septic systems, except for the same small section of Delaware Township that is serviced by a public well is also serviced by the Delaware Township Municipal Utility Authority wastewater treatment facility. This facility discharges to Rose Brook, a tributary to Wickecheoke Creek. According to the TMDL for total phosphorus, the permitted discharge was 0.065 MGD (million gallons per day), or approximately 0.1 cfs (cubic feet per second), with an average monthly total phosphorus limit of 1.0 mg/l (milligrams per liter, also referred to as parts per million).

Shallow bedrock, having only secondary porosity (fractures), overlain with thin soil depths, and seasonal high ground water levels creates problems throughout these watersheds for locating suitable sites for septic systems, particularly in the lower two-thirds of each watershed. The size, spacing, and orientation of water-bearing fractures within the aquifer presents water supply problems to many well users during the summertime and early fall when recharge is minimal, or non-existent, and water use is maximized. Although fractures near the land surface can provide recharge to the aquifer, they can also provide a fast conveyance for surface and septic contaminants to enter nearby well-water supplies. Much of the Lockatong and Wickecheoke hydrogeography is oriented with the northwest to southeast bedrock strike direction, possibly along fractures. More information on the watershed characteristics is available in the ***Characterization and Assessment of the Lockatong and Wickecheoke Creek Watersheds*** report (NJ Water Supply Authority, 2007).

Although forests and wetlands make up almost 50 percent of the land use, agricultural and residential land uses cover nearly the same acreage and can contribute large volumes of stormwater flow containing loadings of nutrients, solids, and bacteria at levels exceeding the surface water quality standards. These loads can adversely affect human, aquatic organism, and livestock health, and increase the level of treatment required for potable water suppliers downstream of the contaminant source(s). **Tables 3 and 4** list the sub-watershed areas and the percentage of land uses in each for the Lockatong and Wickecheoke watersheds, respectively.

Figure 2. HUC 14 sub-watersheds in the study area.



Data quantifying historical and existing water quality, flow, and aquatic habitat conditions within these waterways were very limited, or non-existent, at most locations. To further quantify and isolate potential sources of water quality degradation, an intensive water quality and flow-monitoring project was conducted from 2006 to 2007. More information on the monitoring project is available in the report: ***Lockatong and Wickecheoke Creek Water Quality and Flow Monitoring Project – 2006 Through 2007*** (NJ Water Supply Authority, 2008). Two Total Maximum Daily Load (TMDL) reports, developed by the New Jersey Department of Environmental Protection (NJDEP), for fecal coliform and total phosphorus, were also supported by the monitoring efforts of this project.

EXISTING WATERSHED CONDITIONS

Causes and Sources of Contamination

As determined from the NJDEP 2002 land use and land cover information, the Lockatong and Wickecheoke Creek watersheds land uses are primarily agricultural (38 and 40 percent, respectively), forested (28 and 32 percent, respectively), and wetlands (both watersheds at 18 percent). Approximately 12 percent of the Lockatong and 11 percent of the Wickecheoke watersheds are urban land uses: residential, commercial, industrial, transportation, and communication (Anderson, et al, 1976). Alone, or combined the following land uses and activities can cause large increases in stormwater runoff and contaminant loadings to the streams.

Agricultural Crop Operations

The Natural Resources Conservation Service (NRCS) studied the types of farming activities on 20 percent of the farms in the watersheds (NRCS 2007). They estimated that up to 2,032 tons of sediment is reaching the Delaware and Raritan Canal each year from crop production in the Lockatong watershed, and up to 462 tons per year in the Wickecheoke watershed. Some of the crop farms have installed waterways, terraces, and diversions to control runoff. For crop farms within 300 feet of the streams there are 142 farms covering 26 acres of fields with stormwater controls in the headwaters (upper HUC 14), and 32 farms covering 224 acres of fields with stormwater controls in the lower watershed sections (lower HUC 14), for the Lockatong and Wickecheoke watersheds respectively. This represents stormwater controls on approximately 3 percent (6,041 acres total) of the farms in the Lockatong watershed and 4 percent (6,410 acres total) of the farms in the Wickecheoke watershed. No stormwater controls were present on farms within the mid HUC 14 areas. Nearly 44 percent of the agricultural fields were within 250 feet of the stream channels. Twenty-five percent of the fields were within 50 feet of the stream channels.

Stormwater drainage from non-erosive agricultural and athletic fields can accumulate along the perimeter of the subject area and can quickly change from sheet flow (laminar) to concentrated channelized flow (turbulent). **Photos 1 and 2** show the onset and possible result of this unmanaged flow condition at an agricultural site in Delaware Township.

Livestock

There has been more than a 50 percent reduction in the numbers of beef cattle, dairy, sheep, and swine animals in the watershed municipalities from1983 thru 2004. Numbers of equine have remained steady. Due to the reduction in numbers of animals, this source of erosion and nutrient production was not considered to be a priority unless the animals have direct access to the stream where excrement and activity would severely degrade the aquatic habitat and water quality. **Photos 3 and 4** show cattle and sheep access on a tributary to the Wickecheoke Creek and a tributary to the Lockatong Creek, respectively.

Geese and Deer

The NRCS has specified that much of the watersheds are unattractive to geese since the majority of the land use is agricultural, forest, or urban. Some of the cropland, wetlands, and waterways would provide suitable habitat, but it is difficult to determine the contribution of phosphorus, and other constituents to the streams without additional investigations on the size and locations of the geese populations. Field observations determined that two sites were frequented by geese, one in each watershed.

The estimated deer population is 50 animals per square mile, or an approximate total of 2,500 animals in the two watersheds. Spread over 32,000 acres, or about 1 deer per 13 acres, this density should not pose a significant contribution to the nutrient load.

Site observations have consistently indicated the continuous loss of understory vegetation from deer grazing. Consequently, the loss of vegetation combined with the creation of a network of deer paths causes the formation of stormwater runoff channels that readily convey eroded soil and additional flow to the receiving streams, severely reducing the buffer capacity of the wooded areas.

Table 3. Lockatong Creek – Sub-Watershed Size and Land Use (using 2002 State Land Use/Land Cover data).

Lockatong Watershed Sites[1]	Total Drainage Area (Mile²)	Sub-Watershed Area (Acre)	Acreage/Percent of 2002 Land Use Types Per Sub-Watershed											
			Agricultural		Barren Land		Forest		Urban		Water		Wetlands	
			Acre	%	Acre	%	Acre	%	Acre	%	Acre	%	Acre	%
L0[2]	23.3	231.3	81.5	35.25	2.1	0.89	105.5	45.61	31.9	13.81	5.6	2.42	4.7	34.40
L1	22.9	1,310.5	450.8	34.40	-----	-----	600.6	45.83	161.8	12.34	16.7	1.28	80.6	6.15
L2	20.9	1,822.2	473.7	25.99	-----	-----	1,056.7	57.99	153.4	8.42	15.4	0.85	123.1	6.76
L3	18.0	1,249.3	360.6	28.87	1.3	0.10	476.7	38.15	162.7	13.02	13.8	1.10	234.2	18.75
L3a	1.2	733.4	206.8	28.19	-----	-----	209.3	28.54	79.1	10.79	-----	-----	238.2	32.48
L4	14.9	601.4	212.6	35.36	1.3	0.22	91.7	15.25	101.2	16.83	11.5	1.92	183.0	30.42
L5	2.7	544.4	201.8	37.07	3.0	0.55	87.2	16.02	63.4	11.64	-----	-----	189.0	34.71
L5F	2.2	241.4	83.4	34.55	-----	-----	33.4	13.82	18.7	7.76	-----	-----	105.9	43.88
L5a	1.9	1,191.4	472.0	39.62	2.6	0.22	212.2	17.81	140.5	11.79	-----	-----	364.1	30.56
L6	11.3	406.3	152.5	37.53	24.2	5.95	90.0	22.14	44.6	10.98	7.0	1.72	88.1	21.68
L6a	10.6	409.7	129.3	31.56	-----	-----	58.8	14.36	53.1	12.96	4.5	1.09	164.0	40.04
L7	10.0	574.8	188.0	32.71	-----	-----	98.7	17.18	110.0	19.14	3.8	0.66	174.3	30.32
Rt 12	8.5	2,232.3	1,201.3	53.81	9.4	0.42	375.4	16.82	240.6	10.78	10.2	0.46	395.3	17.71
L7a	0.6	371.8	160.3	43.10	-----	-----	103.3	27.78	39.8	10.69	1.2	0.33	67.3	18.10
L8	1.9	245.2	114.5	46.72	-----	-----	45.0	18.35	63.5	25.88	2.0	0.82	20.2	8.22
L8a	1.6	991.8	564.7	56.94	-----	-----	187.6	18.92	108.8	10.97	2.4	0.24	128.4	12.94
L9	3.1	685.7	270.1	39.39	-----	-----	264.8	38.62	58.2	8.48	2.1	0.31	90.5	13.20
L9a	2.2	793.6	449.0	56.57	-----	-----	129.4	16.31	123.9	15.61	-----	-----	91.4	11.52
L9b	0.8	502.4	351.2	69.90	-----	-----	40.3	8.01	88.2	17.56	1.8	0.35	21.0	4.19

[1] See **Table 2** for descriptions of the monitoring sites.
[2] Mouth of Lockatong Creek.

Table 4. Wickecheoke Creek – Sub-Watershed Size and Land Use using 2002 State Land Use/Land Cover data.

Wickecheoke Watershed Sites[1]	Total Drainage Area (Mile^2)	Sub-Watershed Area (Acre)	Acreage/Percent of 2002 Land Use Types Per Sub-Watershed											
			Agricultural		Barren Land		Forest		Urban		Water		Wetlands	
			Acre	%	Acre	%	Acre	%	Acre	%	Acre	%	Acre	%
W0[2]	26.62	22.8	-----	-----	-----	-----	14.4	63.31	6.4	28.25	1.9	8.43	0.003	0.01
W1	26.58	1,695.9	972.0	57.32	-----	-----	456.8	26.93	206.0	12.15	18.9	1.11	42.2	2.49
W2	23.9	808.4	529.7	65.52	-----	-----	147.2	18.21	87.5	10.82	5.5	0.68	38.6	4.77
W2a	1.0	638.1	371.2	58.17	-----	-----	86.4	13.53	159.5	25.00	-----	-----	21.0	3.29
W3	21.7	1,548.4	570.6	36.85	4.5	0.29	667.4	43.10	164.4	10.62	18.1	1.17	123.5	7.97
W3a	0.7	455.8	196.5	43.11	-----	-----	183.7	40.30	57.7	12.66	-----	-----	17.9	3.93
W4	5.3	1,996.1	580.1	29.06	0.3	0.01	857.0	42.93	284.0	14.23	7.0	0.35	267.7	13.41
W5	15.4	2,411.5	725.5	30.08	4.6	0.19	971.9	40.30	187.3	7.77	12.5	0.52	509.7	21.13
W6	11.7	936.5	285.9	30.53	5.1	0.54	205.6	21.95	92.1	9.84	15.0	1.60	332.8	35.53
W7	2.2	1,384.9	348.8	25.19	2.6	0.19	572.8	41.36	171.5	12.39	-----	-----	289.0	20.87
W8	5.8	782.2	193.8	24.78	-----	-----	238.4	30.47	91.5	11.69	12.1	1.55	246.4	31.50
W9	2.2	688.6	187.1	27.16	-----	-----	201.9	29.32	64.5	9.36	1.4	0.21	233.8	33.95
W9a	1.2	318.8	146.6	45.99	-----	-----	48.2	15.14	30.9	9.68	-----	-----	93.1	29.20
W9b	0.7	422.2	161.0	38.14	-----	-----	162.6	38.51	48.5	11.48	-----	-----	50.1	11.87
W10	1.0	285.4	98.2	34.42	-----	-----	75.7	26.53	18.7	6.54	0.7	0.25	92.0	32.25
W10a	0.6	353.6	181.4	51.30	-----	-----	85.5	24.19	48.8	13.80	-----	-----	37.9	10.71
W11	3.6	529.2	119.4	22.56	2.9	0.54	121.4	22.93	51.2	9.67	0.5	0.09	233.9	44.20
W11a	0.6	385.6	158.7	41.17	-----	-----	102.9	26.69	38.6	10.02	-----	-----	85.3	22.12
W11b	1.1	729.5	427.7	58.63	0.3	0.04	150.6	20.65	64.6	8.86	0.9	0.12	85.4	11.71
W11c	1.0	640.8	156.0	24.35	9.1	1.42	155.5	24.27	69.8	10.89	0.9	0.15	249.4	38.92

[1] See **Table 2** for descriptions of the monitoring sites.
[2] Mouth of Wickecheoke Creek.

Photo 1. Perimeter erosion from concentrating field drainage.

Photo 2. Effect of accumulated field runoff on a drainage channel.

Photo 3. Livestock egress to tributary of Wickecheoke Creek.

Photo 4. Sheep egress to tributary of Lockatong Creek.

All Terrain Vehicle Impacts On the Stream Corridor

In the past 5 years All Terrain Vehicles (ATV) have become increasingly popular as a recreational item. Although recreation is the primary use, they have also become detriments to the stream banks and channels. Trails along, into, and through the stream channels has created a large increase in sediments and related nutrients to the water quality. Trees and other vegetation, that filter and store stormwater, are removed to construct new paths. Trails leading to the stream become runoff channels for stormwater flow, increasing erosion. **Photos 5 thru 8** show some of the indications that ATV activity has begun to substantially degrade the aquatic habitat and water quality. These photos were taken at locations within 200 feet of the Union Road bridge at Kingwood Park. Walking paths in public parks are becoming access roads to sections of the streams. More than 45 tons of sediment per year is likely from erosion that has been observed at accessible locations.

Roadway Stormwater Runoff and Drainage

The estimated length of public roads within the watersheds was 139.3 miles and the total length of private roads was 6.4 miles (NRCS, 2007). Unpaved, including dirt, roadways in the Lockatong watershed was 1.2 miles, and 7.2 miles in the Wickecheoke watershed. Approximately 2,949 tons of sediment per year is lost from the paved roads and 774 tons per year from unpaved roads. About 419 tons of ice-traction material, including ground iron slag, is applied to the roads each year, for a total possible sediment contribution to the streams of 4,142 tons. Large sections of Pine Hill Road, Old Mill Road, and Wickecheoke Road, all in Delaware Township except the northern segment of Wickecheoke Road that is in Kingwood Township, can contribute excessive loads of sediment, nutrients, and other chemicals to the Wickecheoke Creek and Plum Brook.

Photos 5 thru 8. ATV trails along, and in, Lockatong Creek.

Most municipal road drains are cleared of debris on an annual basis. A backhoe or other scooping equipment is usually used to dredge the drainage channels. The channels become erodible and storm runoff begins to undercut the sides of the channels and transport volumes of additional sediment to the streams. **Photos 9 thru 12** show a few of the numerous examples of erosion that were observed along roadways.

Photos 13 and 14 show selected sections of the road surface on Pine Hill Road. **Photos 15 thru 18** show the roadside drainage ravine erosion and sediment transport along selected segments of roadway.

Photos 9 thru 12. Roadside drainage - erosion and transport of sediments to streams.

Photo 13. Pine Hill Road – dirt/gravel surface draining south into Plum Brook.

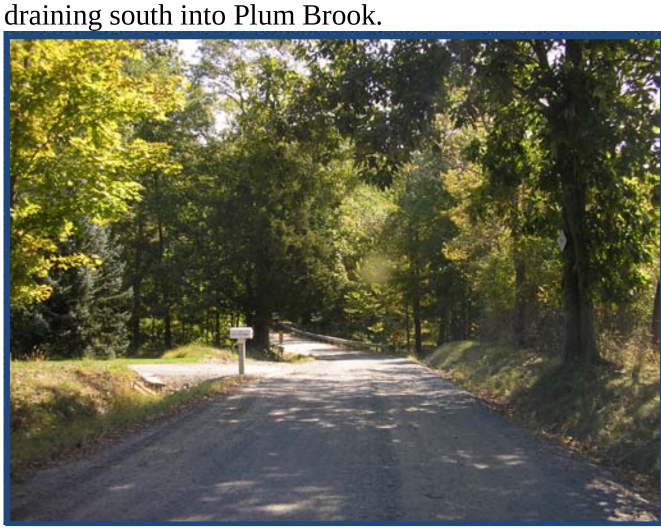
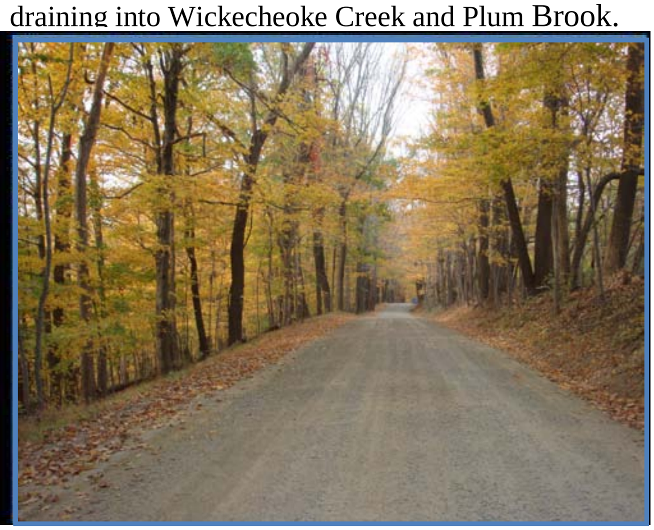


Photo 14. Pine Hill Road – dirt/gravel surface draining into Wickecheoke Creek and Plum Brook.



Photos 15 thru 18. Pine Hill Road - roadside erosion and discharge to Wickecheoke Creek and Plum Brook.

In some areas of the watersheds, particularly in the Rose Brook watershed (tributary to Wickecheoke Creek), asphalt berms have been installed along roadways by County and Municipal roadway departments to contain storm runoff flows from flowing onto adjacent lands, thus directing the concentrated flows into the streams. The effects from this practice are severe erosion of stream banks and channel at the discharge, and the creation of large sediment deposition areas downstream of the inflow. More frequent discharges from the roadway onto the bordering lands, as originally constructed without the berms, provided more opportunity for flow dissipation and infiltration, reducing detrimental impacts to the streams.

Roadways that have inlet structures with a piping system for stormwater either discharge the concentrated flows to the streams, via outlets at bridge/culvert structures, or discharge into eroded drain channels that convey the flow into the stream. Many of the roadway inlet structures are higher than the elevation of the road, whereby the runoff from the road bypasses the structure and goes directly onto and infiltrates the adjoining lands. The runoff onto adjoining lands were natural drainage conditions that had existed prior to the installation of the prefabricated inlet structures and appeared to be providing successful operations. **Photo 19** shows elevated stormwater inlets, and **Photos 20 and 21** show agricultural drainage that inadvertently flows directly to an inlet structure and ultimately into an eroded drainage channel to the Wickecheoke Creek.

Photo 19. Elevated stormwater inlets.

Photo 20. Field drainage flowing into roadside stormwater inlet.

Photo 21. Storm runoff from crop field routed directly into roadside drain.

Malfunctioning or Failed Septic Systems

Thin soil depth, shallow and fractured bedrock, seasonally high or perched ground water table producing saturated soil, and low-permeability soils create areas that are not suitable for septic system installation and function. **Photo 22** shows a system that was installed in the floodplain of a tributary to Lockatong Creek.

On-site wastewater treatment systems should not be located up-gradient of ground water supply wells, or within the floodplain of neighboring waterways, or in areas of hydric soils and wetlands. Innovative treatment systems could be considered for areas having somewhat limited soil permeability conditions. Soil and site assessments must be conducted to assure proper operation of conventional or advanced systems. The NJ Geological Survey's Nitrate Dilution Model is required by the State for every new, modified, or replaced septic system to determine the pervious area necessary to infiltrate precipitation to maintain a ground water nitrate concentration of not more than 0.2 mg/l (milligrams per liter).

Photo 22. Septic system installed in flood plain. Photo taken during higher-flow, but the flow condition was not considered flooding.

Land Disturbance and Soil Compaction From Construction

Clayey and silty soils are prominent throughout the watersheds. During construction and building at development sites, soil compaction occurs, decreasing the permeability of the active project site for infiltration and storage of precipitation, increasing erosive runoff flows. Exposed subsoils can produce sediment-laden runoff flows. The sediment is composed of fine clay and silt particles as well as larger, heavier particles. Sediment is suspended in the flow, carried off the site and deposited into the stream. The heavier particles settle out first with the finer grains carried farther downstream before settling (sometimes days later), creating a large length of degraded stream habitat and water quality. Over time, the sediment settles out of solution, covering crevices and voids between the rock and cobble substrate that are critical habitat for the survival of aquatic macroinvertebrates and species of fish that cannot relocate to unimpacted stream segments. Stormwater basins that are constructed on project sites are frequently compacted from the movement of heavy equipment during construction, defeating any intent of infiltration. **Photos 23 thru 25** present examples of stormwater runoff, unpermitted stormwater pumping, and stream degradation from construction activities.

Photos 23 thru 25. Stormwater and sediment load from construction site on Barbertown-Point Breeze Road, impacting Muddy Run.

Bridge construction or replacement is not regulated for sediment control. The construction activity is scheduled to conclude in a timely manner to limit the duration of sediment disturbance and possible loadings to the stream. Unanticipated higher flows and intense precipitation events can cause extensive erosion and sediment loadings to the stream at the project site. The installation of a catchment basin with storm-water pumped through sediment filters (filter bags) has been used successfully for projects sponsored by the NJ Water Supply Authority. This is one strategy that should be considered for controlling sediment loadings at bridge-construction sites. **Photo 26** shows bare soils susceptible to erosion during the bridge replacement project at Lockatong Creek on Union Road.

Photo 26. Potential erosion from bridge-construction site.

Inconsistent Compliance of Permitted Dischargers

Commercial and industrial discharges or water uses (permitted or illicit) can quickly degrade ambient water quality and flow conditions. An unpermitted discharge to the Wickecheoke Creek on December 19, 2006, from a breached earthen containment basin, discolored the stream for more than 3 days, releasing sediment, metals, organics, and other constituents. Treated wastewater from a municipal wastewater facility discharges into Rose Brook, a tributary to the Wickecheoke Creek. Occasionally, the stream water had a chlorine or sewage (sulfer and ammonia) odor near the confluence with the Wickecheoke Creek. Information on permit-compliance of facilities discharging to C1 streams should be presented to municipal officials and residents on a semi-annual frequency.

Stream Channel Destabilization and Erosion

The NRCS estimated that up to 12,300 tons of sediment are eroded from the stream banks and deposited to the stream channels each year. Channel destabilization and erosion are the most intensive sources of sediment loads. Historical high-flow events, since Hurricane Floyd (September 1999), have increased bank destabilization in nearly every stream channel within these watersheds. Stormwater flows from existing and new development have increased runoff flows and pollutant loads, while decreasing stream baseflows, from the increase of impervious surface. The compaction and covering of soils at development sites has been detrimental to the stream flow regimes. Existing plow-pans (mostly impervious layers about a foot lower than the ground surface) in agricultural crop-production fields also add to the runoff volume from the areal extent of semi-impervious surface.

Water Quality and Flow Monitoring

Results from the ***Lockatong and Wickecheoke Creek Water Quality and Flow Monitoring Project – 2006 Through 2007*** (NJ Water Supply Authority, 2008) revealed sub-basins in the watersheds that were impacted by contaminants. Results from the project were used to: 1) isolate and identify sources/causes of water quality degradation; 2) identify areas contributing baseflow to the mainstem during low-flow conditions, and quantify the contributing flows; 3) quantify pollutant loadings from sub-watershed areas; 4) quantify pollutant mass reductions that will satisfy Surface Water Quality Standards in stream reaches exceeding water quality standards; and 5) develop water quality and flow targets for defining "existing" water quality and "measurable change" for long-term protection of these C1 streams.

The water quality monitoring was conducted in two phases: the first phase was performed on mainstem sites and at the mouth of the larger tributaries; the second phase focused on further isolating sub-watershed areas that were determined in Phase 1 to be contributing to either water quality and/or quantity impacts. Phase 1 monitoring occurred from August through December 2006 with 6 sampling events, and Phase 2 monitoring was conducted from March through July 2007 with 11 sampling events, including sediment and additional bacteria sample collections. A total of 16 ambient and one sediment sampling events were performed in each watershed. A Quality Assurance Project Plan (QAPP), approved by the NJDEP Office of Quality Assurance, provided guidance throughout the project.

Nutrients (total phosphorus, nitrate, nitrite, total Kjeldahl nitrogen, and ammonia), solids (total suspended solids), turbidity, boron, coliform bacteria (fecal and Escherichia), pH, conductivity, and water temperature were analyzed to determine the magnitude and locations of contributions during both lower and higher flows. Levels of pollutants for each flow regime are shown on a sub-watershed basis in **Appendix B**.

The US Geological Survey (USGS) was contracted for installation and maintenance of continuous flow-monitoring stations, one near the mouth of each stream. The Lockatong station, located near the bridge on Raven Rock – Rosemont Road, began operation in November 2005 and the Wickecheoke station, located just upstream of the route 29 bridge, became operational in March 2006. Both monitors remain active at the writing of this report.

In addition to the USGS flow-monitoring sites, the NJWSA developed stage-discharge relationships at 12 water quality monitoring sites along Lockatong Creek, and at 13 water quality monitoring sites along the Wickecheoke Creek. The supplemental flow monitoring sites were developed to provide representative flow estimates for the shallow and fractured bedrock that underlies both watersheds. The Lockatong Creek receives most of its low-flow water supply from the northern headwater tributaries, while most of the Wickecheoke Creek low-flow water originates from springs along tributaries located within the southern 25 percent of the watershed.

"Low-flow," for this project was defined as equal to, or less than, 10 cubic feet per second (cfs) as measured at the USGS flow-monitoring sites. "Higher flow" is greater than 10 cfs. This flow separation was supported from data collected by the Delaware River Basin Commission (DRBC) at these same sites from 2000 through 2003 (Limbeck, Smith, and Kratzer, 2004). The data showed that non-point source pollutant loadings began to increase excessively at flows greater than 10 cfs.

Total Phosphorus Load Reductions to Attain Surface Water Quality Standards

Total Maximum Daily Loads (TMDLs) for total phosphorus, developed by the NJDEP for these watersheds, were derived mostly from water quality data that were collected near the mouth of each stream. The ***Lockatong and Wickecheoke Creek Water Quality and Flow Monitoring Project – 2006 Through 2007*** (NJ Water Supply Authority, 2008) provided total phosphorus and flow data for thirty-three monitoring locations throughout the watersheds that enabled empirical mass-balance relationships to be developed between monitoring sites. The relocation of selected monitoring sites during the project to further isolate potential contamination sources, and zero flows of many headwater sites during dry summertime conditions, disallowed consistent temporal data collection between many of the sites. Therefore, average annual statistics for phosphorus loads were not used for estimating load reductions due to the temporal variability and data densities. Maximum total phosphorus concentrations, and the associated loads, were used to identify exceedences of the Surface Water Quality Standards (SWQS) and to provide estimates of the required load reductions that would attain 0.1 mg/l total phosphorus. **Figures 3 and 4** illustrate percent load reductions for areas in the Lockatong and Wickecheoke Creek watersheds, respectively, that had maximum phosphorus concentrations above the regulatory criteria. All estimated load reductions are based on the cumulative reductions of loads from all upstream watershed areas.

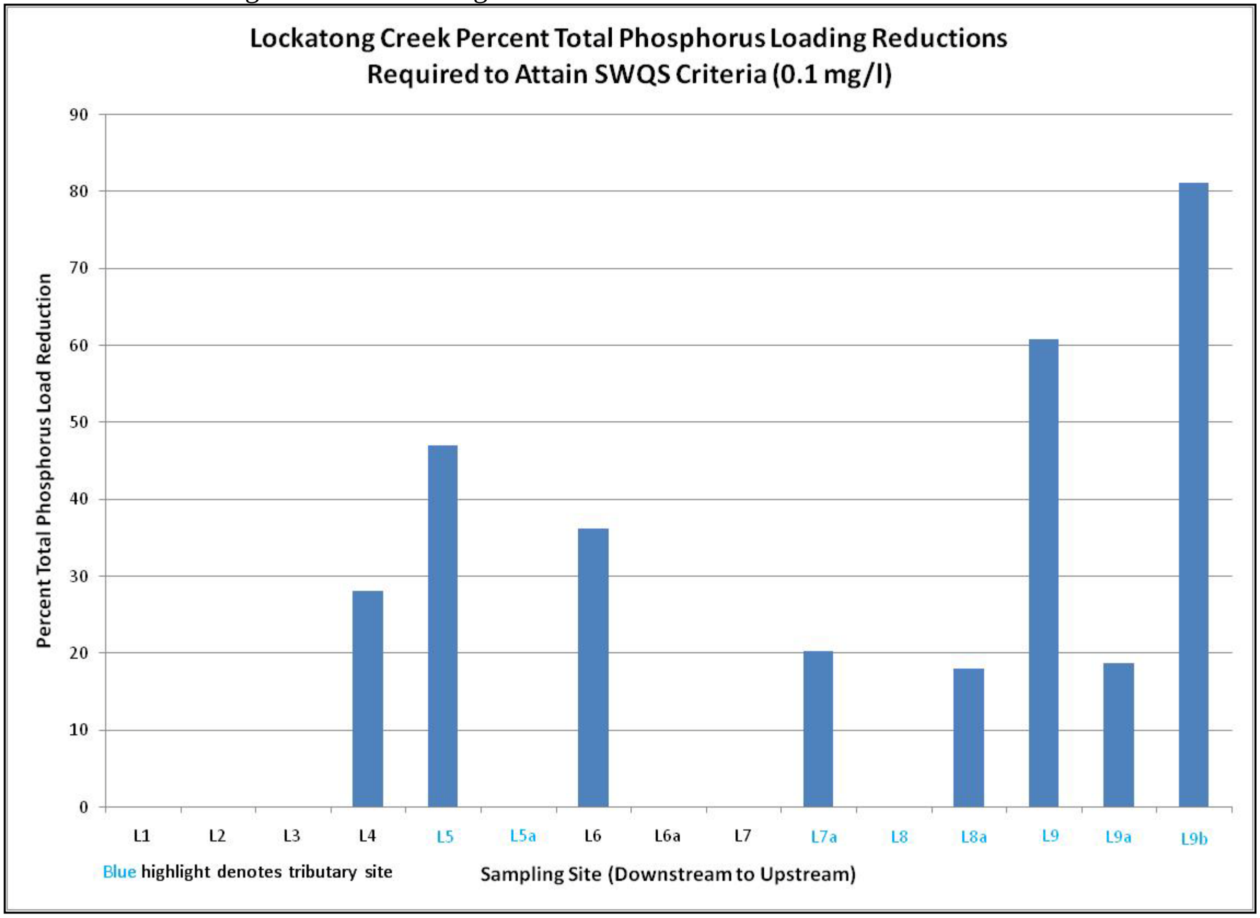
Isolation of Potential Contamination Sources Within The Lockatong Watershed

The Lockatong watershed has been sectioned into three areas for isolating potential contamination sources: upper, middle, and lower watershed areas. The upper area is north of County route 12. The middle and lower are from route 12 to Barbertown-Point Breeze Road, and from State route 519 to Rosemont-Raven Rock Road, respectively. Although somewhat limited in scope and frequency of collections, the macroinvertebrate data collected by NJDEP, NJWSA, Delaware Township Elementary School, and the Delaware Riverkeeper Network showed moderate to no impairments, indicating good population and habitat conditions for most sampling locations along Lockatong Creek and its tributaries. The northernmost section of tributary L9 had the most impairment, having moderate to severe impairment scores.

Upper Watershed Area

Water quality results for low and higher flows in the Lockatong creek and tributaries, revealed greater levels of nutrient concentrations in the headwater streams, north of Lower Oak Grove Road, over the entire range of flows, particularly in the eastern-most tributary northeast of Pittstown Road. Although the mass of contaminants in the water (loading) was relatively low, the concentrations were high due to less flow for dilution. Nitrate, a common

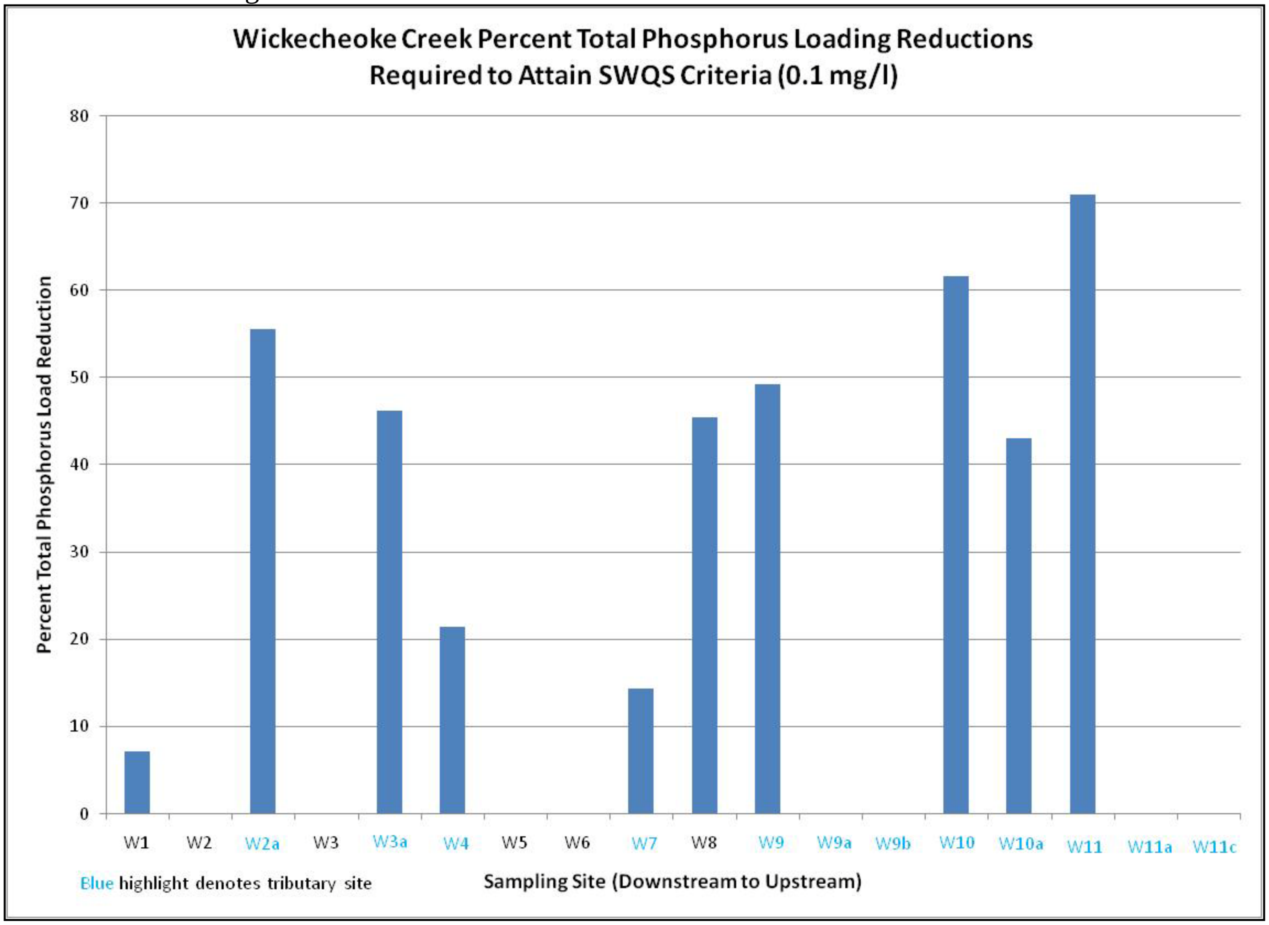
Figure 3. Estimated loading reductions to attain SWQS, targeting maximum total phosphorus concentrations throughout the Lockatong Creek Watershed. All load reductions are cumulative.



form of nitrogen in wastewater (e.g., septic leachate, livestock excrement, and illicit sewage discharges), had elevated loadings for each of the four samples collected at site L9b. The maximum concentration was 7.9 mg/l with an average daily loading of 30.6 lb/day (11,169 lb/year). Six samples were analyzed for bacteria. Three of the fecal coliform and four of the E. coliform values exceeded the 10 percent limits for exceedences. The E. coliform geometric average also exceeded the Surface Water Quality Standard (SWQS). Two of the 6 samples analyzed for total phosphorus exceeded the 0.1 mg/l SWQS with a maximum concentration of 0.482 mg/l and an average daily loading of approximately 0.99 lb/day (361 lb/year). Up to 82 percent of the entire stream baseflow during the lower flows originates from this tributary, upstream of Pittstown Road.

Boron levels were somewhat elevated above background levels. A monitoring site on Lower Oak Grove Road had exceptionally elevated boron levels, greater than those associated with agricultural applications or normal geological conditions. Consequently, the boron load produced elevated boron concentrations at every location downstream of this site. Further assessments located the source of boron just upstream of Lower Oak Grove Road at a wetland spring. Although pesticides were not analyzed during the study, they have historically been used in association with boron as an herbicide and insecticide. Therefore, additional monitoring is required to fully assess the potential historical use of this wetland area as an agricultural waste-disposal site.

Figure 4. Estimated loading reductions to attain SWQS, targeting maximum total phosphorus concentrations throughout the Wickecheoke Creek Watershed. All load reductions are cumulative.



Fecal coliform and Escherichia coliform bacteria were consistently higher at sites north of Oak Grove Road, confirming the possibility of fecal contamination from both human and animal sources in this section of the watershed. Turbidity was consistently higher at sites upstream of Oak Grove Road, in the tributary segment along Hammond Road. Two in-stream ponds were located just upstream of the sampling site with 3 or more additional ponds further upstream. The sizes of 3 of the ponds could have been supporting carp and other fish, in addition to providing a favorable habitat for geese, whereby causing a frequent stirring of the pond substrates that cause turbid water conditions. A farm pond north of Oak Grove Road and along the east side of Pittstown Road was frequented by large flocks of geese.

Middle Watershed Area

From south of County highway route 12 to Barbertown-Point Breeze Road, additional loadings of nutrients and bacteria were entering the stream during all flows. During higher flows, boron was also increased in this section of the creek. Illicit sewage discharges and malfunctioning septic systems would provide such increases during low flow. Increases in boron loads during higher flows may indicate septic systems underlain by semi- or non-pervious materials, causing a ponding condition that could add loading when the adjoining soils become saturated. Septic systems installed in close proximity to the stream channel may also release contaminants during higher stream flows, as the soils become saturated. Additional reconnaissance is required to identify the specific source(s) of contamination.

Total suspended solids and turbidity were elevated in this section of stream during all flow conditions. Channel sediments were finer in this stream section and could become resuspended and cloud the water from human or animal disturbance. The water quality monitoring project determined a good relationship between sediment and water total phosphorus, fecal bacteria, and total suspended solids, indicating that resuspension of sediments may be directly affecting the water quality. During lower flows, water depths were shallow throughout this reach and field crews noted frequent sightings of people and deer wading in the stream, likely resuspending sediments.

In addition to eroding stream banks, ATV activity and stormwater sediment loads from runoff and erosion near athletic fields were adding to the sediment deposits in this reach. The section of Lockatong Creek within Kingwood Township Park was receiving stormwater runoff with sediment loads from eroding stormwater channels, mostly near the stream. The sediment load was estimated at 90 tons per year.

Lower Watershed Area

Nutrients were elevated at all flows in the lower portion of the Lockatong watershed. Boron was only elevated during the higher stream flows, possibly reflecting the characteristics of bedrock and soils near septic systems. Semi- or non-pervious materials in the vicinity of septic systems can limit the amount of leachate dispersal during dry conditions, but may provide conveyance when soils become saturated from precipitation. Septic systems located near the stream channel may also release contaminants during higher stream flows, as the soils become saturated. Fecal bacteria were lower in this stream section. Wide, shallow, and a mostly north-south oriented channel allows more exposure to sunlight. Since fecal bacteria cannot tolerate solar radiation, the lower levels in this reach may be the result of dye-off from natural ultraviolet radiation. Further investigation is warranted to determine the specific source(s).

The orientation and width of the channel, in association with the shallow water depth, provided optimal conditions for growth of aquatic plants. Through photosynthesis and respiration, aquatic plants vary the dissolved oxygen and pH of the stream during daytime and nighttime conditions. Plants increase dissolved oxygen and raise the pH during the day and produce the opposite effects at night. The channel characteristics also produce warmer water temperatures during the day. An in-stream pond, just upstream of Milltown Road, also provided ideal conditions for aquatic plant growth and warming of the water. During the study, pH and water temperature exceeded the Surface Water Quality Standards (SWQS) during the day, particularly during lower flows in July and August. Nighttime levels of pH were not monitored, but may have exceeded the lower limit of the SWQS.

A mill located along the stream on Strimples Mill Road produced a large pile of sawdust next to the stream channel from active operations. During each higher flow this material was naturally washed into the stream, adding organics that can disrupt aquatic habitat, lower the dissolved oxygen, increase aquatic-plant productivity, and increase bacteria populations during decomposition.

Muddy Run flowed into Lockatong Creek just upstream of route 519 (northern end of the lower watershed area). Although total phosphorus exceeded the SWQS during higher flows, the loadings were only slightly increased beyond background. The relatively lower flows in this tributary produced high concentrations with only minor increases in loadings. Bacteria levels were elevated during all flows. Manure piles and fertilizer storage near the stream may be contributing to, or may be, the contamination source(s).
Clearing and construction activity in the watershed produced sediment-laden runoff flows during each storm event and during low flows when stormwater control basins were illicitly drained by pumping. This sediment load increased total suspended solids and turbidity levels, impacting Muddy Run and Lockatong Creek to downstream of route 519.

Isolation of Potential Contamination Sources Within The Wickecheoke Watershed

The Wickecheoke watershed has been sectioned into three areas for isolating potential contamination sources: upper, middle, and lower watershed areas. The upper area is north of County route 12. The middle and lower are from route 12 to the confluence of Plum Brook, and from Rosemont-Ringoes Road (Covered Bridge) to State route 29, respectively. Although somewhat limited in scope and frequency of collections, the macroinvertebrate data collected by NJDEP and NJWSA showed mostly good population and habitat conditions for all sampling locations along Wickecheoke Creek and its tributaries.

Upper Watershed Area

All of the sites north of route 12 had somewhat elevated levels of total phosphorus and organic nitrogen during higher flows. Two sites, Wickecheoke Creek at Rake Road and a tributary on Old Croton Road, had increased phosphorus loadings, and concentrations exceeding the Surface Water Quality Standards. Although nitrate was near background levels, these same sites had higher levels of boron, coliform bacteria, suspended solids, and turbidity, indicating the possibility of illicit sewage discharge(s) and/or septic system malfunction(s). The elevated levels of suspended sediment and turbidity can result from stream egress by livestock and wildlife. Since the channel substrates in this area of the Wickecheoke watershed are mostly larger cobbles and rock, with some sand, channel substrate disturbances by wildlife should not substantially increase suspended solids or turbidity. Nearly 40 percent of the land use is agriculture, with approximately 10 percent as urban. Therefore, fertilizers and/or manure may be other sources of nutrient and bacterial contamination.

During the summer, this portion of the Wickecheoke watershed was frequently dry, indicating a lower aquifer level in this region. Further ground water studies should be conducted to quantify the available water supply.

Middle Watershed Area

Throughout this section of the watershed, stream banks are eroded, contributing fine and coarse substrates to the channel. Except for nitrate, the levels of nutrients, suspended solids, turbidity, and boron were consistently greater in the mainstem Wickecheoke Creek, northeast of Whiskey Lane. A tributary to Wickecheoke Creek, just northwest of the mainstem and northeast of Whiskey Lane, had mostly background levels of all water quality constituents during low flows. Total phosphorus, organic nitrogen, boron, and bacteria increased substantially during higher flows, suspended solids were somewhat elevated. Agricultural activity and the possibility of leachate from septic systems or direct sewage discharge could be loading sources. Stream bank erosion was also evident in this tributary.

Water quality between Whiskey Lane and Locktown Road showed increased levels of nutrients, boron, fecal bacteria, solids, and turbidity during low and higher flows. An unauthorized discharge from the Magnesium Electron Incorporated (MEI, currently known as MEL Chemicals) facility, on December 17, 2006 created substantial increases in TSS and turbidity during the December 20, 2006 sampling run. The increased levels of sewage indicators may warrant additional monitoring for septic-system leachate and/or illicit sewage discharge(s) into the stream, downstream and upstream of the MEI facility. Geese were consistently observed on a pond near the entrance to the facility, possibly a source of additional pollutant loads.

A series of waterfalls between Kingwood-Locktown Road and Old Mill Road created the steepest stream channel slope in the Wickecheoke watershed. Although the water quickly cascades over each of the waterfalls, the pooled areas between the falls are large with very slow water velocities, deeper pool areas at the base of each fall. The slower flows, combined with shallower depths downstream of the scour pools, promote the growth of both submergent and emergent aquatic plants. The plants take in nutrients during the day and the slower velocities allow the deposition of suspended sediments. The fall-pool regime acts as a natural filter during lower flows. This sub-watershed was heavily influenced by the increased loadings at Locktown Road for total phosphorus, nitrate, TKN, boron, and bacteria. Due to the exposed and shallow bedrock, and thin soil layer in this watershed septic systems may contribute to the loadings. The combined influence of a breach in a settling basin wall at the Magnesium Electron Incorporated facility on December 17, 2006, and a breached and draining farm pond that was discharging into a tributary that confluences the Wickecheoke Creek about ½ mile upstream of Old Mill Road, substantially elevated the TSS and turbidity levels. Small groups of ducks were occasionally noted in the pooled areas.

Plum Brook confluences with Wickecheoke Creek approximately ½ mile downstream from Old Mill Road. Greater loadings of nutrients and solids were evident between Locktown-Flemington Road and Pine Hill Road. Phosphorus, boron, and fecal coliform were at increased levels over background during higher flows. Although the loadings were less in the sub-watershed area draining to Locktown-Flemington Road, inherent lower flows produced consistently higher concentrations. Turbidity was also higher at this site along with fecal coliform levels that were increased substantially during higher flows. Other than turbidity, the loadings upstream of Locktown-Flemington Road were near background conditions. The increases of phosphorus, boron, and fecal coliform during higher flows suggests the possibility of malfunctioning septic systems that could leak into the stream when the soils are saturated. These systems may have been installed further back from the stream channel, but may be overlaying clay or other less-permeable materials. Since agricultural land uses are lower in the Plum Brook watershed (less than 30 percent) and urban land uses (12 to 14 percent) are greater than the average for the entire Wickecheoke watershed (11 percent), septic system malfunctions are likely sources.

Lower Watershed Area

The water quality in the stream reach between Rosemont-Sergeantsville Road (covered bridge) and State route 29 indicates combined loadings from direct sewage discharge(s), septic systems, road runoff, and agriculture. Extensive channel erosion has occurred throughout this channel from increasing stormwater-runoff.

Cold Run flows into Wickecheoke Creek from the east, just north of Rosemont-Ringoes Road. Bacteria, phosphorus, and nitrate levels were commonly higher in this tributary watershed. Approximately 43 percent of the watershed area is agriculture, and more than 12 percent is urban, promoting the possibility of sewage and manure loadings. Much of the Wickecheoke flow, up to 44 percent during the lower baseflows, originates from springs in this watershed. Therefore, ground water quality from this sub-basin can influence the mainstem Wickecheoke Creek, particularly during the lower flows. The low-flow data indicate that there may be higher levels of nitrate flowing out of the ground water springs. Other sources of nitrate, bacteria, and phosphorus could be originating from septic systems on older farmsteads and homes, and/or livestock manure.

Wickecheoke Creek, upstream of Rosemont-Ringoes Road, revealed extensive increases in nutrient, coliform bacteria, boron, and suspended solids loadings during all stream flows. Turbidity was somewhat elevated throughout all flows. Relatively, loadings from Cold Run were minimally influencing the loadings of the entire sub-watershed on the mainstem. The sudden surge in loadings may be the result of contamination originating in the local vicinity of Rosemont-Ringoes Road. The seemingly localized increase in loadings during lower flow directs attention to an increased possibility of illicit sewage discharge(s) and septic leachate, and/or anthropogenic disturbance of the stream channel. Agricultural activities make up approximately 37 percent of the land use in this portion of the watershed, possibly adding to the total loadings. Stormwater runoff and erosion from Pine Hill Road and the roadside drains consistently carries large sediment loads, and the associated nutrients, metals, and solids, into Plum Brook and Wickecheoke Creek, increasing these loadings during rain events.

Rose Brook, a tributary of Wickecheoke Creek, flows from the northeast and joins the mainstem approximately 0.6 mile downstream of Rosemont-Ringoes Road. This tributary receives effluent from the Delaware Township Municipal Utility Authority. As reported in the Total Maximum Daily Load (TMDL) report from the NJDEP, the allocated discharge limits for the Delaware Township MUA (permit NJ0027561) was 1 mg/l (milligrams per liter) total phosphorus at a maximum effluent flow of 0.032 MGD (million gallons per day), or 0.05 cfs. This is equivalent to approximately 98 lb/yr (pounds per year) of total phosphorus. Total phosphorus, nitrate, and boron were higher in this sub-watershed. A chlorine odor was frequently noted in this stream during sampling. Extreme stormwater runoff events have recently become more frequent, destabilizing nearly the entire channel.

Increased runoff from recently curbed roadways and additional stormwater being conveyed into this watershed from developments in neighboring watersheds has increased the flows and destabilization of the channel.

From Rosemont-Sergeantsville Road to route 29 the Wickecheoke Creek water quality continued to degrade, in addition to the greatest intensity of stream-bank erosion and the subsequent large quantities of sediment deposited in the channel. Most of the deposition consisted of larger cobble and boulders which become a bed-load that is not readily suspended, but rolled along the bedrock stream bottom during higher flows. Nutrient, boron, and suspended solids loadings were unusually higher in this section of the Creek, particularly during higher flows. The boron load during higher flows reached levels more than 10 times greater than that of lower flows. Older homes with malfunctioning septic systems may be contributing to the elevated water quality constituents. Direct sewage discharge is also possible. During higher flows, a tributary entering Wickecheoke Creek from the west, approximately ¼ mile downstream from Rosemont-Sergeantsville Road, conveyed water from a cattle access just upstream of the confluence. Similar to the lower section of the Lockatong Creek, this section of the Wickecheoke Creek presented a wide and shallow channel that was consistently exposed to sunlight. The increased exposure to solar radiation (ultraviolet light) was not suitable for fecal bacteria and decreased the population proportionately. The increased sunlight provided optimum conditions for aquatic plant production, while also increasing the daytime water temperature. As previously described in the Isolation of Potential Contamination Sources Within The Wickecheoke Watershed section, pH and dissolved oxygen fluctuations increase with increasing aquatic plant growth. During the study there were several pH and water temperature violations for the upper limits of these parameters in this section of the stream. Dissolved oxygen was not monitored. Nighttime pH and dissolved oxygen could have also violated the Surface Water Quality Standards, but was beyond the scope of this project.

WATERSHED REMEDIATION STRATEGIES

Recommendations from the following reports: ***Characterization and Assessment Report;*** the ***Lockatong and Wickecheoke Creek Water Quality and Flow Monitoring Project – 2006 Through 2007 Report;*** and ***An Assessment of Municipal Plans, Policies, and Regulations Effecting Water Quality in the Lockatong and Wickecheoke Watersheds*** determined that the following remediation strategies are critical for long-term protection of the quality and quantity of water within the Lockatong and Wickecheoke Creek Watersheds, and implementation of these measures should be expedited. NJDEP 319(h) grant, NJDEP Corporate Business Tax for Watershed Projects, NJWSA Source-Water Protection, EPA CARE grant, Farm Bill assistance programs, municipal, and private are some of the possible funding sources that would be available to implement selected remediation projects. **Appendix B** describes specific structural and educational remediation strategies.

Municipal Stream Protection Strategies Assessment

A separate report, ***An Assessment of Municipal Plans, Policies, and Regulations Effecting Water Quality in the Lockatong and Wickecheoke Watersheds Report*** (NJ Water Supply Authority, 2008), compares the currently adopted, and possible future remediation strategies that are available for implementation by municipalities. Sample ordinances are included for reference. Cross-boundary cooperation among neighboring municipalities should be developed to provide consistency for those properties and projects located between political boundaries, and to ensure open communication between upstream and downstream communities to protect the watersheds.

Structural and Educational Remediation Strategies

The Lockatong and Wickecheoke Creeks are both classified as C1. Antidegradation is defined as no measurable change in water quality. There are currently no criteria to determine changes in stream water quality or to define measurable change. A user-friendly statistical technique similar to the FIRE method that is used by the NJDEP for total phosphorus TMDLs could also be applied to selected stream sites to establish a water quality reference point. One or more sites could be used for this application. The method would define existing water quality and measurable change for application to potential, or known, point and/or non-point pollution source(s). The targeted stream site could then be used to allocate pollutant loadings throughout the contributing watershed area as part of the permitting process. More details are presented in the ***Lockatong and Wickecheoke Creek Water Quality and Flow Monitoring Project – 2006 Through 2007 Report*** (NJ Water Supply Authority, 2008).

Developed from the need for stormwater quantity and quality controls, several structural and non-structural remediation strategies are presented below. Emphasis is applied to the need for stormwater runoff controls for both private and conservation lands; agricultural crop fields and livestock pastures; residential and commercial lawns, and athletic fields; roadways and roadside drainage, including reductions in width, curbing, and unnecessary roadside storm drains in locations that had previously drained to natural infiltration areas; and expanding on public education. Those controls requiring additional expertise, via contractual services and costs, are detailed in **Appendix B**. Existing proposed projects for stormwater management should be reviewed and considered for funding, when applicable (i.e., Delaware Township's Stormwater Management Plan for projects in the Rose Brook watershed, undergoing planning but unfunded).

Scholastic and volunteer educational programs should include some or all of the following:

- Emphasis and expansion of environmental protection curriculums and programs for schools within the project municipalities, several have already initiated such programs;
- Volunteer stream-cleaning teams, for selected sections of the stream (similar to the "Adopt-a-highway" program) emphasizing visible garbage collection, water quality and aquatic habitat protection, on-site stormwater controls, and the collection and use of water quality data;
- Emphasis on water quality and quantity protection at Community Day, or other community gatherings, with recognition of the progress made by members of each stream-cleaning team;
- Distribution of information on pollution-prevention and lot-specific stormwater controls by Environmental Commissions; and
- Pursue interaction and support between all levels of municipal government through special presentations and community programs.

MILESTONES

Both quantitative and qualitative milestones were achieved during the course of this project and can also be used for the anticipated remediation projects.

Milestones achieved during this project included:

- Coordination and expert contributions between agencies, public and private organizations and companies, municipalities, and other interested participants;
- Characterization and assessment of each watershed prior to and during the project;
- Build-out analyses for each watershed;
- Municipal assessments for each of the 4 municipalities within the project area;
- Quantification of water quality and flow characteristics, including a qualitative assessment of stream-channel stability and aquatic habitat at sites throughout the watersheds, most of which had no history of stream health assessments;
- Identification of contamination areas and potential contamination sources within the sub-watersheds;
- Continued acquisition of land for preservation of open space.
- Stream-channel stability and aquatic habitat assessments;
- Development and implementation of criteria for determining "no measurable change" and for defining "existing" water quality, for any stream type/category;
- Development of required total phosphorus load-reduction estimates for each of the 3 HUC 14 areas in each watershed to be within the SWQS;
- Comparison of in-stream loadings of bacteria and total phosphorus to those of storm-runoff events to further quantify the actual non-point source loadings; and
- Development of a Watershed Remediation and Protection Plan to assist municipalities with adopting and implementing water quality and quantity protection strategies.

Milestones anticipated from Implementation Projects, providing measurable changes to improved water quality and quantity, include:

- Reduction of sediment transport and deposition in the Canal from Lockatong and Wickecheoke loadings, including up to 2,484 tons/yr total suspended solids, equivalent to approximately 13.6 tons/yr of total phosphorus, and more than 12,000 tons/yr of bed load sediment, representing another possible 66 tons/yr of total phosphorus;
- Enhanced scholastic and community awareness of contamination sources, emphasizing the usual pathway(s) to the stream, and protection strategies;
- Determination of storm-runoff reduction from modified soil conditions, an innovative pilot program that can be applied to all post-agriculture conservation and preserved lands;
- Amend municipal roadway drainage criteria to emphasize non-erosive, pervious drainage-channel designs, and slotted/ported curbing;
- Promote water quality pollutant and runoff reduction strategies to farmers as part of their conservation plan and/or to meet the certification requirements for "River-Friendly Farm;"
- Educational program, via installation of various types of rain gardens, for controlling runoff and sediment loads from drainage around athletic fields and for educating homeowners on available options to create naturally-aesthetic on-lot stormwater controls;
- Establish water quality target points for defining existing water quality and measurable change at selected sites in each watershed;

- Provide assistance for existing innovative stormwater management projects, including the restoration of the Rose Brook stream channel through the installation of new stormwater controls and retrofits;
- Revisions to State Erosion and Sediment Control rules for limiting the extent (acreage) and duration (time from initial disturbance) of exposure of subsurface soil to decrease the amount of sediments available for stormwater to convey into a nearby stream; and
- Review and amend the State BMP manual to highlight those methods that are effectively applicable to Hunterdon County soils, based on site-specific conditions.
- Implementation of remediation projects, as prioritized in **Appendix B**, would fulfill TMDL load-reduction requirements for total phosphorus and fecal coliform, while reducing stormwater runoff flow and increasing infiltration for ground water recharge and stream baseflow. Sediment and bacteria loading reductions are expected to be proportional to total phosphorus load reduction and the reduction to stormwater runoff.

MEASURING CHANGES TO WATER QUALITY AND QUANTITY

Each proposed implementation project includes an estimate of the expected reduction in sediment and total phosphorus loads. Projects performed in the field will have pre- and post-implementation analyses to determine the quantifiable reduction in the associated loadings. **Appendix C** compares relative levels of average water quality concentrations and loadings per parameter for low and higher flows, as measured at each sub-watershed during the monitoring project. **Appendix D** compares the effectiveness for each proposed implementation project for reducing stormwater runoff and total phosphorus and total suspended solids loadings.

Educational and outreach projects will be assessed by the number of participants and the amount of progress. Municipal plan elements and/or ordinances adopted in response to the Management Plan will provide a measure of progress.

Although implementation projects can provide estimated reductions to contaminant loadings and changes in the flow regime, actual measurements of changes in water quality and flow are necessary to confirm the estimates. Overall watershed restoration can be measured through a post-implementation monitoring project, reanalyzing water quality and flow at known problem sites. Comparison of the post-implementation results with the current data will present the level of change (percentage, or mass reduction). A frequency of 4 to 5 years between monitoring programs would provide a good determination of trends in both water quality and quantity. The frequency could be adjusted pending results of the first post-implementation monitoring program.

SUBSEQUENT EFFORTS

- Results from the project reports have warranted the collection of additional information and continued efforts of remediation strategies for several watershed issues, including pesticides and illicit and/or malfunctioning/failing septic systems. Although comprehensive, results from this project warrant additional assessments of watershed areas that were not accessible during the field efforts.

- Pesticide monitoring by NJDEP, Hunterdon County Health Department, or HC Soil Conservation District, near site L8, should be performed to determine any correlation with the high levels of boron that were found during the 2006-2007 sampling program.

- Further reconnaissance and monitoring should be conducted by the Hunterdon County Health Department and Soil Conservation District for illicit wastewater discharges and/or malfunctioning/failing septic systems at suspect locations in the watersheds that were not accessible during the study. Also, additional monitoring for nutrient, bacteria, and solids loads in the L7/Route 12, and L9 sub-watersheds should be performed to further isolate sources of contamination.

- Subsequent approval of the program reports by NJDEP should facilitate the acquisition of 319(h) funding for remediation projects. The list of Proposed Implementation Projects in **Appendix B** is not intended as a complete list, since it was compiled from currently-available information to initiate remediation efforts in the watersheds. Additional projects are anticipated to be proposed as more information, and accessibility to non-public sites, becomes available.

- Continuation of land-preservation with assistance from land-acquisition organizations such as New Jersey Green Acres, Hunterdon Land Trust Alliance, New Jersey Conservation Foundation, Hunterdon County Freeholders, and the New Jersey Water Supply Authority.

- Water quality and quantity should be reexamined, approximately every 4 to 5 years for the same group of parameters, in addition to pesticides, to determine the effectiveness of the implementation projects. Possible support for a post-assessment effort could be provided by a NJDEP 319(h) grant, NJWSA Source-Water Protection funding, Lower Delaware Management Committee funding, and/or NJDEP's Corporate Business Tax for Watershed Projects.

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Appendix A

Nine Minimum Elements of the Management Plan

Watershed Plan Elements	Report (Section and page number where applicable)
Preliminary Step – Characterize current status, trends and projected nature of the watershed and determine issues requiring solution through a watershed restoration plan.	Characterization and Assessment of the Lockatong and Wickecheoke Creek Watersheds
Preliminary Step – Establish watershed objectives for each issue identified through the characterization and assessment process.	319(h) Grant Proposal: Watershed Restoration and Protection Plan for the Lockatong and Wickecheoke Creek Watersheds
1. An identification of the **causes and sources** or groups of similar sources that will need to be controlled to achieve the load reductions estimated in this watershed-based plan (and to achieve any other watershed goals identified in the watershed-based plan).	Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan (Causes and Sources of Contamination, Pg. 22)
2. An estimate of the **load reductions needed to be achieved from management measures**, by source or group of sources listed in (1) (recognizing the natural variability and the difficulty in precisely predicting the performance of management measures over time).	Lockatong and Wickecheoke Creeks Water Quality and Flow Monitoring Project – 2006 through 2007 (HUC 14s); Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan (Figures 3 and 4)
3. A description of the **nonpoint source management measures** that will need to be implemented to achieve the necessary load reductions (as well as to achieve other watershed goals identified in this watershed-based plan), and an identification (using a map and description) of the critical areas in which those measures will be needed to implement this plan.	Restoration and Protection Plan (Watershed Remediation Strategies, Pg. 43)
4. An estimate of the amounts of **technical and financial assistance needed, associated costs, and/or the sources and authorities** that will be relied upon to implement this plan.	Restoration and Protection Plan (Appendix B)
5. An **information/ education component** that will be used to enhance public understanding of the project and encourage the public's early and continued participation in selecting, designing, and implementing the NPS management measures.	Restoration and Protection Plan (Structural and Educational Remediation Strategies, Pg. 44)
6. A reasonably expeditious **schedule for implementing** the NPS management measures identified in this plan.	Restoration and Protection Plan (Appendix B)
7. A description of **interim, measurable milestones** for determining whether NPS management measures or other control actions are being implemented.	Restoration and Protection Plan (Milestones, Pg. 45)
8. A set of **criteria** that can be used to **determine whether loading reductions are being achieved** over time and substantial progress is being made towards attaining water quality standards and, if not, the criteria for determining whether this watershed-based plan needs to be revised or, if a NPS TMDL has been established, whether the implementation plan section of the TMDL needs to be revised.	Restoration and Protection Plan (Measuring Changes to Water Quality and Quantity, Pg. 46)
9. A **monitoring component** to evaluate the effectiveness of the implementation efforts over time, measured against the criteria in (8).	Restoration and Protection Plan(Measuring Changes to Water Quality and Quantity, Pg. 46)

Appendix B

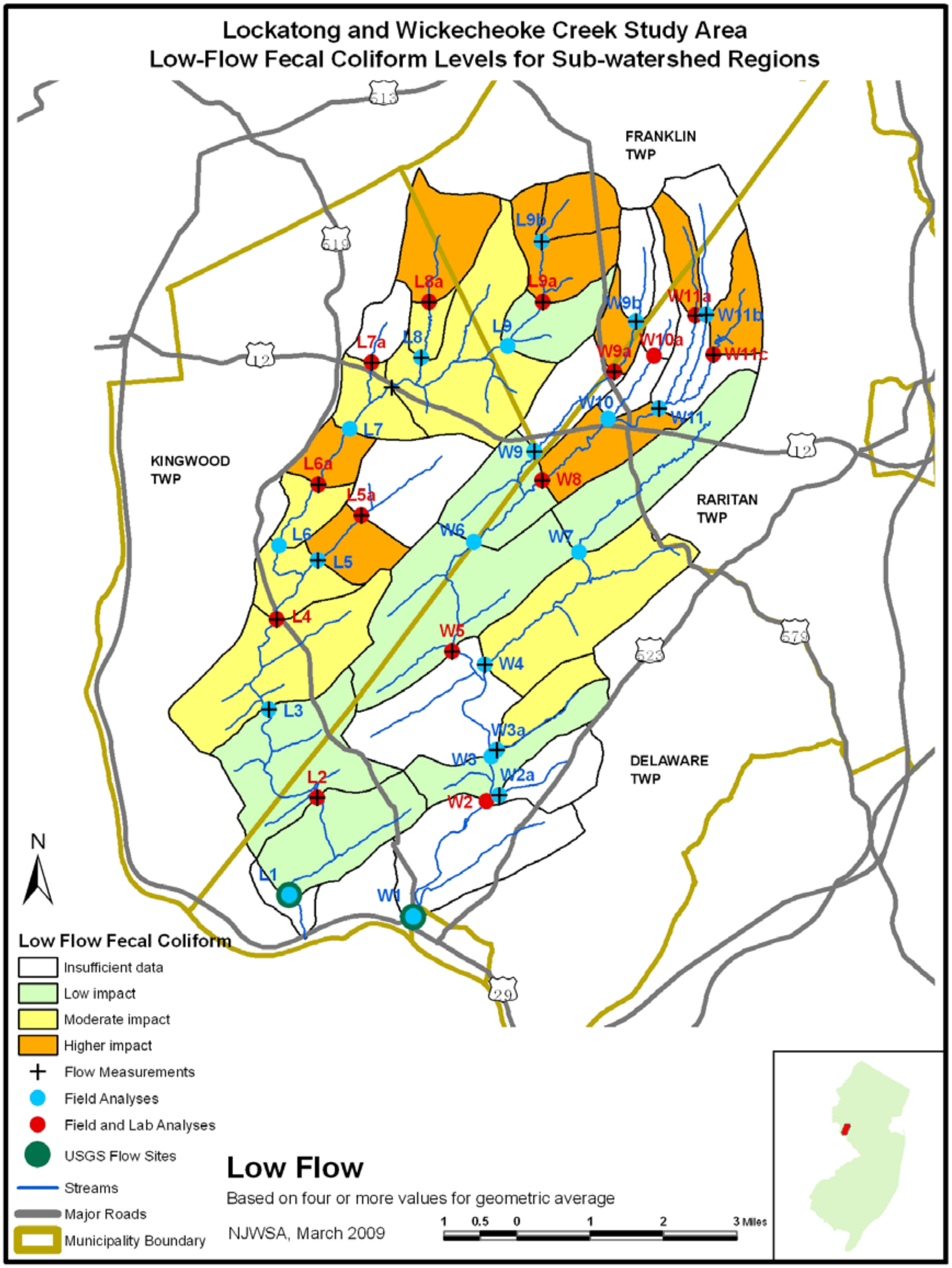
Proposed Implementation Projects (Separate Document)

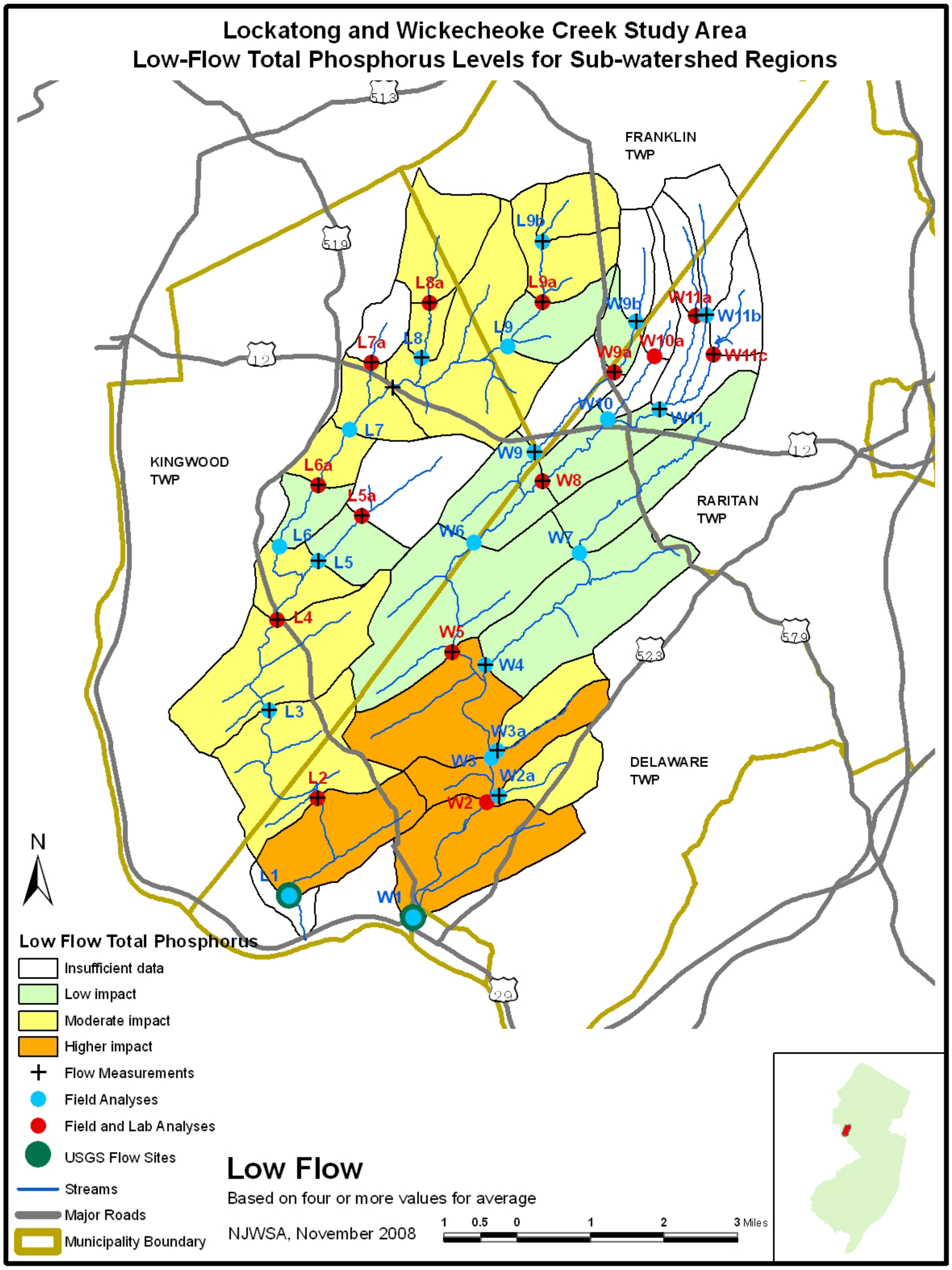
Appendix C

Water Quality Assessments Per Parameter For Low and Higher Flows

Low-Flow Results

(Relative impact assessment using average concentration and loading, where available)




Lockatong and Wickecheoke Creek Study Area
Low-Flow Total Phosphorus Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
Low Flow Total Phosphorus
Insufficient data
Low impact
Moderate impact
Higher impact
Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
Streams
Major Roads
Municipality Boundary
Low Flow
Based on four or more values for average
NJWSA, November 2008
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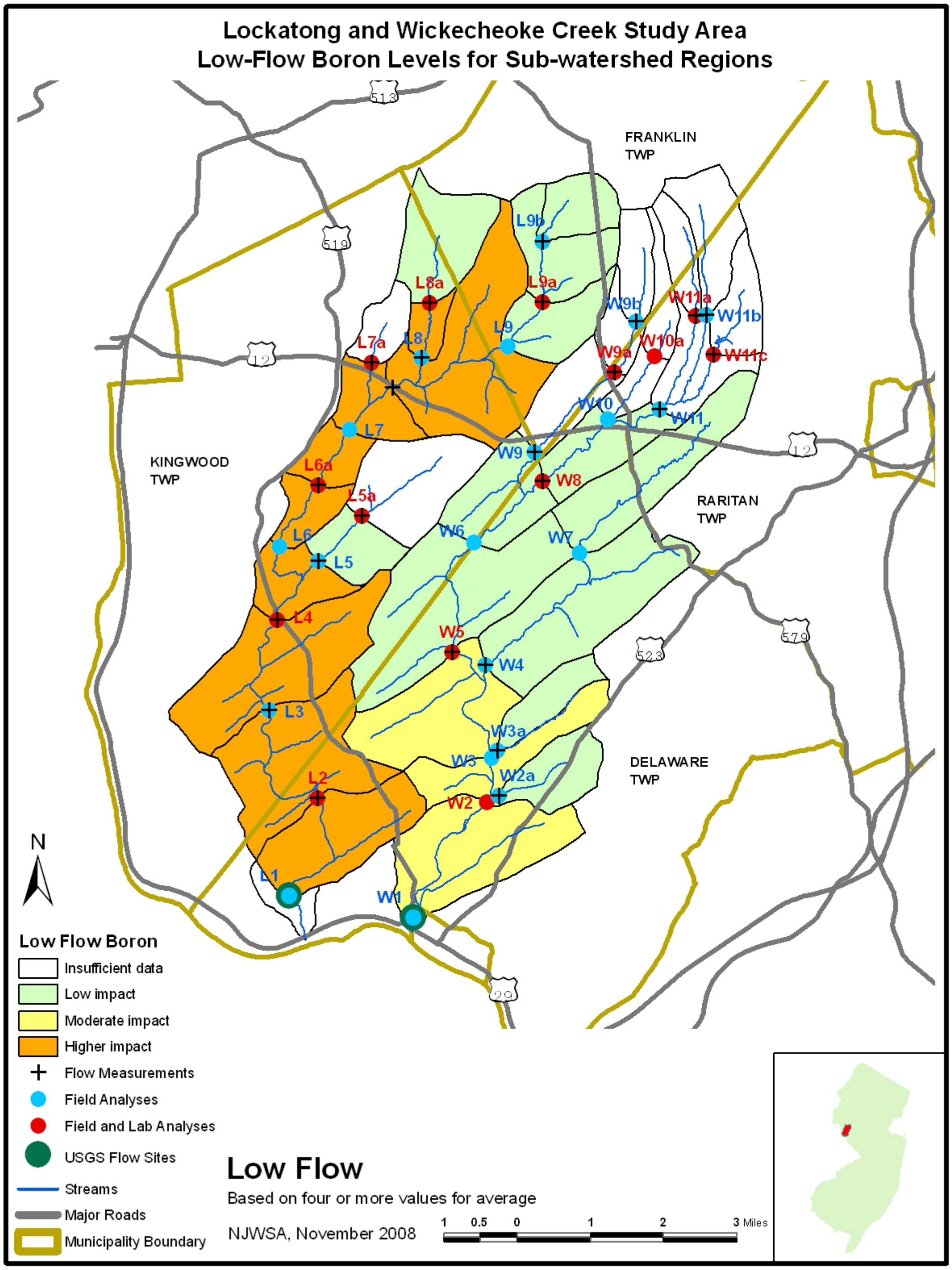
Lockatong and Wickecheoke Creek Study Area
Low-Flow Boron Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
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Flow Measurements
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Field and Lab Analyses
USGS Flow Sites
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Major Roads
Municipality Boundary
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Based on four or more values for average
NJWSA, November 2008
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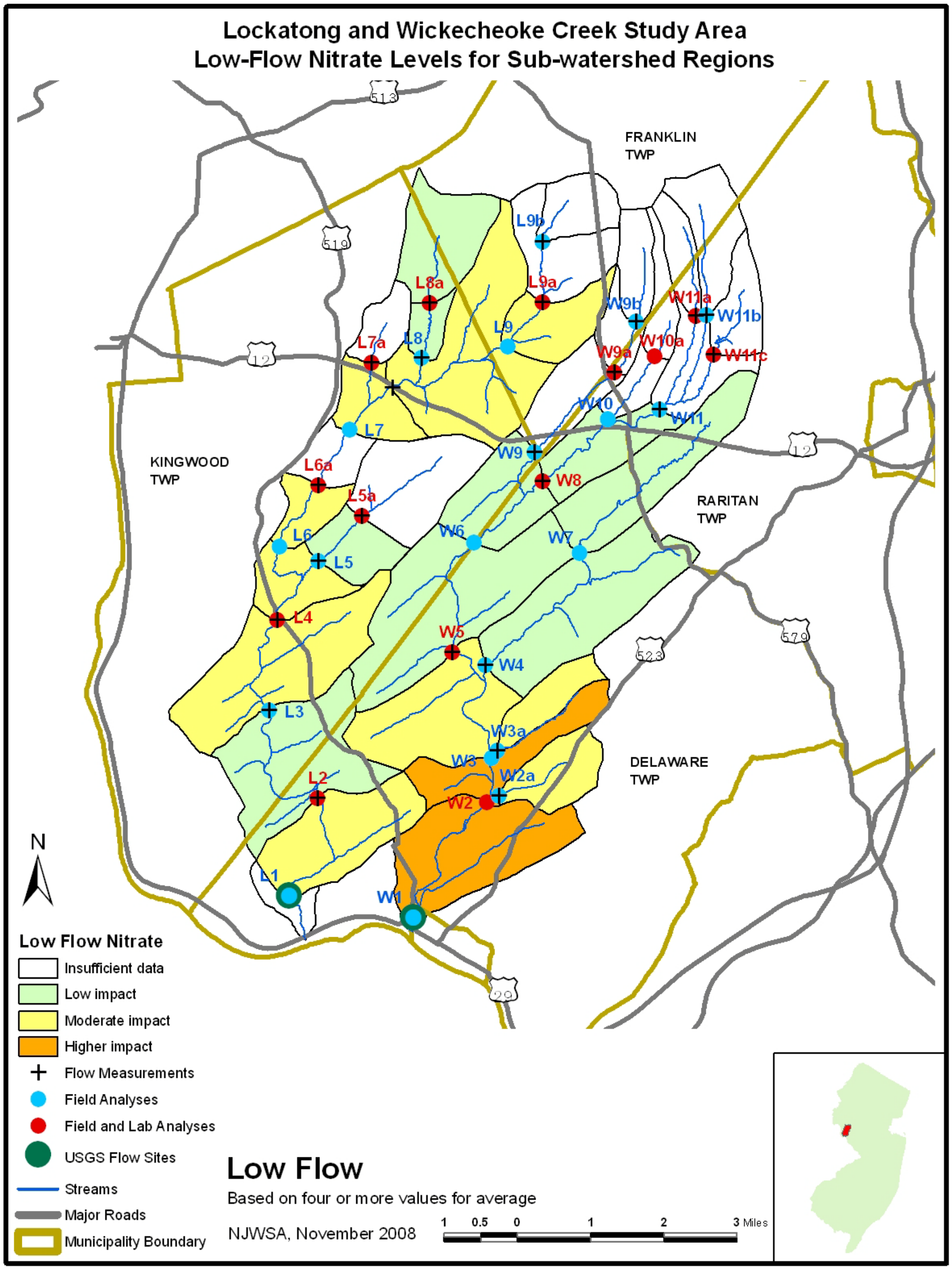
Lockatong and Wickecheoke Creek Study Area
Low-Flow Nitrate Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
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Low Flow Nitrate
Insufficient data
Low impact
Moderate impact
Higher impact
Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
Streams
Major Roads
Municipality Boundary
Low Flow
Based on four or more values for average
NJWSA, November 2008
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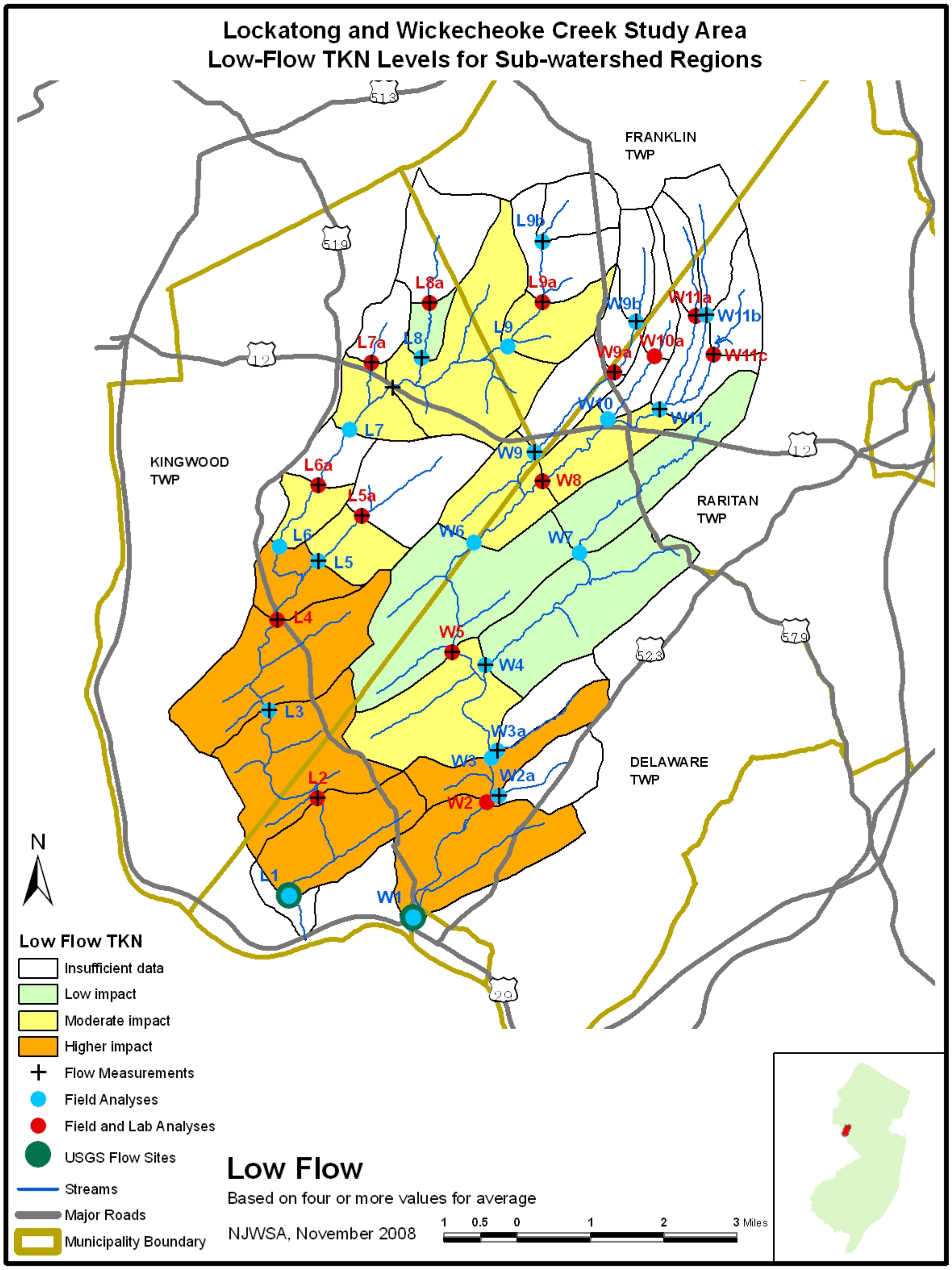
Lockatong and Wickecheoke Creek Study Area
Low-Flow TKN Levels for Sub-watershed Regions
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KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
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Moderate impact
Higher impact
Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
Streams
Major Roads
Municipality Boundary
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Based on four or more values for average
NJWSA, November 2008
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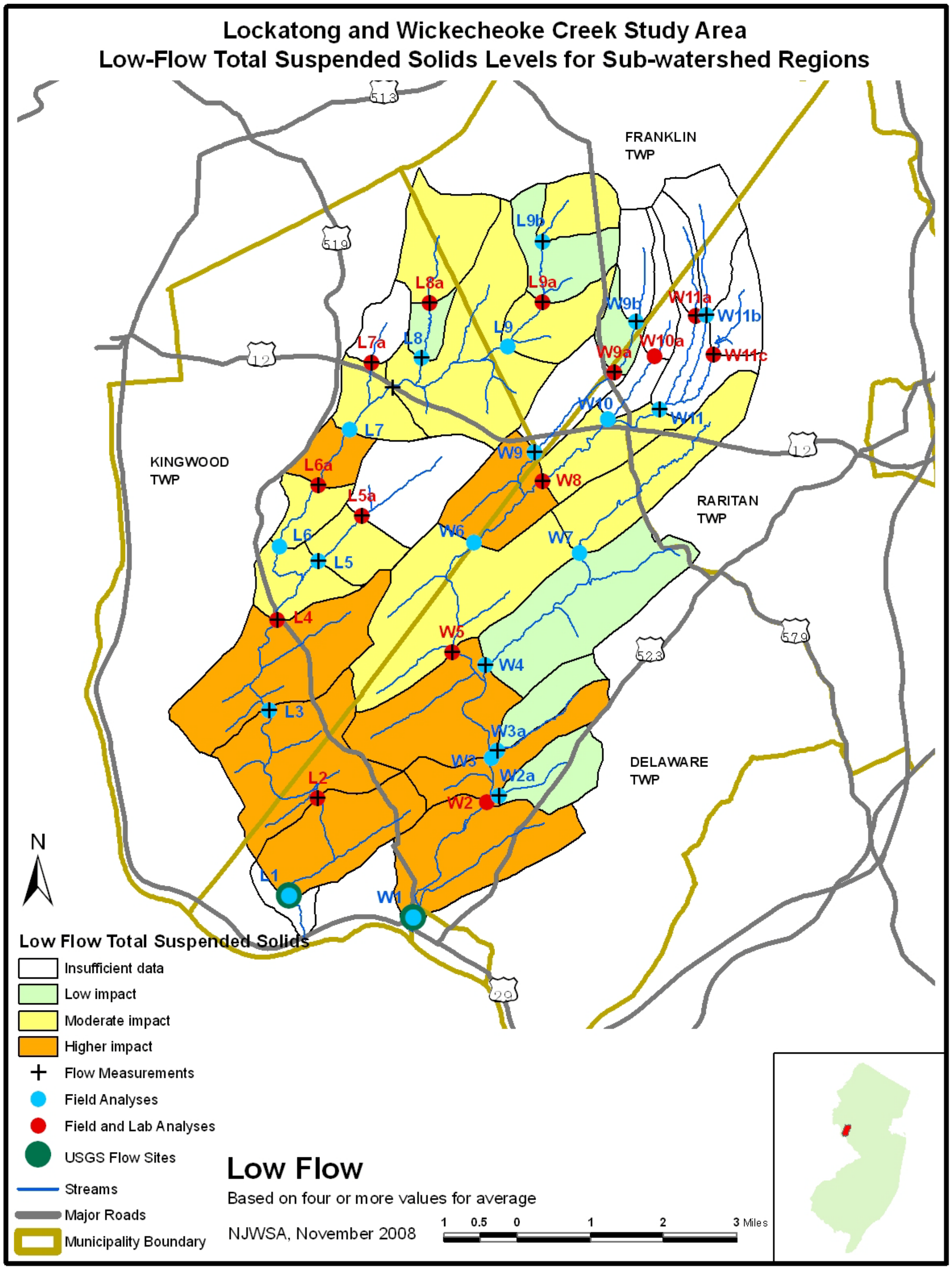
Lockatong and Wickecheoke Creek Study Area
Low-Flow Total Suspended Solids Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
L9b
L8a
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Low Flow Total Suspended Solids
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Moderate impact
Higher impact
Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
Streams
Major Roads
Municipality Boundary
Low Flow
Based on four or more values for average
NJWSA, November 2008
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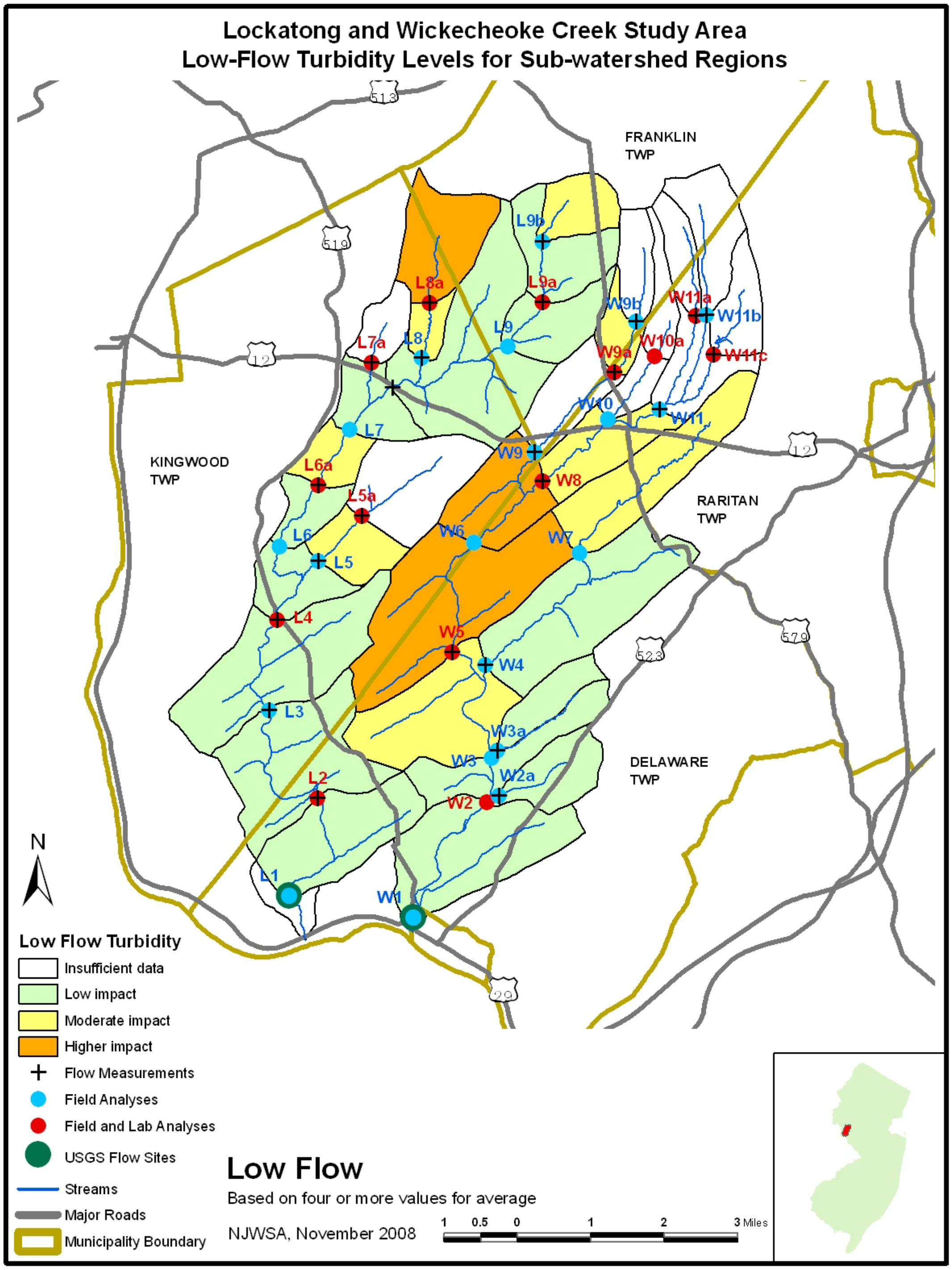
Lockatong and Wickecheoke Creek Study Area
Low-Flow Turbidity Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
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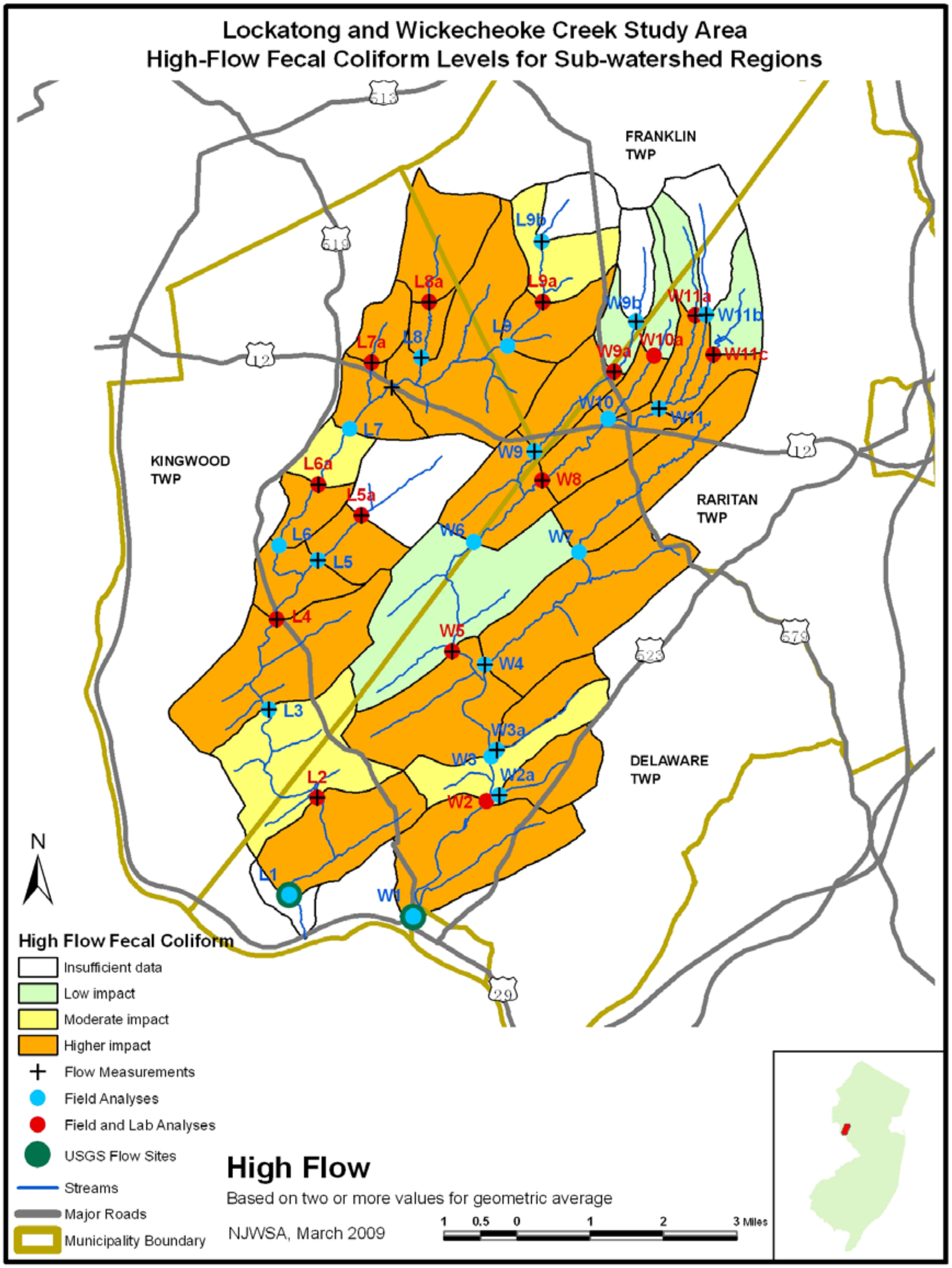
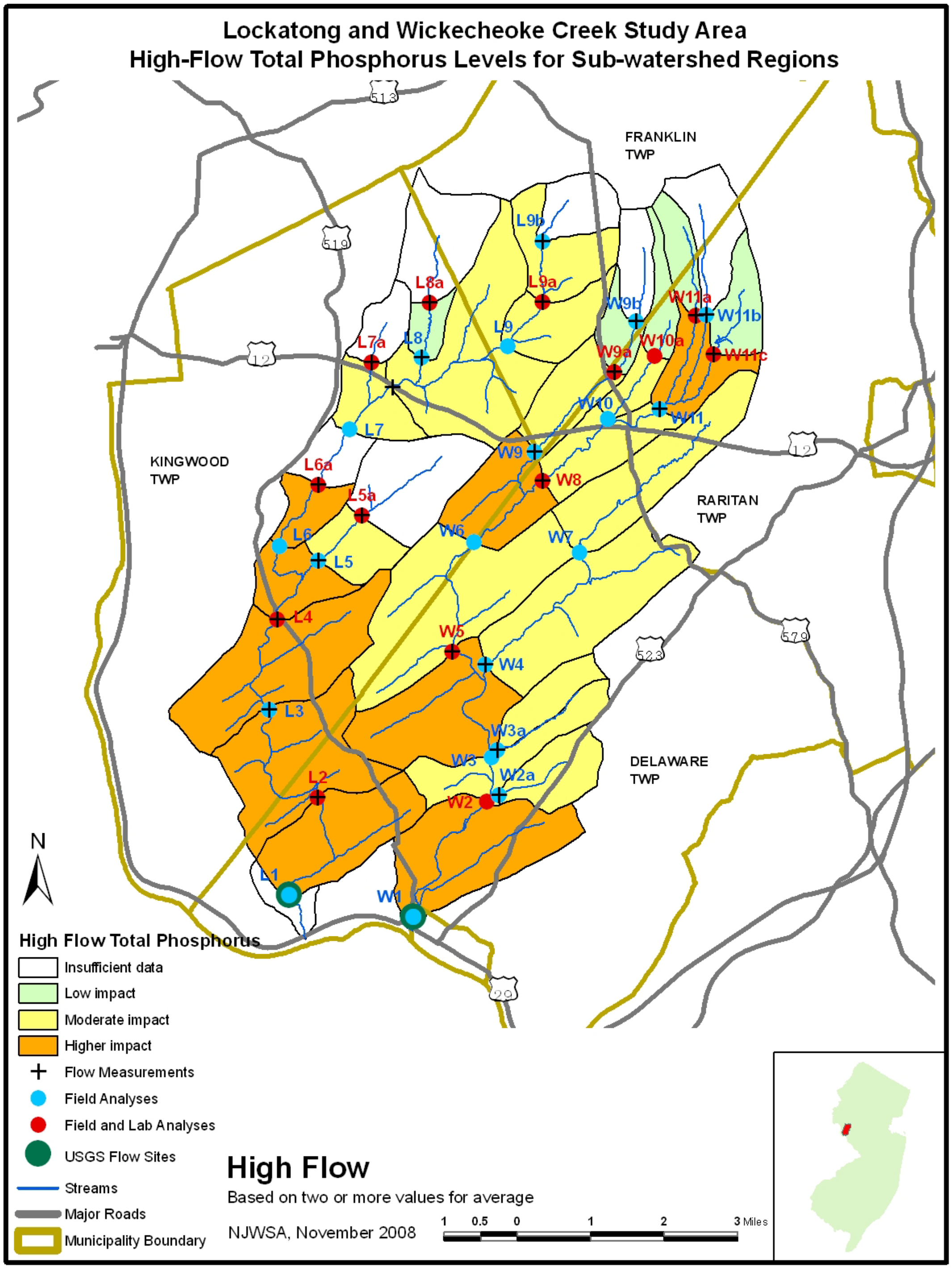
Higher impact
Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
Streams
Major Roads
Municipality Boundary
Low Flow
Based on four or more values for average
NJWSA, November 2008
1 0.5 0 1 2 3 Miles

Higher-Flow Results

(Relative impact assessment using average concentration and loading, where available)




Lockatong and Wickecheoke Creek Study Area
High-Flow Total Phosphorus Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
L9b
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High Flow Total Phosphorus
Insufficient data
Low impact
Moderate impact
Higher impact
Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
Streams
Major Roads
Municipality Boundary
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Based on two or more values for average
NJWSA, November 2008
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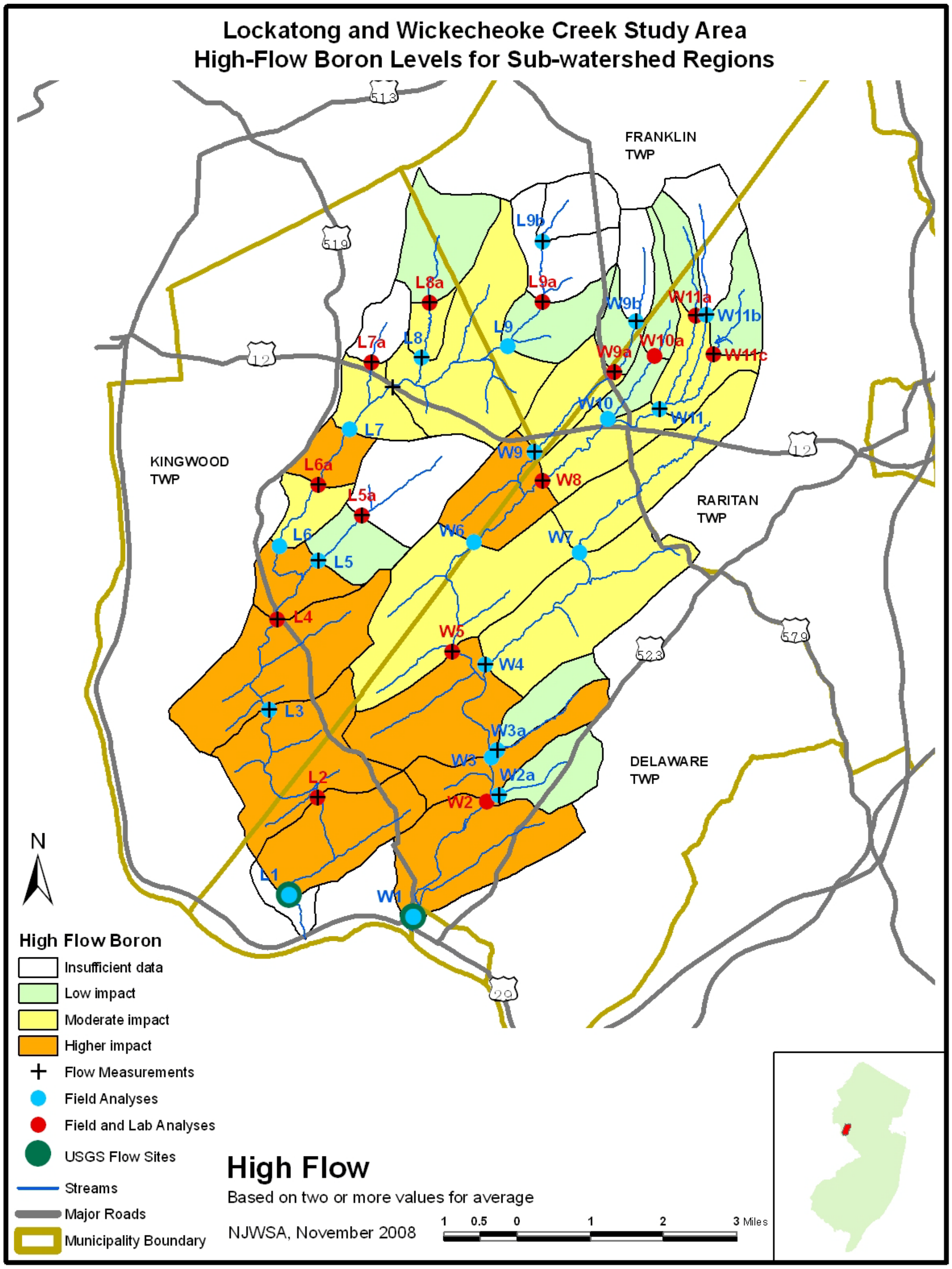
Lockatong and Wickecheoke Creek Study Area
High-Flow Boron Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
High Flow Boron
Insufficient data
Low impact
Moderate impact
Higher impact
Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
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Based on two or more values for average
NJWSA, November 2008
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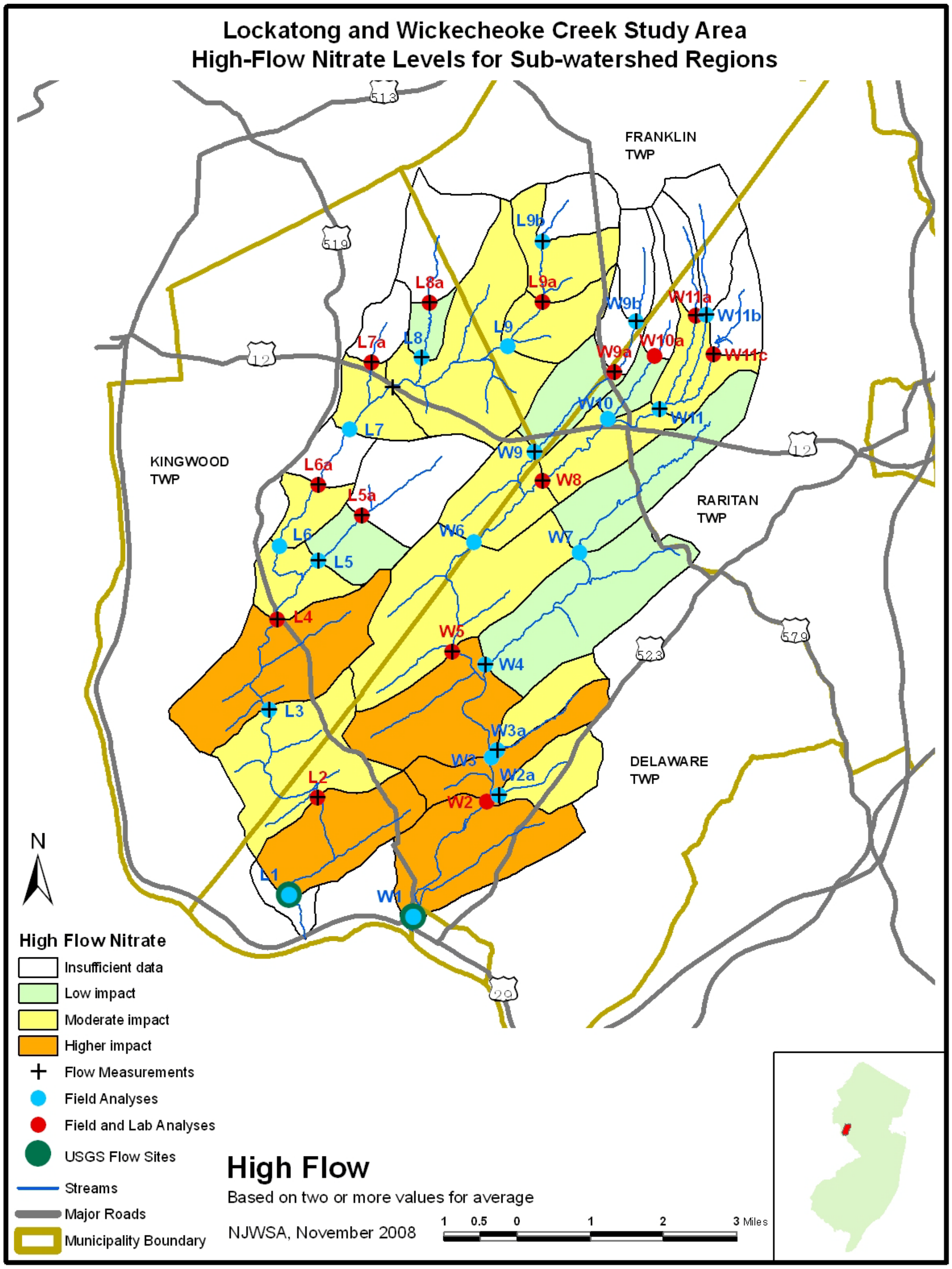
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High-Flow Nitrate Levels for Sub-watershed Regions
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RARITAN TWP
DELAWARE TWP
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Flow Measurements
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Based on two or more values for average
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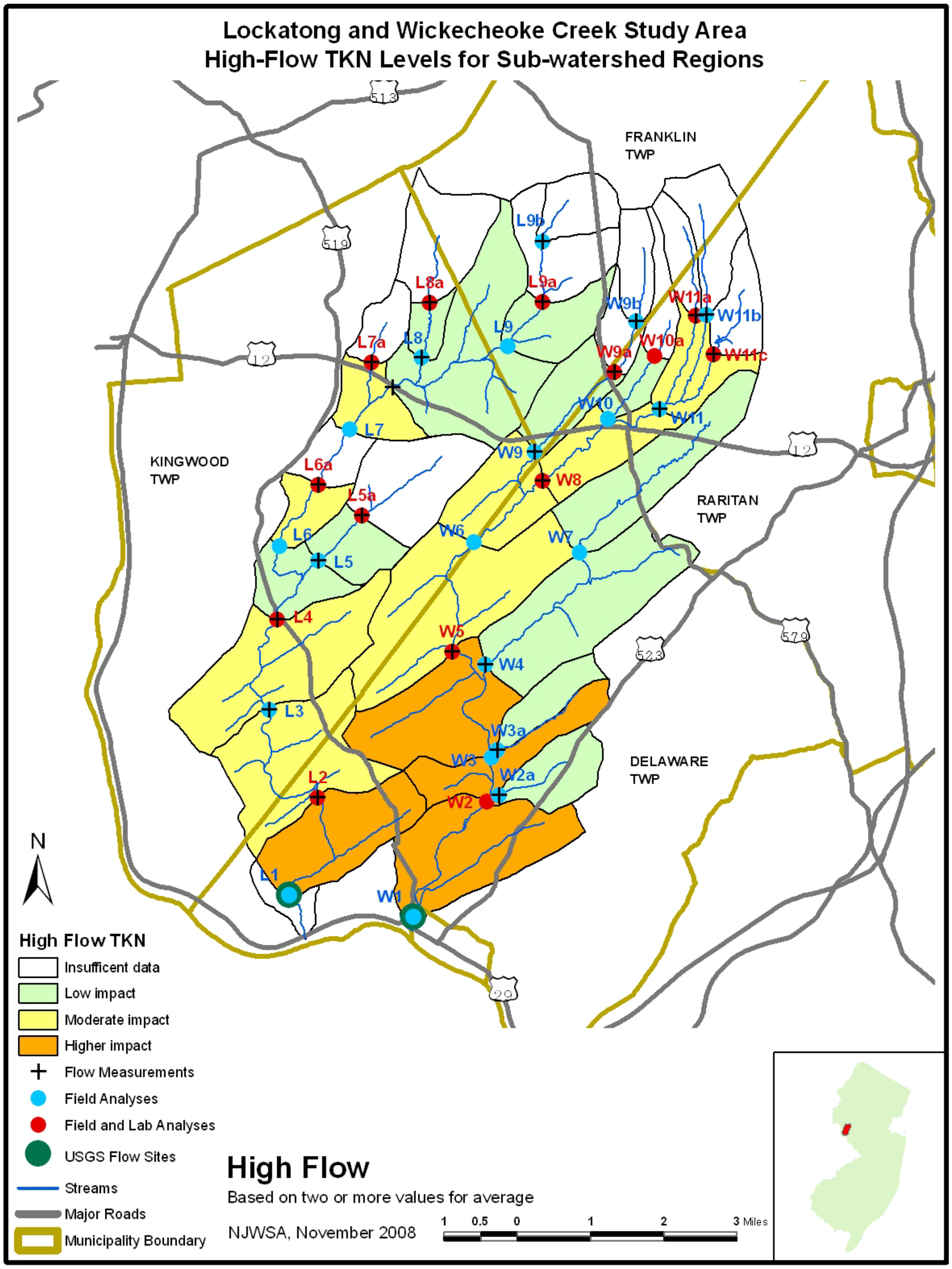
Lockatong and Wickecheoke Creek Study Area
High-Flow TKN Levels for Sub-watershed Regions
FRANKLIN TWP
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RARITAN TWP
DELAWARE TWP
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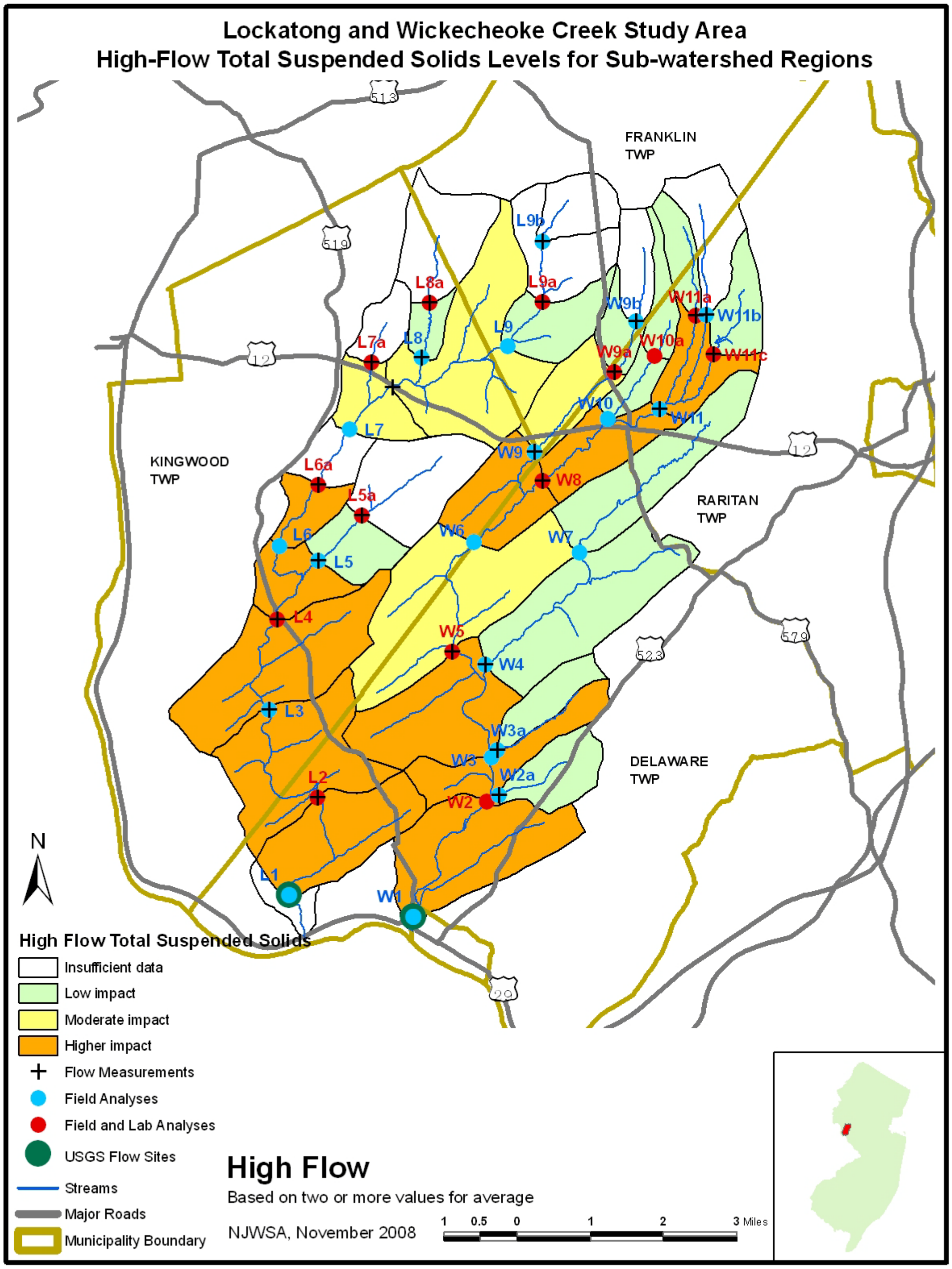
Lockatong and Wickecheoke Creek Study Area
High-Flow Total Suspended Solids Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
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Field and Lab Analyses
USGS Flow Sites
Streams
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Municipality Boundary
High Flow
Based on two or more values for average
NJWSA, November 2008
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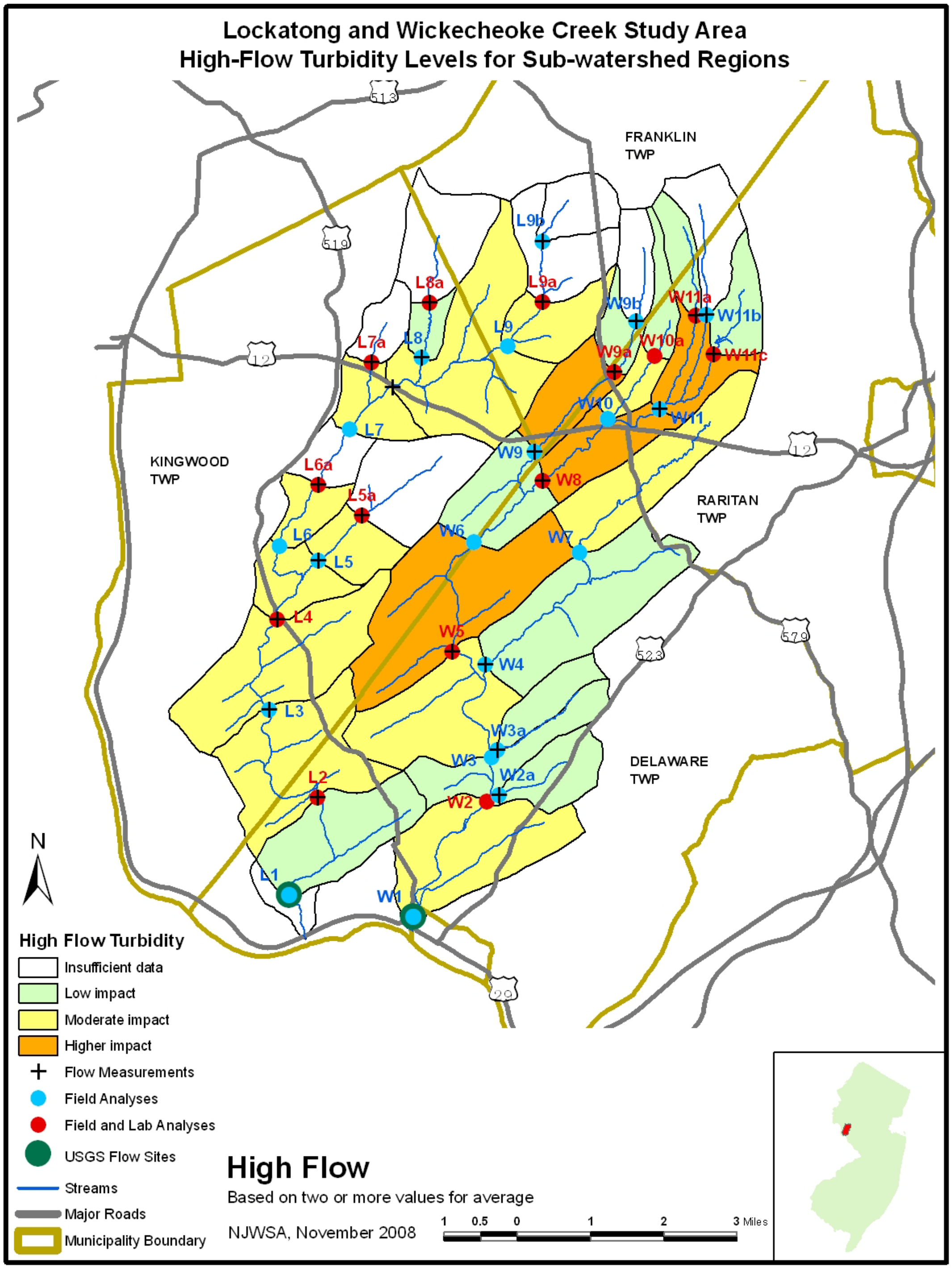
Lockatong and Wickecheoke Creek Study Area
High-Flow Turbidity Levels for Sub-watershed Regions
FRANKLIN TWP
KINGWOOD TWP
RARITAN TWP
DELAWARE TWP
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Flow Measurements
Field Analyses
Field and Lab Analyses
USGS Flow Sites
Streams
Major Roads
Municipality Boundary
High Flow
Based on two or more values for average
NJWSA, November 2008
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Appendix D

Comparison of Implementation-Project Effectiveness

Potential stormwater contaminant and quantity reductions, and estimated unit cost, for watershed remediation/protection projects.

Watershed-Wide Restoration Projects	Priority	Water Quantity	Water Quality	Infiltration	Erosion Reduction	Annual Runoff Reduction	Annual Load Reduction	Cost Estimate
Rehabilitation of Preserved/Conservation Lands	High	X	X	X	X	412,000 gal/acre for 1.25" or less rain events	1.3 lb/acre TP; 300 lb/acre TSS	$50/acre
Agricultural Runoff Remediation, Franklin Twp	High	X	X	X	X		1.3 lb/acre TP; 300 lb/acre TSS	$6,200 - $7,700/acre
Roadside Drainage Design/Retrofit Training	High	X	X		X	304,000 gal/mi for 1.25" or less rain events	Up to 150 lb/mile TP[1]; Up to 14 tons/mile TSS[2]	$337/mile
Targeted agricultural assistance program	High		X				11.6 lb/acre TP; 2,100 lb/acre TSS	$170/acre
Bioretention Applications – Recreational Areas and Private/Public Lawns	High	X	X	X	X	350,000 gal/acre for 1.25" or less rain events	1.26 lb/acre TP;179 lb/acre TSS	$8,400 - $15,400/acre
Rain gardens	High	X	X	X	X	19,600 gal/acre for 1.25" or less rain events	0.03 lb/acre TP 4.8 lb/acre TSS	Up to $5.50/sq ft
Update BMP manual for local soil and geologic conditions	High	X	X	X	X	638,000 gal/acre[3] for 1.25" or less rain events	Up to 0.6 lb/acre[3] TP Up to 77 lb/acre[3] TSS	$21/acre[3]
River-Friendly Farms Certifications	High	X	X		X	Pending existing controls	Up to 1.3 lb/acre TP Up to 300 lb/acre TSS	$190/acre
Watershed Hydrogeologic Study	High	X	X					$168,000

Site-Specific Projects	**Priority**	**Water Quantity**	**Water Quality**	**Infiltration**	**Erosion Reduction**	**Annual Runoff Reduction**	**Annual Load Reduction**	**Cost Estimate**
Del Twp Municipal Garage Retrofit - Rain Garden and Bioretention Swales	Moderate	X	X			7,500 gal/1,000 ft^2 for 1.25" or less rain event	Up to 3.1 lb TP[4] Up to 530 lb TSS[5]	$185,000 total Or, $28,500/acre
Sergeantsville Firehouse Parking-Lot and Municipal Park Retrofit	Moderate	X	X			300 gal/1,000 ft^2 for 1.25" or less rain event	Up to 1.1 lb TP[4] Up to 180 lb TSS[5]	$64,000 total Or, $40,000/acre
Vehicle Maintenance and Storage – SW of Pine Hill/Old Mill Road intersection - Bioretention Swales and check dams	Moderate	X	X[6]			480 gal/1,000 ft^2 for 1.25" or less rain event	Up to 3.8 lb TP[4] Up to 360 lb TSS[5]	$119,000 total Or, $66,100/acre
Roadway Drain Retrofits								
Barbertown-Pt Breeze Road at Fitzer Road intersection, Kingwood Twp	Moderate	X	X	X	X	15,000 gal/300 feet @ 20% retainment using 1.25" event	0.4 lb TP 41 lb TSS	$73,000
Pine Hill Road, Delaware Twp – mid section of approx. 1,250' drains directly to Wickecheoke Creek (see map)	High	X	X		X	205,000 gallons @ 20% retainment using 1.25" event	2.1 lb TP 200 lb TSS	$230,000
Rt 579 just south of Oak Grove Road, Franklin Twp	Moderate	X	X	X	X	15,000 gal/300 feet @ 20% retainment using 1.25" event	0.4 lb TP 41 lb TSS	$101,000

Roadway Drain Retrofits	Priority	Water Quantity	Water Quality	Infiltration	Erosion Reduction	Annual Runoff Reduction	Annual Load Reduction	Cost Estimate
Goose Island Road at W9a, Raritan Twp	Moderate	X	X	X	X	15,000 gal/300 feet @ 20% retainment using 1.25" event	0.4 lb TP 41 lb TSS	$120,000

[1] Based on 0.55% ratio of TP to TSS (Lock/Wick Monitoring Report)
[2] Based on up to 80 percent reduction in TSS (NJSW BMP manual), and loading estimate by NRCS
[3] Impervious land cover
[4] Based on up to 50 percent reduction in TP (NJSW BMP manual)
[5] Based on up to 90 percent reduction in TSS (NJSW BMP manual)
[6] Stormwater runoff may contain metals and other constituents

Appendix E

Responses to Comments Received From NJDEP

Comment: In the characterization and assessment section the Municipal Ordinance assessment is still blank and labeled "In Progress"; as is the Build out Analysis. These sections need to be completed in the Final version.

Response: Narrative was amended to reflect these changes.

Comment: The contract specifies Estimates of Load reductions from Management Measures (page 2 scope of Work). "HUC 17 loading estimates will be provided, with breakdowns by land use type, and BMP category, so that a full understanding of the load reductions can be gained. The load estimates and reduction analyses will be preformed using BASINS, USEPA's modeling platform" please outline where in the report is this information.

Response:

HUC 17 Delineation

The study plan had described the delineation of sub-watersheds as HUC17s. A mapped delineation as a GIS layer was acquired from USGS, but no attributes for characterizing or defining HUC17s was available (personal communication with NJGS and USGS). Therefore, the original reference to HUC17 was considered a typographical error. The project study areas were further segmented to an average sub-watershed size of approximately 1.25 mi^2, providing a much smaller scale for water quality and quantity assessments. The mapped HUC17s presented 13 sub-watershed areas, whereas the project sub-watershed sizes provided 35 sub-areas for assessments, nearly 3 times the coverage of the HUC17s.

BASINS Modeling System

In 2006, the BASINS modeling system was undergoing extensive modifications to enable it to compensate for the changed programming language from ArcInfo 3.1 to ArcGIS 8.0, from Avenue language to Visual Basic language. A beta version update to the system was completed by EPA in 2007 for integrating PLOAD and HSPF (Hydrological Simulation Program Fortran) with ArcGIS. The BASINS system was undergoing testing and further adjustments at that time. The Lockatong and Wickecheoke Creek Watersheds Project used loading estimates for existing and build-out land use and cover based on the PLOAD model technique. The “Export Coefficient Method,” of the PLOAD model was used to estimate total phosphorus, total suspended solids, and total nitrogen loading for existing land uses and cover versus possible future changes to these uses and cover. The use of this model and the application of the Flow Integrated Reduction of Exceedances (FIRE) method for determining total phosphorus load reductions in each HUC 14 were consistent with the techniques used to develop the total phosphorus TMDLs.

The Natural Resources Conservation Service (NRCS) used their RUSLE (Revised Universal Soil Loss Equation) model to predict soil loss from agricultural fields and an empirical model to estimate loadings from road runoff and stream-channel erosion.

Although HSPF can be used to simulate projected changes to water quality and quantity from land use changes, the program requires extensive hydrological and water quality data, including ground water conveyance and quality. Interconnected fractures in the watersheds create a very heterogenous water conveyance system that requires a more extensive study of the ground water hydrology to properly model any interactions between surface and ground water.

Since more than 37 percent of the watersheds land use was agriculture and approximately one third was forested, the Natural Resources Conservation Service applied results from the NRCS Sediment, Erosion, and Animal Waste (SESAW) Study to determine sheet and rill erosion, in addition to the RUSLE model to determine sediment loading potentials from cropland. An empirical relationship was used for estimating sediment loads from erodible stream banks. A GIS analysis was performed to determine the amount of imperviousness due to roadways. Layman's Guide to Access Road Construction: Design Guidelines was combined with information from each municipality including the application of deicing materials to estimate the amount of sediment loss from road surfaces within the watersheds.

The average size of sub-basin areas that were monitored during the project for flow and water quality was approximately 1.25 mi2. This scale of watershed segmentation provided a good measure of existing loadings, enhancing the isolation of possible source(s) of contamination. Sub-basins were ranked for remediation using the measured pollutant concentrations and loads. Most pollutant loads were widespread throughout the watersheds due to the diffuse nature of land uses. Discrete remediation projects, with a few exceptions, targeting individual subwatershed areas may not provide adequate enhancements to either water quality or flow since the problem sites/sources are widespread in the rural watersheds. Although several site-specific remediation projects are listed for implementation, watershed-wide projects must be implemented to control the existing effects of stormwater.

Comment: On page 8 of the scope of work under the Watershed Restoration and Protection Plan section: "the plan will include a priority system and a ranking for implementation of the recommendations, using a combination of cost effectiveness ,availability of funding, potential for modification of existing practices and the degree of certainty that a practice will be implemented." Please outline where this information can be found

Response: Narrative was amended to reflect these changes in **Appendices B and D** of the *Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan*.

Comment: In the section of Recommended Watershed-Based Implementation projects, the identified projects need more information. We were hoping that they would have the detail that was provided in the Mulhockaway plan that was submitted by the NJWSA. Many of the projects outlined do not include specific site locations, this makes me wonder how you can provide an estimate of tons per year of reduced erosion, if you do not have the project sites identified. Please provide specific locations with an estimate of load reductions per site and BMP measure. Below are some examples of projects listed without supporting information.

Response: Narrative was amended to reflect these changes in **Appendix B** of the *Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan*.

Comment: On page 3 in the section titled Recommended Watershed-based Implementation projects; Project name- Rehabilitation of Conservation Lands - The location and size of each parcel needs to be Identified; along with the specific BMP measure to be utilized and the associated anticipated benefits per location. Also please give an estimated cost per location.

Response: Narrative was amended to reflect these changes in **Appendix B** of the *Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan*.

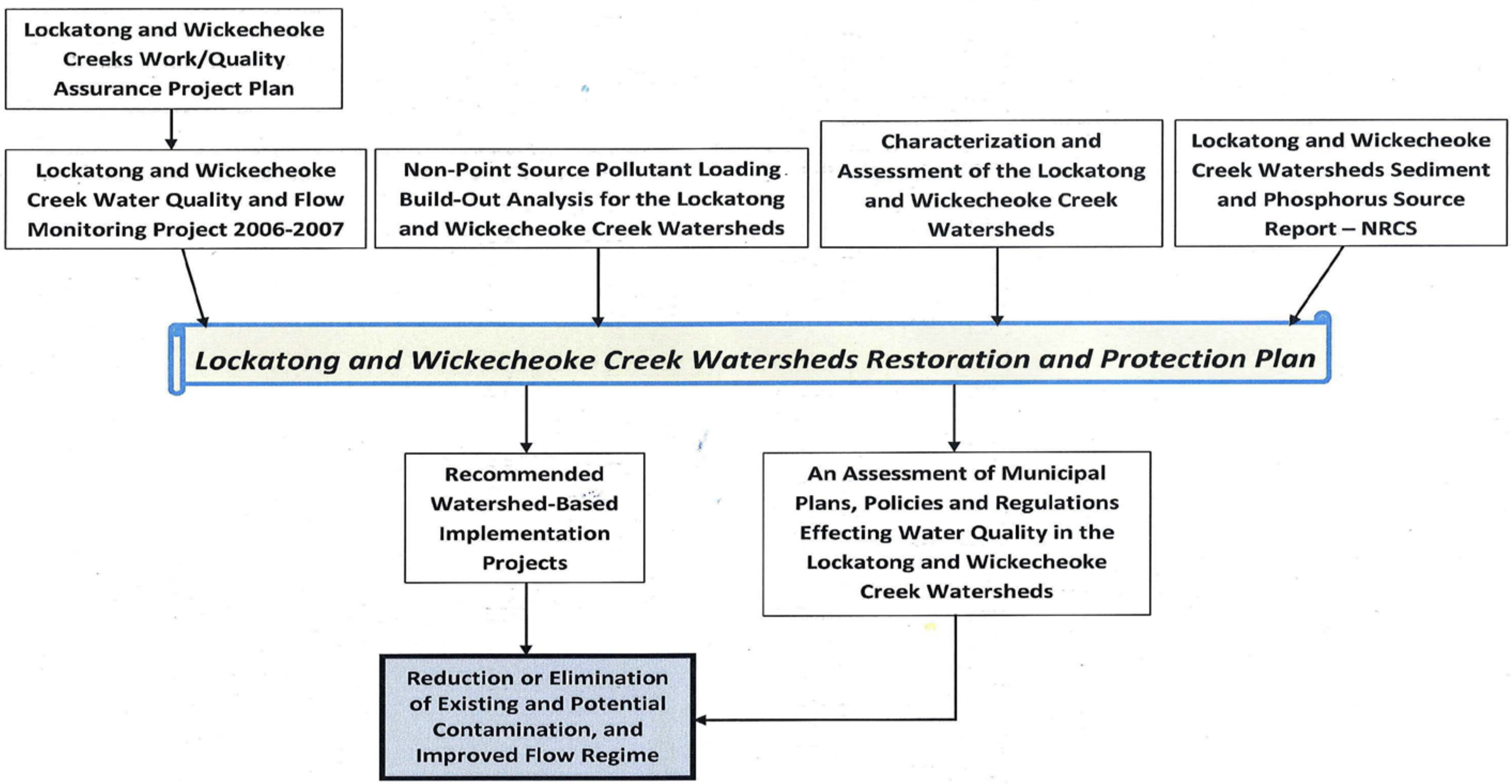
Comment: On page 5 the Roadside Drainage Design/Retrofit Training project; please specify where the retrofits are to be located and what methods at each location are going to achieve the stated sediment loading reduction by 3/4. Please detail what the" innovative strategy to reduce roadway sediment loads" is, i.e. please list specific methods/BMP's are to be used to reduce the sediment loadings. Also please list the cost per site.

Response: Narrative was amended to reflect these changes in **Appendix B** of the *Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan*.

Comment: On page 11 the Streambank Stabilization Measures project; please specify where the stabilization projects are to be located besides the Kingwood Park location, also please include what type of stabilization methods are to be implemented at each site. Also include the anticipated loading reductions for each method per site and the associated cost per measure per site.

Response: Narrative was amended to reflect these changes in **Appendices B and D** of the *Lockatong and Wickecheoke Creek Watersheds Restoration and Protection Plan*.

Appendix F
Digital Copies (CD) and
Interrelationships of Watershed Reports



Reports located on NJ Water Supply Authority (Watershed Protection Programs Unit) website:
http://www.njwsa.org/WPU/lock_wick.htm