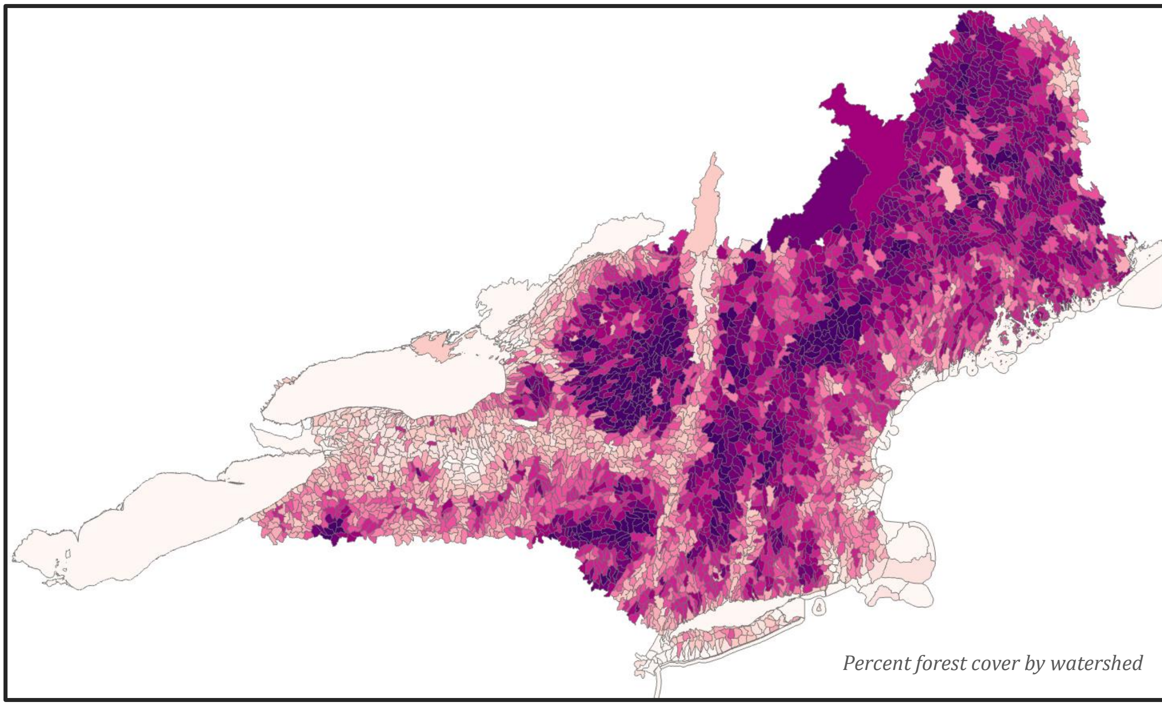
STANDARDIZED SPATIAL DATASETS FOR EXPLORING THE CONNECTION BETWEEN FOREST COVER AND WATER QUALITY IN THE NORTHEAST



Percent forest cover by watershed

FEMC

Forest Ecosystem Monitoring Cooperative

Last Updated: September 30, 2020

Standardized Spatial Datasets for Exploring the Connection Between Forest Cover and Water Quality in the Northeast

Published September 30, 2020
Version 1.0

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DOI: https://www.doi.org/10.18125/5xqty5

Cover Image: Emma R. Tait

Preferred Citation

Tait, E.R., D. Gudex-Cross and J. Duncan. 2020. Standardized Spatial Datasets for Exploring the Connection Between Forest Cover and Water Quality in the Northeast, Version 1.0. Forest Ecosystem Monitoring Cooperative: South Burlington, VT. https://www.doi.org/10.18125/5xqty5. Available online at https://www.uvm.edu/femc/file/info/11005

Acknowledgements

The Forest Ecosystem Monitoring Cooperative (FEMC) would like to acknowledge the contributions of the FEMC's committees in developing this project. Special thanks to Karl Honkonen (USFS) for providing guidance and feedback on direction of the project. We appreciate the input of Rebecca Lilja (USFS), Marc Companion (VTDEC, UVM), Daniel Kelting (Paul Smiths), Bill Keeton (UVM), Donald Keirstead (NRCS), Kelly Boland (NRCS), Rick Ellsmore (NRCS), John Campbell (USFS), James Eikenberry (NRCS), Toby Alexander (NRCS), Vicky Drew (NRCS), Joe Buford (NRCS), Beverly Wemple (UVM), Don Ross (UVM), Scott Hamshaw (UVM), Erin Seybold (UVM) and Matt Vaughn (Lake Champlain Basin Program). We are appreciative of the long-term funding from the U.S. Department of Agriculture, Forest Service State & Private Forestry, Vermont Agency of Natural Resources and the University of Vermont.

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Executive Summary

The connections between forest cover and water quality are complex and depend on the particular aspects of water quality being considered (e.g. temperature or nutrient loading). There are a variety of existing projects and efforts that explore different elements of this relationship. However, there remains an interest to better understand and communicate the relationship between forests and water in a variety of contexts, from understanding impacts of forest networks on sedimentation to the vulnerability of communities to storm events. Our collaborators cited the need for spatial information, data, and models to integrate information on forest cover and its relationship to surface water quality. To answer this need, we developed an inventory of key forest and water spatial datasets for the northeastern region to provide improved access to analytical information. The result is an online inventory of existing spatial data on the hydrology, topography, and forest characteristics for the Northeast.

Through this project we assessed the existing efforts to provide access to data specific to forest-water connections. These programs were assessed for their strengths and limitations to ensure that the work conducted by FEMC would fill a gap in existing tools. We also worked with collaborators to identify datasets that were important for forest-water analyses, and that the community would benefit from having in a single location with a common spatial framework. We then assessed the processing requirements for each dataset and selected 30 based on a combination of accessibility, computing time and relevance to forest-water studies. For the extent boundaries we used the 12-Digit Hydrologic Unit (HUC12) watershed dataset clipped to the watersheds intersecting the regional boundary. The projection for the spatial framework is the North American Albers Equal Area Conic.

To make these processed datasets publicly available, we created the Forests-Water Spatial Data Inventory (www.uvm.edu/femc/cooperative/projects/forest_water) that allows users to view dataset metadata and download the processed datasets. We also created a story map (https://arcg.is/f1vyn) to provide summaries by watershed for key datasets. This work improves access to information and integrated data as well as the capacity of professionals to communicate the importance of forest cover in supporting good water quality.

Introduction

The connections between forest cover and water quality are complex and depend on the particular aspects of water quality being considered (e.g. temperature or nutrient loading). There are a variety of existing projects and efforts that explore different elements of this relationship. However, as noted by the committee, there remains an interest to better understand and communicate the relationship between forests and water in a variety of contexts, from understanding impacts of forest networks on sedimentation to the vulnerability of communities to storm events. Our collaborators cited the need for spatial information, data and models to integrate information on forest cover and its relationship to surface water quality. The relationships between forests and water are spatially heterogeneous, necessitating map-based visualizations. Many spatial datasets that highlight connections between forests and water are difficult to find, access, or use; e.g., datasets may not exist in a useable format and/or may require high level processing skills.

This project was developed by the Forest Ecosystem Monitoring Cooperative (FEMC) Steering and State Partnership Committees in 2018. They identified the connection between forest cover and surface water quality as an issue of regional importance. The overall objective of this project was to improve access to analytical information to address these questions by providing a portal to existing water quality data, enriched by spatial data explaining catchment topography and forest cover characteristics. In doing so, this project not only improved access to information and integrated data but also gives added capacity of professionals to communicate the importance of forest cover in supporting good water quality. These types of data are important for researchers understanding connections between water and forests, but also for managers to identify high risk forests that may require alternative management.

Specifically, the goals of this project were to:

- Assess existing efforts that provide access to forest-water information
- Develop a spatial data model that enables integration of key forest and water datasets
- Deploy online data access portal to enable faster access to the information.

To accomplish these goals, we worked with 19 experts from the USDA Forest Service, Paul Smiths College, University of Vermont, USDA Natural Resources Conservation Service, Lake Champlain Basin Program, Lake Champlain Sea Grant Institute and Vermont Department of Environmental Conservation to determine key factors in understanding connections between forests and water (for a full list of contacts please see Appendix A). We worked closely with collaborators Karl Honkonen (USDA Forest Service) and Rebecca Lilja (USDA Forest Service) to further define the needs of the cooperative in relation to assessing forest-water relationships. We then engaged in a review of existing efforts and tools both regionally and nationally. We identified gaps in these efforts and created a forest water dataset inventory of key datasets in a common spatial framework to address these gaps. At the outset, FEMC had an additional potential charge to develop watershed synthesis maps if data and time allowed, but we determined that this was not possible within the scope of this project.

Methodology

Resource Identification

We began by conducting an inventory of pre-existing tools and datasets available both regionally and nationally, such as the Spatial Hydro-Ecological Decision System (https://ecosheds.org/), and listed in Table 3 below. The initial inventory identified programs that provide access to data specific to forest-water connections. These programs were assessed for their strengths and limitations to ensure that the work conducted by FEMC would fill a gap in existing tools. We also worked with collaborators to identify 43 datasets that were key to forest-water analysis that the community would benefit from having in a single location and common spatial framework. We then assessed each dataset's processing needs and placed the datasets into four priority tiers according to importance level and processing difficulty (Appendix B). For this project we focused on extracting key metadata (Table 1) for the 30 tier 1 and tier 2 datasets (Table 2). The tier 1 datasets were available on Google Earth Engine (GEE) (Gorelick et al. 2017) and had straight-forward processing requirements. Tier 2 datasets were not as readily available and/or required some additional processing. Tier 3 datasets required either significant processing or further consideration as to what processing was required and what the resulting dataset captured. Tier 4 datasets require complex processing, are difficult to access, and need further input from experts to determine the desired resulting outputs.

Table 1: Key metadata

Attribute	*Description*
Dataset	The final desired dataset after processing. Indicates what needs to be derived from the original source dataset and if it requires additional processing for trends or annual averages.
Years	Years available for the original source dataset
Units	Units of raster cell values in the dataset
Resolution	Pixel size of raster datasets
Original source	Original source of the datasets that were processed
Processing steps	The steps required to process the original source into the dataset deliverable. At a minimum, every dataset was clipped to the HUC12 extent and projected to North America Albers Equal Area Conic.

Table 2. List of tier 1 and tier 2 datasets

Dataset Name	*Years*	*Units*	*Resolution*
3-year Averages in Critical Load Exceedance	2000-2018	NA	30 m
Trend in Critical Load Exceedance	2000-2018	NA	30 m
Total Annual Precipitation	1981-2019	mm	2.5 arc minutes
Trend in Total Annual Precipitation	1981-2019	mm	2.5 arc minutes
Forest Loss Year and Location	2001-2019	1 or 0 (loss); 1-19 (year)	1 arc second
Proportion of Forest Loss by Watershed	2001-2019	% of area	1 arc second
Human Population Density: 5 Year Mean	2000-2020	persons/km^2	30 arc seconds
Annual Mean Evapotranspiration	2001-2019	kg/m^2	500 m
Trend in Annual Evapotranspiration	2001-2019	kg/m^2	500 m
Trend in Monthly Growing Season SPEI	1980-2019	NA	2.5 arc minutes
Trend in Annual Growing Season SPEI	1980-2019	NA	2.5 arc minutes
Tree Canopy Cover	2016	% canopy cover	30 m
Average Tree Canopy Cover by Watershed	2016	% canopy cover	30 m
Digital Elevation Model	2000	meters	30 m
Slope	2000	degrees	30 m
Hillshade	2000	NA	30m
Riparian Zone	2016	NA	NA
Hydrologically-Connected Zone	2016	NA	NA
303(d) Listed Impaired Waters NHDPlus Indexed Dataset with Program Attributes	2014	NA	NA
Soils	2020	NA	10 m
Maximum Annual Snowdepth	2003-2018	mm/y	1 km
Trend in Maximum Annual Snowdepth	2003-2018	mm	1 km
Average Annual Snow Depth	2003-2019	mm	2 km
Trend in Average Annual Snowdepth	2003-2020	mm	3 km
Annual Number of Days with Snowdepth Greater Than 1 Inch	2003-20018	days	1km
Trend in Days with Snowdepth Greater Than 1 Inch	2003-2018	days	1 km
Annual Maximum Snowpack Duration	2003-2018	days	1km
Trend in Snowpack Duration	2003-2018	days	1 km
Average Annual Snow Water Equivalent	2003-2018	NA	1 km
Trend in Snow Water Equivalent	2003-2018	NA	1 km

Common Spatial Framework Data Inventory

To create a common spatial framework for the selected datasets we chose North America Albers Equal Area Conic for the projection and the Northeast region (New York, Vermont, Maine, Massachusetts, Connecticut, Rhode Island and New Hampshire) as the extent. For the specific extent boundaries, we used the 12-Digit Hydrologic Unit (HUC12) watershed dataset clipped to the watersheds intersecting the regional boundary (Figure 1). The HUC12 boundary dataset was extracted from the national watershed boundary dataset provided by the United States Geologic Survey (USDA-NRCS, USDA, EPA 2017).

Figure 1: 12-Digit hydrologic unit watershed boundary dataset used as the spatial extent for this project.

All selected datasets were clipped to the HUC12 boundary and projected to North America Albers Equal Area Conic. Many datasets required additional processing outside of Google Earth Engine (GEE). Datasets that were available in GEE (Gorelick et al. 2017) were processed using JavaScript code and projected in ArcGIS Pro 2.5 after being exported from GEE. In the case of the Percent Forest Loss by Watershed and Percent Tree Canopy Cover by Watershed datasets, additional processing was conducted in ArcGIS Pro 2.5 to summarize these attributes by watershed. The processing steps for each individual dataset are given in Appendix C of this report. Trends were calculated for datasets with a temporal component using the non-parametric Sen's slope method (Sen 1968).

Outcomes and Findings

Assessment of Existing Efforts

The complexity of studying the connection between forest cover and water quality has led to numerous efforts to provide access to and summarize data and information related to this topic. We assessed existing efforts that provide data related to forest-water connections and compared the services they offer (Table 3). We worked closely with the version 2.0 effort of Forest to Faucets – a follow up to an assessment by the US Forest Service to show threatened drinking water sources and watershed importance (USDA Forest Service 2017) – to ensure we were not duplicating efforts. Forest to Faucets 2.0[1] (F2F) provides an excellent overview of watershed importance and risk, but it does not provide data downloads for the input datasets. Our effort provides the datasets necessary to repeat F2F's analysis at a regional level as well as some additional datasets for more regionally-specific analyses.

Table 3: Existing tools and datasets assessed

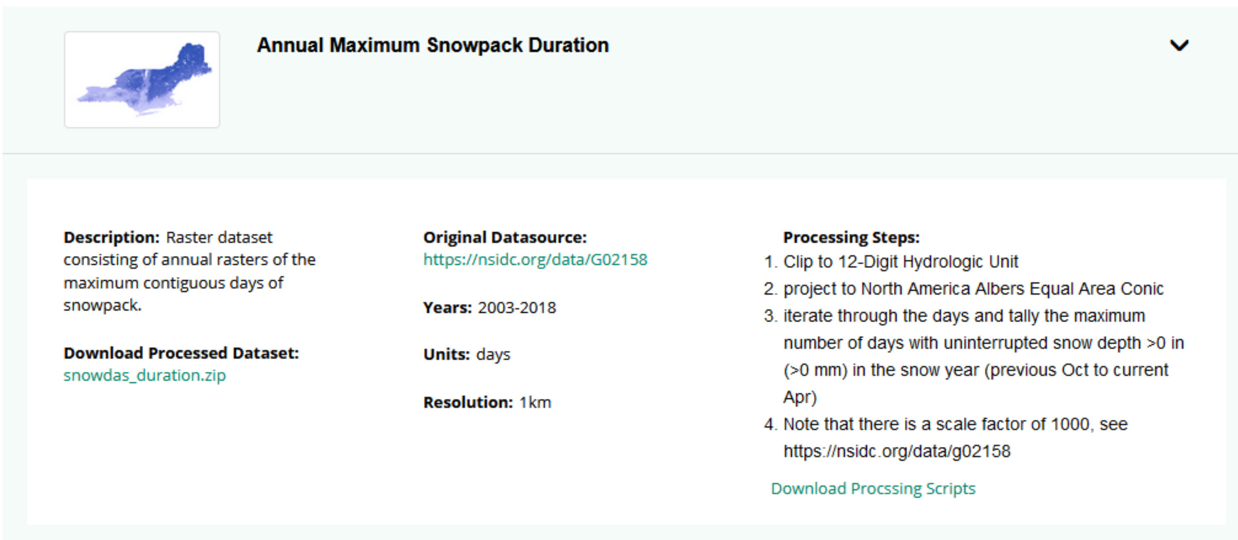
NAME	DETAILS	LIMITATIONS	DATA OPTIONS
CUAHSI Hydroclient http://data.cuahsi.org/	Water quality data access portal; includes water chemistry data.	Cannot integrate with other spatial data (e.g., forest cover, stream flow).	Data Explorer: Yes Data Access: Yes Data Analysis: No
LAGOS https://lagoslakes.org/	Lake water quality data access database; no analysis.	No visualizations or implicit connection to forest; harder to use; focus on lakes.	Data Explorer: No Data Access: Yes Data Analysis: No
SHEDS: Interactive Catchment Explorer http://ice.ecosheds.org/sheds/	Data visualization map, with ancillary variables including forest cover; data downloadable.	Focus on fish; no stream gage data; cannot integrate with other data; no nutrient data.	Data Explorer: Yes Data Access: Yes Data Analysis: Minor
i-Tree Landscape https://landscape.itreetools.org/maps/benefits/	Area based estimates of ecosystem services by forests, including avoided runoff based on user inputs; risk maps.	Slow to run; does not include raw data; cannot download underlying data.	Data Explorer: Yes Data Access: No Data Analysis: Yes
EPA WSIO https://www.epa.gov/wsio	Summaries by HUC12 for many variables, including social and stressors; includes forest cover and LU change; can add other data; can combine variables into risk map.	Offline; does not contain phosphorus; does not include stream gages or stream network.	Data Explorer: Yes Data Access: Yes Data Analysis: Yes
Forest to Faucets 2.0 https://www.fs.fed.us/ecosystemservices/FS_Efforts/forests2faucets.shtml	Watershed importance and risk assessment portal. Highlights connection between forests and the protection of surface drinking water.	Can only download risk and importance maps. Cannot download underlying data.	Data Explorer: Yes Data Access: Yes Data Analysis: Yes

[1] https://www.arcgis.com/apps/MapSeries/index.html?appid=e84fc83c8be542079d3c1d489d45be21

Spatial Data Inventory

Inventory

We created an inventory of 30 processed datasets, available on the FEMC Forests-Water Spatial Data Inventory (https://www.uvm.edu/femc/cooperative/projects/forest_water). The inventory provides key information on the datasets including a description, years, resolution, units, processing steps and original data source (Figure 2). Datasets can also be downloaded from the inventory. All datasets were clipped to the HUC12 boundary and projected to North America Albers Equal Area Conic.



Annual Maximum Snowpack Duration

Description: Raster dataset consisting of annual rasters of the maximum contiguous days of snowpack.

Download Processed Dataset: snowdas_duration.zip

Original Datasource: https://nsidc.org/data/G02158

Years: 2003-2018

Units: days

Resolution: 1km

Processing Steps:

1. Clip to 12-Digit Hydrologic Unit
2. project to North America Albers Equal Area Conic
3. iterate through the days and tally the maximum number of days with uninterrupted snow depth >0 in (>0 mm) in the snow year (previous Oct to current Apr)
4. Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158

Download Procsing Scripts

Figure 2: Sample dataset entry in the Forest-Water spatial data inventory

Story Map

To highlight some of the key datasets in the Forest-Water Spatial Data Inventory we created an ArcGIS online story map. The map provides a summary of the trends in evapotranspiration, critical load exceedance, precipitation, snow pack duration, snow-water equivalent, total days of snow pack greater than 1 inch, average snow depth, and maximum snow depth as well as percent forest loss and percent tree canopy cover by HUC12 sub-watershed (Figure 3). The map is available at https://arcg.is/f1vyn.

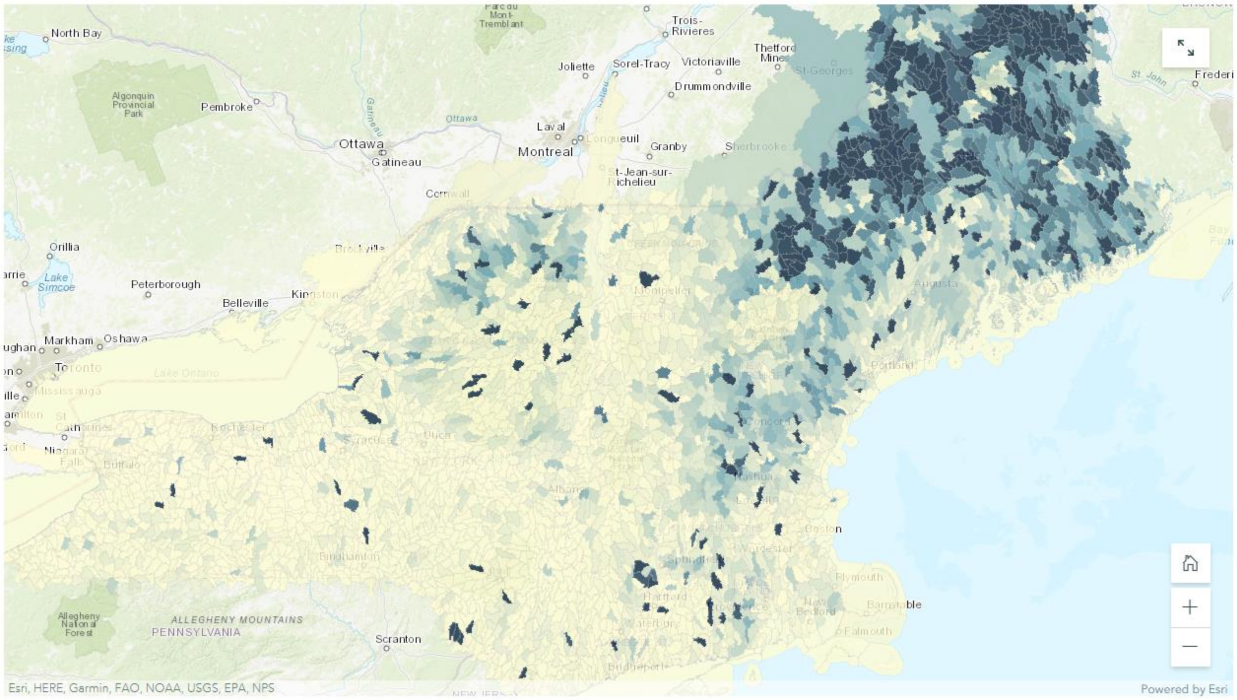


Figure 3: The story map highlights trends in key datasets such as percent forest loss by watershed from 2001-2019

Processing Scripts

To integrate datasets into a common spatial framework we created a series of processing scripts. A significant number of the datasets were available through GEE, so we wrote a master GEE script to process all available datasets. GEE does not handle reprojections well, so datasets were reprojected from GEE's native WGS84 geographic coordinate system to the North America Equal Area Conic projected coordinate system in ArcGIS Pro. The SNODAS snow data (National Operational Hydrologic Remote Sensing Center 2004a; 2004b) and the soils data (NRCS 2020) were processed using a series of Python scripts. These scripts are available for download at https://uvm.edu/femc/file/info/11004.

Future Work

There are several areas of potential future work that could build on this project. The first step would be to process the remaining tier 3 and tier 4 datasets into the common spatial framework (Table 4).

Table 4: Tier 3 and tier 4 datasets that could be processed and added to the inventory

Dataset	***Data Source***	***Category***
Average length of drought	US Drought Monitor: https://droughtmonitor.unl.edu/Data/GISData.aspx	Climate

Number of years of forest damage	USDA Forest Service Insect and Disease Surveys: https://www.uvm.edu/femc/data/archive/project/northeastern_ads	Disturbance
Number of extreme rainfall events>2in	PRISM: http://prism.oregonstate.edu/recent/	Climate
Trend in annual maximum stream temperature	SHEDS: http://db.ecosheds.org/viewer	Hydrology
Average annual maximum stream temperature	SHEDS: http://db.ecosheds.org/viewer	Hydrology
Soil wetness index	EPA: https://www.epa.gov/wsio/wsio-indicator-data-library#zone	Hydrology
Strahler stream order	EPA: https://www.horizon-systems.com/NHDPlus/NHDPlusV2_data.php	Hydrology
Flow accumulation	EPA: https://www.horizon-systems.com/NHDPlus/NHDPlusV2_data.php	Hydrology
National hydrography dataset (NHDPlusV2)	EPA: https://www.horizon-systems.com/NHDPlus/NHDPlusV2_data.php	Hydrology
Integer flow-direction	EPA: https://www.horizon-systems.com/NHDPlus/NHDPlusV2_data.php	Hydrology
Stream gage water quality metrics	USGS: https://waterdata.usgs.gov/nwis/current/?type=quality&group_key=state_cd	Hydrology
Soil Moisture Active Passive (SMAP)	NASA: https://nsidc.org/data/smap/smap-data.html	Soil
Climate change projections	USFS Forests2Faucets: https://www.fs.fed.us/ecosystemservices/FS_Efforts/forests2faucets.shtml	Climate
NRCS Soils – Hydrologic Soil Groups	NRCS: https://www.nrcs.usda.gov/wps/portal/nrcs/site/soils/home/	Soil

The second step would be to include additional regionally specific data such as NRCS soils data and/or LIDAR-derived products such as stream order and stream flow that are too computationally intensive to do on a national scale. Reaching out to the following groups would be a good starting place to expand on regionally specific data

- NRCS soils team – a national group with state offices.
- State soil scientists
- Northeast Glaciated Soil Survey Region 12
- UVM Spatial Analysis Lab for LIDAR derived products

The outcomes of this project have the potential to allow a more regionally refined calculation of Forest to Faucets watershed risk and importance metrics. As such, a third step would be recreating Forest to Faucets' analysis on a regional scale with the added regionally specific datasets.

A fourth avenue for future efforts would be to create an online platform that could host each dataset as individual layers from which users could extract region-specific information. This, however, may be limited by the web mapping platforms available as most of the datasets are raster data which is large and difficult to render online outside a platform such as Google Earth Engine.

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Appendix A: List of experts contacted

NAME	ORGANIZATION
Karl Honkonen	USDA Forest Service State and Private Forestry
Marc Companion	Lake Champlain Sea Grant Institute; Vermont Department of Environmental Conservation
Daniel Kelting	Paul Smiths College
Kacey Clougher	University of Vermont
Bill Keeton	University of Vermont
Rebecca Lilja	USDA Forest Service
Donald Keirstead	NRCS, Dover NH
Kelly Boland	NRCS, Dover NH
Rick Ellsmore	NRCS, Dover NH
John Campbell	USDA Forest Service
James Eikenberry	NRCS, Colchester VT
Toby Alexander	NRCS, Colchester VT
Vicky Dre	NRCS, Colchester VT
Joe Buford	NRCS, Colchester VT
Beverly Wemple	University of Vermont
Scott Hamshaw	University of Vermont
Don Ross	University of Vermont
Erin Seybold	University of Vermont
Matt Vaughn	Lake Champlain Basin Program

Appendix B: Full list of datasets assessed

Tier 1 datasets were available on Google Earth Engine (GEE) (Gorelick et al. 2017) and had straight-forward processing requirements. Tier 2 datasets were not as readily available and/or required some additional processing. Tier 3 datasets required either significant processing or further consideration as to what processing was required and what the resulting dataset captured. Tier 4 datasets require complex processing, are difficult to get ahold of, and need further input from experts to determine the desired resulting datasets. NOTE: The complete citations for the data sources referenced in this table are available in the References section of this report.

Tier	Dataset	Data Source	Category
1	Proportion of sub-watershed with forest loss	Hansen et al. (2013)	Disturbance
1	Average annual evapotranspiration	MOD16A2.006: Terra Net Evapotranspiration 8-Day Global 500m (Running et al. 2017)	Vegetation
1	Trend in evapotranspiration	MOD16A2.006: Terra Net Evapotranspiration 8-Day Global 500m (Running et al. 2017)	Vegetation
1	Total annual precipitation	PRISM (2004)	Climate
1	Trend in total annual precipitation	PRISM (2004)	Climate
1	Tree canopy cover (2016)	Multi-Resolution Land Characteristics Consortium. 2018	Vegetation
1	USGS Hill Shade Base Map	USGS 2017	Geographic
1	USGS Slope Map	USGS 2017	Geographic
1	USGS Digital Elevation Model	USGS 2017	Geographic
2	**Trend in snowpack duration**	**National Operational Hydrologic Remote Sensing Center (2004a)**	**Climate**
2	Maximum annual snow depth	National Operational Hydrologic Remote Sensing Center (2004a)	Climate
2	Trend in maximum snow depth	National Operational Hydrologic Remote Sensing Center (2004a)	Climate
2	Annual number of days with snowdepth greater than 1 inch	National Operational Hydrologic Remote Sensing Center (2004a)	Climate
2	Trend in the number of days with snow depth >1 in (>2.54 cm) over time	National Operational Hydrologic Remote Sensing Center (2004a)	Climate
2	Average snow water equivalent per snow year	National Operational Hydrologic Remote Sensing Center (2004b)	Climate
2	Trend in snow water equivalent	National Operational Hydrologic Remote Sensing Center (2004b)	Climate
2	Annual Maximum Snowpack Duration	National Operational Hydrologic Remote Sensing Center (2004a)	Climate
2	Average Annual Snow Depth	National Operational Hydrologic Remote Sensing Center (2004a)	Climate

2	Trend in Average Annual Snowdepth	National Operational Hydrologic Remote Sensing Center (2004a)	Climate
2	Trend in standardized evapotranspiration-precipitation index	Vicente-Serrano et al. (2010)	Climate
2	Location and year of forest loss	Hansen et al. (2013)	Disturbance
2	Watershed boundaries	USDA-NRCS, USDA, EPA. 2017	Geographic
2	Listed impaired waters	EPA 2019	Hydrology
2	Three year average critical-load exceedance	EPA 2018	Pollutants
2	Trend in critical-load exceedance	EPA 2018	Pollutants
2	Population density	Center for International Earth Science Information Network 2018	Socioeconomic
2	Percent tree canopy cover (2016) per HUC12 watershed	Multi-Resolution Land Characteristics Consortium. 2018	Vegetation
2	100-m riparian buffer	EPA 2016	Hydrology
2	Hydrologically-Connected Zone	EPA 2016	Hydrology
2	SSURGO Soils	Soil Survey Staff, Natural Resources Conservation Service	Soil
3	Average length of drought	US Drought Monitor	Climate
3	Number of years of forest damage	USFS Insect Disease Surveys	Disturbance
3	Trend in annual maximum stream temperature	SHEDS 2018	Hydrology
3	Average annual maximum stream temperature	SHEDS 2018	Hydrology
3	Soil wetness index	USGS 2016	Hydrology
3	Strahler stream order	USGS 2012	Hydrology
3	Flow accumulation	USGS 2012	Hydrology
3	National hydrography dataset (NHDPlusV2)	USGS 2012	Hydrology
3	Integer flow-direction	USGS 2012	Hydrology
3	Number of extreme rainfall events >2in	PRISM (2004)	Climate
4	Stream gage water quality metrics	USGS 2019	Hydrology
4	Soil Moisture Active Passive (SMAP)	National Operational Hydrologic Remote Sensing Center. 2020	Soil
4	Climate change projections	USDA Forest Service 2019	Climate
4	NRCS Soils	Contact NRCS soils team directly	Soil

Appendix C: Processing steps for each dataset

Dataset Name	*Processing Steps*
3-year Trends in Critical Load Exceedance	Calculate 3-year average from yearly datasets; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic

Trend in Critical Load Exceedance	Calculate 3-year average from yearly datasets; Compute trend in 3-year averages using non-parametric Sen's slope; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Total Annual Precipitation	Yearly rasters created from monthly dataset; total annual precipitation calculated; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Trend in Total Annual Precipitation	Yearly rasters created from monthly dataset; Calculate total annual precipitation per year; Compute trend in precipitation across all years using non-parametric Sen's slope; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Forest Loss Year and Location	Extracted loss and loss year datasets from Hansen Global dataset; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Proportion of Forest Loss by Watershed	Calculated using Hansen Global Forest Loss raster and 12-digit hydrologic unit polygon shapefile, "Tabulate Area" tool in ArcGIS Spatial Analyst. Result gives area of loss in meters. Then converted the "areaacres" field in the HUC12.shp to meters and divided Forest Loss (ForLoss_m) by watershed area (WSHEDAREAm) = Proportion of Forest Loss per 12-digit hydrologic unit watershed (prForLoss). Stored as a shapefile with original fields from 12-digit hydrologic unit shapefile + Forest Loss fields; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Human Population Density: 5 Year Mean	Extract 5-year calculations from population density dataset; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Annual Mean Evapotranspiration	Calculate annual evapotranspiration value from 8-day datasets; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Trend in Annual Evapotranspiration	Calculate annual evapotranspiration value from 8-day datasets; Compute trend in evapotranspiration using non-parametric Sen's slope; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Trend in Monthly Growing Season SPEI	Compute regression for each growing season month (Apr - Sep) using non-parametric Sen's Slope; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Trend in Annual Growing Season SPEI	Calculate annual growing season SPEI (Apr-Sep); Compute regression using non-parametric Sen's Slope; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Tree Canopy Cover	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Average Tree Canopy Cover by Watershed	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic; Calculated using "Zonal Statistics" in ArcGIS Spatial Analyst. Result gives mean % tree cover per Hydrologic Unit Code watershed. Stored as a shapefile with original fields from 12-Digit Hydrologic Unit shapefile + Mean % Tree Cover (ForestCov) field.
Digital Elevation Model	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Slope	Calculated using a Digital Elevation Model and ArcGIS Spatial Analyst 'Slope' tool; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Hillshade	Calculated using a Digital Elevation model and ArcGIS 'Hillshade' tool; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic

Riparian Zone	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Hydrologically-Connected Zone	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
303(d) Listed Impaired Waters NHDPlus Indexed Dataset with Program Attributes	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Soils	Merge state rasters and key attribute tables into a single regional raster; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic
Maximum Annual Snowdepth	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic. Compute maximum snow depth per snow year (previous Oct to current Apr). Note that there is a scale factor of 1000 see https://nsidc.org/data/g02157
Trend in Maximum Annual Snowdepth	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic project; compute maximum snow depth per snow year (previous Oct to current Apr); compute the linear trend across snow years using nonparametric Sen's Slope. Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
Average Annual Snow Depth	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic. Compute mean snow depth per snow year (previous Oct to current Apr). Note that there is a scale factor of 1000 see https://nsidc.org/data/g02157
Trend in Average Annual Snowdepth	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic project; compute mean snow depth per snow year (previous Oct to current Apr); compute the linear trend across snow years using nonparametric Sen's Slope. Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
Annual Number of Days with Snowdepth Greater Than 1 Inch	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic. Compute total days with snow depth >1 in (>2.54 cm) per snow year (which is October through the following September). Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
Trend in Days with Snowdepth Greater Than 1 Inch	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic. Compute total days with snow depth >1 in (>2.54 cm) per snow year (which is October through the following September); calculate across snow years using nonparametric Sen's Slope. Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
Annual Maximum Snowpack Duration	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic; iterate through the days and tally the maximum number of days with uninterrupted snow depth >0 in (>0 mm) in the snow year (previous Oct to current Apr); Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
Trend in Snowpack Duration	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic; iterate through the days and tally the maximum number of days with uninterrupted snow depth >0 in (>0 mm) in the snow year (previous Oct to current Apr); calculate trend in day length over time using non parametric

	Sen's Slope. Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
Average Annual Snow Water Equivalent	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic; compute average snow water equivalent per snow year (previous Oct to current Apr). Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
Trend in Snow Water Equivalent	Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic; compute trend in average annual snow-water equivalent dataset computed above over years using nonparametric Sen's Slope. Note that there is a scale factor of 1000, see https://nsidc.org/data/g02158
12-Digit Hydrologic Unit Watershed Boundary	Clip to features within or intersecting the boundaries of Vermont, New York, New Hampshire, Massachusetts, Connecticut, Maine, and Rhode Island; project to North America Albers Equal Area Conic
3-year Trends in Critical Load Exceedance	Calculate 3-year average from yearly datasets; Clip to 12-Digit Hydrologic Unit; project to North America Albers Equal Area Conic