CONNECTICUT SEA GRANT PROJECT REPORT

Please complete this progress or final report form and return by the date indicated in the emailed progress report request from the Connecticut Sea Grant College Program. Fill in the requested information using your word processor (i.e., Microsoft Word), and e-mail the completed form to Syma Ebbin syma.ebbin@uconn.edu, Research Coordinator, Connecticut Sea Grant College Program. Do NOT mail or fax hard copies. Please try to address the specific sections below. If applicable, you can attach files of electronic publications when you return the form. If you have questions, please call Syma Ebbin at (860) 405-9278.

Please fill out all of the following that apply to your specific research or development project. Pay particular attention to goals, accomplishments, benefits, impacts and publications, where applicable.

Name of Submitter:

Date of Report submission:

Project #: LI 00A00284 Check one: [ ] Progress Report [X] Final report

Duration (dates) of entire project, including extensions: From [03/01/2021] to [02/28/2024].

Project Title or Topic: Can Watershed Land Use Legacies Inform Nitrogen Management?

Principal Investigator(s) and Affiliation(s):

1. Ashley Helton, Dept. of Natural Resources and the Environment, Center for Environmental Science and Engineering, University of Connecticut

2. Wilfred Wollheim, Dept. of Natural Resources and the Environment, University of New Hampshire

3. Paul Stacey, Footprints in the Water, LLC

4. Emily Wilson, Center for Land Use Education and Research, University of Connecticut

A. <u>COLLABORATORS AND PARTNERS</u>: *(List any additional organizations or partners involved in the project.)*

- David Bjerklie, University of Connecticut
- Christopher Bellucci, CT DEEP
- Mary Becker, CT DEEP
- Chet Arnold, University of Connecticut
- Janet Barclay, USGS
- Marty Briggs, USGS
- Qian-Li (Rachel) Parent, University of Connecticut

B. PROJECT GOALS AND OBJECTIVES:

Obj 1. Develop a geospatial classification scheme of vulnerability to watershed land use legacies. Our approach is to quantify trends in satellite-derived land use land cover (LULC) and classify historic aerial imagery to identify areas with high percentages of historic agricultural land practices and deforestation, and subsequent changes in land use over the last century. We expect the outcome to be a state-of-the art map of land use legacies that will inform watershed selection in Obj 2 and guide our engagement efforts in Obj 3.

Obj 2. Quantify the influence of watershed land use legacies on present day water quality. Our approach is to synthesize existing water quality datasets and measure stream nitrogen dynamics along a gradient of contemporary and legacy watershed disturbance (identified by maps produced in Obj 1). For a subset of streams, we will also assess longer-term water quality indicators (macroinvertebrate & diatom biointegrity indices) to evaluate interactions between water quality and ecosystem recovery from watershed legacies. We posit that legacy signals from historic land uses may obscure relationships between contemporary watershed LULC and non-point source (NPS) loading, water quality, and biointegrity. Hence, outcomes for understanding N dynamics in a land use legacy context include: 1) solidified relationships between watershed condition and water quality; and 2) better constrained estimates of NPS delivery of nitrogen to LIS.

Obj 3. Engage the public and resource managers in how watershed land use legacies can guide better watershed management decisions*.* Our approach is to engage diverse stakeholders through webinars, direct communication, and creation of an interactive online map. Our findings will be directly useful to managers by providing a framework for action that targets watersheds with land-use legacy concerns. By refining relationships between LULC and water quality, improved management goals can be developed that more effectively guide land conservation and NPS reduction management practices towards desired, ecosystem-health outcomes.

C. LISS CCMP IMPLEMENTATION ACTIONS: (*List the top 3 primary CCMP Implementation Actions that this project addresses. LISS CCMP Implementation Actions can be found at https://longislandsoundstudy.net/2021/01/ccmp-implementation-actions-supplemental-documents/)*

1. WW-1: Evaluate how drivers of pollutant loads and management responses will affect current and future pollutant loads from point and nonpoint sources.
2. WW-27: Improve ability of models and/or studies to estimate contaminant and nutrient loads to embayments and evaluate the effectiveness of remedial actions.
3. WW-29: Develop and implement a water quality monitoring strategy for nitrogen in the upper basin states of Massachusetts, Vermont, and New Hampshire.

D. PROGRESS: (*Summarize progress relative to project goals and objectives. Highlight outstanding accomplishments, outreach and education efforts; describe problems encountered and explain any delays.)*

Obj 1. Develop a geospatial classification scheme of vulnerability to watershed land use legacies.

Internal project GIS: The first task was to assemble geospatial datasets covering the entire Long Island Sound watershed to inform site selection (Objective 2). A key dataset is land cover change, especially those change patterns that have the highest likelihood of legacies. For example, we identified and mapped agricultural areas, areas of agricultural change to forest, and areas of agricultural change to developed land cover. The land cover was shared and displayed in an interactive map viewer with dozens of other layers, such as rivers and waterbodies, habitat, soil, groundwater, crop density and elevation. The team used the viewer to guide site selection and sampling.

Site-based Watershed Mapping: We delineated all watersheds for the field research (~100 sites) and the water quality database (~1000 sites; see descriptions below in Obj 2). For all of these watersheds, we summarized land cover and land cover changes since 1985.

Historical Aerial Imagery Processing: A total of 23 field sample watersheds were selected for historical agricultural land cover mapping. The 1934 aerial photos for these selected watersheds were collected and georeferenced to Connecticut State Plane Coordinate System. The georeferenced aerial photos were classified using an object-based approach which groups contiguous pixels into objects with similar spectral and spatial properties. A decision-tree approach was developed to identify potential agricultural land cover based on spectral and spatial characteristics of the objects. Based on the preliminary visual assessment, the computer-based approach provided inadequate results due to the limited spectral properties in the single-band 1934 aerial photos. Manual on-screen digitizing was then used to correct classification errors and delineate polygons for historical agricultural land cover. The delineated polygons were categorized into crop and pasture (or hay) lands, and quality checked by a second analyst to ensure accuracy. The delineated polygons were used to calculate percent areas of historical agricultural land cover for each sample watershed.

Geospatial Classification Scheme of Vulnerability to Legacies: For the entirety of the Long Island Sound watershed, the team leveraged the internal project GIS to map high, medium and low vulnerability to agriculture legacies and moderate-high and low vulnerability based on sewage infrastructure. This map is complete and its publication is forthcoming.

Obj 2. Quantify the influence of watershed land use legacies on present day water quality.

<u>*Preliminary water chemistry dataset:*</u>

We selected and sampled 94 headwater streams for water chemistry from August to October 2021. We selected streams based on their historic and contemporary land cover (Objective 1) and sampled sites across CT, MA, and NH. For each location we used handheld probes to measure water temperature, specific conductance, dissolved oxygen and pH. Qualitative observations were recorded for substrate and riparian zone characterization. Samples were collected to be analyzed for alkalinity and a suite of solutes. A sample for pH analysis was collected each sampling day to verify that handheld probe measurements were accurate. Samples were analyzed in labs at both UCONN and UNH. Total dissolved nitrogen was measured using high temp oxidation with chemiluminescent detection, dissolved organic carbon was measured using high temp catalytic oxidation, anions (chloride, bromide, nitrate, and sulfate^{-}) and cations (sodium, potassium, magnesium, and calcium) were measured using ion chromatography, and silica was measured using colorimetry. Dissolved nutrients (nitrate, ammonium, and phosphate) were analyzed colorimetrically on a discrete analyzer.

Seasonal baseflow sampling:

We used water chemistry datasets to inform selection of stream locations to sample for water chemistry and biointegrity during year 2 of the project. In Connecticut, we leveraged available 1934 aerial photos to select 14 core sites that fell across a land cover change gradient of agriculture (1934) to forest (2016) with four watersheds containing low agricultural land cover (<%10) in 1934 as well as the present day. Watershed delineations were created from the point of sampling using USGS StreamStats and ranged from 2 km^2 to 14 km^2. All sites contained < 8% developed land cover with shallow bedrock and till as common parent material ("Soil Survey Geographic Database (SSURGO) Soil Parent Material" 2019). Sites were located in three different vegetation zones: transition hardwoods - white pine - hemlock, central hardwoods - hemlock - white pine, and central hardwoods - hemlock

In NH and MA, since we lacked historic aerial imagery, we used agricultural soils maps and current forested land cover to select a total of 12 sampling locations that represented contemporary agricultural end members (n = 4), sites that were likely agricultural in the past but forested today (n = 4), and sites that were forested today and also likely forested in the past several decades (n = 4).

During year 2, and each of the 26 core sites, surface water samples were collected once per month from May to October 2022 during base flow conditions (for five total samples per site). Surface water samples were analyzed for temperature, dissolved oxygen, conductivity, pH, alkalinity, nutrients, and ions (Br^-, Na^+, K^+, Mg^{2+}, Ca^{2+}, and Si^{4+}). We measured in situ temperature, dissolved oxygen, conductivity, and pH using a calibrated, handheld multimeter (YSI ProQuatro). Alkalinity samples were collected and refrigerated with no headspace until analysis. A water sample for nutrients and ion measurements were filtered in the field using a 0.7 micron GF/F Whatman filter and frozen until analysis. All water samples were collected in acid-wash and field-rinsed HDPE bottles and transported on ice to the lab.

For each site, groundwater discharge surveys were conducted in July and August 2022 along the stream reach upstream of the surface water sampling location for 12 sites. One of the most efficient ways to survey the presence of groundwater discharge along stream banks is utilizing Thermal Infrared (TIR) cameras to locate thermal anomalies (Barclay et al. 2022). During the summer season groundwater is colder than surface water. Cool shallow pools along the stream bank can also be mistaken for cold water seeps, to ensure sample collection came from a seep we looked for evidence of flow from the seep (observed flowing water and/or cool to warm temperature mixing that can be spotted on the TIR camera) and verified the cold temperature by measuring the subsurface temperature with a handheld soil thermometer. We used E8 and T540 TIR FLIR cameras and waded upstream while scanning the left and right banks of the stream. The cameras were set at a temperature range that would encompass the surface (high end of the range) and groundwater temperatures (low end of the range). Once a seep multiple degrees cooler than the surface water was found GPS coordinates were marked on Garmin max 64sx GPS; and then a push point sampler, connected to a three-way valve and 60 ml syringe, was inserted 20 cm deep into the coldest part of the seep. We flushed the push point sampler until water was clear, and then collected groundwater samples for alkalinity, nutrients, and ions (Br^-, Na^+, K^+, Mg^{2+}, Ca^{2+}, and Si^{4+}) following the same procedure as surface water.

At each site, we also measured sediment size distribution, surveyed for large woody debris, and conducted geomorphic transects to describe stream width, curvature, and slope.

For biological sampling sites, we sampled macroinvertebrates and diatoms across an agriculture to forest land cover gradient; these sites possessed <5% developed land cover. We sampled 14 macroinvertebrate sites and 19 diatom sites. These sites overlapped our core water chemistry sampling sites in CT and were also sites that had been sampled multiple times by CT DEEP, such that we used CT DEEP's historic macroinvertebrate dataset for our analyses.

Our field dataset is complete, and initial findings are reported in Dionisio 2023 (MS Thesis, University of Connecticut, attached to final report). A summary of our results is provided in section L. below.

Water quality database and watershed land cover:

We completed synthesizing publicly available water quality, stream discharge, and water quality through the construction of a database. The water quality database is published and described online here - https://clear.uconn.edu/projects/lis_water_quality_dashboard/.

Briefly, All water quality data within the LIS water quality dashboard were downloaded from the Water Quality Portal (WQP; https://www.waterqualitydata.us/) with the 'dataRetrival' package (De Cicco et al. 2022) in R Statistical Software (R Core Team 2021). The dashboard includes all available stream/river site locations within the U.S. portion of the LIS watershed sampled between 1957 and 2021. We snapped all locations within the site list to nearest stream reach (based on the National Hydrography Dataset (NHD); USGS, 2019a) within 500m, and used these updated locations as "pour-point" locations for watershed delineations. Each point was delineated using the StreamStats R package (https://github.com/markwh/streamstats.git).

Results were manually inspected for accuracy with a focus on small watersheds since there is a stronger tendency to snap those locations to incorrect stream reaches. Sites with clear corrections were manually adjusted to represent the accurate 'pour point' location and run via online StreamStats tools (Ries et al., 2017; USGS, 2019b). We eliminated 235 sites because the location did not clearly coincide with a stream reach.

Data were filtered to only includes sites that had a corresponding watershed delineation, and had one or more of the following common water quality measurements: "Ammonia and ammonium", 'Total dissolved solids', "pH", "Specific conductance", "Nitrate", "Orthophosphate", "Phosphate-phosphorus", "Phosphate-phosphorus as P", "Soluble Reactive Phosphorus (SRP)". For each site in the data portal, we determined whether it was likely affected by a dam, diversion, or wastewater treatment plant (WWTP). For dams, we snapped locations from the National Inventory of Dams (USACE, 2021.) to NHD stream reaches. For each water quality site, we identified two categories as being potentially dam influenced if it was <10km or <50km downstream from the nearest dam. We only considered dams with the purpose of "Water Supply" and have a minimum of 100 Storage acre ft. For WWTPs, we snapped locations from the EPA Wastewater Treatment facilities database (https://echo.epa.gov/tools/web-services/facility-search-water) to NHD stream reaches, and flagged any sites downstream within the network of a WWTP. For diversions, we used the Connecticut Department of Energy and Environmental Protection hydrography data (CT DEEP, 2011), which identified stream reaches with varying diversion types ("Aqueduct","Canal, Lock, or Sluice Gate","Underground Aqueduct","Spillway", or "Ditch or Canal"). We do not include diversion information for states other than Connecticut. Dates are not considered within the analysis, thus only current conditions are used within the site influence analysis.

We conducted baseflow regression using 'bfi' function within USGS-R 'DVstats' package version 0.3.4 (Lorenz, 2017) for all available site locations with streamflow data. We used R 'flowfill' from the R package 'baytrends' (Murphy et al. 2023) to fill data gaps less than seven days. For data gaps longer than seven days, we ran separate baseflow regressions for each time period. The result is daily baseflow metrics (proportion of streamflow as baseflow and proportion of streamflow as quickflow) for all streamflow sites and collection time periods. For each streamflow site and day, we categorized conditions as baseflow when the proportion of baseflow was greater than 75%.

For each water quality sample collected, we determined whether it was collected during baseflow or nonbaseflow conditions. Because the majority of sites within the water quality dataset are not directly associated with streamflow data, we joined each water quality site with all available streamflow records within the same HUC06 basin (USGS, 2016). For each HUC we determined that all water quality samples collected on a given day were collected during baseflow conditions when all of the streamflow sites within that HUC were at baseflow (i.e., baseflow proportion greater than 75%). For time periods where there were no flow records for a given HUC06, all records within the LIS basin are used and if all were at greater than 75% baseflow, then that period was considered to be baseflow conditions, and workflow can be found within the repository code "2_NHD_DownloadSetUp.R".

All of the code used to download, clean, and analyze the information presented in the LIS Water Quality Dashboard is available https://github.com/Haredkb/LIS_WaterQualityData.git. We have begun analysis of this dataset, and a summary of our findings thus far are included below in section L.

Citations:

- CT DEEP— Connecticut State Department of Environment and Protection. (2011). Connecticut Hydrography. Retrieved from https://services1.arcgis.com/FjPcSmEFuDYlIdKC/ArcGIS/rest/services/Connecticut_Hydrography_Set/FeatureServer.
- De Cicco, L.A., Hirsch, R.M., Lorenz, D., Watkins, W.D., Johnson, M., 2022, dataRetrieval: R packages for discovering and retrieving water data available from Federal hydrologic web services, v.2.7.12, doi:10.5066/P9X4L3GE
- Lorenz D (2017). DVstats: Functions to manipulate daily-values data_. R package version 0.3.4.
- Murphy R, Perry E, Keisman J, Harcum J, Leppo EW (2023). baytrends: Long Term Water Quality Trend Analysis. R package version 2.0.9
- Ries, K. G., III, Newson, J. K., Smith, M. J., Guthrie, J. D., Steeves, P. A., Haluska, T., Kolb, K., Thompson, R. F., Santoro, R. D., & Vraga, H. W. (2017). StreamStats, version 4 (USGS numbered

series No. 2017–3046), StreamStats, version 4, fact sheet. U.S. Geological Survey. https://doi.org/10.3133/fs20173046

- USACE—U.S Army Corps of Engineers. National Inventory of Dams. 2021. Available online: https://nid.sec.usace.army.mil/ (accessed on 15 January 2023).
- USGS—U.S. Geological Survey, 2016, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), accessed [January 10, 2023], at URL [http://waterdata.usgs.gov/nwis/].
- USGS—U.S. Geological Survey, 2019a, National Hydrography Dataset (ver. USGS National Hydrography Dataset Best Resolution (NHD) for Hydrologic Unit (HU) 4 - 2001 (published 20191002)), accessed 05 Feb, 2023 at URL https://www.usgs.gov/national-hydrography/access-national-hydrography-products
- USGS—U.S. Geological Survey, 2019b, The StreamStats program, online at https://streamstats.usgs.gov/ss/, accessed on 05 Feb 2023.

***Obj 3. Engage the public and resource managers in how watershed land use legacies can guide better watershed management decisions**:*

Public presentations: We have engaged stakeholders through webinars and seminars that describe watershed land use legacies. Helton has presented to approximately 65 people over three webinars, and given two academic seminars. Wollheim has given two academic seminars and one outreach seminar. See presentation details listed below.

Online maps and dashboards: We have engaged the public through our online dashboard of water quality and watershed characteristics (https://clear.uconn.edu/projects/lis_water_quality_dashboard/), as described above in objective 2. We are also in the process of posting our watershed legacy vulnerability map (see objective 1 above) to be hosted on CLEAR's website.

Story map: We have begun the development of a story map to be published on watershed legacies in the Long Island Sound. This story map will describe the concept of legacies and present major findings from the research project.

Application of the Local Watershed Assessment Tool (LWAT): We leveraged our water chemistry dataset and geospatial analysis to implement LWAT, which is a spreadsheet-based tool designed for managers that predicts stream biointegrity as a combined condition index that describes the connection to watershed health in the combined riparian and upland areas (Combined Condition Index or "CCI") and stream biointegrity (Local Watershed Assessment Tool (arcgis.com)). The macroinvertebrate diversity samples were consistent with LWAT's statewide assessments in CT, reaffirming the CCI connection to biointegrity along the biocondition gradient. LWAT also estimates nitrogen yields and loads based on the CCI, generally providing a good correlation to median TDN and DIN surface water monitoring data from 63 study sites in CT and MA samples. (Note that the NH sites could not be compared because of differences in buffer width (100-m) and resolution (30-m)) Since only 9 of the 63 sites had a low CCI value of <0.50 on a 0 to 1 scale (actual range was 0.11 – 0.39 for the 9 sites), most would benefit from conservation and recovery practices to sustain good water quality.

Using a general Best Attainable Condition (BAC) estimate in LWAT's Decision Support Framework (DSF) scenario builder by converting all the land cover in the 100' buffer to natural condition, and half the cultured land cover (lawn and agriculture) in the area upland of the buffer, CCIs were raised to 0.5 or above at all but 5 sites with all but 10 sites exceeding 0.75 CCI. This is attributed to the generally good current condition of all sites but also the recovery potential of good riparian and landscape conservation and recovery practices.

LWAT's total nitrogen (TN) yield estimates exceeded 5 lbs/acre-yr only at the 9 low diversity sites. The predicted desirable range correlative to biocondition outcomes protective of stream water quality and a prospective LIS loading target range is 3 – 5 lbs/acre-yr. Strategic management decision support parallels biointegrity with a focus on conservation and recovery although stormwater mitigation practices can also effectively reduce TN; however, reducing TN is not likely to improve biointegrity independent of land cover improvements in the CCI according to LWAT. Nevertheless, land management under the BAC scenario would lower TN yield substantially with only 3 sites exceeding the 5 lbs/acre-yr benchmark for TN yield and 6 sites greater than 3 lbs TN/acre-yr.

In sum, LWAT provides decisionmakers and managers with the necessary information to make strategic management decisions to conserve, promote recovery or mitigate conditions and provide quantifiable, site-specific actions for land cover management at 1-m resolution with potential to set targets and chart progress based on land use, all consistently supported by the project findings. Details of the tool and its application are provided in full in the attached Technical Memorandum.

E. PROJECT PUBLICATIONS, PRODUCTS, PRESENTATIONS AND PATENTS: *(Include published materials with complete references, as well as those which have been submitted but not yet published and those in press. Please attach electronic versions of any journal articles, reports, and abstracts not previously provided.)*

Journal Articles (List URLs):

Conference Papers:

Proceedings or book chapters:

Web sites, Software, etc.:

- LIS Water Quality Dashboard - https://clear.uconn.edu/projects/lis_water_quality_dashboard/
- Land use legacies in New England Story Map – Forthcoming
- Land use legacies vulnerability map - Forthcoming.

Technical Reports/Other Publications:

- Long Island Sound Study Research Project – Management Applications. Technical Memorandum. Stacey, PE. Footprints in the Water, LLC. Attached to this final report.

Other Products (including popular articles):

Publications planned / in progress:

- A framework for how watershed land use legacies affect stream ecosystems in New England, USA. Planned for submission to *Freshwater Science*.
- Long-term trends in water quality in streams of the Long Island Sound watershed. Planned submission *TBD*.

Patents: *(List those awarded or pending as a result of this project.)*

Presentations and Posters: *(Include name and date of the conference or meeting, whether it was a talk or poster, if it was invited, and who the presenter was.*)

- (Invited) Helton, AM. Thames River Basin Partnership quarterly speaker: Can Watershed Land Use Legacies Inform Nitrogen Management? (April 21, 2021)
- (Invited) Helton, AM. Center for Land Use Education and Research (CLEAR) Webinar, Can watershed land use legacies inform nitrogen management? (June 16, 2021)
- (Invited) Helton, AM. CT DEEP Brown Bag Webinar, Can watershed land use legacies inform nitrogen management? (August 12, 2021)
- (Invited) Wollheim, W.M. 2021. Scaling cumulative function of aquatic networks. Natural Resources and the Environment Seminar Series. University of Connecticut. Storrs CT. September 2021
- (Invited) Wollheim, W.M. 2021. Scaling cumulative function of aquatic networks. Water and Environment Seminar Series. Helmholtz-Zentrum für Umweltforschung-UFZ June 2021.
- Wollheim, W.M. 2021. Fluvial Wetlands and Nitrogen Retention in Coastal Watersheds. Parker, Ipswich, Essex River Restoration Annual Meeting, December 2021.
- Moore, EM, JR Barclay, KE Jackson, AB Haynes, MA Briggs, AM Helton. 2021. Connecting land cover to groundwater discharge nutrient concentrations across stream sizes. Society of Freshwater Science Annual Meeting. Virtual Presentation.
- (Invited) Helton, AM. 2022. Where the past meets the present (and the future): Connecting the dots between streams, groundwater, land use history, and climate change. Department of Biology seminar, University of Louisville, virtual
- (Invited) Helton, AM. 2022. Where the past meets the present: Connecting streams to their watersheds through groundwater flow paths and land use legacies. Land Resources and Environmental Sciences seminar, Montana State University, virtual
- Hare, DK, J Buonpane, A Dionisio, Q Lei-Parent, EM Moore, M Becker, C Bellucci, D Bjerklie, PE Stacey, EH Wilson, W Wollheim, AM Helton. 2022. Can watershed land use legacies inform nitrogen management? Long Island Sound Research Conference (May 18, 2022)
- Dionisio, AB, J Buonpane, EM Moore, W Wollheim, C Arnold, M Becker, Q Lei-Parent, P Stacey, E Wilson, AM Helton. 2022. How Do Historic Land Uses Affect Stream Ecosystems? The Role of Structural Legacies. Joint Aquatic Sciences Meeting. Grand Rapids, MI.
- Dionisio, AB, J Buonpane, EM Moore, W Wollheim, M Becker, Q Lei-Parent, E Wilson, P Stacey, AM Helton. 2023. Past or present: How structural and signal legacies are realized in afforested watersheds. Society of Freshwater Science Annual Meeting. Brisbane, Australia
- Helton, AM, A Dionisio, EM Moore, DK Hare, D Bjerklie, EH Wilson, Q Lei-Parent, W Wollheim, J Buonpane, J Barclay, C Bellucci, M Becker. 2023. How watershed land use legacies can inform nitrogen management. Northeast Aquatic Biologists Conference. Plymouth, MA.
- Dionisio, A, EM Moore, DK Hare, D Bjerklie, EH Wilson, Q Lei-Parent, W Wollheim, J Buonpane, J Barclay, C Bellucci, M Becker, AM Helton. 2023. Imprints in colonial agriculture: The role of legacies in stream ecosystems. Northeast Aquatic Biologists Conference. Plymouth, MA
- Malk, N. 2024. Decadal trends in land use and water quality in the Long Island Sound watershed. Frontiers Undergraduate Research Forum. University of Connecticut

F. <u>FUNDS LEVERAGED</u>: *(If this Sea Grant funding facilitated the leveraging of additional funding for this or a related project, note the amount and source below.)*

- Wollheim: New Hampshire Agricultural Experiment Station (20K). The response of water quality and aquatic ecosystem function to changing land use and variable climate in New England

- Helton, Lei-Parent, Wilson: Interactive map of water quality data for the Long Island Sound watershed ($14,309) College of Agriculture, Health and Natural Resources Strategic Visioning Implementation Funding
- Wilson, E.H., Q. Lei-Parent. Historic Land Use Mapping in Support of Using Sediment Diatoms from Lake Sediment Cores to Develop a Better Assessment of Connecticut Lakes. Southwest Conservation District, April 2023-Sept 2024, $15,000.

G. STUDENTS: ***(****Document the number and type of students supported by this project.)*
Note: ***"Supported"*** *means supported by Sea Grant through financial or other means, such as Sea Grant federal, match, state and other leveraged funds. "****New"*** *students are those who* ***have not*** *worked on this project previously. "****Continuing"*** *students are those who* ***have*** *worked on this project previously. If a student volunteered time on this project, please use section G, below.*

Total number of **new*** K-12 students who worked with you: 0
Total number of **new** undergraduates who worked with you: 2
Total number of **new** Masters degree candidates who worked with you: 0
Total number of **new** Ph.D. candidates who worked with you: 0

Total number of **continuing**** K-12 students who worked with you: 0
Total number of **continuing** undergraduates who worked with you: 0
Total number of **continuing** Masters degree candidates who worked with you: 3
Total number of **continuing** Ph.D. candidates who worked with you: 2

Total number of volunteer hours: 120

*(Note: *New students are those who have not worked on this project previously. **Continuing students are those who have worked on this project previously.)*

In the case of graduate students, please list student names, degree pursued, and thesis or dissertation titles related to this project.

Student Name: Ariana Dionisio
Degree Sought: MS
Thesis or Dissertation Title: How do Historic Land Uses Impact Stream Ecosystems? The Role of Structural Legacies
Date of thesis completion: Spring 2023
Expected date of graduation: Spring 2023

Student Name: Joshua Buopane
Degree Sought: MS
Thesis or Dissertation Title: Functional differences between stream microbial communities in a suburbanizing watershed
Date of thesis completion: August 2023
Expected date of graduation: December 2023

Student Name: Eric Moore
Degree Sought: Ph.D.

Thesis or Dissertation Title: From land source to watershed outlet: How groundwater discharge influences river network nitrogen cycling
Date of thesis completion: Spring 2024
Expected date of graduation: Spring 2024

Student Name: Danielle Hare
Degree Sought: Ph.D.
Thesis or Dissertation Title: Climate change effects on the temperature regimes and carbon processing of stream ecosystems
Date of thesis completion: Spring 2023
Expected date of graduation: Spring 2023

Student Name: Elana Berlin
Degree Sought: MS
Thesis or Dissertation Title:
Date of thesis completion: 2022
Expected date of graduation: 2022

H. VOLUNTEER HOURS:

(List the number of hours provided to the project by volunteers, i.e., individuals who were not compensated in any way or for whom involvement is not part of their paid occupation. This could be students or citizens. What was their contribution?)

Graduate student volunteer at the University of New Hampshire to help scout sites and collect water samples. 20 hours.

Undergraduate and graduate student volunteers at the University of Connecticut to collect water samples and measure geomorphic features. 100 hours.

I. PICTORIAL:

PICTORIAL: Please provide high resolution images/photos of personnel at work, in the field or laboratory, equipment being used, field sites, organism(s) of study. Attach images as separate files (do not embed). Include links to websites associated with the research project. Please include proper photo credits and a caption with date, location, names of people, and activity. These images are useful to document your project in future CTSG publications, websites and presentations.

- IMG_5048. UConn MS Student Ariana Dionisio conducts a geomorphic transect along a CT stream. Photo credit: Nicolette Nelson
- IMG_4450 – UConn undergraduate student walking down study stream reach in CT. Photo credit: Nicolette Nelson

J. HONORS AND AWARDS:

(List any honors or awards received during the reporting period, for anyone working on the project. This can be for best paper or poster, university awards, etc.) Specify:

a) Name of person or group receiving recognition: Danielle Hare
b) Name of award or honor: Student Research Award (PhD) in the College of Agriculture, Health and Natural Resources/Ratcliffe Hicks School of Agriculture
c) Group or individual bestowing the award or honor: Office of Dean and Director, College of Agriculture, Health and Natural Resources, University of Connecticut

d) What it was for: This award recognizes outstanding scholarly/creative productivity and national visibility in research
activities.
e) Date: January 2022

a) Name of person or group receiving recognition: Ashley Helton
b) Name of award or honor: Research Excellence Award
c) Group or individual bestowing the award or honor: College of Agriculture, Health and Natural Resources, University of Connecticut
d) What it was for: This award recognizes outstanding scholarly/creative productivity and national visibility in research
e) Date: January 2024

a) Name of person or group receiving recognition: Ashley Helton
b) Name of award or honor: Excellence in Mentorship Award
c) Group or individual bestowing the award or honor: Office of Undergraduate Research, University of Connecticut
d) What it was for: Student-nominated award for undergraduate research mentorship
e) Date: March 2024

a) Name of person or group receiving recognition: Nesy Malk (undergraduate student on project)
b) Name of award or honor: Summer Undergraduate Research Fellowship (SURF)
c) Group or individual bestowing the award or honor: Office of Undergraduate Research, University of Connecticut
d) What it was for: Summer research project on long-term water quality trends
e) Date: Summer 2023

a) Name of person or group receiving recognition: Josh Buonpane (MS student on project)
b) Name of award or honor: Endowment Award
c) Group or individual bestowing the award or honor: Society of Freshwater Science
d) What it was for: Excellent graduate research
e) Date: March 2023

K. **DATA MANAGEMENT PLANS:** Proposals funded in 2014-2016 and later cycles are required to have a data management plan in place. All environmental data and information collected and/or created must be made visible, accessible, and independently understandable to general users, free of charge or at minimal cost, in a timely manner (typically no later than two years after the data are collected or created). This is a reminder that your CTSG funded research data needs to be archived and accessible as outlined in the data management plan you submitted with your proposal. If there have been any modifications, adjustments or new information available regarding the location, timing, type, formatting and metadata standards, content, sharing, stewardship, archiving, accessibility, publication or security of the data produced please elaborate here.

FOR FINAL DEVELOPMENT AND RESEARCH GRANT REPORTS, PLEASE COMPLETE THIS SECTION:

L. PROJECT OUTCOMES AND IMPACTS

RELEVANCE OF PROJECT: *(Describe briefly the issue/problem / identified need(s) that led to this work.)*

Past land use activities (or land use "legacies") can be strong indicators of contemporary water quality; yet, watershed management strategies often neglect the lag times associated with land change trajectories. We proposed that a more complete understanding of land use legacies within the LIS watershed and how they interact with patterns of N dynamics and stream biointegrity could better inform and improve management goals and expectations that align with watershed processes. Healthy watersheds will provide the right amount of nitrogen to the LIS; yet, specific management actions and goals often do not address the overall structure and function of watersheds. In this project, we used the context of land use history combined with water quality and stream biointegrity to provide a holistic view of streams and rivers as an intrinsic reflection of physical and ecological processes occurring in their watersheds, rather than simply transporters of nitrogen to the Sound. As our technology for reducing large nitrogen point sources from WWTP plateaus, management of more diffuse and distance sources of nitrogen to the LIS requires this type of alignment with watershed condition and processes. Already, and for upper basin states in particular, understanding land use change is the most important factor in determining nitrogen load to LIS. Thus, outputs and outcomes from our project could help extend the ability of managers to make informed decisions and take appropriate actions to conserve stream biointegrity and reduce river N loading, enhancing the health and sustainability of the LIS.

RESPONSE: *(Describe briefly what key elements were undertaken to address the issue, problem or need, and who is/are the target audience(s) for the work.)*

1. We developed a geospatial classification scheme of vulnerability to watershed land use legacies. For this objective, we quantified trends in satellite-derived land use land cover and classify historic aerial imagery to identify areas with high percentages of historic agricultural land practices and deforestation, and subsequent changes in land use over the last century.

2. We quantified the influence of watershed land use legacies on present-day water quality. For this objective, we synthesized existing water quality and stream biointegrity datasets to evaluate whether incorporating land use history improves broad scale relationships between watershed land cover and water quality; and we measured surface and ground water quality and surface water biointegrity in targeted watersheds that reflect the gradient of potential agricultural land use legacies.

3. We engaged the public and resource managers in how watershed land use legacies can guide better watershed management decisions. For this objective, we developed an online dashboard of water quality linked to watershed characteristics, developed a Story Map (in progress) that explains legacy land use pollution and puts the results in a more narrative form for the public, and we held a series of public webinars, with more planned in the future.

RESULTS: *(Summarize findings and significant achievements in terms of the research and any related education or outreach component; cite benefits, applications, and uses stemming from this project, including those expected in the future. Include qualitative and quantitative results.)*

Mapping: We georeferenced 54 tiles of 1934 aerial photos to cover 23 field sample watersheds and then classified historical agricultural land cover. The georeferenced imagery and historical agricultural land cover were published as ArcGIS map services and included in an interactive map viewer as described in Section D - Obj 1. The land cover statistics calculated based on the historical agricultural land cover served as a foundation of the water quality analysis. In addition, approximately 120 tiles of 1934 aerial photos were georeferenced for potential future uses.

All georeferenced 1934 tiles are part of a growing service and map that will be available on the CT ECO website. CT ECO is a statewide mapping website accessed by tens of thousands of users a year. It also shares data with the new State GIS Office GeoData Portal. Historic aerials, especially from 1934, are highly requested and the mosaic of 1934 aerials is the most locationally accurate available. Sharing it on CT ECO will make it available to a wide range of users and many uses.

To share results of the project, in progress is an interactive map that will include data layers created for this project, such as the 1990 septic density map, as well as already existing reference layers. The viewer will bring the select layers together making it easy to assess water quality in one place. Accompanying the map viewer will be a story map, also in development, that is being designed for the non-professional reader. It will explain what a legacy is, why legacies are important, share results of the project, and the ability to explore relevant maps.

Following the publishing of the 1934 service, the project interactive map, and the story map, we anticipate a range of outreach activities including at least one webinar, a newsletter article, a webinar, and potential conference presentations.

Summary of major findings from field data collected in CT: Relationships between past and present watershed agricultural land cover make it difficult to disentangle relationships between legacy land use and present-day stream ecosystems. Substantial 1934 cropland was converted to hay by 2016, masking the potential legacy effects of 1934 cropland. Relationships we observed could indicate a prolonged structural legacy from over 100 years of agricultural land use or we could simply be seeing impacts from contemporary hay or pasture land cover; even though it makes up a small proportion of watershed land cover. Importantly, we did not find significant relationships between land use land cover and nitrogen concentrations, indicating that after agricultural fields have been reforested for decades they do not generate a detectable legacy nitrogen signal. Other than nitrogen, we found a potential legacy signal of specific conductivity (salinity) and phosphate, which though are less important for the Sound, can have profound impacts on freshwater ecosystems. Detailed results are presented in Dionisio 2023 (MS Thesis, University of Connecticut, attached to final report) and summarized in Figure 1, below.

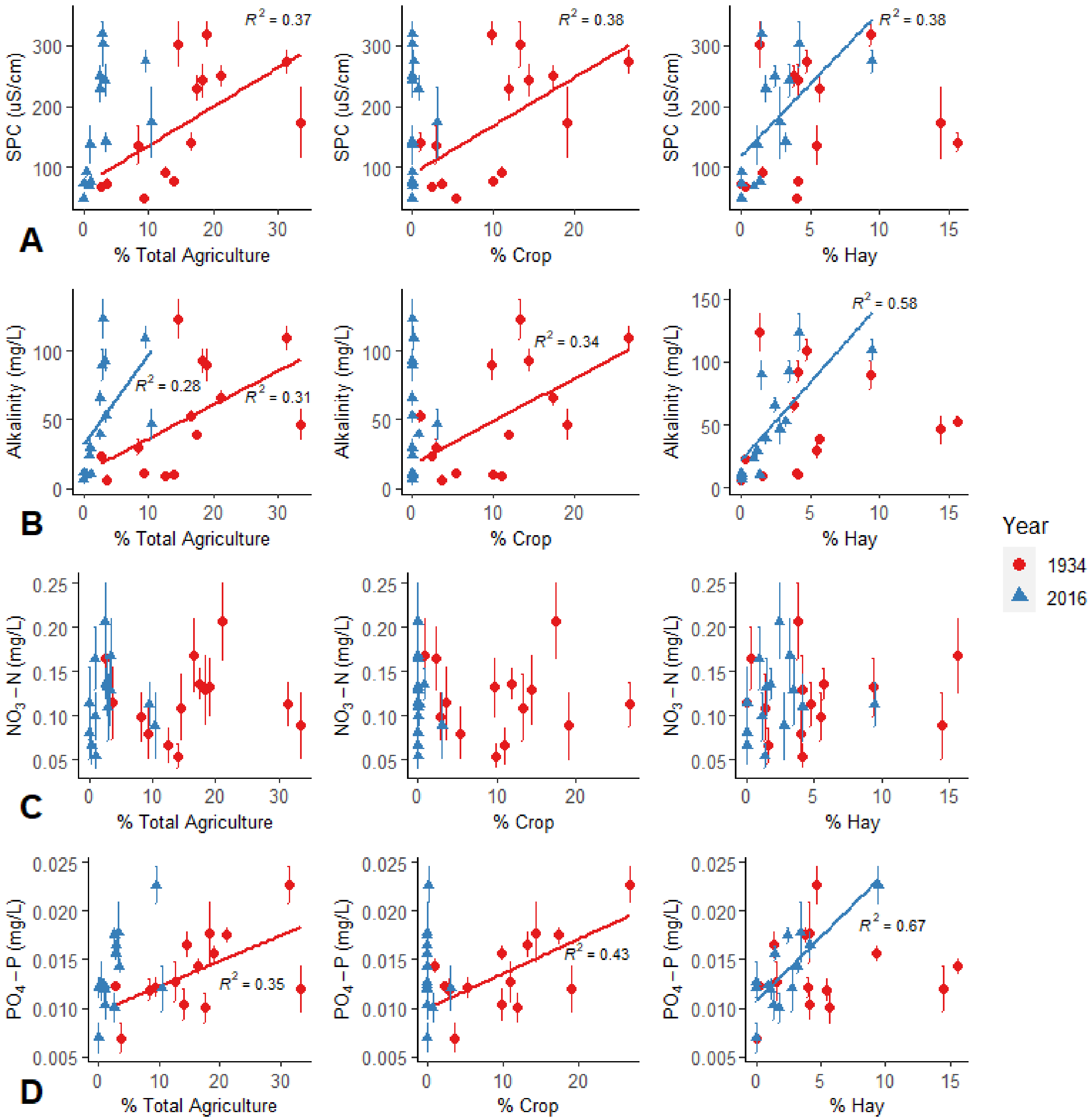

Figure 1. Mean surface water concentration for specific conductance (SPC, row A), alkalinity (row B), nitrate (row C), and phosphate (row D) versus 1934 (red circles) and 2016 (blue triangles) watershed percent total agriculture, percent crop, and percent hay. Error bars are +/- one standard error among five baseflow surface water samples collected monthly from May to September. Lines are significant simple linear regression model fits.

Summary of preliminary findings from long-term water quality database: We have begun but not completed the full statistical analysis of the water quality database. The water quality database includes over 250 watershed records (1000s of datapoints) from the 1950s to the 2020s. Our results suggest that from the 1950s to the 2020s, nitrate concentrations did not change significantly. Both salinity and total dissolved solids did increase over time for both across all flow conditions and for baseflow conditions (for which we expect the biggest potential legacy affect) (Figure 2). Nitrate, salinity, and total dissolved solids were all related to watershed land use land cover, with slightly stronger relationships for baseflow conditions (e.g., as shown for developed land cover in Figure 3). We will continue to analyze this dataset for a forthcoming publication.

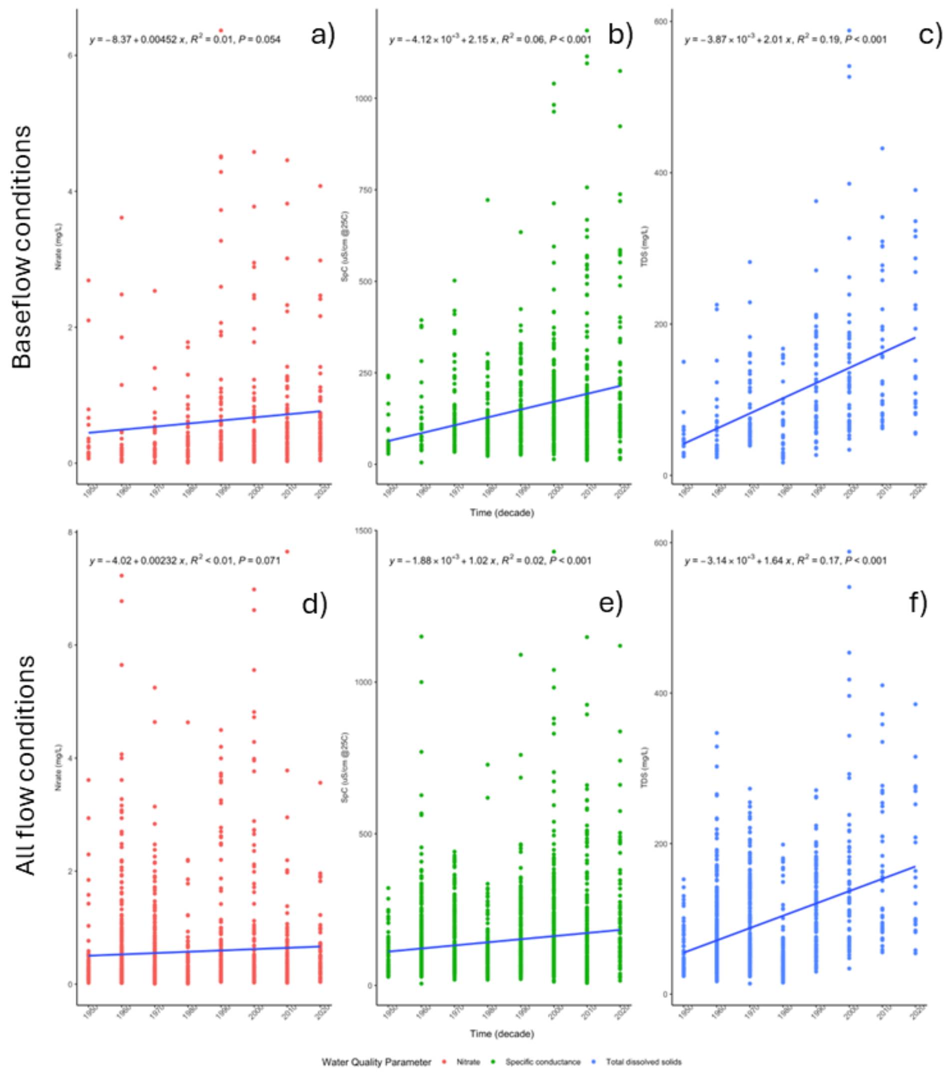

Figure 2. Water quality over time for baseflow conditions (a-c) and all flow conditions (d-f) for nitrate, specific conductivity, and total dissolved solids.

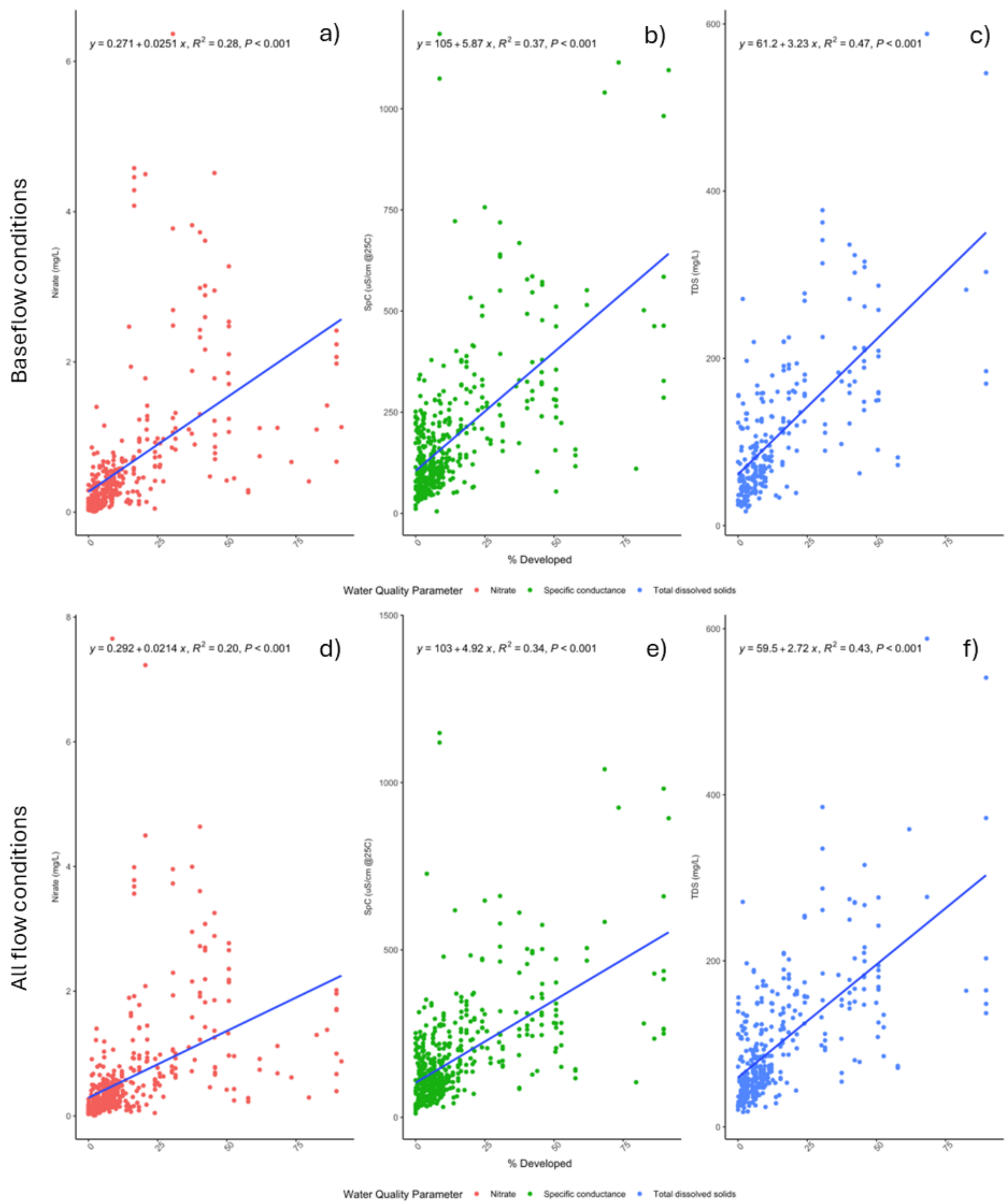

Figure 3. Water quality versus watershed developed land cover for baseflow conditions (a-c) and all flow conditions (d-f) for nitrate, specific conductivity, and total dissolved solids.

Consider the following as they apply to your research and any related outreach/education.

- What new tools, technologies, methods or information services were developed from this work? Have any been adopted / implemented for use and by whom?

- *Water quality dashboard*: The goal of the Long Island Sound Watershed Water Quality Dashboard is to provide users with an interactive mapping tool that allows them to explore publicly available stream and river water quality data, change in water quality data over time, and water quality data linked with common human impacts, including watershed land use land cover, septic density, dams, and wastewater treatment plants.
- *1934 georeferencing and land use classification schema*: The developed methods of georeferencing CT 1934 aerial imagery proves to be efficient and reliable, and has been applied for additional projects (e.g., lake sediments as described in Section F). The method enables the geospatial team to continue to apply it to future projects that will contribute to the completeness of the georeferenced dataset.
- *LWAT application*: We applied LWAT, a spreadsheet-based tool designed for managers that predicts stream biointegrity as a combined condition index that describes the connection to watershed health in the combined riparian and upland areas (Combined Condition Index or “CCI”) and stream biointegrity, as described in section D above.

- What are the environmental benefits of this work? Have policies been changed? How has conservation (of ecosystems, habitats or species) been improved?

  We examined the potential role for legacy N in formerly agricultural watersheds that have now been reforested for decades, and we did not find a significant difference in baseflow stream or groundwater discharge nitrogen concentrations. This suggests that contemporary forested watersheds that have had decades to recover from agriculture in the New England landscape have indistinguishable nitrogen signals from land that was not recently used for agriculture. Thus, managers in New England can continue to assume that forested watersheds behave similarly in terms of nitrogen loading, regardless of whether they were used for agricultural purposes decades ago. Interestingly, we did find some evidence of salt and phosphorus legacies, even after decades of reforestation. This suggests that managers and policy makers should carefully consider the risks of infiltrating contaminants (nitrogen, but also other constitutions including well-known contaminants like salts and phosphorus and emerging contaminants like pesticides, PFAS, etc.). We should continually manage the risk of creating the legacies of tomorrow with infiltration practices today.

- What are the social payoffs of this work? Who has benefited from this work? Have attitudes / behaviors of target audience changed? Elaborate. Have policies been changed?

  NA

- What are the economic implications / impacts of this work? (Where possible, please quantify.) Have new businesses been created /or existing businesses retained as a result of this research? Have new jobs been created or retained? Are new businesses or jobs anticipated?

  NA

J. Stakeholder Summary (This is an abstract of your research and findings written for a lay audience)

Past land use activities (or land use "legacies") can be strong indicators of contemporary water quality; yet, watershed management strategies often neglect the lag times associated with land change trajectories. We proposed that a more complete understanding of land use legacies within the LIS watershed and how they interact with patterns of N dynamics and stream biointegrity could better inform and improve management goals and expectations that align with watershed processes. Healthy watersheds will provide the right amount of nitrogen to LIS; yet, specific management actions and goals often do not address the overall structure and function of watersheds. In this project, we used the context of land use history combined with water quality and stream biointegrity to provide a holistic view of streams and rivers as an intrinsic reflection of physical and ecological processes occurring in their watersheds, rather than simply transporters of nitrogen to the Sound. As our technology for reducing large nitrogen point sources from WWTP plateaus, management of more diffuse and distance sources of nitrogen to the LIS requires this type of alignment with watershed condition and processes. Already, and for upper basin states in particular, understanding land use change is the most important factor in determining nitrogen load to LIS. Perhaps more important are the combined social-ecological system benefits of health and well-being for both the environment and the community. This, especially, given the long-overdue attention to environmental justice that healthy watersheds could bring to the neighborhood level throughout the LIS watershed in addition to controlling nitrogen. Thus, outputs and outcomes from our project could help extend the ability of managers to make informed decisions and take appropriate actions to conserve stream biointegrity and reduce river N loading, enhancing the health and sustainability of LIS, its watershed, and the people who live there.

1. We developed a geospatial classification scheme of vulnerability to watershed land use legacies. For this objective, we quantified trends in satellite-derived land use land cover and classify historic aerial imagery to identify areas with high percentages of historic agricultural land practices and deforestation, and subsequent changes in land use over the last century. We also developed an approach and classified many of Connecticut's 1934 aerial photos to better understand reforestation dynamics across the state.

2. We quantified the influence of watershed land use legacies on present-day water quality. For this objective, we synthesized existing water quality and stream biointegrity datasets to evaluate whether incorporating land use history improves broad scale relationships between watershed land cover and water quality; and we measured surface and ground water quality and biointegrity in targeted watersheds that reflect the gradient of potential agricultural land use legacies. We found that contemporary forested watersheds that have had decades to recover from agriculture in the New England landscape have indistinguishable nitrogen signals from land that was not recently used for agriculture. Yet, we did find some evidence of salt and phosphorus legacies, even after decades of reforestation. This suggests that managers and policy makers should carefully consider the risks of infiltrating contaminants to manage the risk of creating the legacies of tomorrow with infiltration practices today.

3. We engaged the public and resource managers in how watershed land use legacies can guide better watershed management decisions. For this objective, we developed an online dashboard of water quality linked to watershed characteristics, developed a Story Map (in progress) that explains legacy land use pollution and puts the results in a more narrative form for the public, and we held a series of public webinars, with more planned in the future.