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Tracking the Fate of Watershed Nitrogen: The "N-Sink" Web Tool and Two Case Studies

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Tracking the Fate of Watershed Nitrogen: The "N-Sink" Web Tool and Two Case Studies

by

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Nitrogen is increasingly being identified as a pollutant of concern in both coastal and inland waters. In some areas, the majority of the nitrogen loading comes from wastewater treatment plants and/or combined sewer overflows. However, in less urbanized watersheds nonpoint source runoff and nitrogen from septic systems are the primary vehicles of nitrogen delivery. In these areas, watershed land use has a direct relationship with both sources and sinks of nitrogen.

The "N-Sink" tool was created to provide a useful and accessible tool for local land use managers to explore the relationship of land use in their towns and counties to nitrogen pollution of their waters. N-Sink uses the best available science on land use/nitrogen interactions, plus widely available basic datasets for hydrography, soils and land use, to highlight major sources and sinks of nitrogen within a watershed context.

N-Sink was originally designed as an ArcMap extension for use with desktop software, but during this project was redesigned as a geospatial web tool using ArcGIS Viewer for Flex. The tool highlights N sources and sinks within a watershed, and allows the non-technical user to estimate relative N removal efficiencies from any chosen location within the watershed. The project team used N-Sink to generate N source/sink information for two case study coastal HUC-12 watersheds, the Niantic River watershed in southeastern Connecticut and the Saugatucket River watershed in southern Rhode Island on the west side of Narragansett Bay. Next steps will include using N-Sink-generated information in educational programs for decision makers within the two watersheds. In addition, the team will explore the challenges and methods of making N-Sink a nationally available tool.

1.1 Purpose

Although nitrogen fertilization is vital to maintain a productive and vigorous food supply, excess reactive nitrogen (N) released to the environment causes deleterious effects on human and ecosystem health. In some areas, the majority of the nitrogen loading comes from wastewater treatment plants and/or combined sewer overflows. However, in less urbanized watersheds nonpoint source runoff and nitrogen from septic systems are the primary vehicles of nitrogen delivery. In these areas, watershed land use has a direct relationship with both sources and sinks of nitrogen.

In order to manage the widespread N pollution problem in watersheds it is critical for decision makers to have a strong technical grasp of the factors that control N sources, sinks (regions or areas that can retain N), and pathways along which nitrogen is moved and transformed (U.S. EPA 2011). Here we define landscape N sinks as areas where N cycling processes such as denitrification, as well as plant and microbial uptake remove, bury or sequester N, thereby reducing downstream N transport. Denitrification removes N permanently, while burial and sequestration are not permanent but represent long-term storage of N.

The "N-Sink" nitrogen management tool is different from other N transportation models in several ways. First, N-Sink focuses on sinks rather than sources. Instead of estimating N loading from land use and runoff data, N-Sink estimates N attenuation along a flow path from source to receiving water. This directs the focus of decision makers on landscapes that might be valuable to preserve in the future, rather than just source areas than need to be addressed in the present. Second, N-Sink is designed to use widely available national datasets as its input, rather than rely on potentially more accurate field derived data. N-Sink is intended as a decision support tool for widespread and easy use, not a state-of-the-art model. N-Sink does, however, use state-of-the-art techniques when it comes to the actual use of the tool for decision support. It is configured as a web tool, relatively self-explanatory and accessible to anyone with internet access.

In summary, N-Sink has been designed based on the best available science, but with the explicit goals of communicating information to decision makers in an accessible and understandable manner (U.S. EPA 2012). This paper describes the development to date of this effort.

1.2 Nitrogen and Coastal Watersheds

Nitrogen pollution is emerging as a major threat to coastal watersheds, estuaries and embayments, and the communities within their watersheds. Nitrogen loading to coastal waters can spur harmful algal blooms, hypoxia, decline of eelgrass, and destruction of critical spawning habitats in coastal waters (Valiela et al. 1990; Oviatt et al. 1995; Nixon 1995; Short and Burdick 1996; NRC 2000; Nixon et al. 2001; Conley et al. 2009). Coastal communities in New England and along the entire East Coast of the Atlantic [e.g., Long Island Sound, CT (NYDEC and CTDEP 2000); Cape Cod, MA (MA DEP 2008); Pawcatuck River, RI (RI DEM 2010); Christina Reservoir, ME (ME DEP 2010); Neuse River estuary, NC (NC DENR 1999; Stow et al. 2011)] have been forced to address N pollution as a result of state and federal water quality programs such as TMDLs (Total Maximum Daily Loads) that can mandate community investments in N controls.

The sources, sinks, and conveyance of N are highly landscape and hydrology dependent. N export from urban and suburban watersheds is much higher than from forested watersheds, although lower than from agricultural watersheds (Groffman et al. 2003). High concentrations of nitrate in shallow groundwater and streams are correlated with agricultural land use and unsewered residential developments (Nowicki and Gold, 2008). Sink areas include wetlands (characterized by hydric soils), reservoirs, small-order streams and impoundments (Groffman et al., 2003). In particular, riparian wetlands can be a significant sink for N due to the combination of surface filtering of sediments, plant and microbial uptake, and subsurface denitrification (Gold et al., 2001). Studies in both urbanizing (Kaushal et al. 2008) and agricultural (Clausen et al. 2000) watersheds have demonstrated that riparian restoration can reduce the delivery of nitrogen to streams.

1.3 Land Use Decision Makers and Geospatial Technology

The N-Sink tool is based on the premise that local decision makers require environmental data that is highly localized, easily accessed and immediately understandable (Last 1995; Merry et al. 2008a). Since N sources and sinks are so closely linked to land use, land use decision makers are a critical audience for tools that can translate science into management-relevant information. The primary purpose of the work described in this paper is to incorporate scientific understanding of land use and nitrogen cycling relationships into practices that local land-use decision makers can adopt and act upon to support sustainable and healthy communities. To optimize N control strategies for coastal waters, it is important for land use managers to recognize that N delivery is linked to areas that serve as sources and sinks within their watersheds.

Most land use decisions are made by volunteers – elected officials or appointed members of planning, zoning and appeals boards – most of whom have little or no training in land planning or natural resource protection (Arnold 1999; Gold and Joubert 2007). Few have training in watershed management and water quality issues (Arnold 1999), and most do not have the time to become experts on all water-related topics of concern in their communities such as stormwater, sediment, nonpoint source pollution, etc. This extends also to the professionals (e.g. planners, engineers) that support these volunteers in the towns lucky enough to have this capacity.

Thus, community decision makers often have no way in which to factor N pollution into their land use policies and decisions. A tool that combines maps and local data related to N source and sink potential can be extremely useful in helping land use managers identify areas that could benefit from source controls, as well as areas that serve to reduce N delivery downstream and thus should be targeted for protection and restoration.

Geospatial tools, based on geographical information systems (GIS), geographic visualization, exploratory data analysis tools, and spatial statistical analysis and modeling (Armstrong 1992), provide new opportunities to help land use managers improve their access to, and use of, watershed science to make wise land use decisions. Remotely sensed land cover data, placed in a GIS environment in combination with other natural resource data, has been used effectively to inform land use decisions in Connecticut and elsewhere (Wilson et al., 2011; Arnold et al. 2000). Merry et al. (2008a and b) found that digital maps and GIS databases were the preferred way to view land use change data among Extension professionals and land use planners. GIS-based tools have improved the capacity of local decision makers to examine and compare the cumulative impacts of a variety of alternative decisions (Cova and Church 1997; Davis and Keller 1997; Thumerer et al. 2000; Tulloch et al. 2003; Lant et al. 2005;

Brown 2006). Combining data management capabilities, display functions, and modeling tools generates a more robust and sophisticated means for problem evaluation and resolution (Carver 1991).

The increasing "fusion" of geospatial and internet technologies has opened up an even wider range of possibilities for decision support and information-sharing, allowing the creation of web-based tools that require no geospatial expertise to use (Dickson et al., 2011; Dickson and Arnold, 2009; Rozum et al. 2005).   For this reason, a web-based platform is the goal of this project.

2.0
The N-Sink Tool

2.1 Overview

N-Sink estimates the extent of N delivery from a source area, such as unsewered residential development, croplands or livestock areas, to a watershed outlet. Land cover and N movement relationships taken from the scientific literature are used to identify N source and sink areas, and to roughly quantify their impact on the N budget.

N-Sink uses the particle tracking capabilities provided by data from NHDPlus v2 to estimate flow paths from source areas to a watershed outlet. The focus is on examining the landscape N sinks (streams, ponds/lakes, and wetlands) that are encountered along a flow path to estimate incremental N removal based on sink characteristics such as wetland size, stream reach length, and pond area (Figure 1). More detail can be found in Section 2.3.

There are a variety of tools currently available on the web to estimate N delivery from a watershed. Examples include L-THIA, focused on the mid-West, (*https://engineering.purdue.edu/~lthia/*), and NLoad (*http://nload.mbl.edu/*). Both of these tools provide important services to the decision-making community. N-Sink builds on this foundation and seeks to improve upon these tools by using flow path analysis to understand the spatial relationships between N sources and sinks on the landscape. Other web-based tools generally use a lumped sum approach to estimate N delivery from a watershed or user-defined area, summing contributions from different land use/soils combinations, but ignoring location within a hydrologic context. N-Sink's unique approach allows users to better understand how landscape sinks contribute to N removal and to
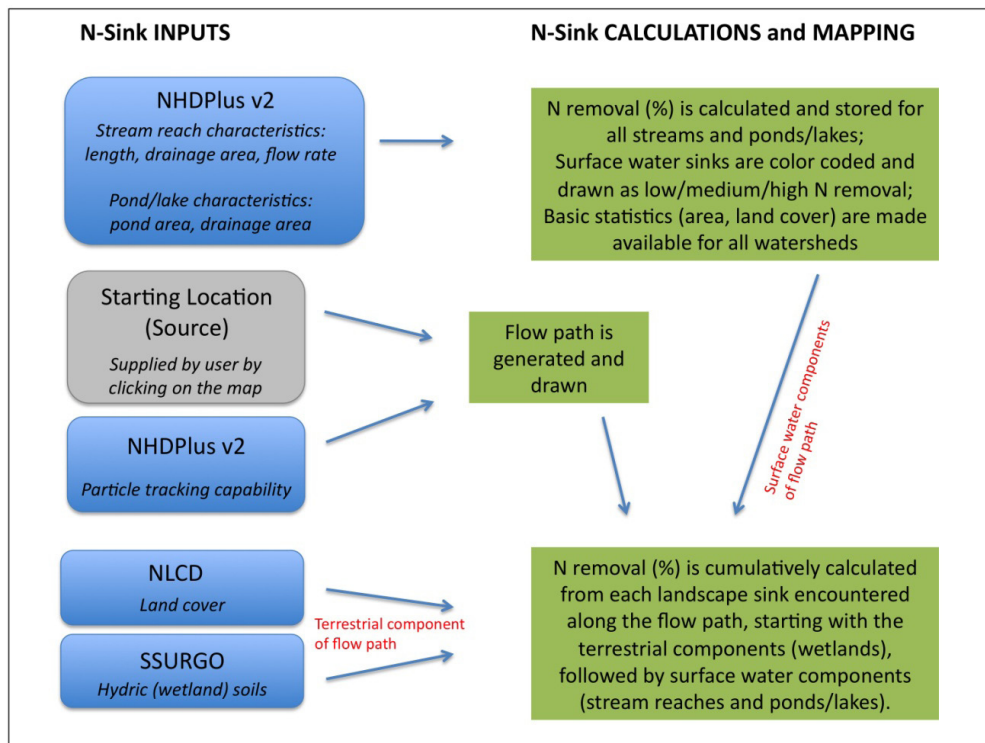

Figure 1. *Conceptual diagram of N-Sink*

compare N delivery to a receiving water body from different source locations.

The prototype for N-Sink, created by the University of Rhode Island in partnership with Arizona State University and the University of Connecticut, was supported by both USDA and EPA. The prototype was originally planned and designed as an extension to be used with ArcMap desktop GIS software (Kellogg et al., 2010). During the current project, supported by U.S. EPA's Nitrogen Management Group as part of the Sustainable and Healthy Communities program, N-Sink has been transformed into a web-based tool using ArcGIS Viewer for Flex.

ArcGIS Viewer for Flex is a configurable web mapping application that can be used to create customized interactive maps on the web. The Viewer is built using the ArcGIS API for Flex and utilizes Adobe's Flash browser plugin. The N-Sink web tool includes basic Flex "widgets" that make the web tool easy and efficient to use. These allow a map reader to control the visibility of data layers, draw and measure features on the map and view the map legend. At the center of the N-Sink web tool is the Nitrogen Removal widget. This widget allows a map user to click on any location within a watershed and retrieve the estimated relative nitrogen removal efficiencies from that location. The data is processed on the back end of the tool through a geospatial model created in Modelbuilder for ArcGIS and published as a geoprocessing service using ArcGIS Server. See Appendix C.

2.2 Data Used and Calculations Performed

In the tool, nitrogen removal from sink areas is based on a wide range of published studies. Some guiding principles in N-Sink (Kellogg et al. 2010) are listed below. See also Section 2.3 for a more complete explanation of the scientific basis for N-Sink calculations.

- Riparian zones are more effective sinks with hydric soils (Lowrance et al. 1997; Gold et al. 2001) and the extent of the riparian sink can be related to the width of the vegetated hydric soils (Mayer et al. 2007);

- The extent of the sink potential of lakes and reservoirs is higher with longer retention times and shallower depth (Seitzinger et al. 2006; David et al. 2006). Similarly sized lakes with relatively smaller drainage areas will have longer retention times than those with larger drainage areas; and

- Stream depth is also critical in assigning N removal potential in stream reaches, with more N being removed in shallower streams with longer retention times (Alexander et al. 2007).

N-Sink was developed using widely available national databases in order to provide broad applicability. These data are listed in Table 1 and include:

- Topography, hydrography and watershed boundaries (NHDPlus v2, an integrated geo-spatial dataset that incorporates the National Hydrography Dataset (NHD), the National Elevation Dataset (NED) and the Watershed Boundary Dataset (WBD). From EPA, with assistance from USGS)

- Soils (SSURGO, Soil Survey Geographic Database. Soil maps and tabular data with information on soil properties and uses, covering most of the US. From USDA/NRCS)

- Land cover (National Land Cover Dataset, Landsat-based land cover data, organized by class and including descriptive data; multi-agency consortium)

Table 1. Databases used in N-Sink.

Type of Data	Source of Data	Resolution of Data
Hydrography, Topography and Watershed Boundaries	NHDPlus v2(*www.horizon-systems.com/NHDPlus/index. php*), incorporating the National Hydrography Dataset (NHD; *http://nhd.usgs.gov*), National Elevation Dataset (NED; *http://ned.usgs.gov/), and the Watershed Boundary Dataset (WBD; http://www.nrcs.usda.gov/wps/portal/nrcs/ main/national/water/watersheds/dataset/)*	10 m
Soils	Soil Survey Geographic (SSURGO) Database *http://soils.usda.gov/survey/geography/ssurgo/*	1:15,840
Land use	2006 National Land Cover Data (NLCD 2006) *http://www.mrlc.gov/nlcd_2006.php*	30 m

NHDPlus v2 is an integrated suite of geo-spatial datasets that combine features of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), and the Watershed Boundary Dataset (WBD). The flow direction data from NHDPlus v2 are the basis for particle tracking, which allows the user to generate a flow path from any chosen point within a watershed to the watershed's outlet. This capability supports the Nitrogen Removal widget.

Ultimately, two types of N delivery information will be available to the user. One analysis, focused on highlighting N sinks and delivery, calculates the percent reduction of N from the source to the outlet. This is regardless of the magnitude of the source, and is meant primarily to give the user an understanding of the way N interacts with the various sinks (wetlands, stream reaches, ponds) along a flow path, and to allow analysis and comparison of various locations within the watershed. The delivery analysis is currently available in the beta version of the tool delivered with this report.

The second analysis, focused on loadings, will estimate the mass of N exported per unit land area per unit time (kg N/ha/yr) from source areas, based on land cover and standard data available in the literature on nutrient export coefficients (e.g., Beulac and Reckhow 1982). The user can choose a specific area and either use a pre-set 1-acre box, or a user-drawn polygon. The land cover within the area will be changeable, allowing the user to compare loadings of existing and proposed land cover. The loadings analysis is not yet available on the beta version but will be on the next version, which the authors hope to have out in early 2014.

2.3 Scientific Basis for N-Sink

Earlier work on the first (desktop) version of the N-Sink tool by URI and ASU is described in detail in Kellogg et al. (2010) and Kellogg et al. (2011). Excerpts from these two publications describing the basic science behind the N-Sink model assumptions are included here in adapted form.

2.3.1 Landscape N sinks

N-Sink identifies three types of landscape N sinks: freshwater wetlands, lentic water bodies (ponds, lakes, or reservoirs), and lotic water bodies (stream reaches). All landscape N sinks are characterized as having Low, Medium, or High potential for N removal, based on estimates calculated for each sink. Because each type of sink has a different range of N removal potential, we have currently chosen to create

break points for Low/Medium/High that differ for the three types (Table 2).

Table 2. N-Sink High/Medium/Low N removal designations for landscape N sinks

N Sink Type	% N removal		
	High	Medium	Low
Riparian Wetlands	> 60%	40 to 60%	< 40%
Pond/Lakes/ Reservoirs	> 50%	25 to 50%	< 25%
Stream Reaches	> 30%	15 to 30%	< 15%

For example, 30% removal would be considered High for stream reaches, but Low for riparian wetlands. This approach recognizes the inherent characteristics of the different types of sink that affect critical N removal factors, such as retention time. The breakpoints can be changed in future versions.

2.3.1.1 Freshwater Wetlands

Riparian wetlands have been identified by many researchers as a significant potential sink for nitrogen. Mayer et al. (2007) performed a meta-analysis on data available in the scientific literature, based on a wide range of field studies, to identify trends between riparian N removal efficiency and riparian buffer width, surface vs. subsurface flow, and vegetation.

Using widely available GIS data, vegetation type and surface vs. subsurface processes cannot be readily identified. However, riparian land use and soils can be readily identified. It has been well documented that riparian zones are most effective as N sinks when undeveloped and vegetated, and relatively ineffective if hydrologically altered to bypass the riparian ecosystem through residential, agricultural or other types of development (e.g., Carpenter et al., 1998). Research also suggests that riparian wetlands, characterized by hydric soils, act as effective N sinks while riparian areas with non-hydric soils are less reliable N sinks

(e.g., Lowrance et al., 1997; Gold et al., 2001). Hydric soils provide conditions that favor microbial denitrification: high water table, low dissolved oxygen, and high soil organic matter to provide carbon as an electron donor.

N-Sink therefore uses a series of if/then statements to estimate riparian N removal efficiency. If land use is developed, then we assume no removal. If land use is undeveloped and soils are non-hydric, then we assume no removal. If riparian land use is undeveloped and soils are hydric (i.e., wetland soils), then N removal efficiency is based on the width of the undeveloped (vegetated) hydric soils (Table 3). Regression equations provided by Mayer et al. (2007) guide estimates of N removal effectiveness in vegetated riparian areas as a function of wetland width. The selected width classes recognize commonly used regulatory limits. These estimates are comparable to estimates derived from field assessments that are used to direct management efforts in the Neuse River watershed (Osmond et al., 2008).

Table 3. N-Sink estimates of N removal based on width of riparian wetland

Riparian Land Use	Hydric Soil Status	Width (m)[a]	% N removal
Developed			0
Vegetated	Non-hydric		0
	Hydric	< 5	0
		5 to 15	40
		15 to 30	60
		> 30	80

[a] Width classes are based on current regulatory practices and are relevant to local decision-makers

2.3.1.2 Lentic Waterbodies: Ponds, Lakes and Reservoirs

Ponds, lakes and reservoirs are potentially large sinks for N because of their long retention times (Seitzinger et al., 2002, 2006; Harrison et al., 2009), and hypoxic and anoxic

benthic zones that provide conditions favoring denitrification. A linear regression analysis of lake and reservoir data from Seitzinger et al. (2002), representing a variety of lentic waterbodies, yields the following relationship between N removal and the ratio of reservoir depth, D [m], and residence time, T [years]:

$$\text{N removal (\%)} = 79.24 - 33.26 \times \log_{10}(D/T)$$

(1)

Average lake/reservoir depth can be expressed as volume, V [km^3], divided by surface area of the lake/reservoir, A_r [km^2]. Residence time, T [y], can be expressed as volume, V [km^3], divided by annual discharge, Q_{yr} [km^3 y^{-1}]. Thus,

$$D/T \ [m \ y^{-1}] = (V/A_r)/(V/Q_{yr}) \times 1000$$
$$= Q_{yr}/A_r \times 1000$$

(2)

In this Beta version of N-Sink, we obtain flow data from NHDPlus v2. GIS data also provide us with the lake surface area. Due to occasional water releases, reservoirs can be viewed as hydrologically distinct from lakes and ponds. Outflow from reservoirs can be regulated by dam(s), thereby shifting residence time from that expected for a natural lake based on drainage area. Because of the uncertainty associated with dam manipulation schedules, N-Sink treats reservoirs the same as lakes when characterizing N removal potential.

2.3.1.3 Lotic Waterbodies: Stream Reaches

The role of streams in watershed nitrogen dynamics has been the focus of intensive research, with early studies formulating the nutrient spiraling model (e.g., Newbold et al., 1981), which has since been used to assess in-stream denitrification (e.g., Royer et al., 2004). The wide range of observed nitrogen loss rates within streams has spurred research using both field experiment techniques and statistical approaches based on spatial data. The Lotic Intersite Nitrogen Experiment (LINX) has used N addition and isotopic analysis to explore the extent to which stream characteristics – hydrodynamic, chemical, and metabolic – might explain the wide variation among streams in nitrogen uptake, removal and cycling.

Alexander et al. (2000) developed a hybrid statistical/mechanistic mass-balance model to estimate N flux in the Mississippi basin (SPARROW – SPAtially-Referenced Regression On Watershed attributes), correlating observations of stream N flux with spatially referenced N sources and physical characteristics of the landscape and water bodies. Regression results showed that N loss rates were inversely related to stream depth and that much of the N removal in streams was occurring in lower order reaches. They concluded that the proximity of N sources to higher order streams and rivers is an important factor in N delivery to the Mississippi basin outlet. Recognizing the variability of stream function among different regions of the U.S., SPARROW has since been developed for other parts of the country, including New England (Moore et al., 2004). An important result of the New England modeling effort was the lack of statistically significant annual modeled N reduction for streams with flows greater than 2.83 m^3 s^{-1}, highlighting the importance of lower-order streams in mitigating watershed N export.

Alexander et al. (2007) further refined this New England SPARROW model to investigate and quantify the influence of headwater streams of the northeastern U.S. on N delivery to downstream waters. The extent of N removal and cycling in streams, including the permanent removal of N via denitrification, is limited by the extent of interaction with the stream channel and hyporheic zone, both of which decrease with increasing stream order and drainage area. Alexander et al. (2007)

incorporated what was currently known about N transport to arrive at an expression for the fraction of N transported along a stream reach as a function of stream characteristics. We used this expression as follows:

$$N\ (\%)\ \text{removed along stream reach}$$
$$= (1 - \exp(-\theta_{S1} D^{\theta_{S2}} T)) \times 100$$

(3)

where
$\theta_{S1} = 0.0513$ m d^{-1}, $\theta_{S2} = -1.319$, D = water depth [m], and T = time of travel [d].

Water depth, D, is expressed as a function of mean annual stream flow, Q [m^3 s^{-1}] (Alexander et al., 2000):

$$D = 0.2612\ Q^{0.3966}$$

(4)

This expression originates from Leopold and Maddock (1953) with flow data from 112 streams in the South and MidWestern U.S. Kellogg et al. (2010) used similar methods to examine the appropriateness of this expression to estimate stream reach depths in southern New England and found close agreement (within 10%) when Q is less than 10 m^3 s^{-1}. N-Sink therefore uses Equation 4 to estimate stream depth because it is based on a larger sample of streams that encompasses a wide range of geographic settings and is in line with widely-used relationships.

Mean travel time, T [d], along a given stream reach can be expressed as reach length [m]/ mean velocity [m d^{-1}]. Reach length can be extracted from the spatial data using simple GIS tools. In this Beta version of N-Sink, we get velocity from NHDPlus v2 data.

Both the flow [Q0001E] and velocity [V0001E] from the NHDPlus v2 dataset have been adjusted with stream gauge measurements. Both of these variables are in the Extended Unit Runoff Method (EROM) table. They are linked back to the flowlines using the common ID field (McKay et al. 2012).

2.3.2 Landscape N Sources

N-Sink currently recognizes two types of N sources: unsewered developed land and agriculture as row crops. Future versions can be modified to recognize a more extensive array of sources and corresponding loads.

2.3.2.1 Developed Land

N-Sink lumps all developed land (e.g., residential development, institutional, commercial) and assumes that it leaches N at a rate similar to unsewered medium density residential development. Future versions of N-Sink will distinguish between different types of developed land, such as different densities of residential development, and different types of agricultural land. Future versions will also allow the user to change the N loading rate from selected areas.

N-Sink assumes that unsewered developed land contributes 41.7 lb N/acre/yr, from the combined contributions of septic systems and lawns, based on the following assumptions:

For one household (or dwelling unit, d.u.), N input to the septic system is 8.8 lb N/cap/yr (U.S. EPA, 2002). If we assume an average of 3 people/household, this comes to 26.4 lb N /d.u./yr. Medium density residential is typically characterized by ½ acre zoning, or 2 d.u./acre. Thus, septic system input is 52.8 lb N/ac/yr. We assume that 79% of that N leaches from the septic system (Gold et al., 1990), which comes to 41.7 lb/ac/yr. Gold et al. (1990) also found that fertilized lawns contributed only a fraction of the total N load.

2.3.2.2 Agricultural Land

N-Sink currently assumes that agricultural land is cultivated as row crops, with N loading similar to silage corn. This is a crop that is common to southern New England and can contribute N loads comparable to unsewered residential development. N-Sink assumes crops are fertilized with manure and that no cover crop is planted. By assuming no

cover crop, we are presenting a "worst case" scenario. Cover crops can serve to sequester excess nutrients present in the soil, and reduce the leaching of nutrients from the field. N-Sink uses the average of two years of data presented in Gold et al. (1990), arriving at a load of 53.7 lb N/ac/yr from agricultural row crops.

N sources are characterized as Low, Medium, or High in N loading, based on the area and loading rate. The Low N loading is characterized as < 5,000 lb N/yr, Medium is 5,000 to 25,000 lb N/yr, and High is > 25,000 lb N/yr. Note that the Table of Contents mis-labels the units as lb/acre/yr. This will be addressed in future versions. In particular, we may find that distinguishing developed lands according to intensity (lb/acre/year) rather than total load (lb/yr) would be more useful to decision makers.

2.4 Assumptions and Limitations

The goals of broad applicability and ease of use dictate a trade-off in the precision of the N delivery estimates, while still incorporating many complex biogeochemical and hydrologic relationships otherwise unavailable to decision makers (Figure 1; Section 2.3). N-Sink works as a prioritization and visualization tool, which enables users to understand how N moves in a given watershed and investigate the relative N-related impacts of various land use scenarios. As such, the numeric outputs of the tool focus on percent removal of nitrogen from source to receiving water and loading estimates suitable for planning purposes, such as comparing N loadings from different locations or types of development. However, these estimates are not accurate enough to use in any applications where the quantity of N is being tracked, for instance, in documenting compliance with a TMDL.

Assumptions and caveats for N-Sink calculations include:

- For the sake of simplicity and ease of use N-Sink does not incorporate all aspects of

watershed nitrogen dynamics. Rather, it focuses on landscape nitrogen sinks and their spatial relationship to nitrogen sources with the goal of informing the decision-making process at the local level.

- N-Sink assumes that groundwater flow paths are similar to surface water flow paths.

- Landscape sinks are currently limited to riparian wetlands (as characterized by vegetated hydric soils), lakes/ponds, and stream reaches, and do not include site-specific BMP's, with the exception of restored riparian wetlands.

- Flow paths are characterized by a terrestrial component and a surface water component. If the terrestrial portion of a flow path intercepts vegetated hydric soils, then N removal will be estimated from the wetland. If, however, the *surface water* portion flows through a wetland, removal is estimated based on surface water characteristics, not as a wetland.

- The surface water component of a flow path may be initiated by the flow path entering a stream midway along a stream reach. Currently N-Sink estimates N removal based on the entire stream reach, as if the flow path had entered the stream at the upgradient end of the reach. Because N removal estimates within stream reaches are usually low, this is not likely to cause significant error. It may be more of an issue in headwater streams that would have slower flow and longer retention times and therefore higher removal estimates. However, future work plans include adjusting N removal from the first stream reach encountered based on where the flow path entered that stream reach.

- Users are strongly encouraged to visit areas under consideration to enhance their understanding of the system and confirm the

viability of any important landscape sinks identified with N-Sink, such as riparian wetlands.

2.5 Tool Description

The beta version of N-Sink is now available at: *www.edc.uri.edu/nsinkv2/*

A basic web portal for the tool, including background information on the project and instructions on using the tool, has been created at:

http://clear.uconn.edu/projects/nsink (Figure 2):

Currently, the following functions are available on the web-based tool.

1. Basemaps: Topographic, States, Imagery, and Neutral Gray.

2. Data layers:

   a. Nitrogen removal (%) of landscape sinks, color coded.

   b. HUC12[1] Watersheds, with flow direction arrows and outlet point.

   c. NHDPlus hydrography, including flow lines (terrestrial and surface water), water bodies, stream reaches, and catchments (sub-basins).

   d. Land Cover, using NLCD 2006 data.

3. Pop-up boxes with the ability to zoom to the selected feature and obtain more detailed information, including (by feature):

   a. HUC12s: Land cover summary as pie chart, with numeric information available when hovering the mouse over pie slices.

   b. Stream reaches: Stream name, reach length (km), local drainage area (km^2), cumulative drainage area (km^2), flow

rate (m^3/s), and estimated N removal (%) (Figure 2).

   c. Ponds/Lakes: Pond name, pond area (m^2), local drainage area (km^2), cumulative drainage area (km^2), flow rate (m^3/s), estimated N removal (%) (Figure 3).

4. N removal tool (Figures 4 & 5, Appendices A & B)

   a. The user clicks on the blue dot (Figure 4) and then clicks on a location on the map. The tool then generates a flow path from that location allowing the user to see the N sinks that the flow path encounters and to calculate the relative percentage of source N that is removed by these sinks (Figure 5). Currently, the tool uses an arbitrary N source value of 100 for this calculation. The team continues to work on the interface for this tool – the Flex viewer software currently has many limitations on output design.

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1 HUC12 refers to Hydrologic Units with 12 digit codes, as defined by USGS.

Figure 2. *Screen capture of N-Sink web portal, currently residing on the UConn CLEAR server.*
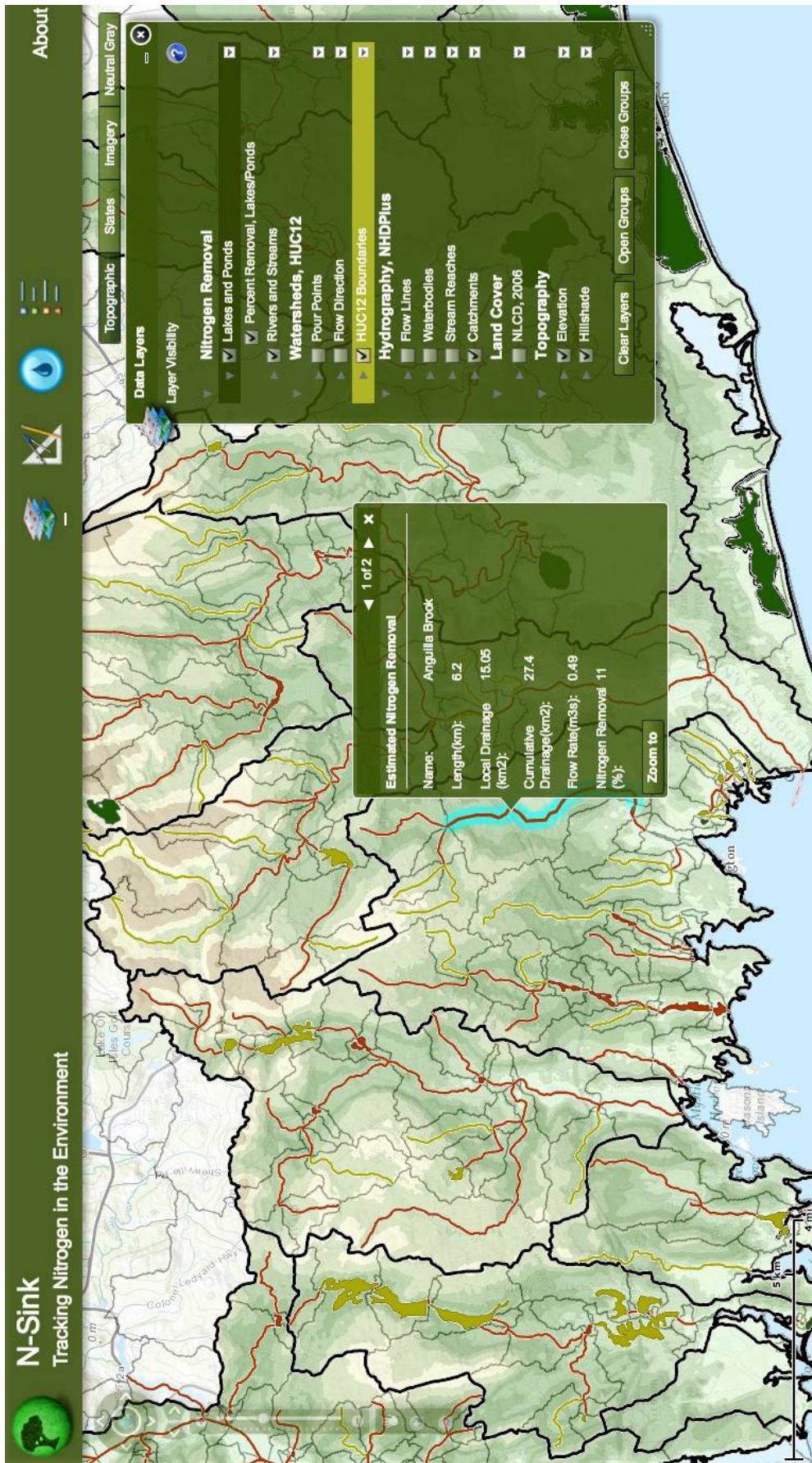
Figure 3. *Example of pop-up box showing details for selected stream reach (highlighted on map). Includes stream name, reach length, local drainage area, cumulative drainage area, flow rate, and N removal estimate. Page 2 of the box shows land use within the local drainage area.*

Figure 4.   *Example of pop-up box showing details for selected pond/lake (highlighted on map). Includes pond name, pond area, local drainage area, cumulative drainage area, flow rate, and estimate N removal. Page 2 of the box shows land use within the local drainage area.*

Figure 5. *N Removal tool. The user clicks on the blue dot and then clicks on a location on the map. The tool then calculates and draws the flow path from that location to the watershed outlet, and calculates percent N removal.*

Figure 6. *Example of flow path (thick red line on map) generated by the N removal tool. The pop up box includes the calculations – see Appendix A for in-depth examples.*

2.6 Future N-Sink improvements

During this project period the team was able to successfully migrate N-Sink from an out-of-date prototype ArcMap desktop tool to a state-of-the-art ArcGIS for Flex web tool. However, the programming work to accomplish this was extensive, and as a result there are a number of additions and improvements to the tool still to be undertaken before we feel that it is ready to use by the intended target audience. In addition, the downside of the web tool is that it is not as customizable as a desktop tool, so more work remains on crafting final user interface items. A brief list of this unfinished agenda, in rough order of priority, appears below:

a. **N Loadings estimation tool.**
This tool will allow the user to draw a polygon and get land cover-based loadings estimates for either existing or assigned land cover. N-Sink uses land cover, literature loading estimates, and the particle tracking tool to estimate N loadings, in kg/ha/yr, of that polygon.

b. **Automated NHD database updates.**
Both CT and RI are due for major National Hydrography Dataset (NHD) upgrades in the next year. In addition, NHD data is routinely updated. We need to ensure that N-Sink will automatically incorporate these updates.

c. **Watershed-wide N processing intensity map**
Currently, the N-Sink user can select any point in the watershed to get N reduction estimates. The project team would like to have another, watershed-wide tool output to relate these issues. The output would be a watershed map, colored to show areas of high, medium, and low N delivery to the outlet.

d. **Website enhancements**
As the tool is enhanced and improved, so should the framework provided by the overall website. Future website improvements include additional information on strategies to reduce N loadings and examples of ways to use N-Sink.

3.1   Study area

The current version of N-Sink was developed for the coastal watersheds of Rhode Island and southeastern Connecticut, from Narragansett Bay to the Connecticut River area (Figure 7). The area comprises 19 watersheds at the USGS classification of Hydrologic Unit Code 12, which average about 40 square miles in size, nationally (Seaber et al., 1994).

Our initial outputs are from the Niantic River and Saugatucket River watersheds (Figure 8). Both of these watersheds have a recognized N pollution problem, a state approved watershed management plan, and well-developed citizen participation in watershed matters. The latter criterion is particularly important, as the planned next step for this project will be to use N-Sink outputs as the basis for educational programs for watershed stakeholders (see last section).

We explored both watersheds using N-Sink, looking at N removal rates for various parts of the watershed, including sites in close proximity with one another. The results of these analyses are included as Appendix A (Niantic) and Appendix B (Saugatucket); these comprise the case studies. Background information on the two watersheds appear below.
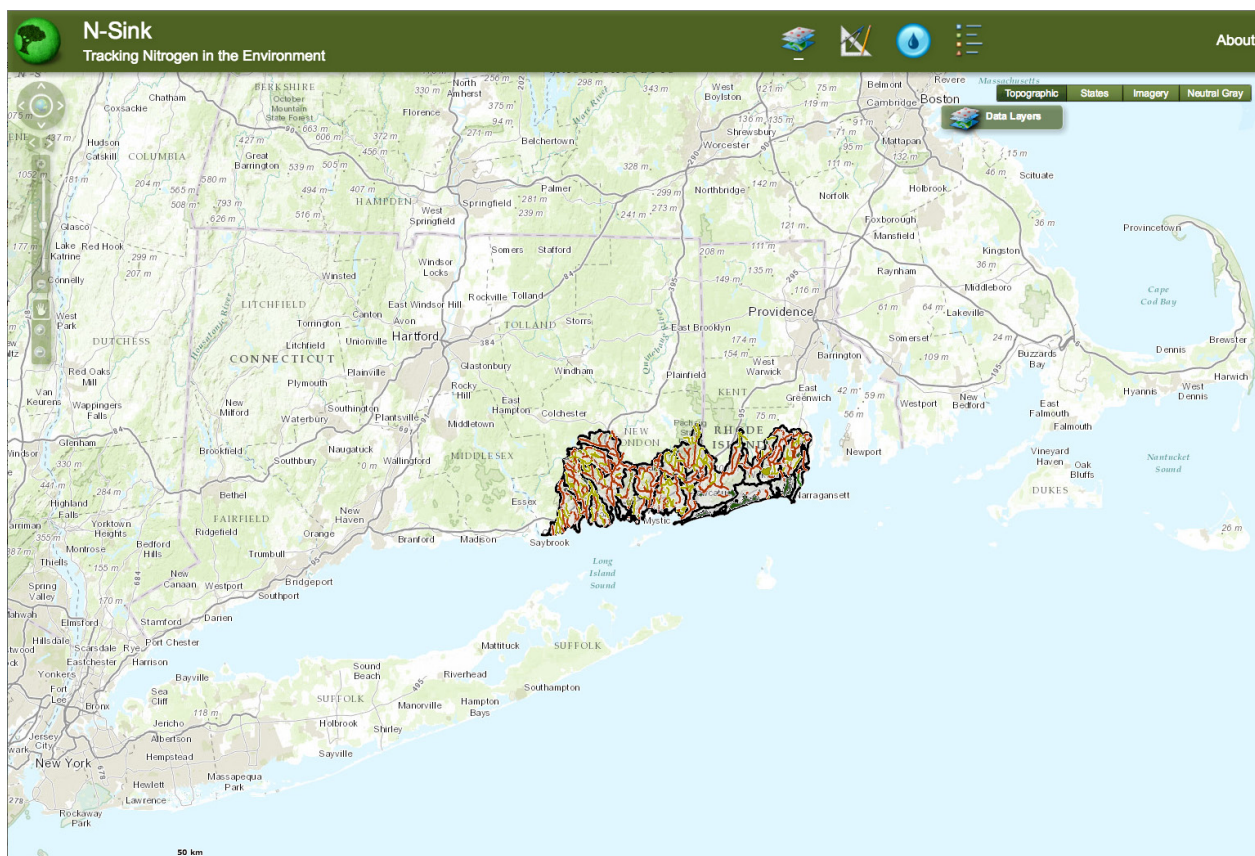
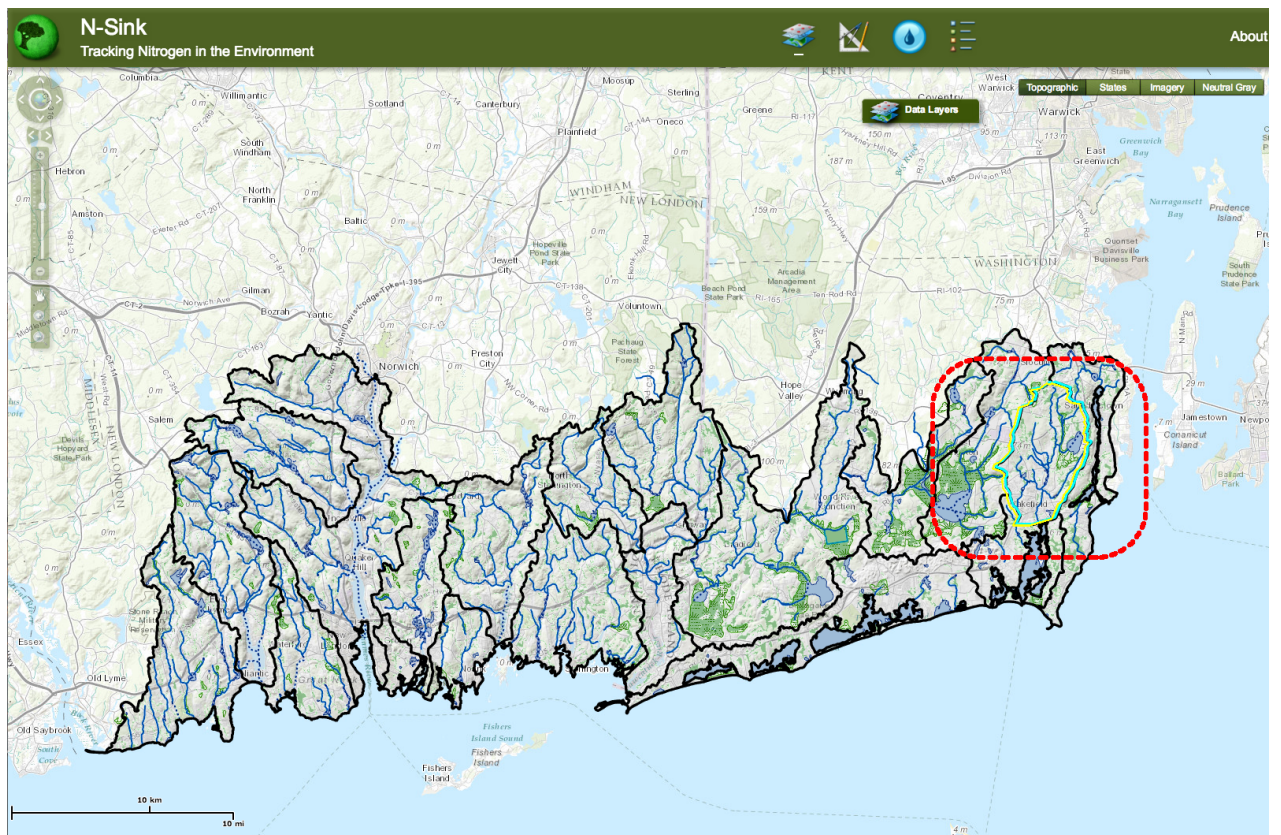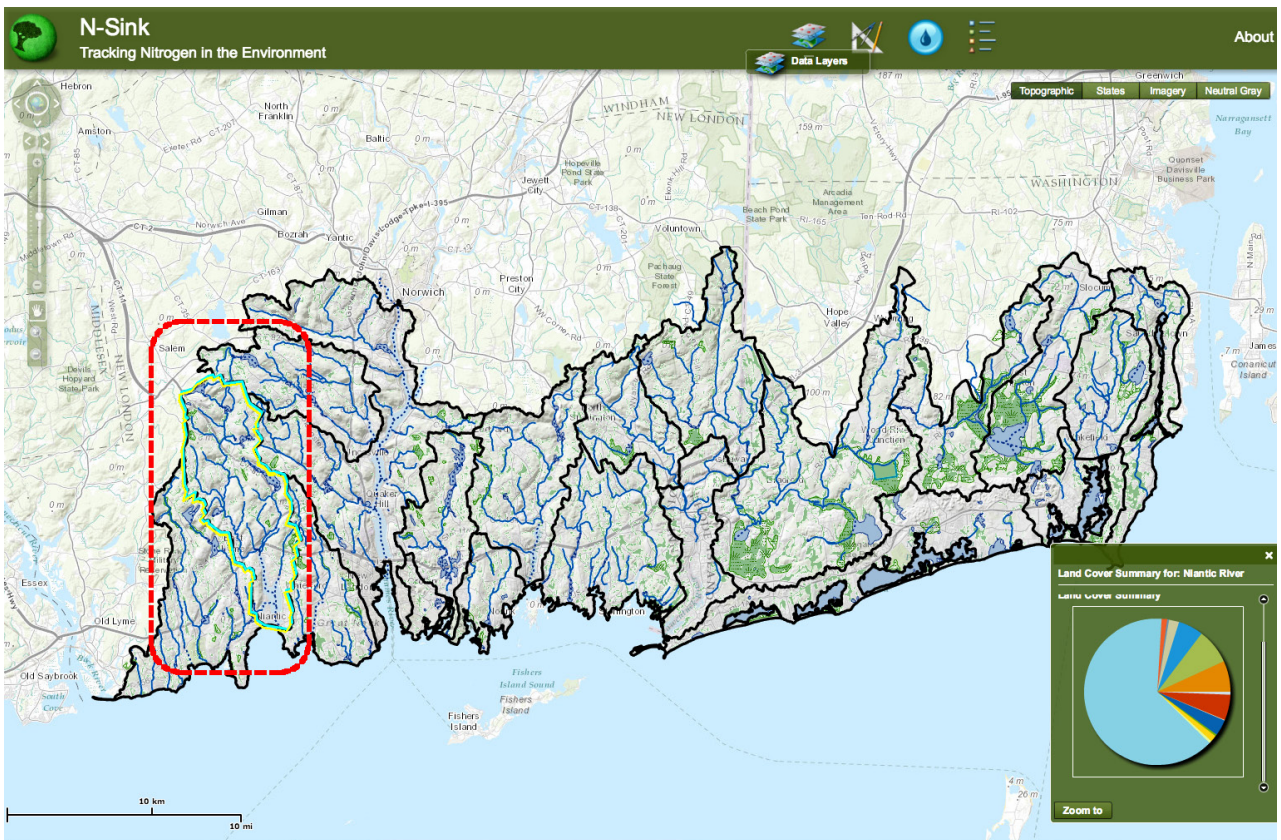

Figure 7.   *Study area in eastern CT and RI coast.*

Figure 8. *Close-up of study area showing Case Study watersheds highlighted in blue: Niantic River (top) and Saugatucket River (bottom).*

3.2 Case Study #1: The Niantic River Watershed, CT

The Niantic River watershed is a Hydrologic Unit Code (HUC) 12 drainage basin in Southeastern Connecticut that covers 31.3 square miles, or approximately 20,000 acres. It is comprised of three subregional basins: Latimer Brook, Oil Mill Brook, and the main stem Niantic River (CT DEEP, 2009) (Figure 9). The watershed includes portions of four municipalities, including large portions of the downstream towns of East Lyme and Waterford, and smaller portions of the upstream communities of Salem and Montville. UConn CLEAR's 2010 30-meter land cover data for the watershed breaks down as follows for the major categories: 13.5% developed; 4.5% turf and grass; 3.3% agriculture; 61.1% forest; 4.6% wetland.
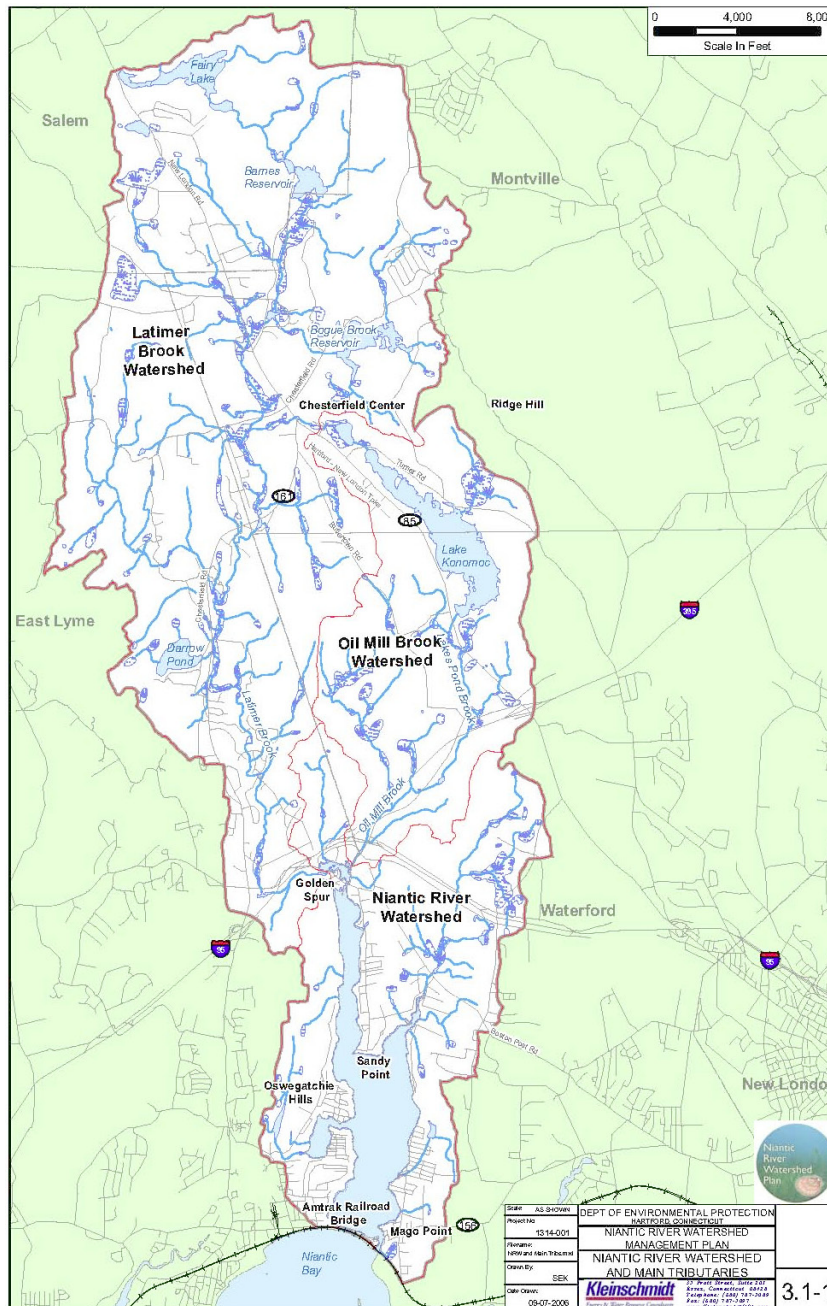

Figure 9. *Niantic River watershed, showing towns and subbasins. From the watershed plan, CT DEEP.*

The River is on the state's impaired waters list for a variety of reasons, nitrogen pollution being chief among them. The Niantic River Watershed Management Plan (CT DEEP, 2009) summarizes (emphasis added):

The Niantic River does not currently meet state water quality standards because of high levels of indicator bacteria and observed degradation of aquatic life. According to the State of Connecticut's §303(d) List of Impaired Waters, the Niantic River is not supporting activities such as shellfishing and swimming; the Niantic River's shellfish beds are closed after rain events of one inch or more. The §303(d) List of Impaired Waters states that the water quality of the Niantic River is not supporting the aquatic life known to inhabit the estuary. Symptoms of this condition include, algal blooms, seasonal variations in eelgrass populations, loss of scallop populations and changes to the fish communities. **These ecological changes are thought to be linked to excessive nutrients, especially nitrogen, entering the river.**

In addition, the Niantic is part of a much larger area (incorporating almost all of Connecticut) that is covered by a nitrogen TMDL approved for Long Island Sound, where nitrogen has been identified as a major cause of harmful algal blooms leading to hypoxia (US EPA, 2009).

A citizen Board of Directors has been formed to oversee the implementation of the state-approved Watershed Management Plan. In addition, there is a Niantic River Watershed Nitrogen Work Group made up of technical and scientific representatives that meets regularly to discuss monitoring challenges and knowledge gaps pertaining to managing nitrogen in the Niantic system.

We looked at N reduction/delivery from several places in the watershed. Some examples were placed near each other, to explore changes in N delivery estimates based on small but important changes in the flow path. Please see Appendix A.

3.3 Case Study #2: The Saugatucket River Watershed, RI

The Saugatucket River watershed is a Hydrologic Unit Code (HUC) 12 drainage basin in southern Rhode Island that covers 17.2 square miles, or approximately 11,000 acres (Figure 10). The Saugatucket drains into the northern end of Point Judith Pond, a coastal salt pond with a permanent breachway to Block Island Sound. Approximately 13% of the watershed is in low intensity development, 8% in medium and 2% in high intensity development. Agricultural activities, such as pasture and hay cultivation, are 4% of the watershed. Roughly 40% of the watershed is forested, and just under 17% is wetlands. Most of the watershed (83%) lies within South Kingstown, 16% in North Kingstown, and slivers of the watershed lie within the towns of Narragansett and Exeter, RI.

Water quality issues include both the river itself and its receiving waters, Point Judith Pond. Point Judith Pond is the site of restoration projects focusing on both eelgrass and scallops. The pond also supports oyster aquaculture. The Saugatucket River is on the state's 303(d) List of Impaired Waterbodies for fecal coliform, with stormwater runoff identified as a major contributor. Although bacteria has been the primary pollution concern, several of the watershed's ponds have been found to have low dissolved oxygen levels due to high ammonia and nitrate loadings (Rhode Island Rivers Council, 2013). As a coastal salt pond, Point Judith Pond is sensitive to nitrogen loading from the Saugatucket, as well as from development surrounding the pond.

The watershed has a nonprofit organization, the Saugatucket River Heritage Corridor, that
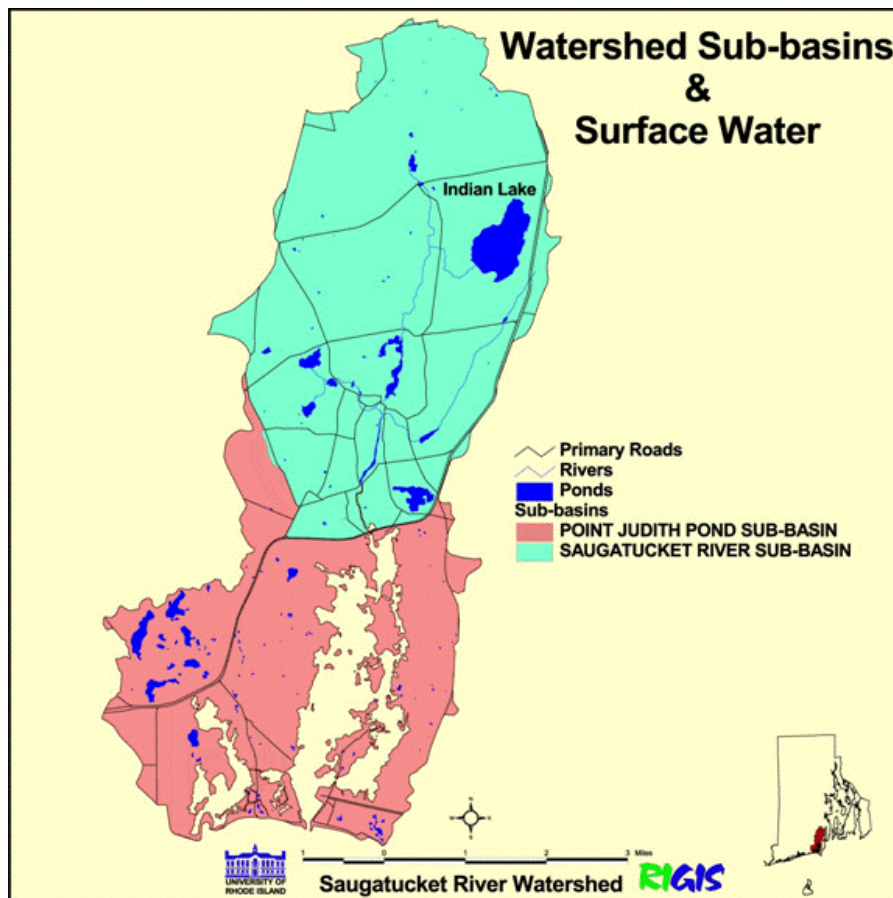
Figure 10. *Saugatucket River watershed. The HUC-12 watershed explored by N-Sink consists of the upper half (blue) of the overall watershed. From RI GIS center.*

was established in 1994 and designated by the Rhode Island Rivers Council in 1999 as the watershed council for the Saugatucket River. This group works in partnership with the Salt Ponds Coalition on Point Judith Pond.

We looked at N reduction/delivery from several places in the watershed. Some examples were placed near each other, to explore changes in N delivery estimates based on small but important changes in the flow path. Please see Appendix B.

3.4 QA and Model Verification: Comparing N-Sink N Reduction Tool Results to Conventional Calculations.

All research projects making conclusions or recommendations based on environmentally related measurements and information and funded by the Environmental Protection

Agency are required to comply with the requirements of the Agency Quality Assurance Program. This model was developed under an approved Quality Assurance Project Plan.

In order to confirm that the formulas were coded correctly in the N Reduction Tool, we compared the N removal estimates along several flow paths in the Saugatucket watershed with the removal estimates calculated with the formulas in Excel. Typically model validation also involves comparing model estimates with field data. However, because N-Sink is a decision support tool and does not attempt to include all components of N cycling in a watershed, it is not possible to compare N-Sink estimates with any existing field data. For example, nitrate concentrations of samples taken at a watershed outlet reflect the entire spectrum

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of N cycling over a period of time throughout the entire watershed. It would be impossible to tease out the effects of one stream reach or pond without designing a field study for this purpose. The equations used in N-Sink are empirical and the distillation of many field studies, reflecting our current understanding of N removal in these landscape sinks (Kellogg et al., 2010). However, work is currently underway at the *URI Watershed Hydrology Lab* to explore N removal in the landscape sinks identified in N-Sink, especially streams and ponds. This work will help us compare N-Sink N removal estimates with field data from studies designed for this purpose. We are also exploring the possibility of extracting the relevant estimates of N movement from a calibrated and validated watershed model such as SWAT. This would not be a direct comparison to field data, but has potential to enhance our assessment of N-Sink performance.

3.4.1 Methods

The N Removal Tool in N-Sink was used to create a flow path and calculate removal along each reach of that flow path. A table is generated and shown in a pop-up box. In order to save the information for each flow path generated, the table was copied using the clipboard icon, then pasted into an Excel spreadsheet. Each new flow path calculation clears the information from the previous calculation [Note: the next iteration of N-Sink should have the ability to save previous flow paths and their associated calculations].

A separate Excel spreadsheet was created to do the calculations using the formulas detailed in Section 2.3 and Kellogg et al. (2010). We focused on the calculations for % removal from stream reaches and ponds because those are more complex, while the wetland is a check on presence/absence. We gathered the necessary GIS data to be plugged into the equations by clicking on each sink (pond or stream reach) and recording data such as reach length (km), pond area (m^2), cumulative drainage area (km^2), and average annual flow rate (cms). The stream removal calculation in the spreadsheet used an estimated velocity generated from the equation presented in Section 2.3, while the stream removal calculation in N-Sink used the estimated velocity provided by NHDPlus v2. [Note: When this comparison was done, the NHDPlus velocities were not available to us from the pop-up information box for each reach. This information will be added in future and another comparison will be done using the velocity provided by NHDPlus v2.] The original intent was not to compare the velocity provided by NHDPlus v2 to that estimated using the equation in Section 2.3. However, circumstances were such that this was how the comparison had to be made.

3.4.2 Comparison Results

Tables 4.1 to 4.4 show % N removals along each of the four flow paths in the four examples generated for the Saugatucket watershed. The absolute difference in the cumulative removal along the flow path ranges from -4% to +1% N removal. The absolute difference along reaches ranges from -4.9% to +1.8% N removal. Given that the velocity estimates were derived from two different sources, the difference is within acceptable limits. Uncertainty is a component of the calculations that has not been addressed to date. This is something we will explore in future development, asking how to incorporate uncertainty into the calculations and whether to communicate uncertainty to the user, and if so, how best to do that.

Table 4.1 Comparison of % N removal by reach along flow path shown in Saugatucket Example A. Note that the difference in cumulative removal (%) is not the sum of the differences along each reach because each % removal is applied to the output from the previous reach.

Example A		% N Removal		
NHD Reach Code	**Feature Type**	**N-Sink**	**Excel Spreadsheet**	**Difference**
Null	Non-hydric	0	0	
Null	Wetland	80	80	
1090005000333	Pond	9.3	9.6	+0.3
1090005000333	Stream	6.9	4.3	-2.6
1090005000332	Stream	3.6	2.2	-1.4
1090005000331	Stream	0.3	0.3	0.0
1090005000330	Stream	0.6	0.5	-0.1
1090005000734	Pond	8.7	8.8	+0.1
1090005000321	Stream	0.7	0.3	+0.4
1090005000320	Stream	0.2	0.2	0.0
1090005000319	Stream	2.9	2.4	-0.5
Cumulative		86	85	1

Table 4.2 Comparison of % N removal by reach along flow path shown in Saugatucket Example B. Note that the difference in cumulative removal (%) is not the sum of the differences along each reach because each % removal is applied to the output from the previous reach.

Example B		% N Removal		
NHD Reach Code	**Feature Type**	**N-Sink**	**Excel Spreadsheet**	**Difference**
Null	Non-hydric	0	0	
1090005000340	Stream	15.6	10.7	-4.9
1090005000331	Stream	0.3	0.3	0.0
1090005000330	Stream	0.6	0.5	-0.1
1090005000734	Pond	8.7	8.8	+0.1
1090005000321	Stream	0.7	0.3	+0.4
1090005000320	Stream	0.2	0.2	0.0
1090005000319	Stream	2.9	2.4	-0.5
Cumulative		26	22	-4

Table 4.3 Comparison of % N removal by reach along flow path shown in Saugatucket Example C. Note that the difference in cumulative removal (%) is not the sum of the differences along each reach because each % removal is applied to the output from the previous reach.

Example C		% N Removal		
NHD Reach Code	**Feature Type**	**N-Sink**	**Excel Spreadsheet**	**Difference**
Null	Non-hydric	0	0	
Null	Non-hydric	0	0	
1090005000346	Stream	16.0	13.5	-2.5
1090005000347	Pond	35.0	36.8	+1.8
1090005004979	Stream	3.5	2.6	-0.9
1090005004973	Pond	0.4	0.3	-0.1
1090005004972	Stream	1.7	1.3	-0.4
1090005000342	Stream	3.1	4.1	+1.0
1090005000320	Stream	0.2	0.2	0.0
1090005000319	Stream	2.9	2.4	-0.5
Cumulative		52	51	-1

Table 4.4 Comparison of % N removal by reach along flow path shown in Saugatucket Example D. Note that the difference in cumulative removal (%) is not the sum of the differences along each reach because each % removal is applied to the output from the previous reach.

Example D		% N Removal		
NHD Reach Code	**Feature Type**	**N-Sink**	**Excel Spreadsheet**	**Difference**
Null	Non-hydric	0	0	
Null	Wetland	80	80	0
1090005000346	Stream	16.0	13.5	-2.5
1090005000347	Pond	35.0	36.8	+1.8
1090005004979	Stream	3.5	2.6	-0.9
1090005004973	Pond	0.4	0.3	-0.1
1090005004972	Stream	1.7	1.3	-0.4
1090005000342	Stream	3.1	4.1	+1.0
1090005000320	Stream	0.2	0.2	0.0
1090005000319	Stream	2.9	2.4	-0.5
Cumulative		90	90	0

The primary purpose of this work is to incorporate scientific understanding of landscape N sinks (freshwater wetlands, streams and ponds/lakes) into practices that local land-use decision makers can adopt and act upon to support sustainable and healthy communities. Work to this point has focused on construction of a research based, accessible tool with simple outputs that the project team has judged to be useful, based on their extensive experience in working with community decision makers.

As noted, the migration to a web tool format is a tremendous step toward our goal of accessibility, but it has left the team with more work to do. So, our next steps fall into three basic categories:

1. **Improvements and enhancements to the tool** and its interface, as listed in Section 2.6. Creating the loading estimation tool is the highest priority.

2. **Testing the model in the field**, working with decision makers and community groups in the Niantic and Pawcatuck watersheds. This will be accomplished by an expanded project team that includes Cooperative Extension and Sea Grant Extension faculty from both UConn and URI. Extension programs across the U.S., implemented through Land Grant and Sea Grant University Systems, use an integrated research and extension approach to educating land use decision makers. These programs are ideal vehicles for reaching this critical audience (Arnold, 2000). Both UConn and URI are members of the National "NEMO" Network of projects focused on assisting communities protect their natural resources. NEMO, which stands

for "Nonpoint Education for Municipal Officials," has programs in 30 states (Rozum and Arnold 2004; Dickson and Arnold 2009); the UConn and URI programs are the two oldest of these programs, dating back more than 20 years.

3. **Evaluating the opportunities and barriers to adapting N-Sink nationwide**. As noted, N-Sink was intentionally developed using nationally available data for its primary inputs, with an eye to adaptability. Despite this fact, regional climatic and hydrologic differences exist to the point that "one size" definitely does not fit all. In addition, the concept for the prototype N-Sink tools was as an ArcGIS extension rather than a web tool, and the effects of this change on national dissemination need to be evaluated. If, as seems likely, it is found that N-Sink can be adapted nationally, then the project team will use its contacts in various national networks to assess interest and get user feed back. These networks include:

- The NEMO Network, as described.

- The National Geospatial Technology Extension Network that teaches and facilitates the use of new and advanced geospatial technologies;

- The Sea Grant Sustainable Coastal Community Development Network that shares resources and tools to help coastal communities thrive.

- The Land Grant Water Program Network of research and outreach projects focused on water resource protection in each of the 50 states.

5.0
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Appendix A. Case Study 1

Screen captures from N-Sink v2 (beta)

Niantic River Watershed, CT

http://www.edc.uri.edu/nsinkv2/
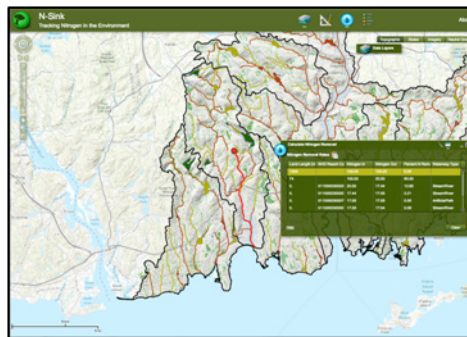
Niantic River Watershed
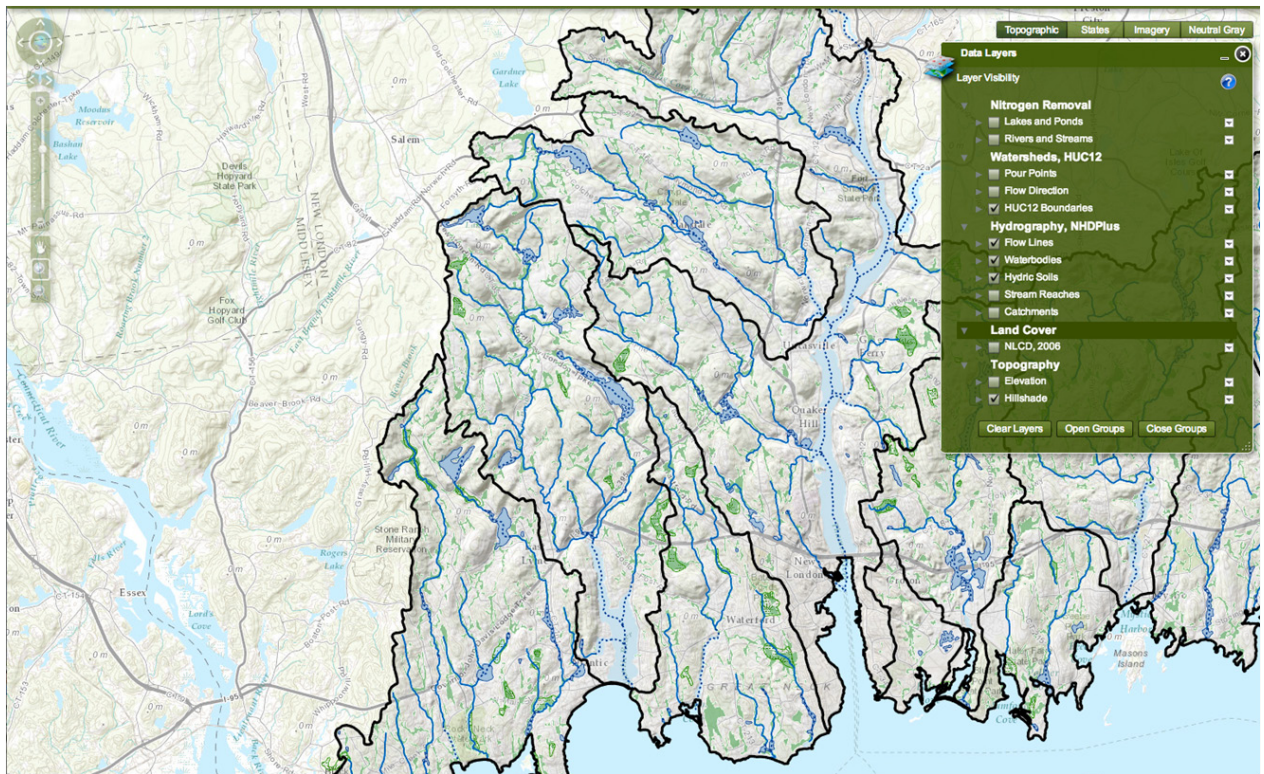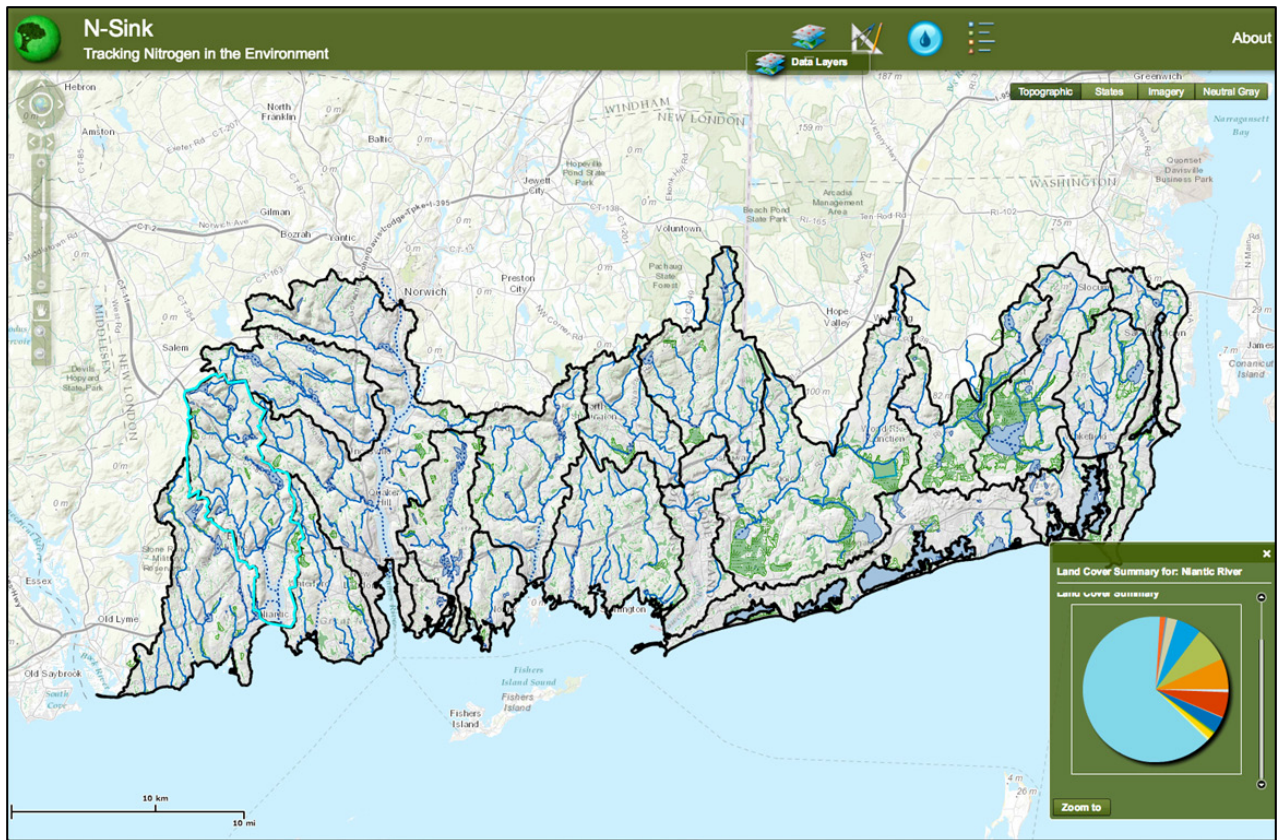
1. *Hydrography and hydric soils.*

Niantic River Watershed
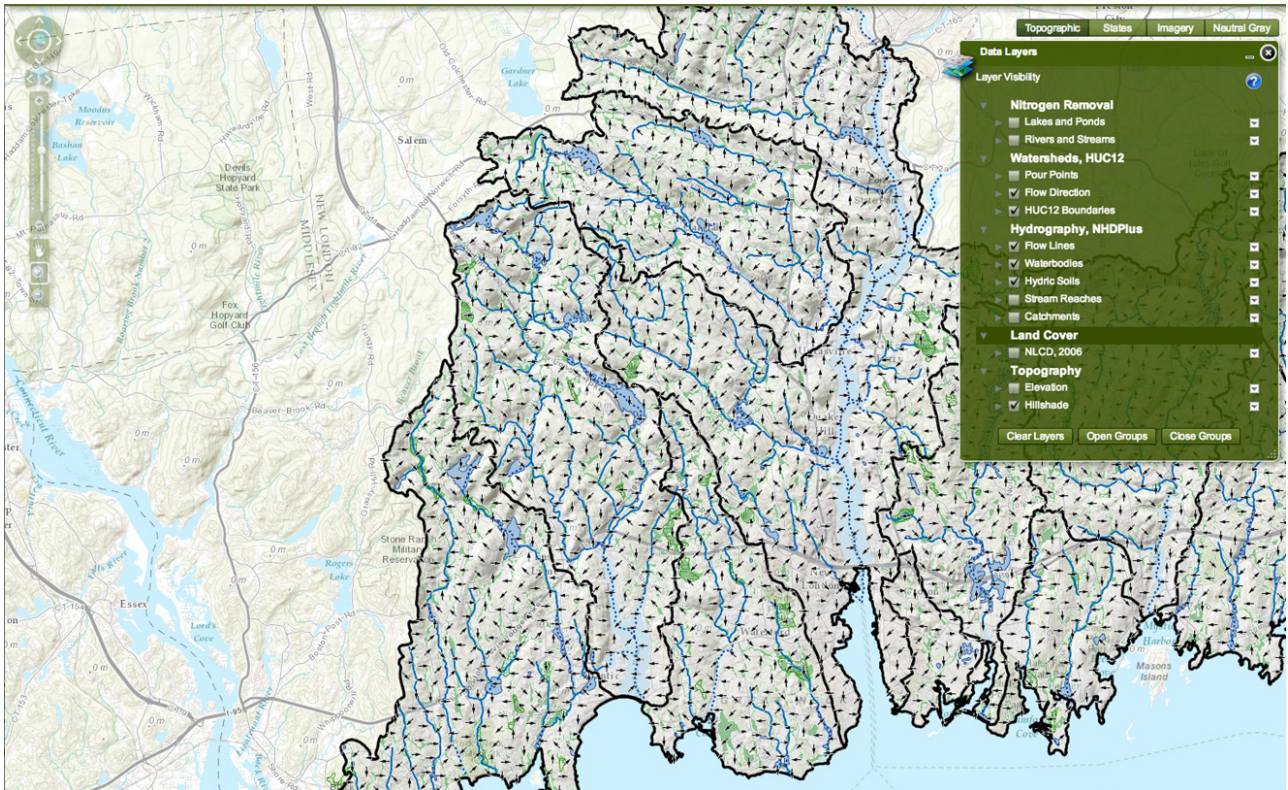
2. Flow direction.
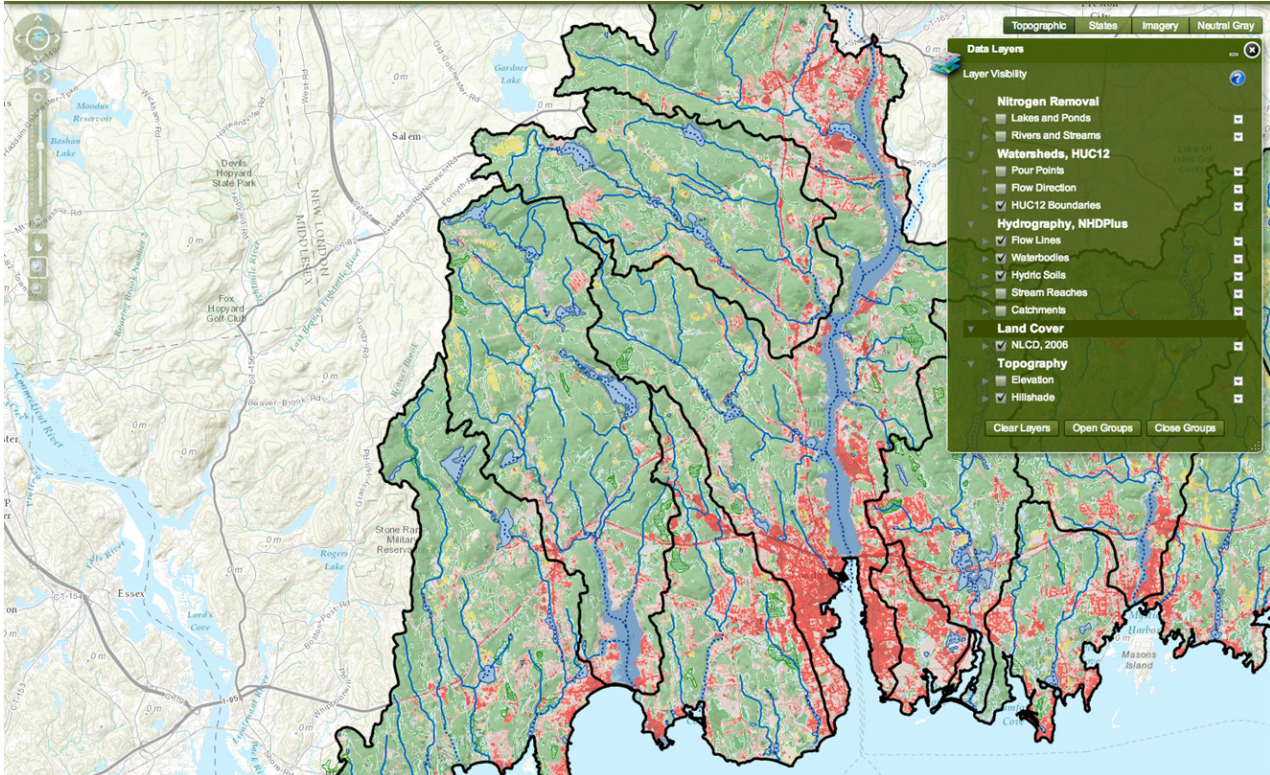
3. Land Cover (NLCD 2006).

Niantic River Watershed
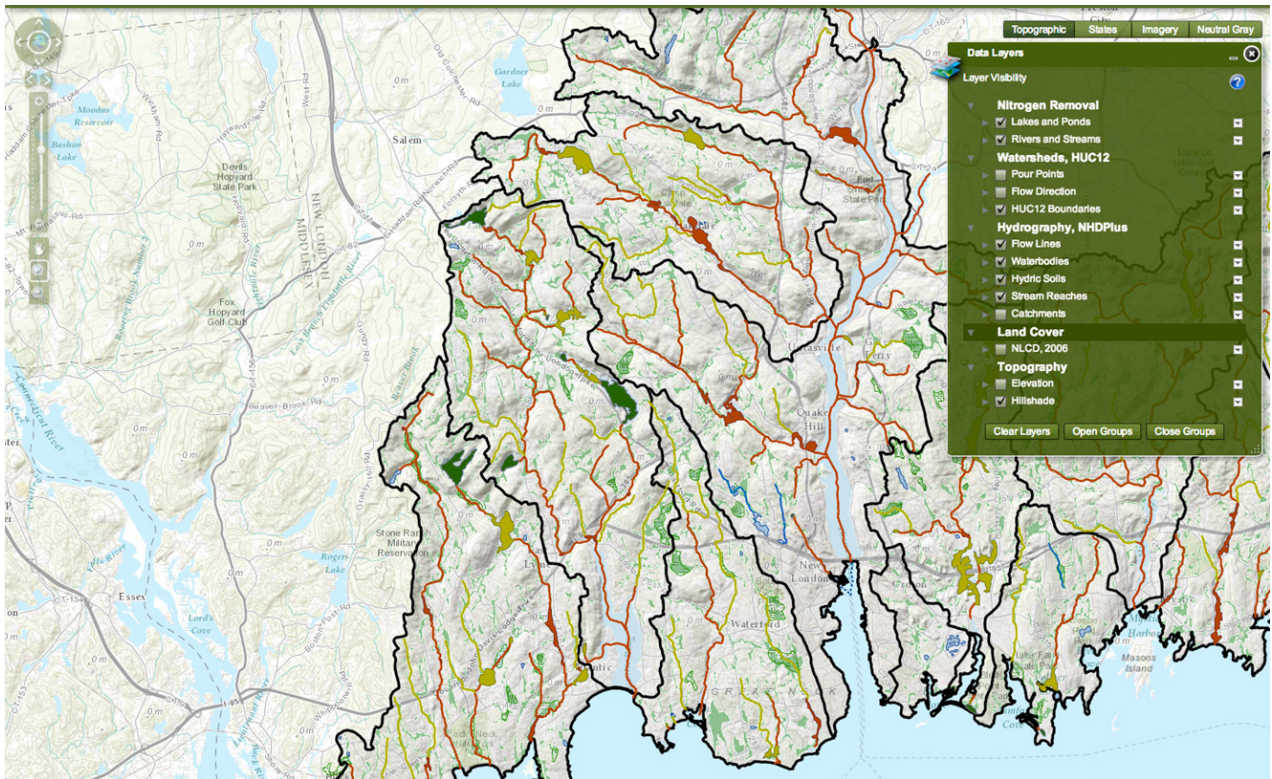

4a. *Hydrography coded for N removal of stream reaches and features.*
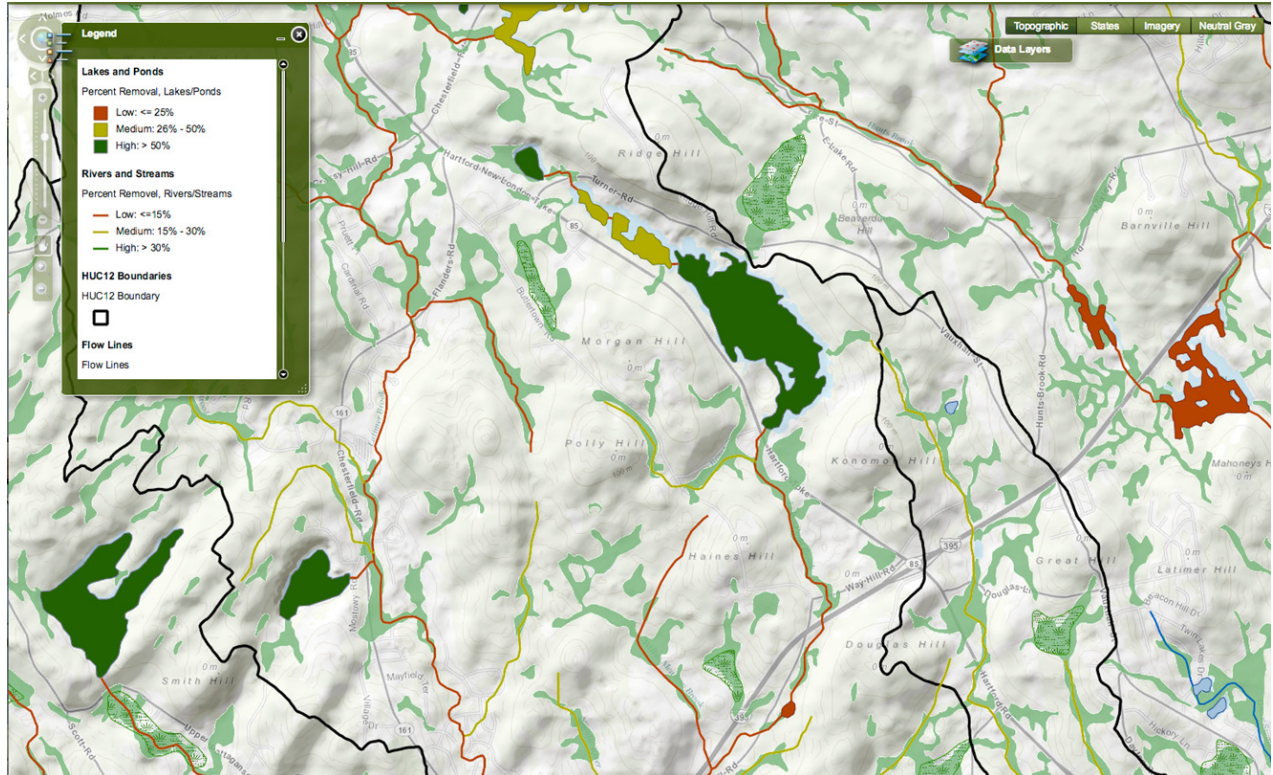
4b. *Hydrography coded for N removal of stream reaches and features: detail*

Niantic River Watershed
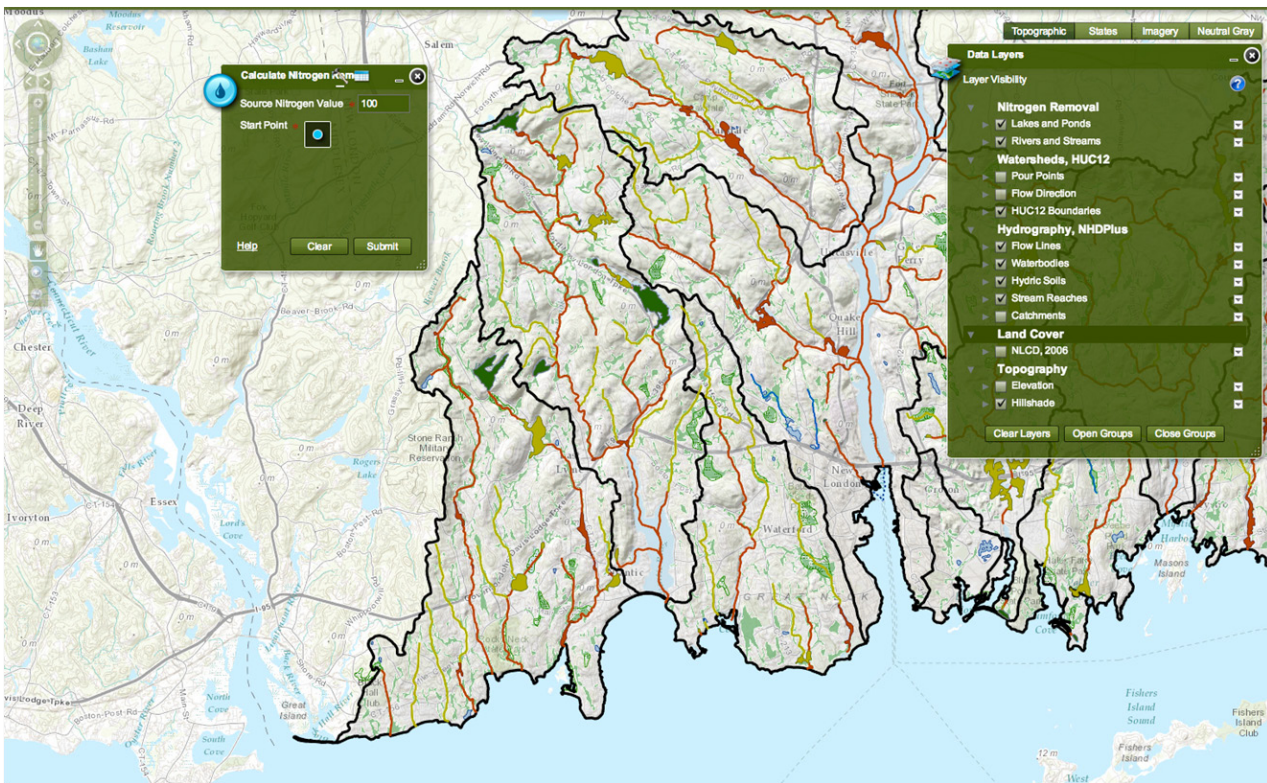

5a. Nitrogen calculator box opened (top left). Clicking on blue dot allows user to then select any location in watershed.
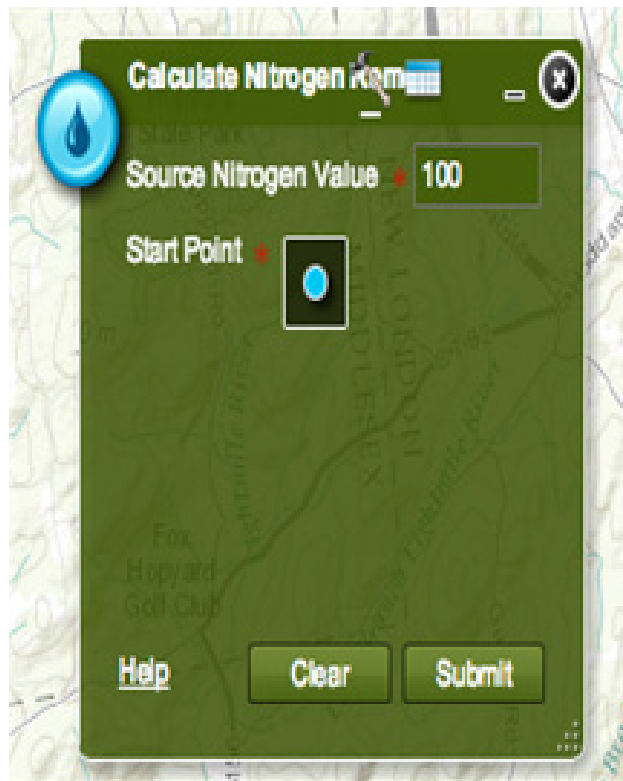
5b. Close-up view of N calculation box. For beta version, N value is set to arbitrary input of 100 units.

Niantic River Watershed
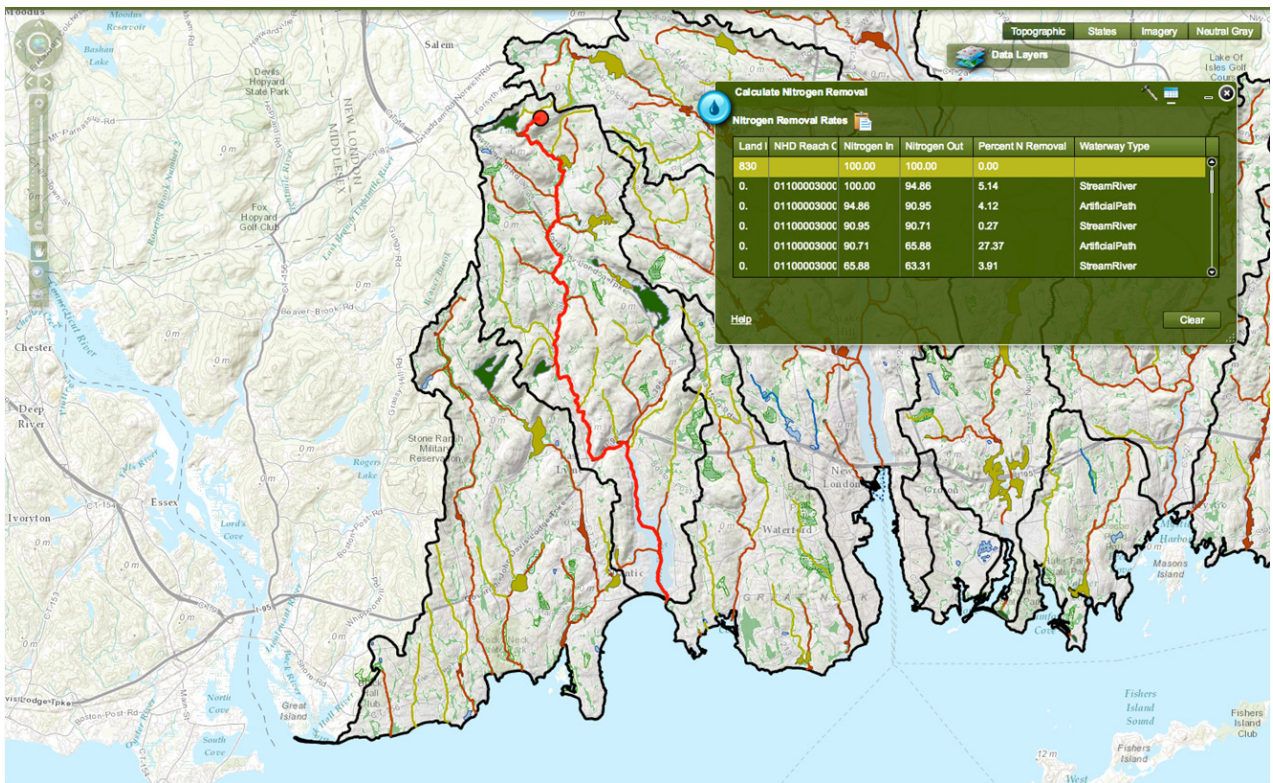

6a. Example 1: Flow path noting input value of 100 units.
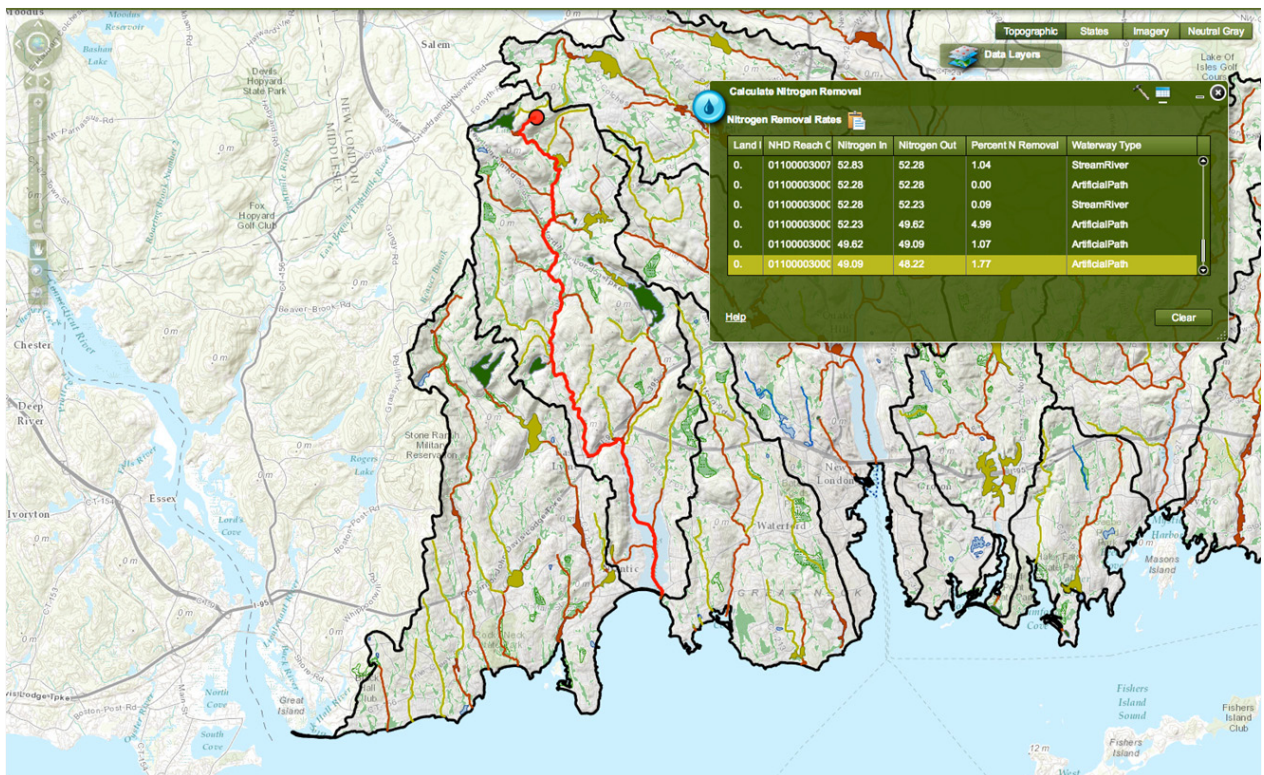
6b. Example 1: Flow path noting output value of 48 units.

Niantic River Watershed

Land Length (m	NHD Reach Co	Nitrogen In	Nitrogen Out	Percent N Rem	Waterway Type
1264		100.00	100.00	0.00	
74		100.00	20.00	80.00	
0.	011000030002	20.00	17.44	12.80	StreamRiver
0.	011000030000	17.44	17.05	2.21	StreamRiver
0.	011000030007	17.05	17.05	0.00	ArtificialPath
0.	011000030000	17.05	17.04	0.09	StreamRiver

7a. Example 2: Flow path noting input value of 100 units.

Land Length (m	NHD Reach Co	Nitrogen In	Nitrogen Out	Percent N Rem	Waterway Type
0.	011000030000	17.44	17.05	2.21	StreamRiver
0.	011000030007	17.05	17.05	0.00	ArtificialPath
0.	011000030000	17.05	17.04	0.09	StreamRiver
0.	011000030000	17.04	16.19	4.99	ArtificialPath
0.	011000030000	16.19	16.02	1.07	ArtificialPath
0.	011000030000	16.02	15.73	1.77	ArtificialPath

7b. Example 2: Flow path noting output value of 16 units.

Niantic River Watershed
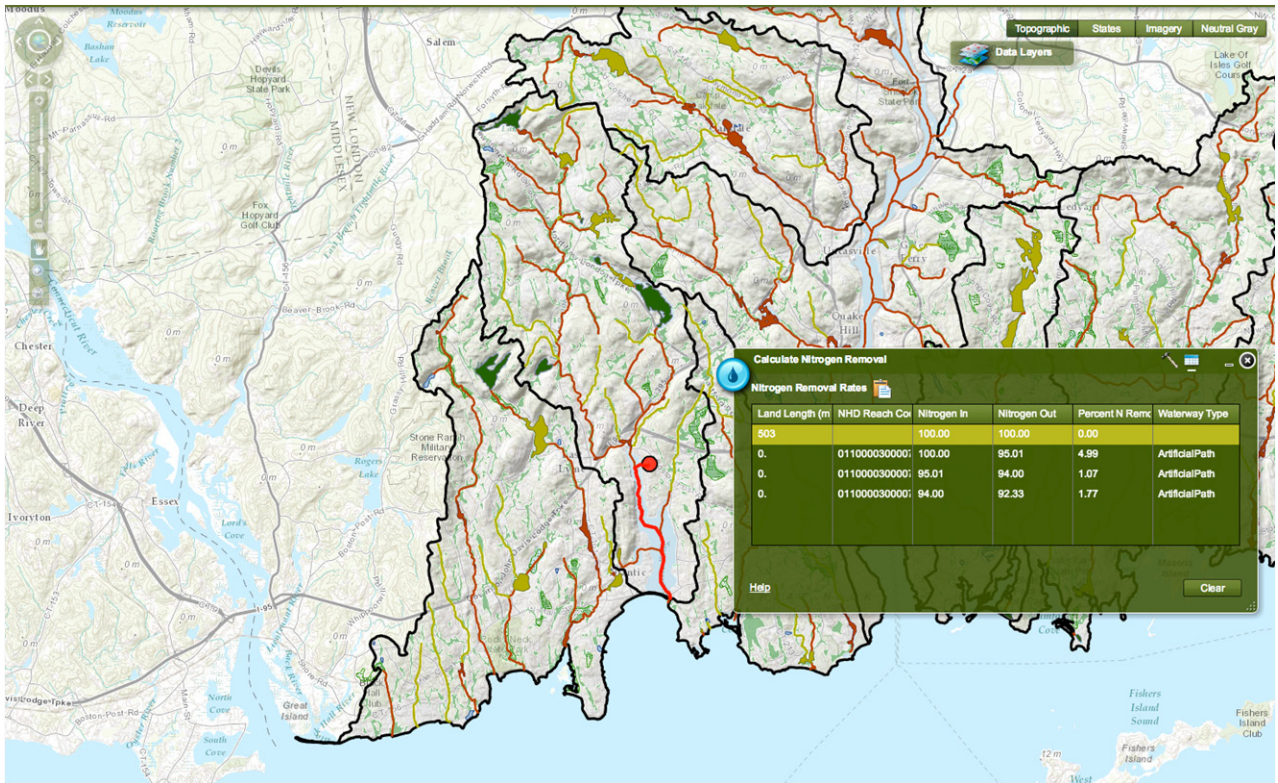
8a. *Example 3: Flow path noting input value of 100 units.*
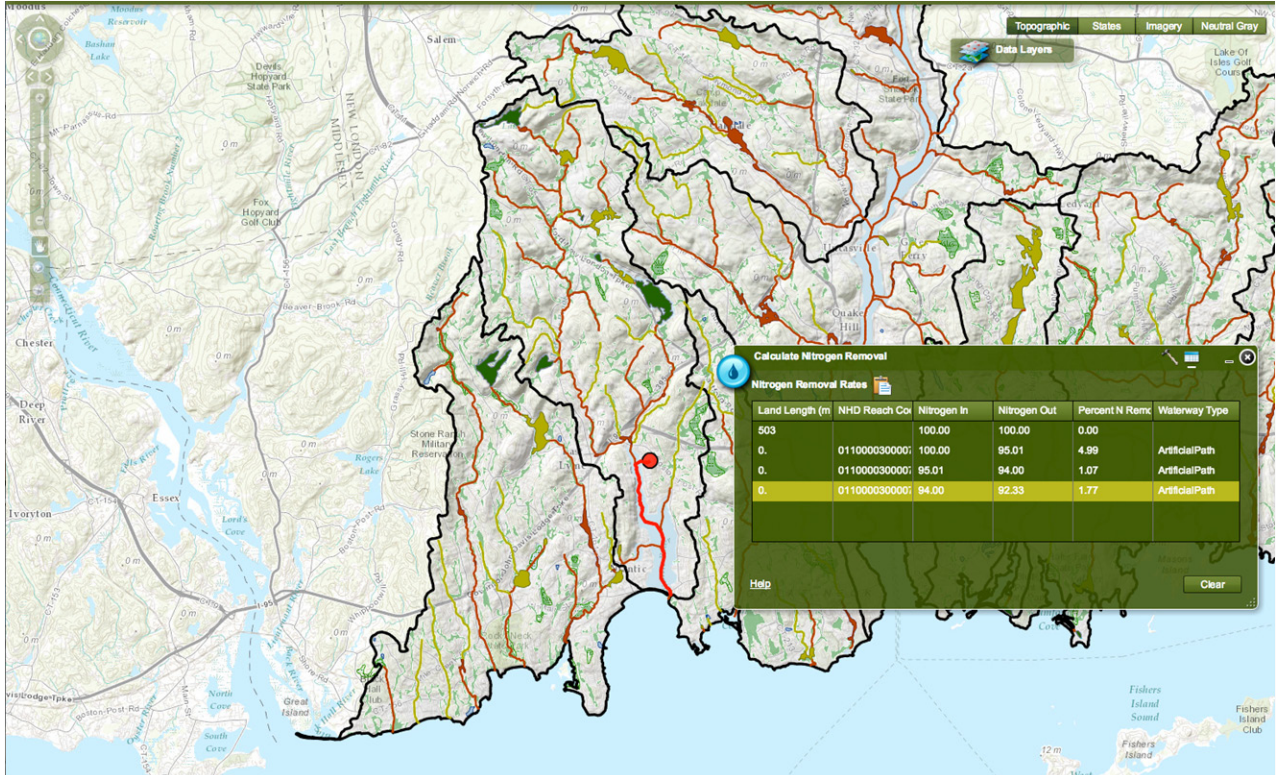
8b. *Example 3: Flow path noting output value of 92 units.*

Niantic River Watershed
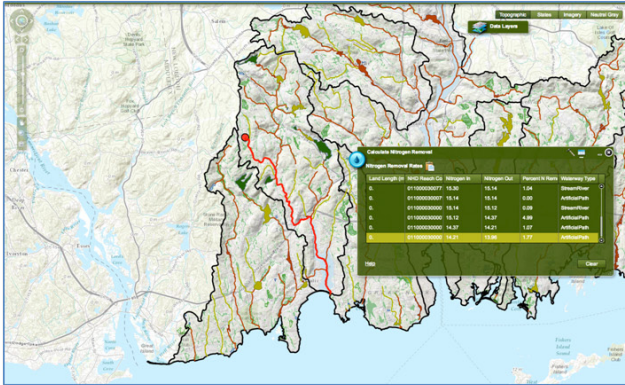
Output = 14 units. (86% N removal)
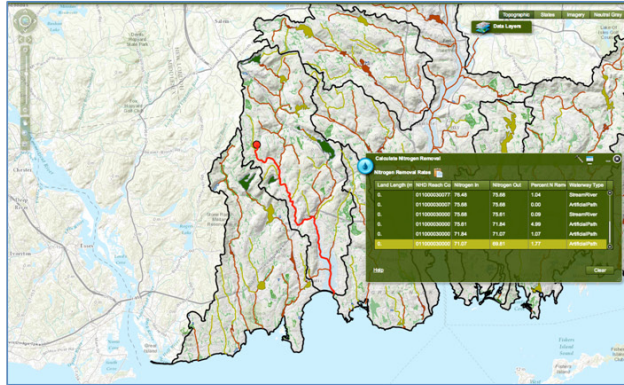
Output = 70 units. (30% N removal)

10.   *Two closely placed selection points showing very different outputs. Both scenarios had arbitrary 100 unit input.*

Output = 15 units. (85% N removal)
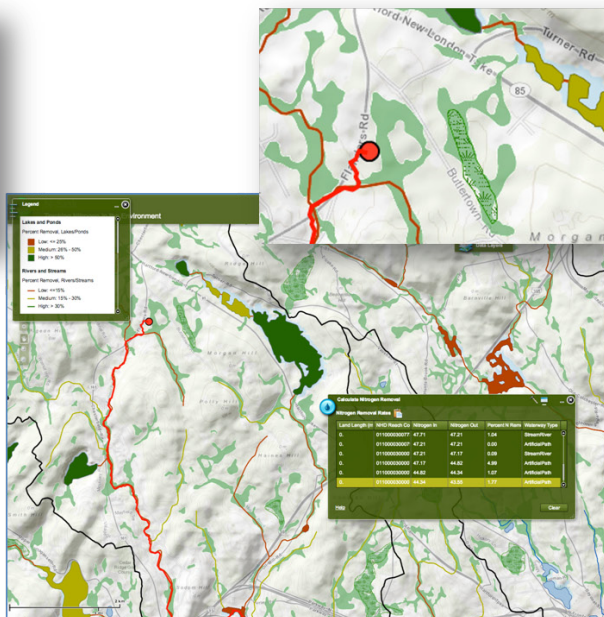
Output = 44 units. (56% N removal)

10.   *Two closely placed selection points, close-up view, showing different outputs. Both scenarios had arbitrary 100 unit input.*

Appendix B. Case Study 2

Screen captures from N-Sink v2 (beta)

Saugatucket River Watershed, RI

http://www.edc.uri.edu/nsinkv2/
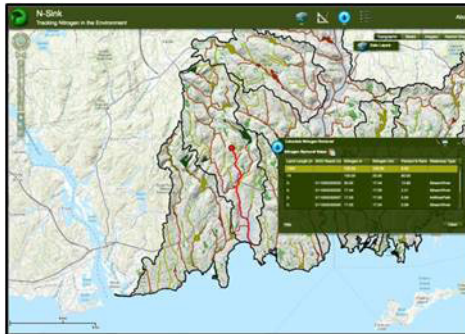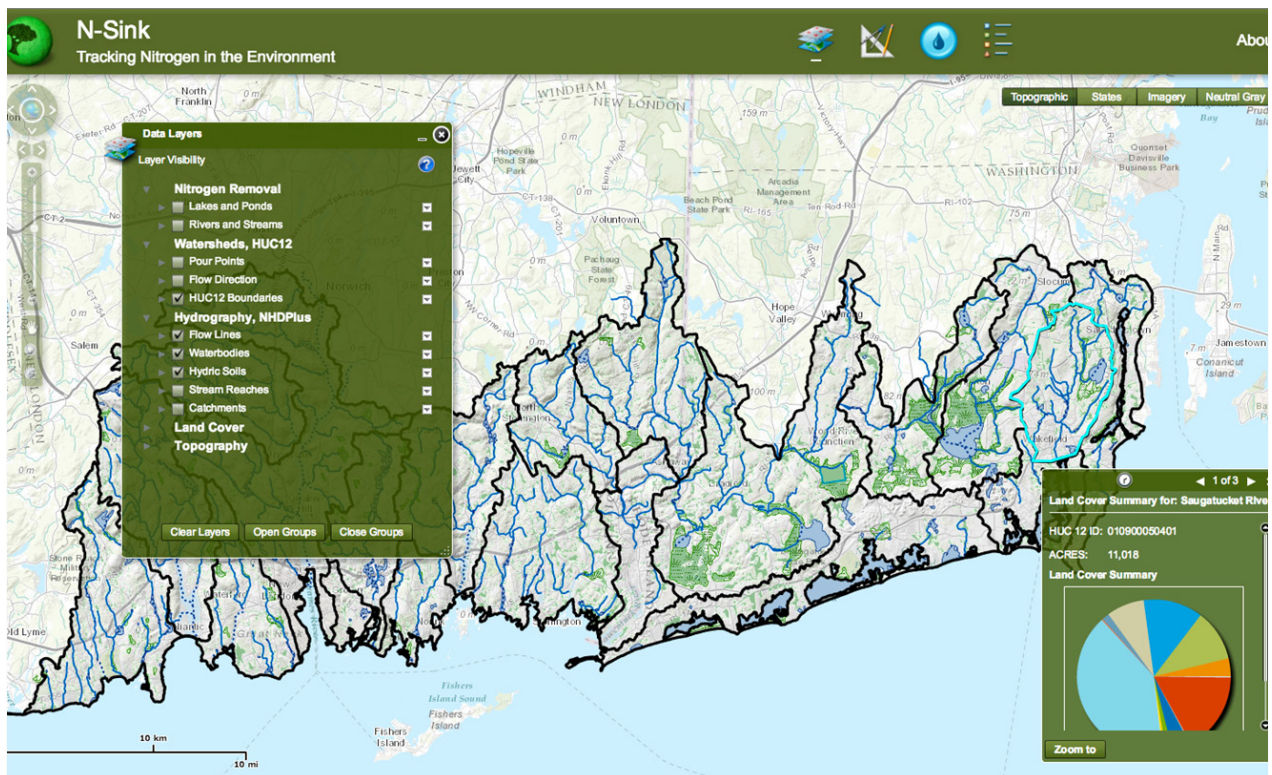
Saugatucket River Watershed

Saugatucket River Watershed
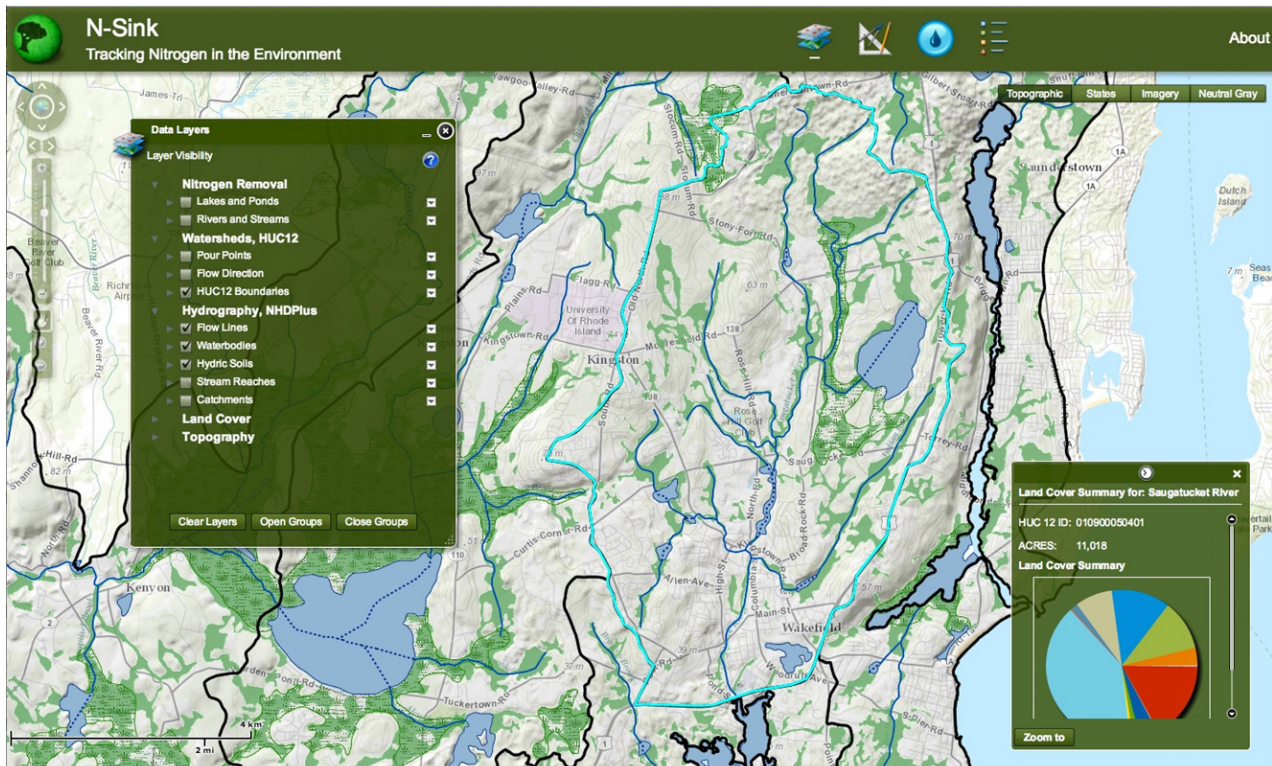
1. Hydrography and hydric soils.
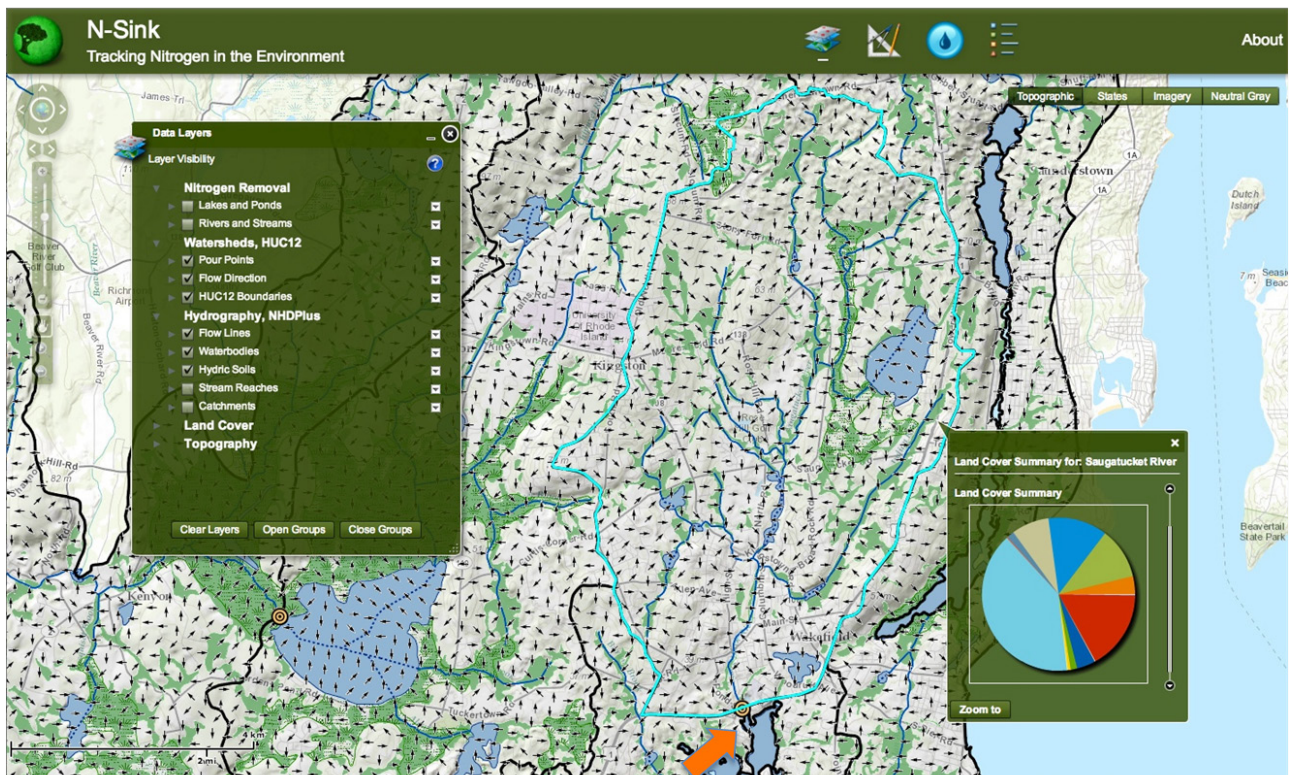
2. Flow direction and outlet point (arrow).

Saugatucket River Watershed
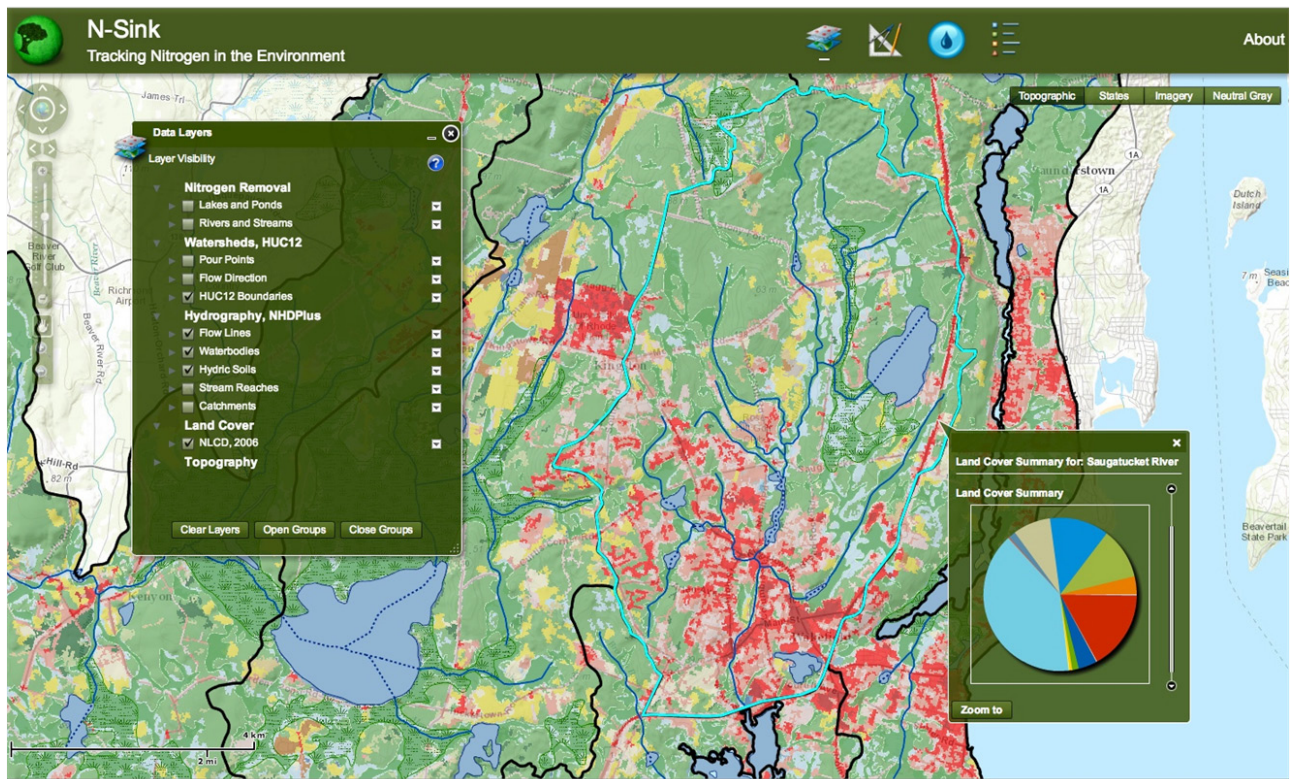
3. Land Cover (NLCD 2006).
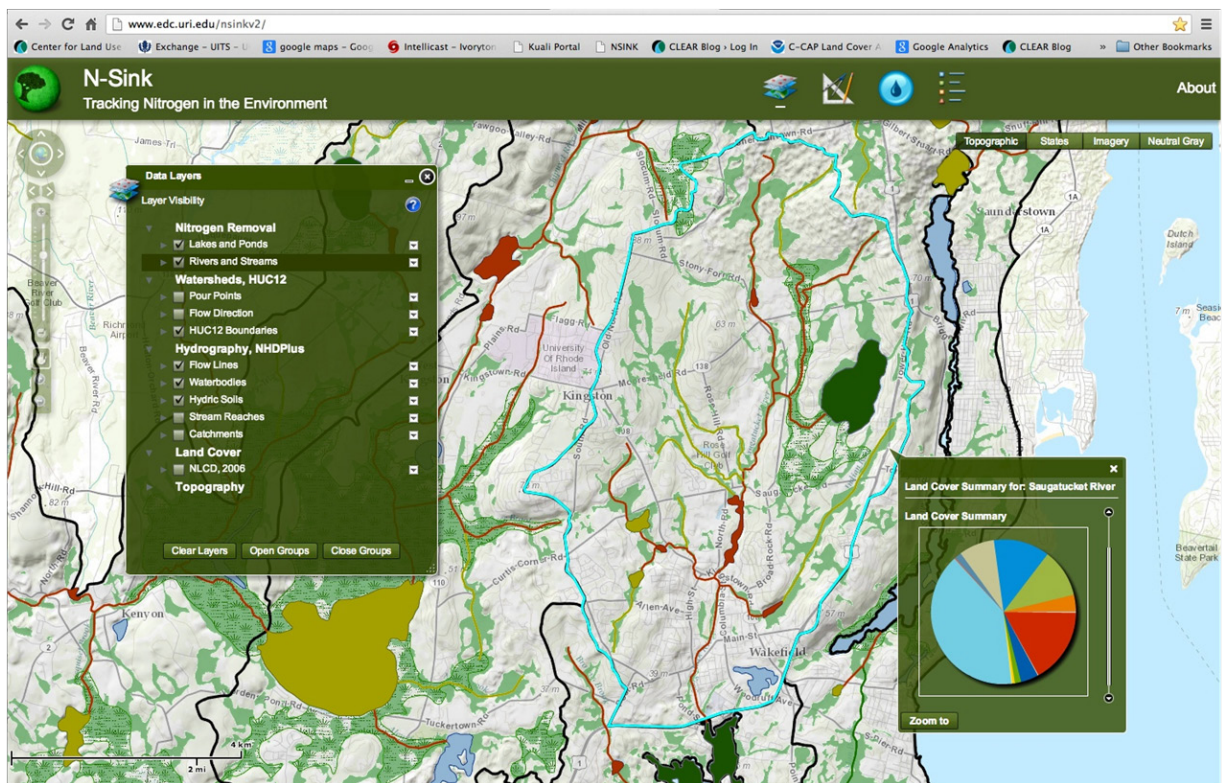
4a. Hydrography coded for N removal of stream reaches and features.

Saugatucket River Watershed
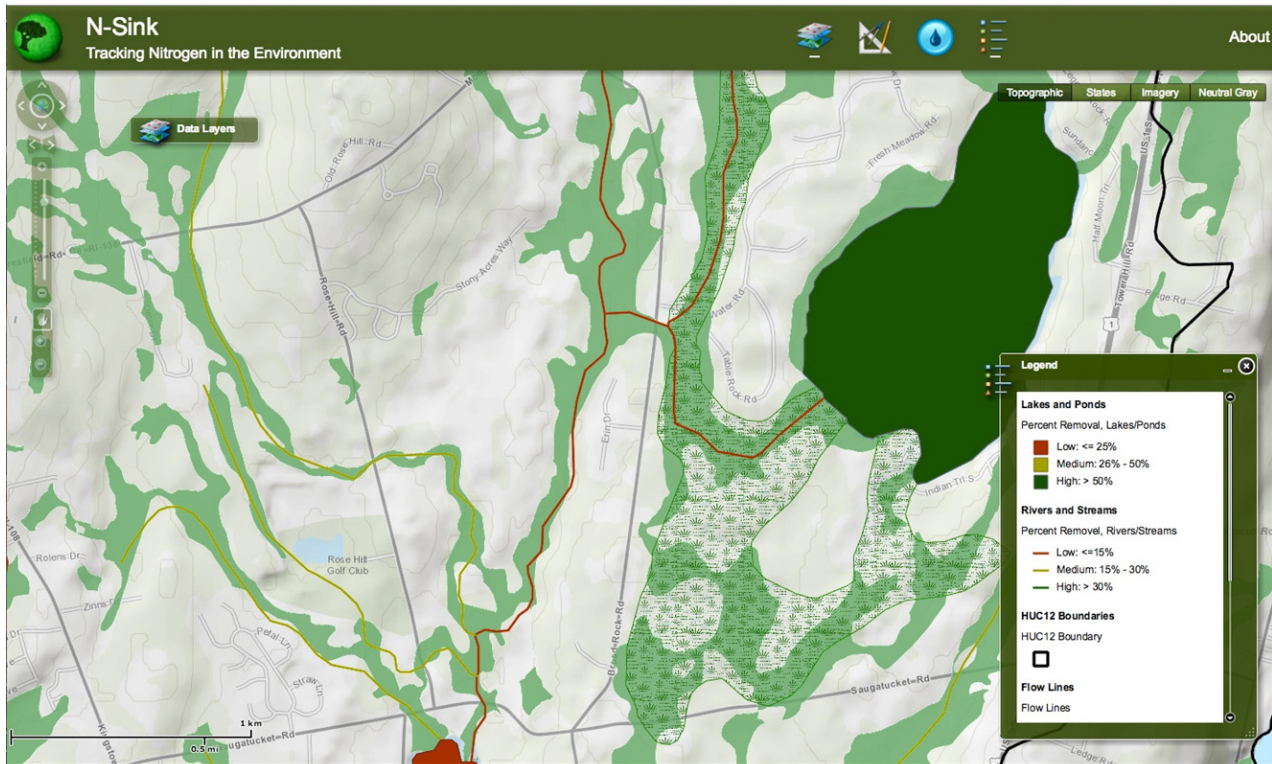
4b. Hydrography coded for N removal of stream reaches and features: detail
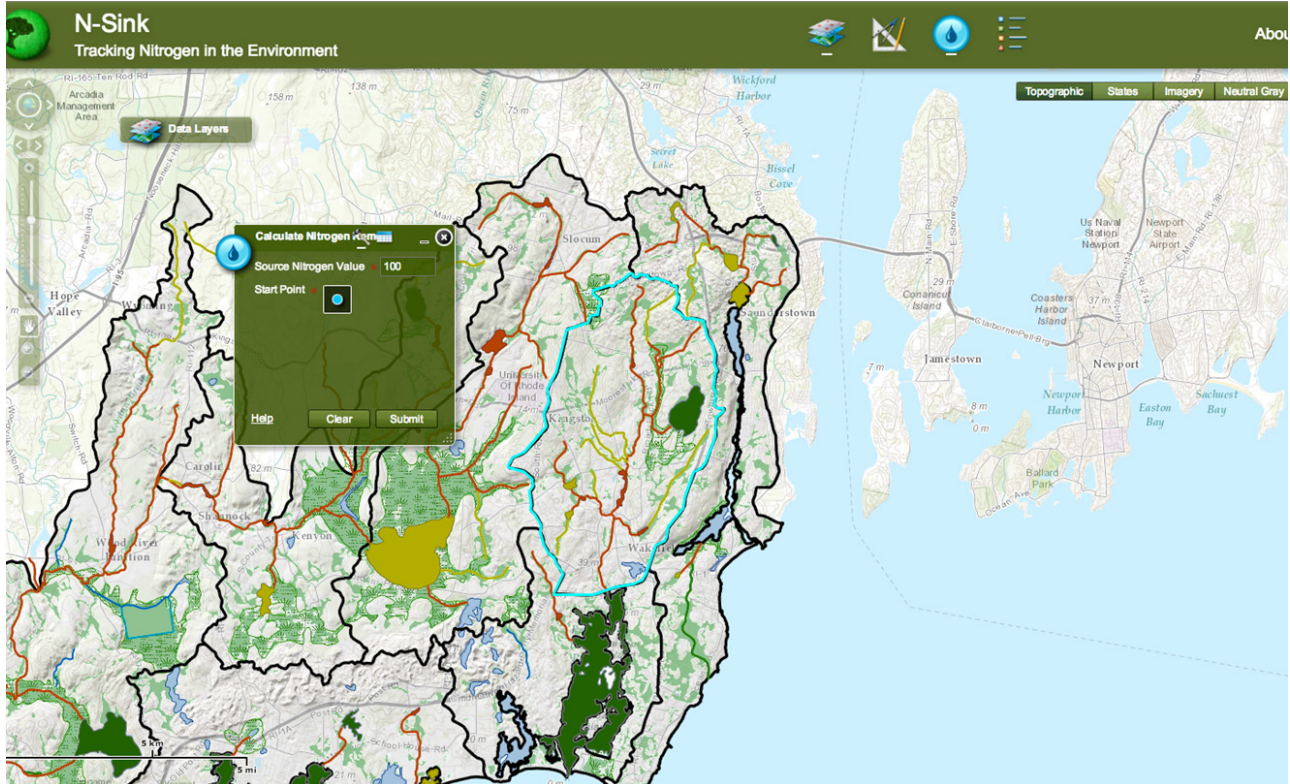
5a.   Nitrogen calculator box opened (top left). Clicking on blue dot allows user to then select any location in watershed.

Saugatucket River Watershed
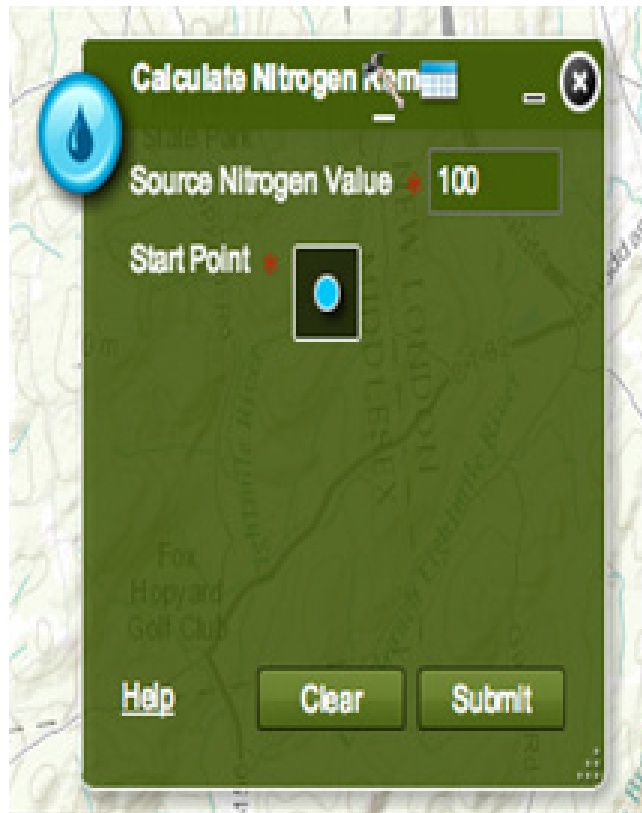
5b. Close-up view of N calculation box. For beta version, N value is set to arbitrary input of 100 units.
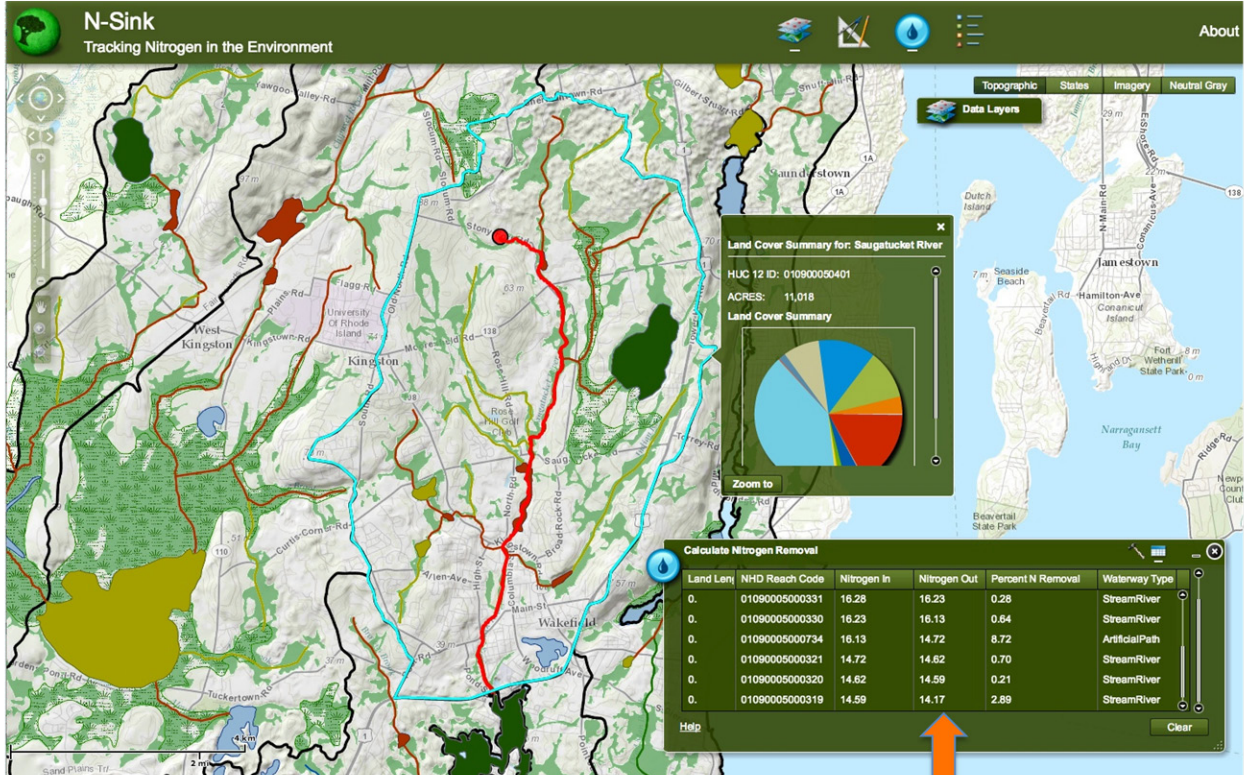
6a. Example A: Flow path from upper watershed. N removal to the ultimate coastal outlet is 86%.

Saugatucket River Watershed
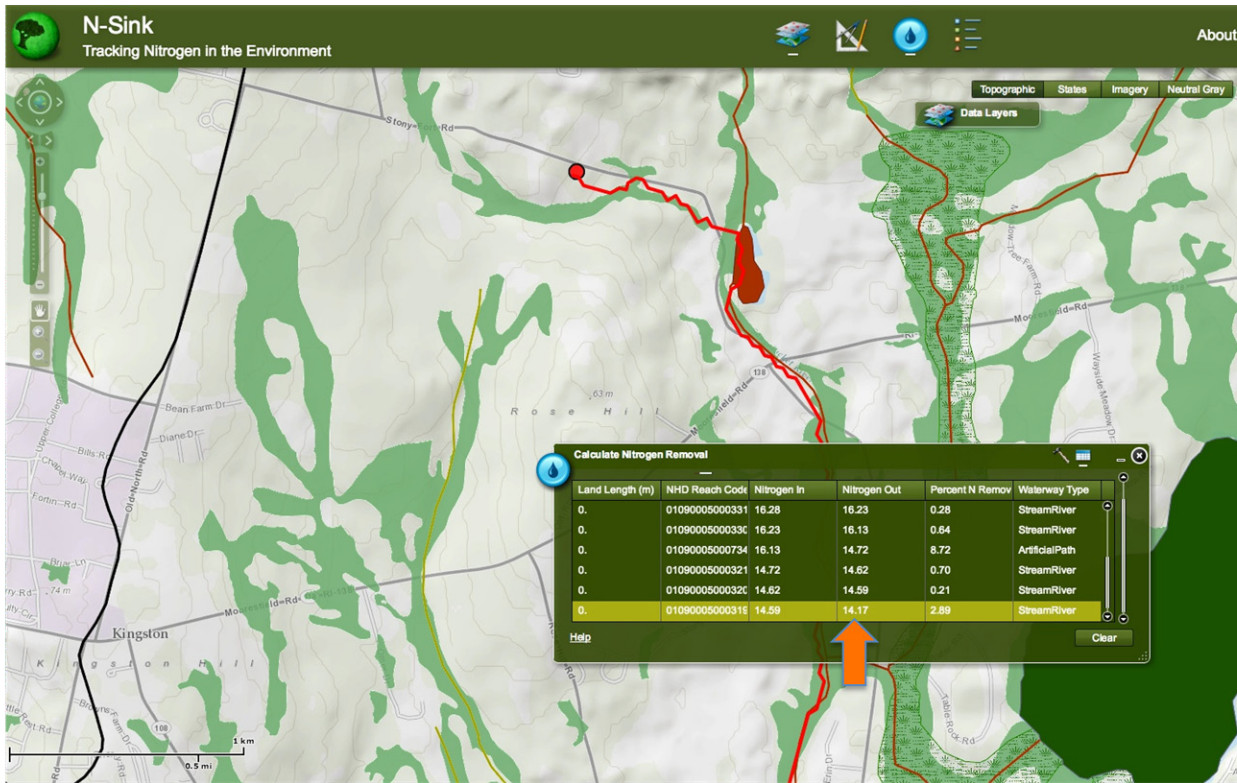
6b. Example A: Close-up.
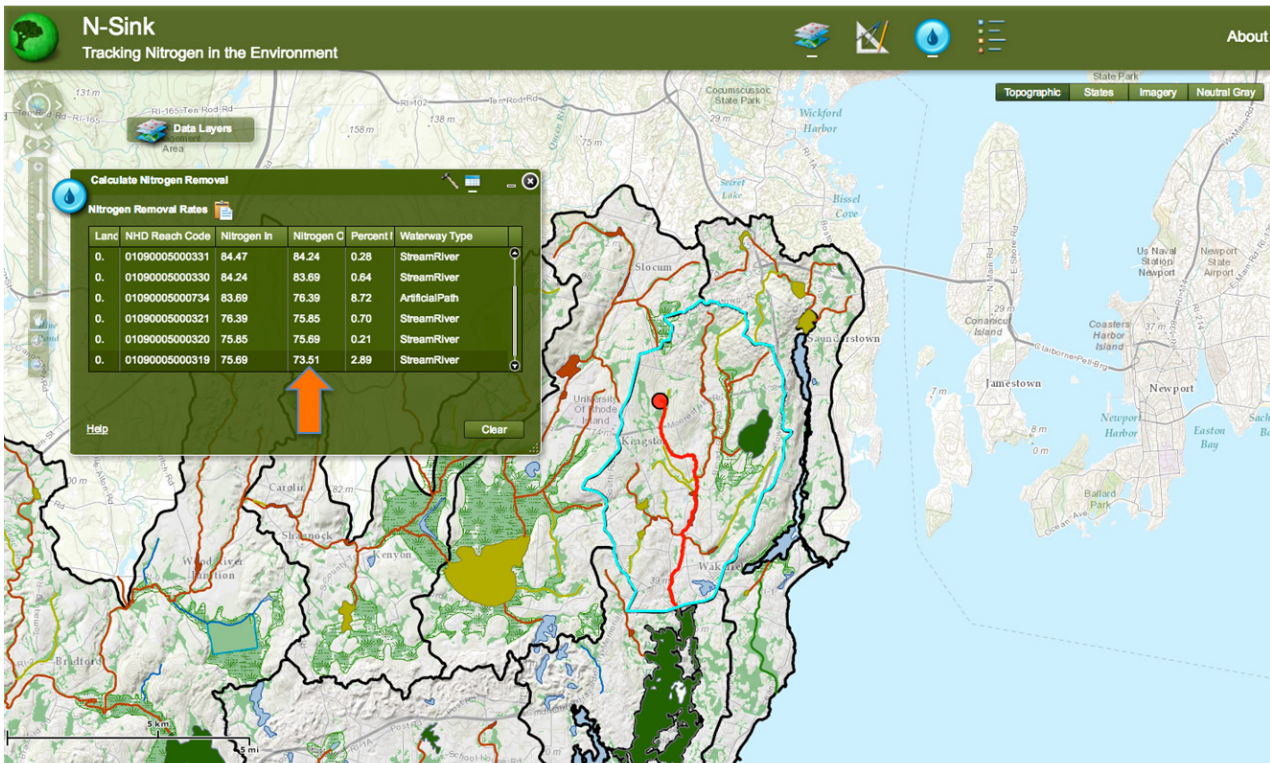
7a. Example B: Flow path from upper watershed, close to site A. N removal is 26%.

Saugatucket River Watershed
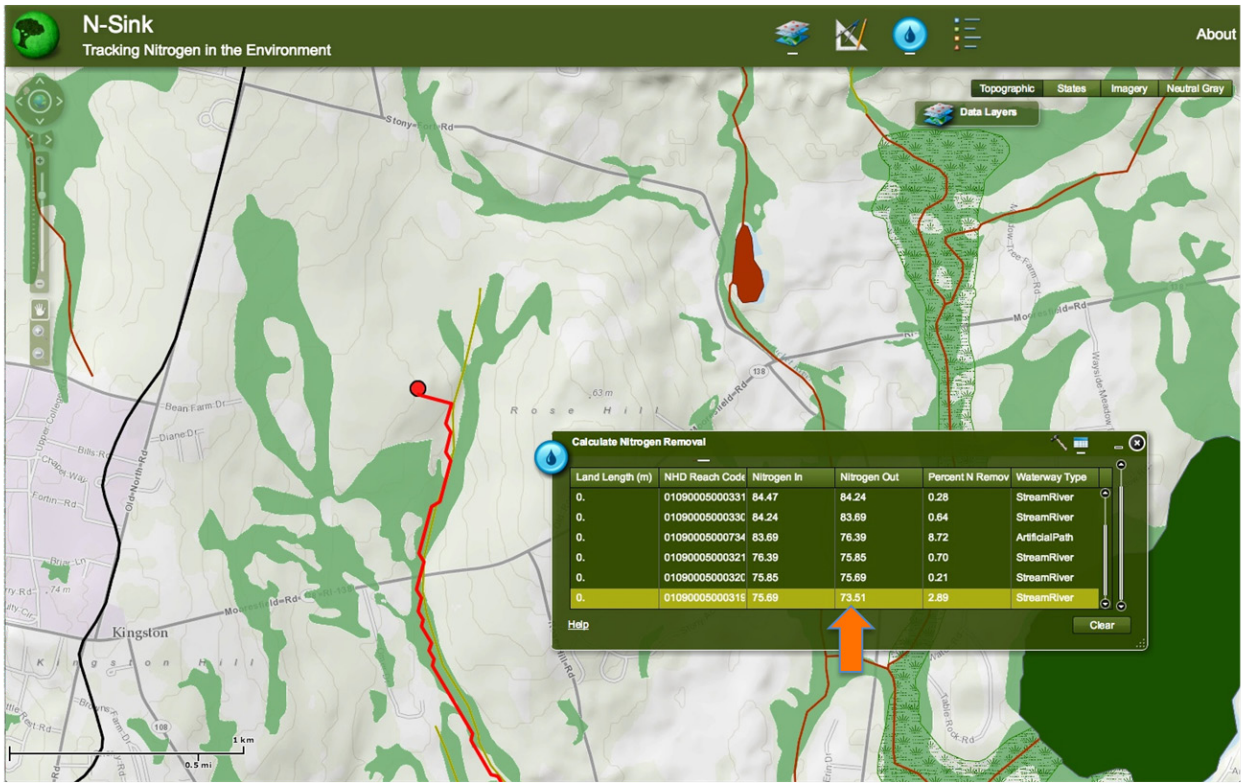
7b. Example B: Close-up.
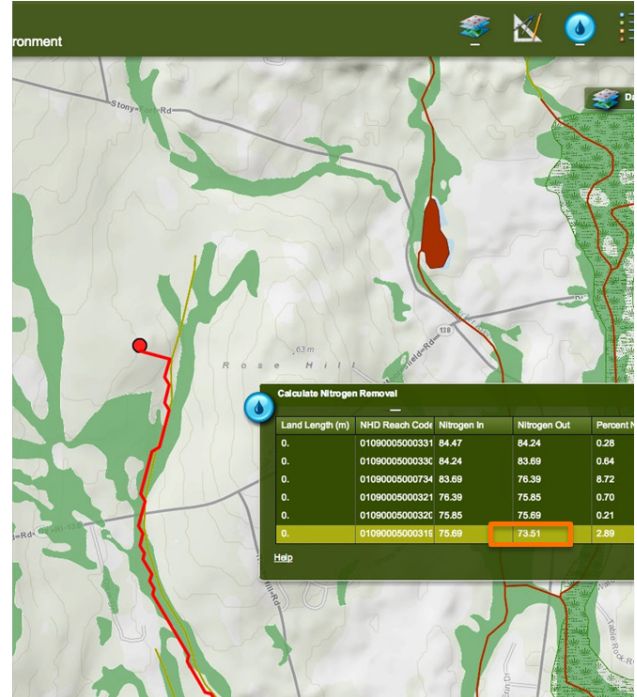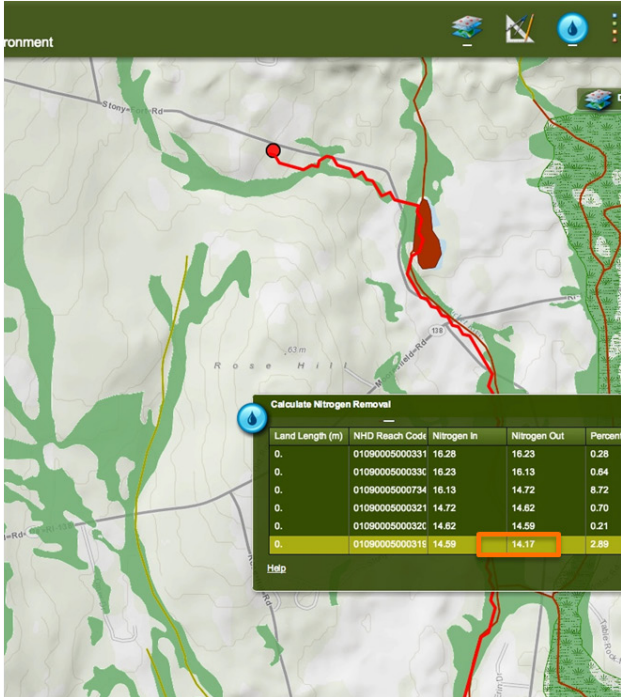
10. Sites A and B compared side by side.

Saugatucket River Watershed
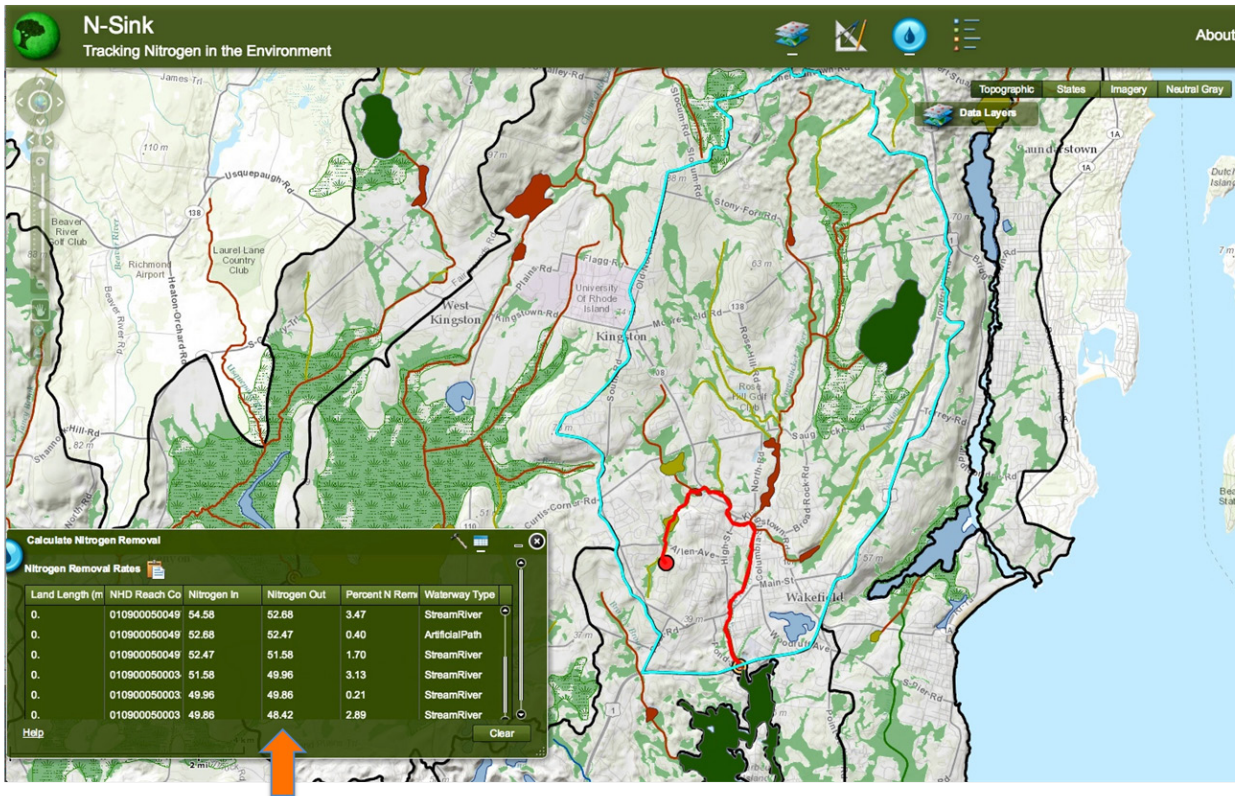
8a. Example C: Flow path from SW corner of watershed. N removal is 52%.
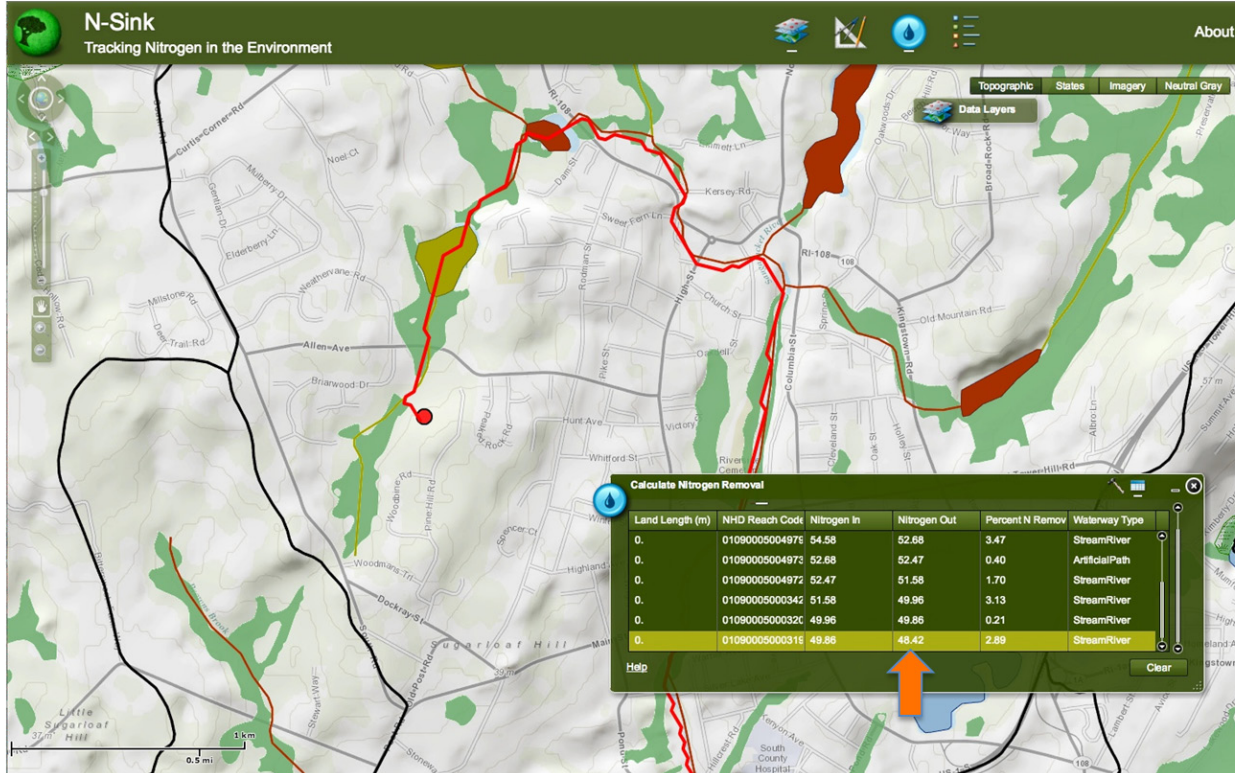
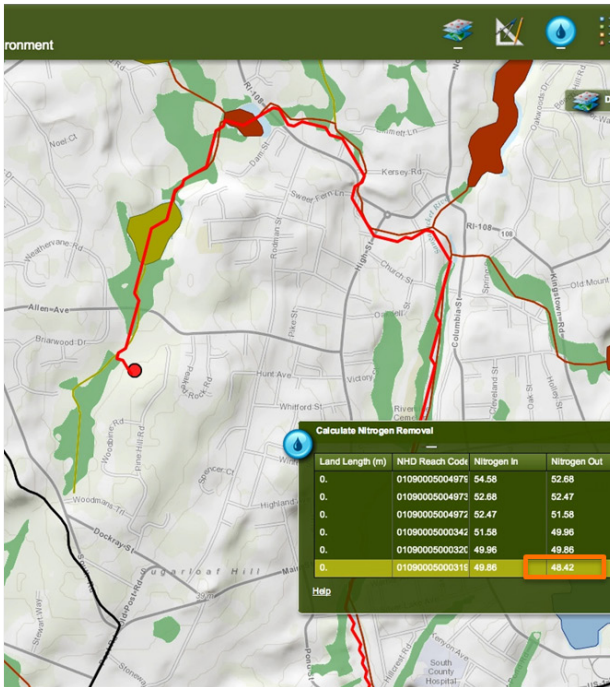*8b. Example C: Close-up.*

Saugatucket River Watershed
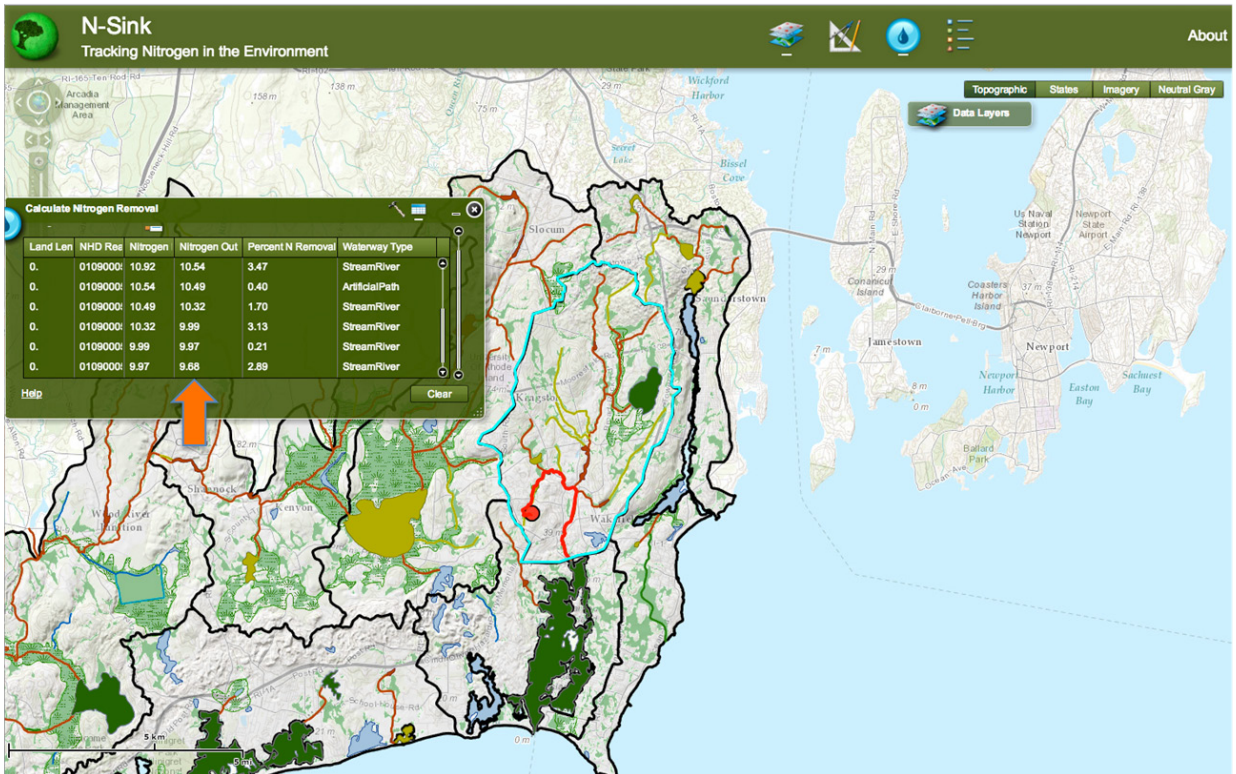
9a. Example D: Flow path from SW corner of watershed, close to site C. N removal is 90%.
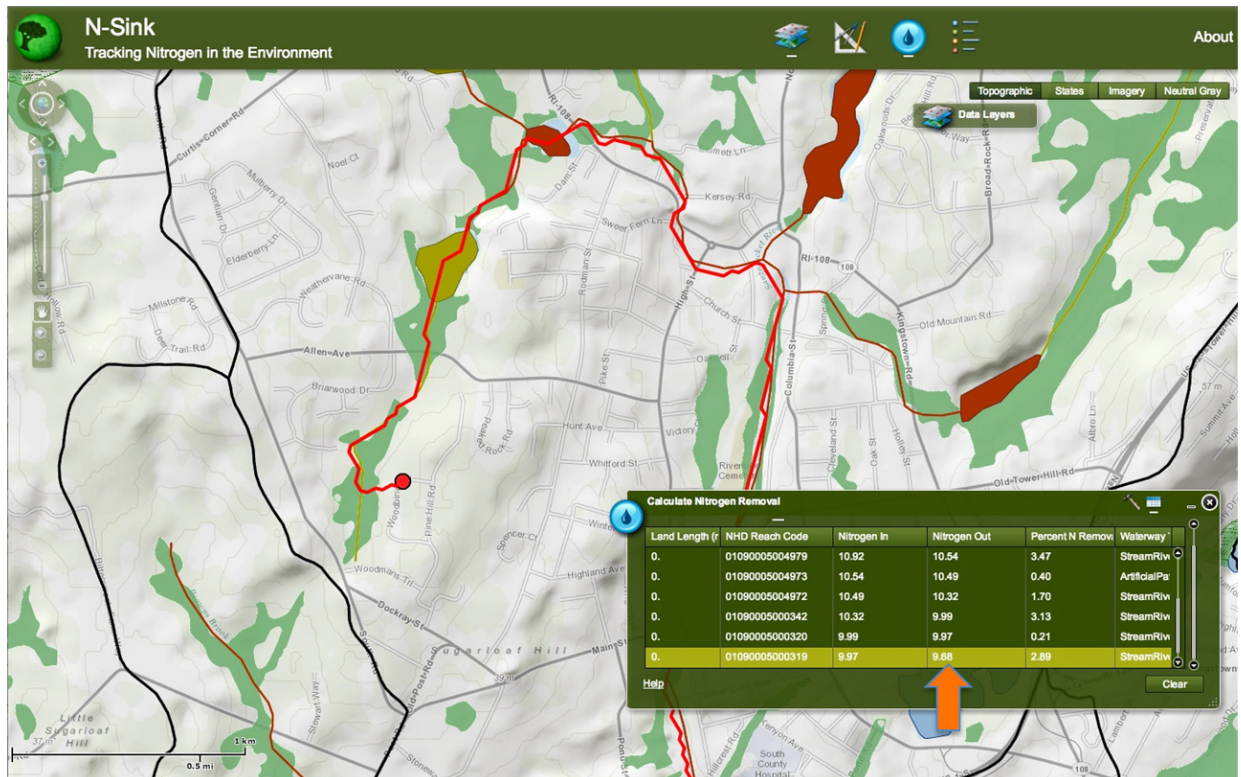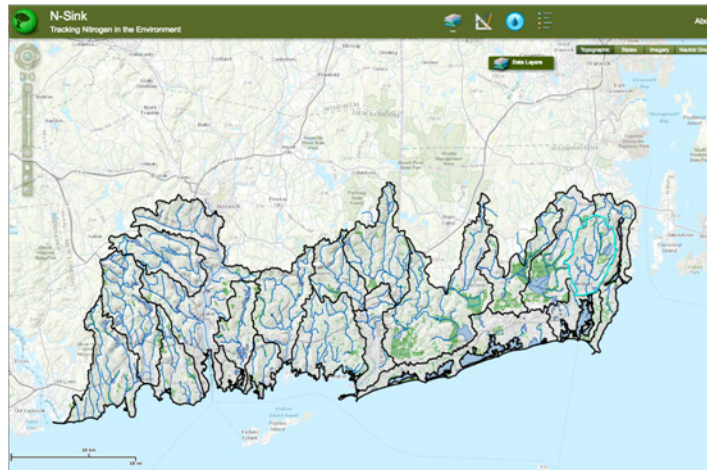

9b. Example D: Close-up.

Saugatucket River Watershed
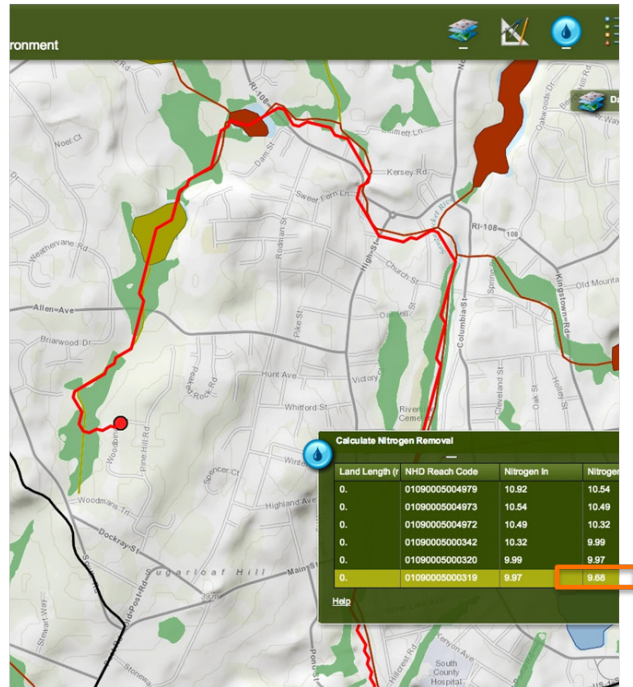
10. *Sites C and D compared side by side.*

Appendix C

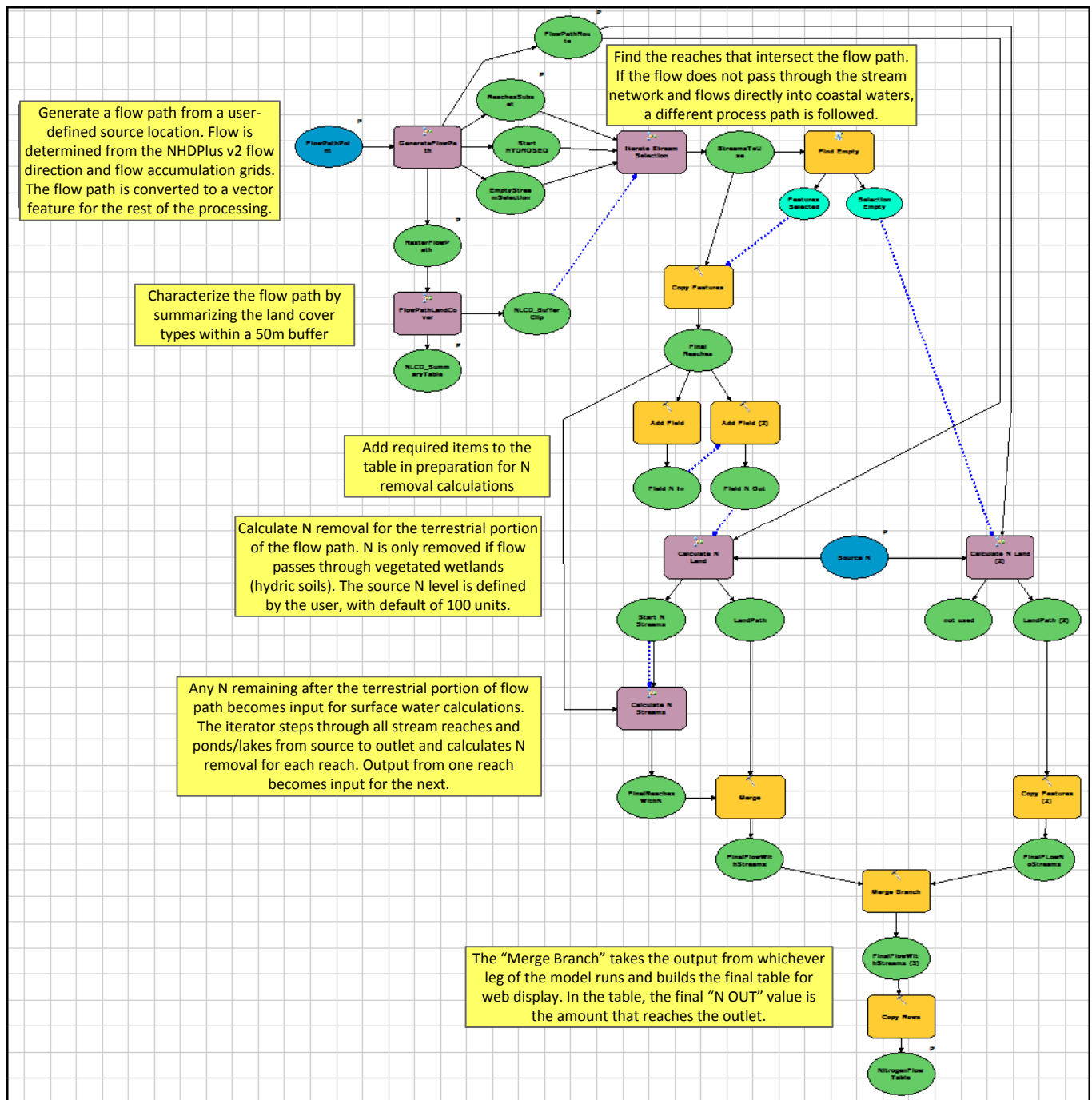## Screen captures showing selected Modelbuilder © models created for N-Sink analyses

Figure C-1. *Overall layout of how the final model is constructed. Yellow boxes explain the procedure. Blue ovals are input; Green ovals are output that pass to the next level. Mauve boxes are individual sub-models that do most of the actual calculations; Gold boxes are tools; The dotted blue lines are preconditions that have to be satisfied before the model can continue.*
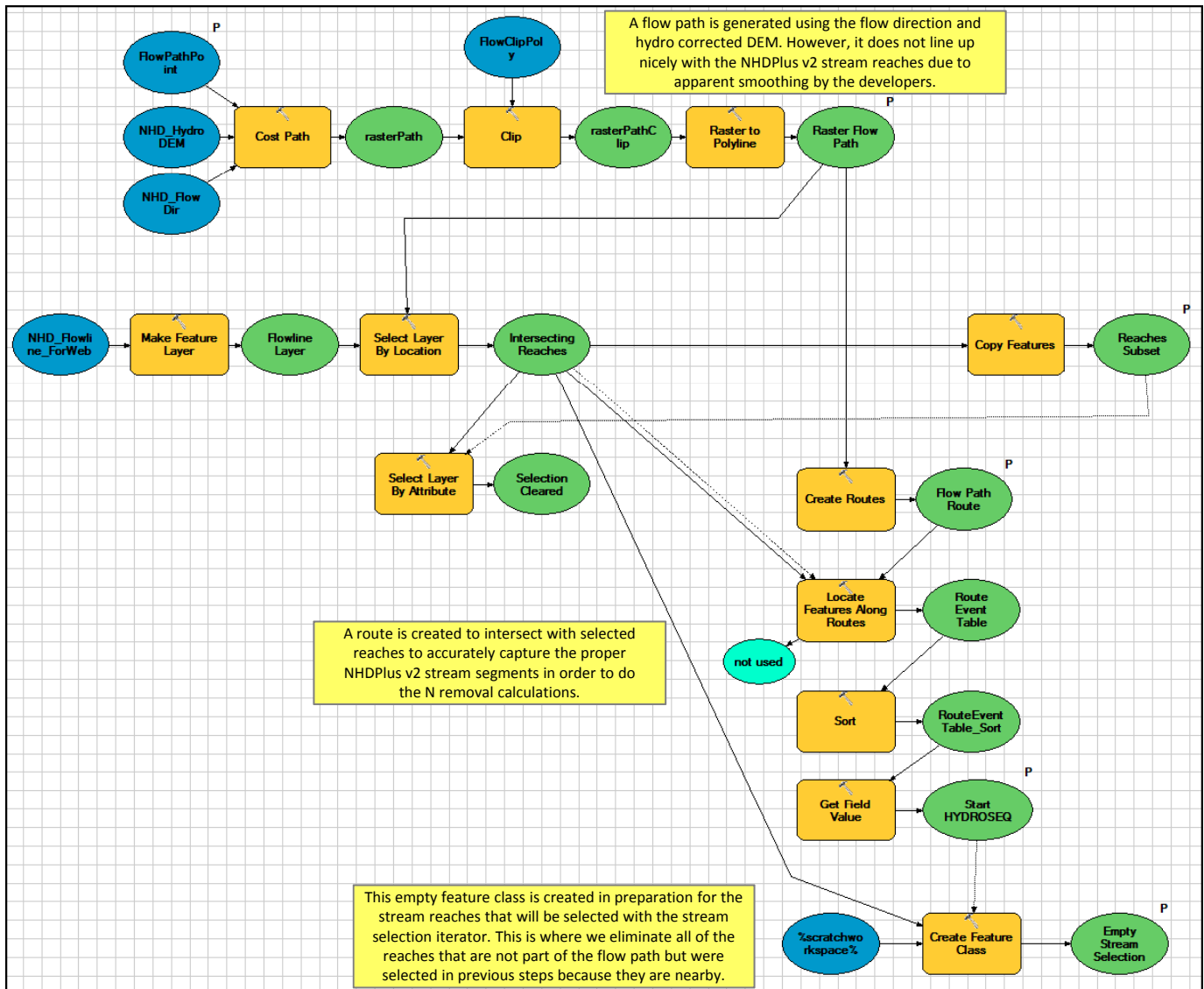
Figure C-2. *FlowPath sub-model. This is the first sub-model that runs, showing how the flow path is generated using the user-defined start location; the NHD flow direction grid; and the NHD hydro-corrected elevation grid. Any output (green oval) with a "P" is used as input further along in the processing. Yellow boxes explain the procedure.*
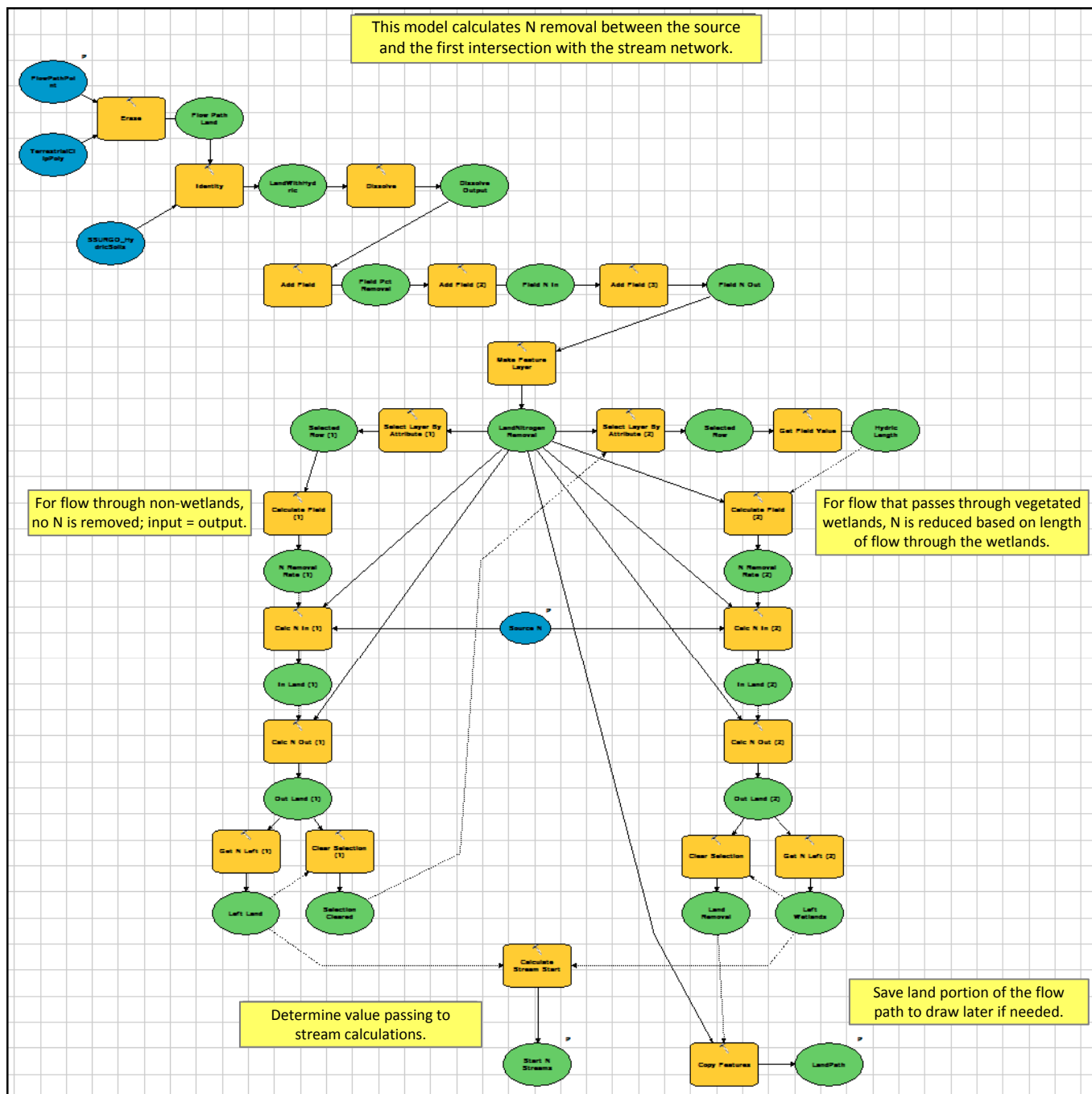
Figure C-3. *LandRemoval sub-model. The sub-model that determines how much N is removed before the flow path connects with the stream network. Different calculations are run depending on if the flow path crosses vegetated wetlands (determined using SSURGO hydric soils and NLCD land cover).*

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