RECHARGE MAPPING:

A GIS-based tool for identifying areas of land with significant groundwater recharge

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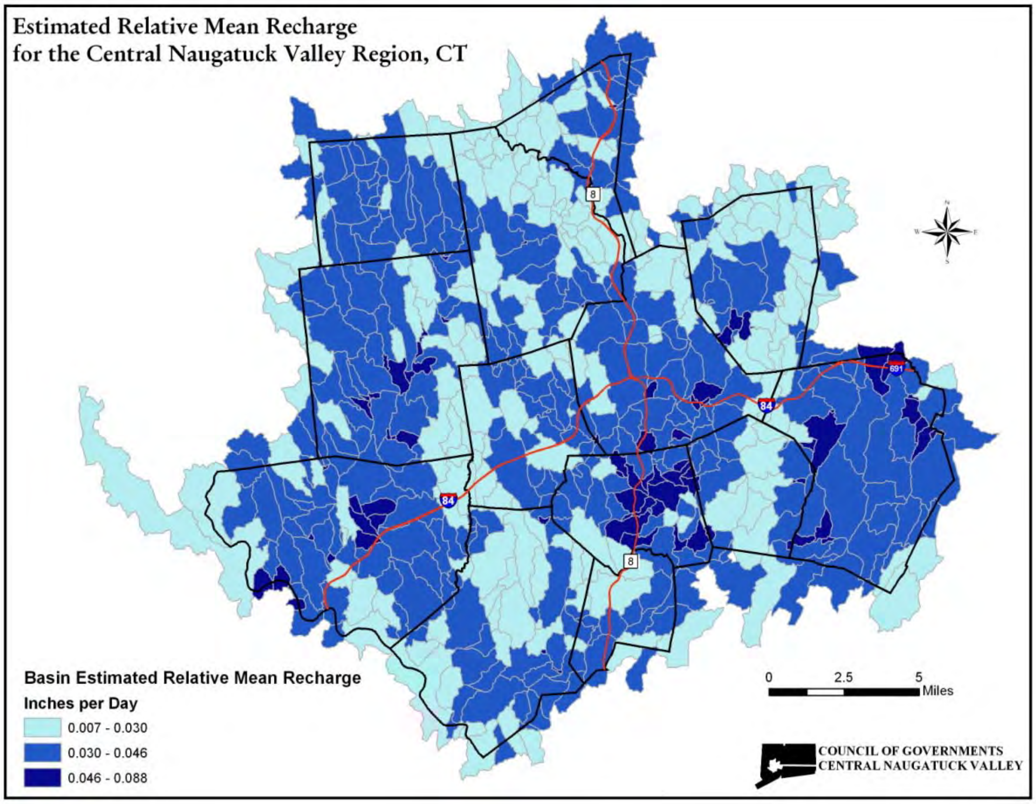

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POMPERAUG RIVER WATERSHED COALITION

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CENTRAL NAUGATUCK VALLEY

HVA

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The funding for this project comes through the Connecticut Community Foundation's (CCF) grant made to the Pomperaug River Watershed Coalition (PRWC) to support the addition of its Outreach Program, and was made to the PRWC to work collaboratively with the Housatonic Valley Association (HVA). The PRWC is known for extensive scientific research of their watershed, and HVA has many years of experience in outreach and education. The collaboration allows the organizations to work together and learn from each other in terms of the research and outreach methods each uses. The goal being to export the science completed in the Pomperaug Watershed to other organizations and regions as well as to determine the best methods for sharing the research findings with stakeholders in their own watershed. The Recharge Mapping Tool is an example of a product that achieves both of these goals.

The Recharge Mapping Tool, documented by Carol Haskins--PRWC Outreach Director, is the culminating product of many meetings and discussions with a dedicated workgroup. Countless thank you's go to the staff at the Council of Governments of Central Naugatuck Valley for providing meeting space and, more importantly, the expertise of Glenda Prentiss and Virginia Mason. Glenda, GIS Specialist, was instrumental in developing and documenting the GIS (geographic information systems) methods presented in the Recharge Mapping Tool, and would not be possible without her expertise. Virginia, Assistant Director, provided invaluable insight towards how the resulting recharge data can be best applied in town planning and watershed management situations. Kirk Sinclair, GIS Manager at HVA, also provided invaluable input towards developing the GIS methodology, while Mark Brown, GIS Associate at HVA, was the first person outside the initial workgroup to test the Recharge Mapping Tool and ease in following the methods. David Bjerklie, with the US Geological Survey (USGS), provided the essential statistical results from the Precipitation Runoff Modeling System project completed by the USGS for the Pomperaug Watershed on which the Recharge Mapping Tool is derived.

We all hope that the information presented herein will assist other watershed groups and towns estimate how much water should recharge into their underlying aquifers and how that data can be used in the context of planning and watershed management to ensure the quantity and quality of their water supplies.

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I. OVERVIEW

This *Recharge Mapping Tool* is a simplified geographic information system (GIS)-based version of the United States Geological Survey's (USGS) Precipitation Runoff Modeling System, a mathematical watershed model. While the PRMS model provides a thorough analysis of land use impacts on streamflow and groundwater recharge, it is both cost prohibitive and time consuming to model every watershed. Yet much of the physical watershed characteristics ("attributes") used in the model can be obtained from publicly available geospatial data sources and can be mapped using GIS software.

The availability of the physical parameter data and widespread use of GIS, together with a statistical understanding of how physical watershed characteristics impact streamflow and groundwater recharge obtained from the PRMS modeling, made it feasible to develop this *Tool* to estimate the average annual amount precipitation that recharges into the underlying aquifer in a given area. Thus, the science of the PRMS model can readily and inexpensively be applied to other watersheds or geographically and politically defined regions beyond the Pomperaug Watershed. The *Tool* allows watershed and other environmental organizations, municipal commissions, developers, consultants, and state agencies to identify areas of land with significant groundwater recharge for the purposes of making planning level watershed management decisions involving the quality and quantity of their water resources.

Presented here is the procedure developed by the Pomperaug River Watershed Coalition (PRWC), the Council of Governments of Central Naugatuck Valley (COGCNV), and the Housatonic Valley Association (HVA) for creating a Recharge Map that displays an estimated relative mean recharge value (in inches/day) for a given area of land. It includes descriptions of the attributes that influence the quantity of recharge, a listing of where to obtain the necessary data layers, steps to extract the specific attributes of interest, the procedure to create the final Recharge Map, and different watershed management applications of the data.

I. PHYSICAL ATTRIBUTES THAT INFLUENCE RECHARGE

The United States Geologic Survey (USGS) has worked in cooperation with the PRWC to develop the precipitation runoff modeling system watershed model (PRMS) to evaluate the relationship between precipitation and runoff in the Pomperaug Watershed. In general terms, the model determined the fate of precipitation as it landed on the ground – whether it would (1) flow over the surface of the ground into the stream right away (surface runoff) or (2) if it would soak into and flow through the ground or underlying aquifer until it feeds into the stream at a later time (subsurface runoff or groundwater runoff). The relationship between precipitation and the form of runoff was evaluated using many attributes of the watershed. Attributes used in the model included climate, precipitation, surficial geology (coarse stratified drift), soil type (class D soils), land cover (impervious surface cover), drainage density, topography (slope, aspect, and elevation), land use, and others. The physical attribute data was obtained from publically available geospatial data sources.

To best understand the relationship between precipitation and runoff, the Pomperaug Watershed was divided into smaller hydrologic research units (HRUs), which were delineated based on the distribution and hydrologic homogeneity of the above attributes. The model was calibrated by comparing modeled results of streamflow to actual recorded streamflow for the given period of historic precipitation data imported into the model.

The relationship between the simulated groundwater runoff (and conversely surface runoff) and each of the physical attributes listed above was statistically analyzed for each hydrologic response unit using multiple linear regression analysis. The results of this analysis are shown in **Table 1**, which is included in **Attachment A**. The analysis was completed to provide a greater understanding of which physical attributes have the greatest influence on the fate of precipitation – surface runoff versus groundwater runoff. In the terms of this *Recharge Tool*, it is important to note that an assumption was made that the groundwater runoff modeled in the PRMS model is the same as recharge, and here forward will be referred to as recharge. It was assumed that when water infiltrates into and recharges the aquifer the pressure displaces and equal amount of water already stored in the aquifer; thus, the stored water becomes the groundwater runoff that flows into a river or stream.

For the Pomperaug River watershed, the statistics indicate that together all of the physical attributes that were modeled account for 64% of the variation in recharge, which gives the data user confidence that the physical attributes are strong indicators for assessing recharge (and conversely surface runoff) within the hydrological research unit. In an effort to develop a predictive equation for estimating recharge in an HRU, statistical analyses were also used to directly compare the magnitude of the effect of each attribute on the estimated recharge, and how significant each attribute was in the predictive outcome. The results of these analyses are also included in Table 1. These results indicate that four particular attributes, which happen to be the ones that differ the most from HRU to HRU, have the most significant influence on recharge. These attributes are:

Surficial geology – Coarse stratified drift (sand and gravel material deposited by glaciers) is the surficial material of key interest. These deposits allow for easy water movement or infiltration. They also form the principal water bearing units in the watershed and transmit the greatest amount of water to wells. In the PRMS model, the HRUs with the most recharge occurred in areas of coarse stratified drift.

Soil type – The key soil type of interest here is the Class D soils, which are clayey soils with low permeability. These soils hold water but do not transmit water vertically (as recharge) very rapidly, and thus tend to be sources of higher surface runoff. Class D soils are generally characteristic of wetland environments, but may also be in unique ecosystems where soil is shallow to bedrock.

Impervious Cover – Impervious surfaces are hard, compacted areas of land cover (like buildings, roads, parking lots, driveways, etc.) that prohibit vertical recharge of precipitation and result in high surface runoff (surface runoff in the PRMS model equates to streamflow). The case of high surface runoff is especially notable where the runoff from impervious surfaces is collected in storm drains and routed directly into stream courses.

Drainage Density - The drainage density (length of stream per unit area, usually mile / square mile) is an indicator of the perennial drainage characteristics of the sub-watershed. Where the density is higher and the drainage network is well established, a more stable discharge regime is indicated, which also indicates a well established baseflow.

In the Pomperaug Watershed, the presence of coarse stratified drift and high drainage density indicated higher recharge (or lower surface runoff) and the presence of Class D soils and impervious surfaces indicated reduced recharge (or increased surface runoff). It is worth noting that because the Pomperaug Watershed, in its current condition, has relatively low amounts of ***effective impervious surface***, a hypothetical model was developed with a wider range of percent impervious surfaces across the watershed. The statistical significance of impervious cover is based on this hypothetical model.

Coefficients arrived at in the statistical analyses of these attributes were used in the simplified predictive equation for estimating mean relative recharge within each HRU (**Equation 1**).

Recharge (in inches per day) = *(Equation 1)*
0.032953 + 0.002036*(Drainage Density) + 0.031247*(% Stratified Drift)
– 0.03792*(% Class D Soils) – 0.09292*(% Effective Impervious Surface)

Please note that this predictive equation permits a quantitative estimation of mean relative recharge for a hydrologic research unit. The recharge estimate, made in inches per day, is based on the mean annual precipitation records for the Pomperaug Watershed, with the assumption made that rainfall is distributed evenly over the course of a calendar year. The recharge estimate is made relative to other hydrologic research units within in the watershed.

II. MAPPING METHODOLOGY

While the predictive equation was derived using precipitation data specific to the Pomperaug Watershed, it can be extended to regions with similar climatic conditions as the Pomperaug. Instead of using hydrologic research units, the predictive equation is applied at the basin scale, which is a geographic unit of area roughly equivalent in size to the HRUs defined in the PRMS model (both approximately one square mile in size).

The physical attribute data needed to make the recharge estimate is available from publically available geospatial data sources, and can be mapped using GIS software. The analytical tools in GIS software allow the user to extract the specific attribute data required to complete the calculation that estimates recharge (Equation 1), which is also completed in GIS. Please note, specific GIS extensions and "plug-ins" are required to use this *Recharge Mapping Tool*: Spatial Analyst, ISAT Tool (discussed below under Impervious Cover), and Soil Data Viewer (discussed below under Class D Soil).

Utilizing the example maps for the Central Naugatuck Valley region (**Attachment B**), created by the Council of Governments for the Central Naugatuck Valley (COGCNV) during the collaborative process of developing this Tool, the data acquisition steps and the simplified recharge calculation are discussed in detail below.

A. Data Acquisition and Preliminary Data Manipulation

The data sources for each of the physical attributes used in the recharge equation and additional geospatial data required in this Recharge Mapping Tool are summarized in **Table 2**, which is included in **Attachment A**. The data sources discussed above for each attribute are also summarized in **Table 2**, which is included in **Attachment A**. Sample maps for the Central Naugatuck Valley Region are included in **Attachment B**.

1. **Base Layer Data**
   Obtain base layer data necessary to define the spatial extent of area of interest. This could be defined by political boundaries for a town, a region (cluster of towns or a county), a state, or hydro-geographic boundaries for a watershed. Major roads may also be included on the base layer, in addition to rivers

(hydrography lines) and waterbodies (hydrography) within the town and/or watershed boundary to help orient the map reader.

The data source for the town boundary, major roads, rivers and waterbodies was the Connecticut Department of Environmental Protection (CTDEP), which provided data on a scale of 1:24,000. This information is available for download from the CTDEP website using the following link: http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898. More accurate and up-to-date road information may be obtained from Tele Atlas (c1984-2006, Rel. 10/06). Municipalities can obtain this data from the Department of Public Safety.

2. Basins

Even if rivers and waterbodies are not displayed on the base layer map, hydrography data is necessary to complete the recharge estimate calculation, as recharge is estimated at the basin level. The **basin data layer**, provided at the scale of 1:24,000, is available for download from the CTDEP website using the following link: http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898.

3. Coarse Stratified Drift

The surficial geology considered in the PRMS model was the presence of coarse stratified drift (or glacial deposits). As part of the overall CTDEP geology database, a **surficial materials** data exists on the 1:24,000 scale. The source for this GIS datalayer was the CTDEP: http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898.

A coarse stratified drift layer is created by using GIS tools. All surficial materials, except the coarse stratified drift data (sand and gravel) are separated out of the surficial geology data layer. Note: We used data with ANY coarse material (coarse, coarse over fines, fines over coarse, etc).

4. Class D Soil

The soil type considered in the PRMS model was the Class D soil. The source for this GIS datalayer was the United States Department of Agriculture (USDA), Natural Resources Conservation Services (NRCS). The soil data is available for download from USDA/NRCS website using the following link: http://soildatamart.nrcs.usda.gov/. The source included all soil types, but using GIS tools, all soils types were separated out except for Class D soils.

Unlike some of the other data layers, the soils data requires a little more manipulation to obtain the specific attribute of interest. The following steps outline how to download the data and separate out Class D Soils:

a. Download the NRCS soils for Connecticut from http://soildatamart.nrcs.usda.gov
b. Clip to your area if desired.
c. Download the Soil Data Viewer from http://soildataviewer.nrcs.usda.gov/download.aspx
d. Open ArcMap and add the Soil Data Viewer and the NRCS soils to the project.
e. Click on the button to activate the Soil Data Viewer and select the soil layer to use as input.
f. Select the "Soil Qualities and Features - Hydrologic Groups" from the list on the left Then choose the "Map" tab along the bottom right
g. Right click on the "hydrologic group" in ArcMap's table of contents and select "data -export data" to save this data as a shape file ("Hydro Soil Group")
h. In this shapefile, selecting by attribute equaling D in the field "Hydrolgrp" will give you the Class D soils. Save just the class D soils as a separate shapefile ("Class D Soil").

5. Existing Imperviousness

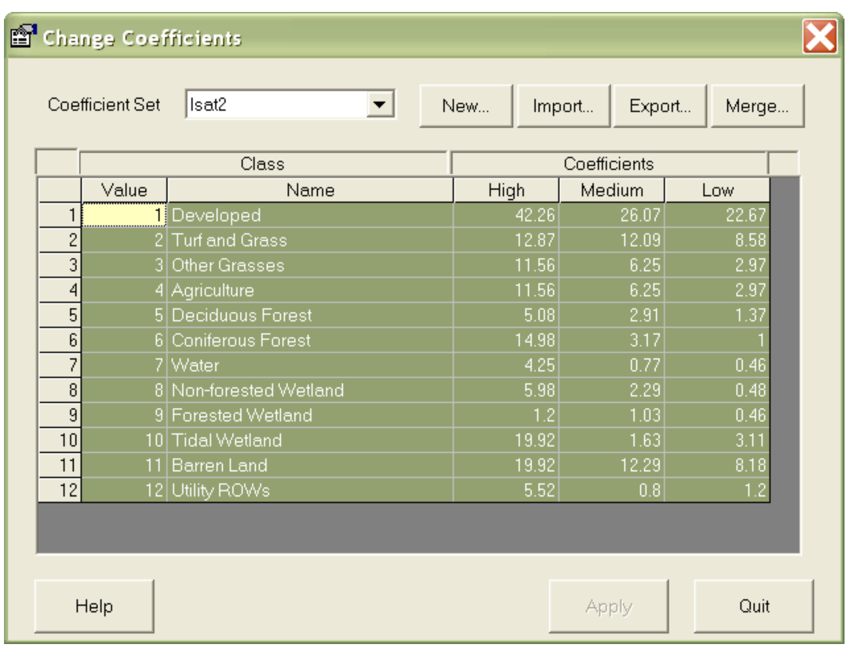
The PRMS model took into account the impervious surfaces within each local basin. The source for the existing imperviousness GIS datalayer is Connecticut's Center for Land use Education and Research (CLEAR) 2006 LandCover database: http://clear.uconn.edu/projects/landscape/index.htm. This land cover data must be used conjuction with the ISAT Tool in order to apply the impervious coefficients from the 2002 dataset. The ISAT Tool is available for download from http://www.csc.noaa.gov/crs/cwq/isat.html. The GIS extension, Spatial Analyst®, is required in order to run the ISAT Tool and the following inputs are required to apply to the 2002 coefficients to the 2006 dataset:

- Land cover grid
- Polygon data set for which percentage of impervious surface is to be calculated
- Set of land cover impervious surface coefficients calibrated for low, medium, and high population densities
- Option population density theme

Please note some towns may have more up-to-date data based on recent flyovers. For accuracy, the most up-to-date information should be used. Also note the data represents current land use data, not that of a projected build-out.

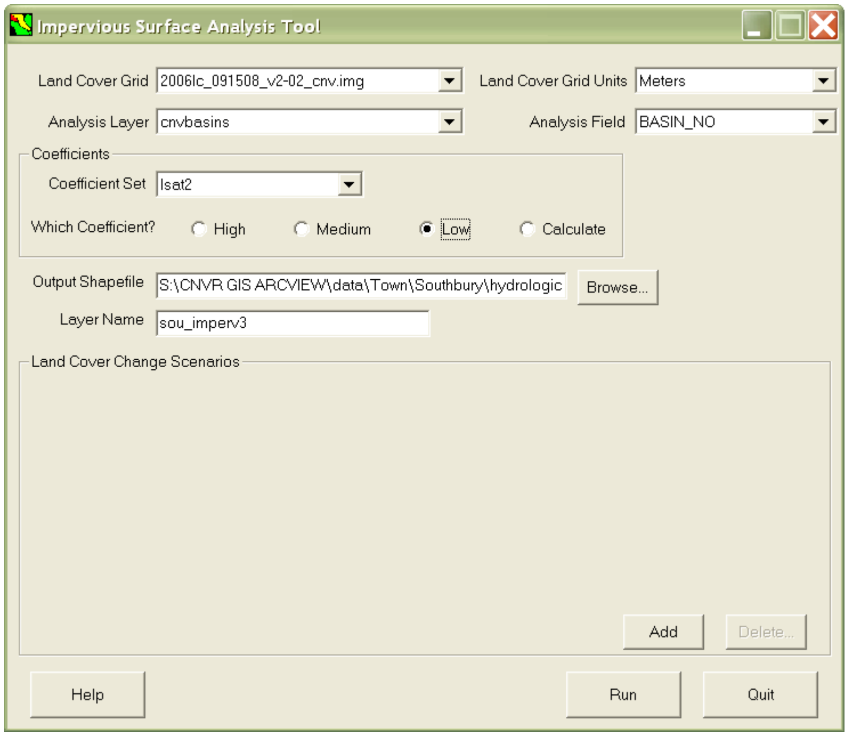
To apply to the 2002 impervious coefficients to the 2006 data set:

a. Add the ISAT and Spatial Analyst tools to your toolbar.
b. Turn on the ISAT and Spatial Analyst tools (Tools - Extensions).
c. Add the 2006 LandCover grid to your project.
d. Add the Basin polygon shapefile that will be used to define the areas over which impervious surface estimates will be calculated.
e. Add the ISAT Coeffients developed by NEMO for the 2002 land cover data for Connecticut as shown below. On the Impervious Surface Tools menu, choose Change Coefficients. Click New and create a new coefficient set as shown below.



	Class		Coefficients		
	Value	Name	High	Medium	Low
1	1	Developed	42.26	26.07	22.67
2	2	Turf and Grass	12.87	12.09	8.58
3	3	Other Grasses	11.56	6.25	2.97
4	4	Agriculture	11.56	6.25	2.97
5	5	Deciduous Forest	5.08	2.91	1.37
6	6	Coniferous Forest	14.98	3.17	1
7	7	Water	4.25	0.77	0.46
8	8	Non-forested Wetland	5.98	2.29	0.48
9	9	Forested Wetland	1.2	1.03	0.46
10	10	Tidal Wetland	19.92	1.63	3.11
11	11	Barren Land	19.92	12.29	8.18
12	12	Utility ROWs	5.52	0.8	1.2

f. Choose "Run Impervious Surface Analysis" from the Impervious Surface Tools menu and Select the density (High, Medium, or Low based on population per square mile) of your town.



g. The output attribute table includes a calculated value for the percent impervious area and total impervious surface area of each selected polygon (i.e. basins).

h. ***Effective Imperviousness*** is the value that needs to be calculated for using the Recharge Model equation. Bjerklie (USGS) developed an equation **(Equation 2)** for calculating effective imperviousness, which is based on the Alley and Veenhuis model in conjunction with the Charles River model and then adjusted based on variables considered in the PRMS model.

Effective Impervious (Bjerklie) = ***(Equation 2)***
$0.0001*(\text{Actual Impervious})^3 - 0.005*(\text{Actual Impervious})^2 + 0.2282*(\text{Actual Impervious})$

To calculate Effective Imperviousness, create a new field in the ISAT impervious table called "EffectiveImp." Field calculate this value for each basin using Equation 2. Use the field "pctIS" for Actual Impervious. Note: Actual Impervious is a percent value and is inserted into the equation as a percent (ex. 16% would be 16 – not 0.16).

6. Drainage Density

In the PRMS model, drainage density is one of the key physical attributes of the land surface in each local basin that controls runoff. The source for the hydrography line datalayer ("hydronet") and local basin datalayer is the CTDEP: http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898.

To calculate the length of stream per unit area, the hydrography line datalayer was unioned with the local basin datalayer, and each local basin was summarized by "stream length in miles" divided by the "area" of the local basin in square miles.

B. *Calculating and Mapping Recharge Using ArcGIS*

While the above attributes are mapped for the greater area of interest, recharge is quantified at the small basin scale. As such, the attributes are summarized for each basin within the greater area of interest before applying the weighted, statistically based equation to quantify recharge (Equation 1). The following steps guide the GIS-user in summarizing each of the physical attributes for the basins within the area of interest and, ultimately, calculating recharge for each basin.

1. Define the ***Area of Interest*** (AOI) – a town, a region (cluster of towns), state, or watershed – and save selected area as a new shapefile.

2. Select all basins from ***basin*** that overlap the Area of Interest and save as a new shapefile. (Note: The basin layer breaks up the "local basin" level in smaller areas and the basin is roughly equal in size to the HRUs used in the PRMS model.)

3. Calculate ***Drainage Density***. Intersect ***hydronet*** with the AOI ***basin*** layer. "Calculate Geometry" for the length of each segment. Summarize the attribute table based on the “BASIN_NO” field and include sum for the "length" column. Link this table to the AOI ***basin*** layer and save as a separate shapefile called ***Recharge.*** Add a new field to the Recharge table called DRAIN_DENS. Field Calculate the drainage density (DRAIN_DENS) by dividing length of stream by area of basin (miles/square miles).

4. Calculate percentage of ***Class D soils*** in each basin. Intersect ***Class D soils*** with AOI ***basin*** layer. "Calculate Geometry" for the “AREA_SQMI” field. Summarize based on the “BASIN_NO" field and include sum for the “AREA_SQMI” field. Join this table to the ***Recharge*** shapefile based on the “BASIN_NO” field. Create a new field in the Recharge table called “PERCENT_D”. Field calculate for this field (=***ClassDSoil***AREA_SQMI/***basin***AREA_SQMI)

5. Calculate percent of ***Coarse Stratified Drift*** in each basin. Intersect ***Coarse Stratified Drift*** with AOI ***basin*** layer. "Calculate Geometry" for the “AREA_SQMI" field. Summarize based on the "BASIN_NO" field and include sum for the "AREA_SQMI" field. Join this table to the ***Recharge*** shapefile based on the "BASIN_NO" field. Create a new field in the Recharge table called "PERCENT_SD". Field calculate for this field (***=CoarseStratifiedDrift***AREA_SQMI/***basin***AREA_SQMI)

6. ***Effective Imperviousness*** was calculated for each basin in the ISAT tool impervious table in the Preliminary Data Manipulation procedure above. Join this shapefile to the ***Recharge*** shapefile based on the "BASIN_NO" field. Create a new field in the Recharge table called "EFFECT_IMP.” Field calculate this field to equal the “Effective Imp” field from the ISAT Impervious table divided by 100. This division changes the numbers in the table from percentage to decimal form so that it matches the format of the other items in Equation 1 for the recharge calculation (e.g. 16% was previously listed as 16 but now will be listed as 0.16).

7. Calculate ***Estimated Relative Mean Recharge*** (inches per day) for each basin. Once you have values needed for the calculation of recharge (inches per day) in the ***Recharge*** table, add a new field, RECHARG_INDAY, and Field Calculate recharge:

Recharge (inches per day) =
0.032953 + 0.002036 (Drainage Density) + 0.032147 (% Stratified Drift) - 0.03792 (% Class D Soils) - 0.09292 (% Effective Impervious Surface)

OR

Recharge (inches per day) =

0.032953 + 0.002036 (***Recharge***DRAIN_DENS) + 0.032147 (***Recharge***PERCENT_SD) - 0.03792 (***Recharge***PERCENT_D) - 0.09292 (***Recharge***EFFECT_IMP)

Note: The % stratified drift, % class D soil, and % effective impervious should all be values less than or equal to 1.0. The drainage density value should be mostly 0-10, with a few basins higher than this.

8. Display the Estimated Relative Mean Recharge on a **Recharge Map** to identify areas of high, medium, and low recharge within the area of interest. This done by changing the symbology for the Recharge shapefile to 3 "natural breaks" for the recharge value field that was calculated in step 7. This divides the range of recharge values (calculated in inches per day) equally into three categories, thus the basins of high, medium, and low recharge are relative to other basins in the larger area of interest.

III. APPLICATIONS OF RECHARGE DATA

So what? Why does it matter if an estimate can be made as to how much water will recharge an aquifer? And, how can this information be used in a land use planning, development, conservation context?

In a development and stormwater context, a dilemma exists when there is a choice between developing in a high recharge area vs. a low recharge area. In a high recharge area, there is capacity to absorb storm water; these areas have good infiltration potential. Thus, one could argue this would be a great site to develop as stormwater can easily be mitigated on site. The only concern here would be if the stormwater infiltrates too rapidly, foregoing the filtering capacity of the soil, as in the case of Class A soils. In a low recharge areas, infiltration is naturally inhibited and the addition of more impervious surface won't reduce total watershed recharge that much. However, it could cut off the little that currently exists and may be sustaining a small headwater stream during the summer. Development in these areas may also have a detrimental impact on the associated ecosystems (wetlands / shallow to bedrock).

To further address this dilemma between developing in high recharge versus low recharge areas, the locations of Public Water Supply Wells and Aquifer Protection Areas can be overlaid on the recharge map. Note, the spatial data available from the CTDEP (http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898) for Aquifer Protection Areas and well locations, may not be the well locations themselves, and may instead be the business's address.Infiltration is important to recharge wells (both public and private). With this information, major recharge areas feeding public water can be identified as perhaps more "valuable" than other high recharge areas that don't feed public water supply wells. In relation to public supply wells, the quantity of water recharging the aquifer is certainly important, but the quality of water recharging is equally as important. Concerning the quality of water, some caution may want to be taken in regards to the types of land use and resulting stormwater near public water supply areas.

Also in relation to public water supply wells, it may also be worth considering the amount of water that recharges the aquifer on an annual basis in comparison to the amount of water withdrawn from the aquifer to ensure a "sustainable yield."

While groundwater recharge is clearly important to maintaining well water supplies, recharge is also valuable in terms of maintaining stream flows. Water stored in the soil is slowly released and provides "baseflow" to streams. This baseflow is particularly important during times of dry weather or during prolonged periods of no precipitation as groundwater may be the only source of water supplying streamflow. This flow from groundwater to stream is the typical directional exchange between these "reservoirs" of water. However, there are "losing reaches," where the opposite exchange occurs; the stream loses water to the surrounding soil and recharges groundwater.

Overlaying hydrography (streams) and the location of losing reaches may be helpful for thinking about recharge as it pertains to stream flow. Typically groundwater feeds the stream and maintains the baseflow, losing reaches are just the opposite. Losing reaches located in basins of high recharge may be of particular interest as the stream, itself, feeds water to the aquifer. In terms of development, this may be an area where you do not want to increase impervious surfaces as more surface water runoff (potentially polluted runoff) flows to stream, then feeding into the aquifer.

Maintaining streamflow is also critical for fish and other aquatic organisms. From the MesoHabSim study conducted in the Pomperaug Watershed by Piotr Parasiewicz of the Northeast Instream Habitat Program, the PRWC has information about existing fish populations in the watershed and knowledge of important habitat characteristics (including streamflow) for each species at various times of the year. This information could potentially be used to identify critical areas of maintaining recharge for the preservation of instream biodiversity.

So, while consideration can be given to where to develop with groundwater recharge, the location of public water supplies, and stream flows in mind, the reality of the matter is that each building and road that gets constructed reduces water infiltration into the soil. Ideally, each person living or working in those buildings should feel the responsibility to put the water back where it used to be. As the landscape is developed, efforts should be made to mimic the natural processes of the landscape. Mimicking natural recharge will help maintain the quantity and quality of our already clean groundwater as soil acts as a filter to remove pollutants as water infiltrates. The infiltration alone is important to recharge wells and recharge streams in dry weather. As such, it seems most feasible to look at recharge on the basin scale in attempts to mimic the natural amount of recharge in an area.

IV. LIMITATIONS OF DATA

The first limitation of the recharge data is the geographic area for which this simplified version of the USGS's PRMS model can be applied. The *Recharge Tool* was derived from the PRMS model developed specifically for the Pomperaug Watershed. One of the key elements of the PRMS model is the precipitation and climatic data that is input into the model. Thus, the estimate of recharge calculated using this Recharge tool is based on the historical precipitation record for the Pomperaug Watershed and it should only be applied to regions with climatic conditions similar to those of the Pomperaug. Note that the recharge estimate is also made in a way that averages out the total amount of rainfall per year on a daily basis. Thus, the estimate of recharge in inches per day is based on the assumption that an equal amount of rain will fall every day of the year. The reality is that the quantity of rainfall varies from day to day and week to week, and the Recharge Tool does not account for the soil moisture conditions that may result in a greater volume of surface runoff when the ground is saturated.

The scale at which the recharge data can be applied is also limited. The original intent of this methodology was to develop a model that would allow watershed organizations, land trusts, municipal commissions like Inland Wetlands, Planning, and Zoning, and other agencies to quantify recharge at the parcel scale in order to help prioritize parcels identified in open space conservation efforts. The resolution of the available spatial data makes this impossible at this time. Most of the data is available at the 1:24000 while parcel data is available at a much finer resolution. The scale dictates how confident you can be that the particular feature will be present at that spatial extent. For example, if you are viewing coarse stratified drift, which has a scale of 1:24000, the largest scale (finest resolution) you can view the data at and still be confident that you have accurately delineated that feature is 1:24000. When you zoom in closer, you lose confidence that the feature will still be present. So, if you were to overlay parcels onto the coarse stratified drift and zoomed into a particular parcel, you cannot be totally sure that coarse stratified drift will be found within that parcel.

Related to scale limitations, it was decided that basins were the most appropriate scale at which estimations of recharge could be made given the spatial extent of the data required. Similarly, the basin scale is most comparable to the size of the geographic units used in the PRMS model to evaluate the relationship between precipitation and recharge.

Lastly, the overall rankings of "High", "Medium", and "Low" recharge are based on natural breaks in the data. Natural breaks evenly divide the range of values so an even number of basins will fall under each category. Thus, the high, medium, or low recharge designation is given relative to the quantity of recharge estimated in each of the basins within the area of interest. For example, a basin with 1 inch per day of recharge may be considered high if it is in the highest third of the estimated recharge values for the basins in the area of interest. The relative ranking may change as the area of interest is increased or decreased. This is an important consideration if land use policies are developed in recognition of high and low recharge areas.

V. FUTURE REFINEMENTS & EXTENSIONS

Considering the limitations of the *Recharge Mapping Tool*, areas of refinement and possible extensions come to light. The resolution of the spatial data is perhaps the greatest limitation at this time. As technology advances and the resolution of spatial data become more refined, so will the scale at which the recharge data can be applied. The ultimate goal is to quantify the amount of recharge (or runoff) from a given parcel based on its physical attributes, so the data can be used in the context of land use planning, stormwater management, low impact development, and open space preservation.

The geographic extent at which the *Tool* can be applied can be increased as the USGS's PRMS model has been applied in other areas of the country with differing physical characteristics and climatic conditions, and a similar, but regionally based *Recharge Tool* could be derived. The statistical confidence in this *Tool* could also increase if the PRMS model were to be applied in other locales similar and in relatively close proximity to the Pomperaug Watershed. Likewise, the relative designations of "high", "medium", or "low" recharge could be better delineated in terms of absolute measures if the PRMS model were applied in other areas and then a refined version Recharge Tool is applied to a greater geographic extent.

ATTACHMENT A

Tables

<u>Table 1</u> - Regression Statistics for Multiple Linear Regression of Physical Attributes to Predict Groundwater Recharge

<u>Table 2</u> - Summary Table of Sources and Associated Links for Physical Attribute GIS Datalayers

ATTACHMENT A

Table 1 - Regression Statistics for Multiple Linear Regression of Physical Attributes to Predict Groundwater Recharge, in inches per day

Regression Statistics	
Multiple R	0.813615
R Square	0.66197
Adjusted R Square	0.639053
Standard Error	0.009251
Observations	64

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.032953	0.003666	8.989751	1.19E-12	0.025618	0.040288
Coarse Stratified Drift Percent	0.032147	0.005286	6.081957	9.45E-08	0.021571	0.042724
Class D Soil Percent	-0.03792	0.010748	-3.52784	0.000818	-0.05942	-0.01641
Drainage Density	0.002036	0.001031	1.975862	0.052853	-2.6E-05	0.004099
Percent impervious	-0.09292	0.027984	-3.32032	0.001546	-0.14891	-0.03692

Note: The coefficients can be used to directly compare the magnitude of the effect of each attribute on the recharge estimate, and the t-stat indicates how significant the attribute was in the prediction outcome. The most important attributes for predicting recharge are the stratified drift, class D soils, and the impervious surface, and to a lesser degree the drainage density. For the Pomperaug River watershed, the presence of stratified drift and high drainage density indicates higher recharge and the presence of Class D soils and impervious surfaces indicates reduced recharge.

ATTACHMENT A

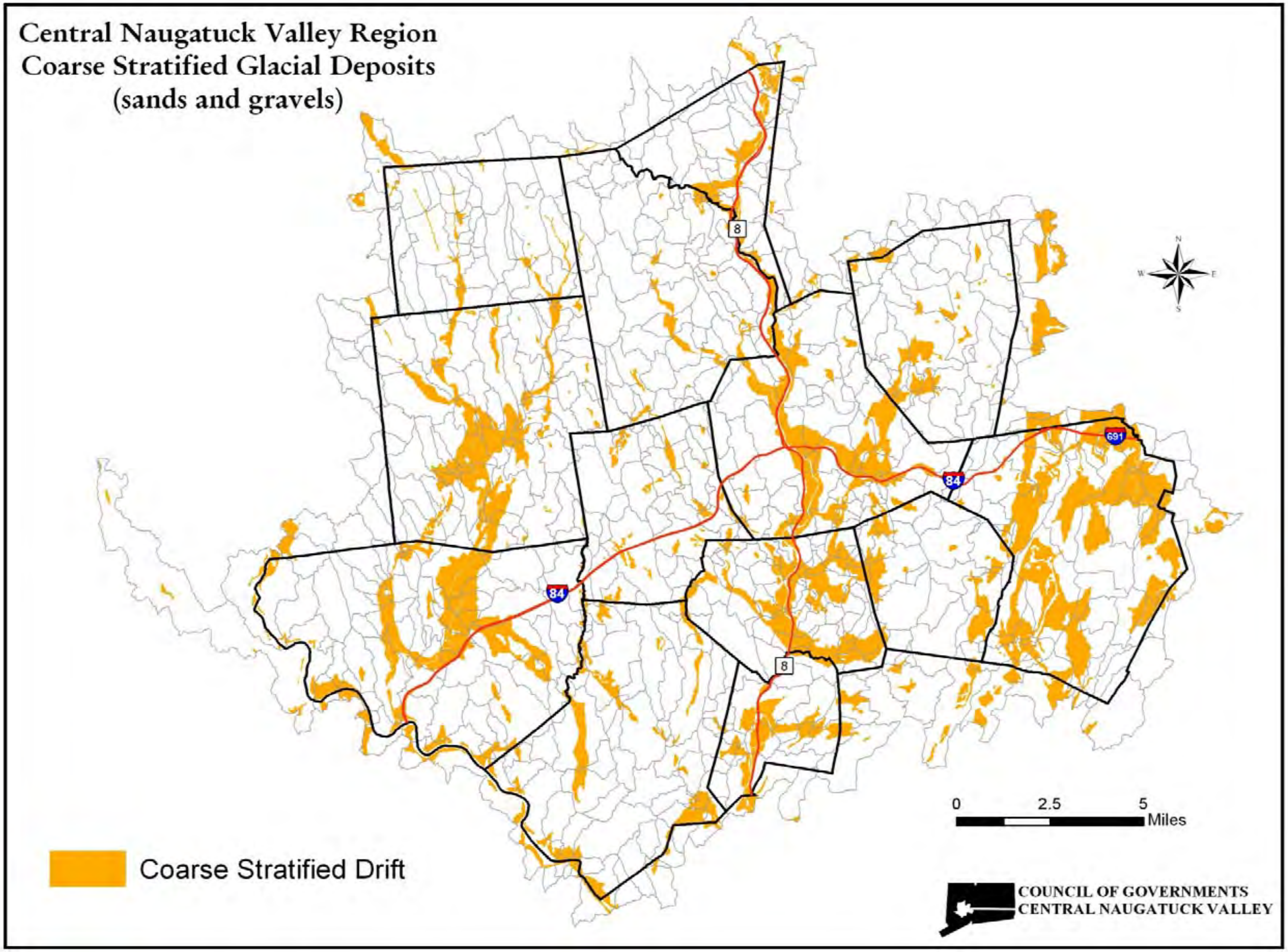
Table 2 - Summary Table of Sources and Associated Links for Physical Attribute GIS Datalayers

Data Layer	Source	Link
Base Layer		
Town Boundary	CTDEP	http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898
Major Roads		
Waterbodies		
Rivers		
Basins		
Physical Attributes (Hydrologic Parameters)		
Coarse Stratified Drift	CTDEP	http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898
Class D Soils	NRCS	http://soildatamart.nrcs.usda.gov/
Percent Impervious Surface	CLEAR 2002	http://clear.uconn.edu/projects/landscape/index.htm
Drainage Density	CTDEP	http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898
Other Attributes		
Aquifer Protection Areas	CTDEP	http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898
Digital Land Parcels	Local Town Assessor's Office or Council of Governments	

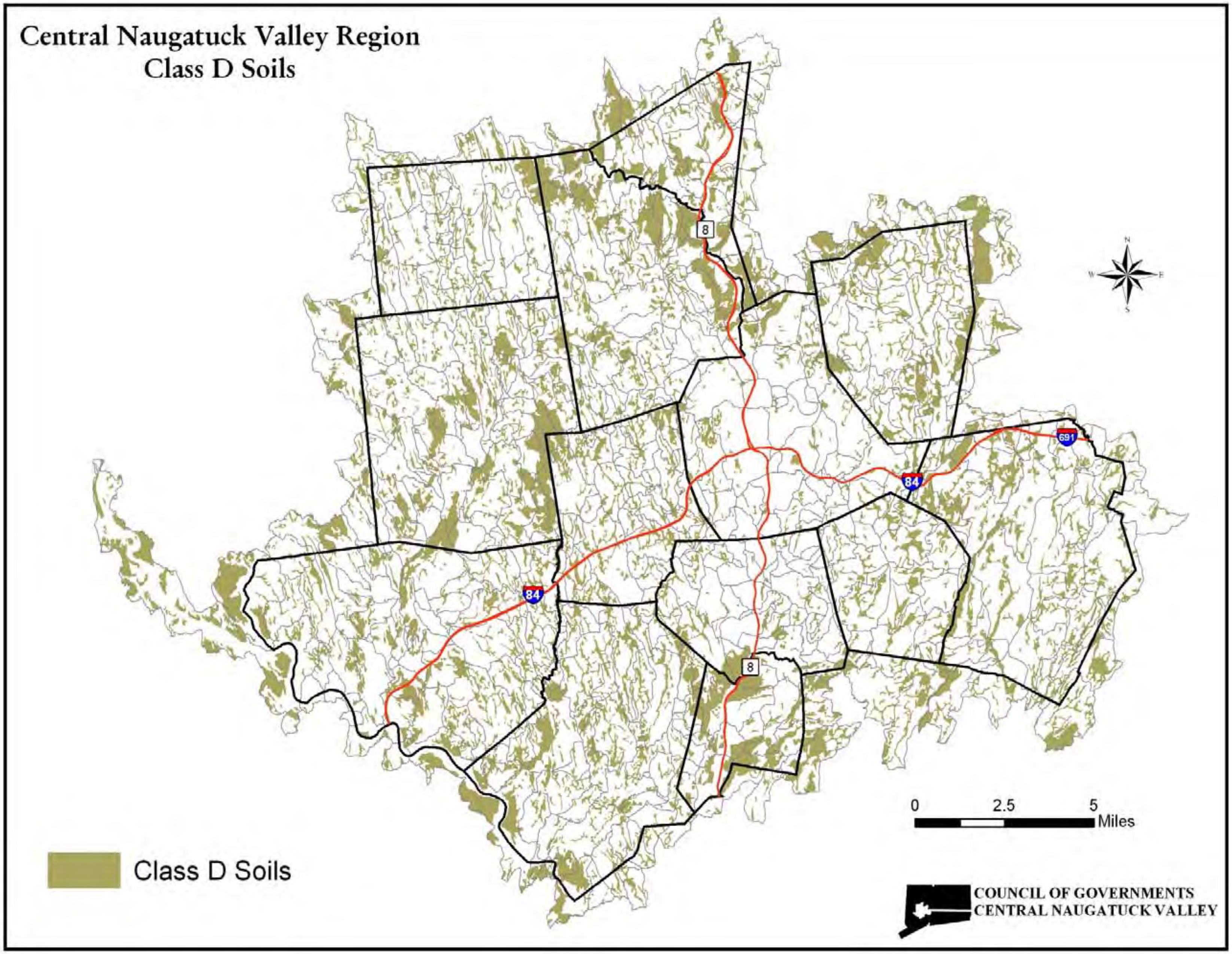
ATTACHMENT B

Maps

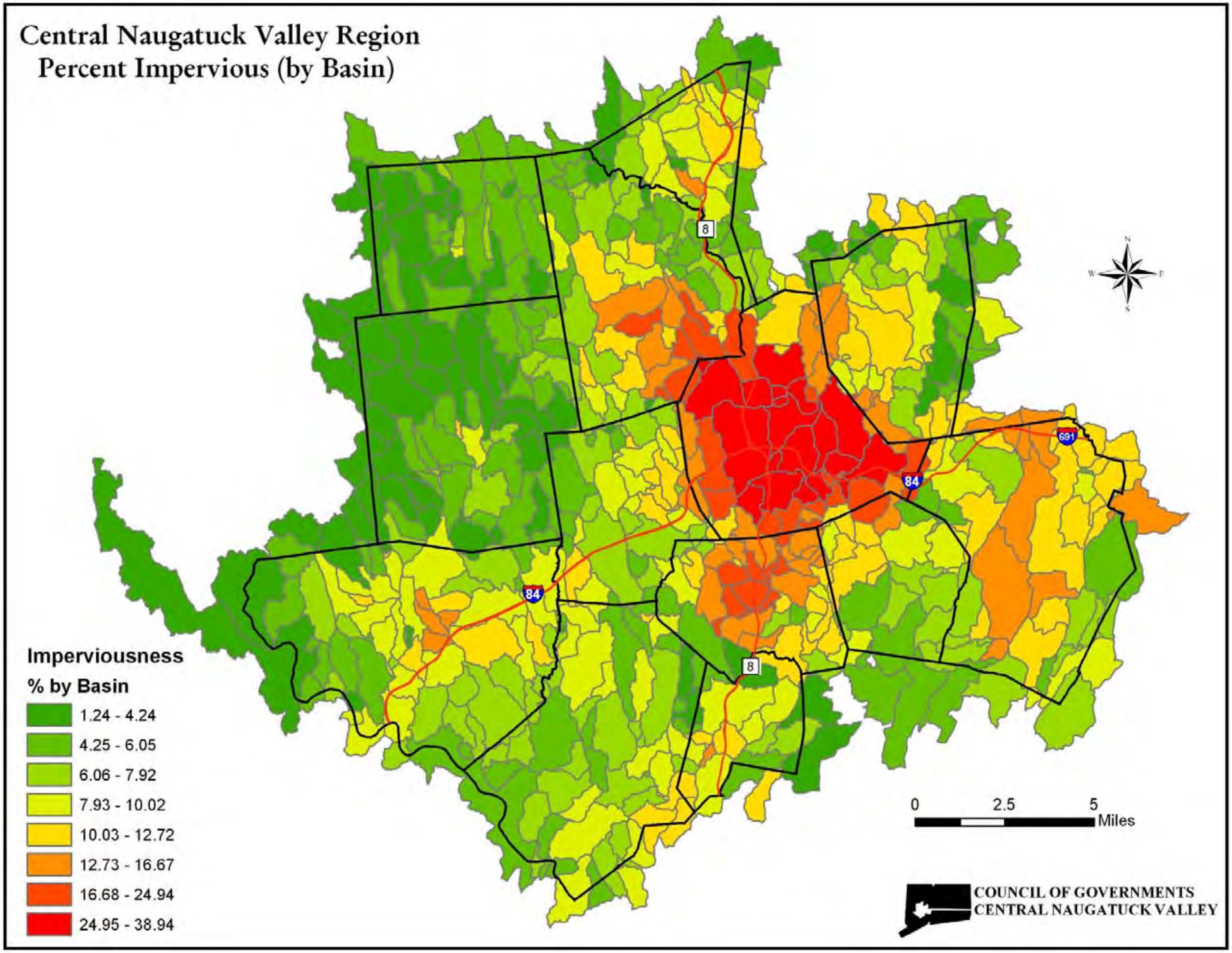
Physical Attribute Maps for the Central Naugatuck Valley Region



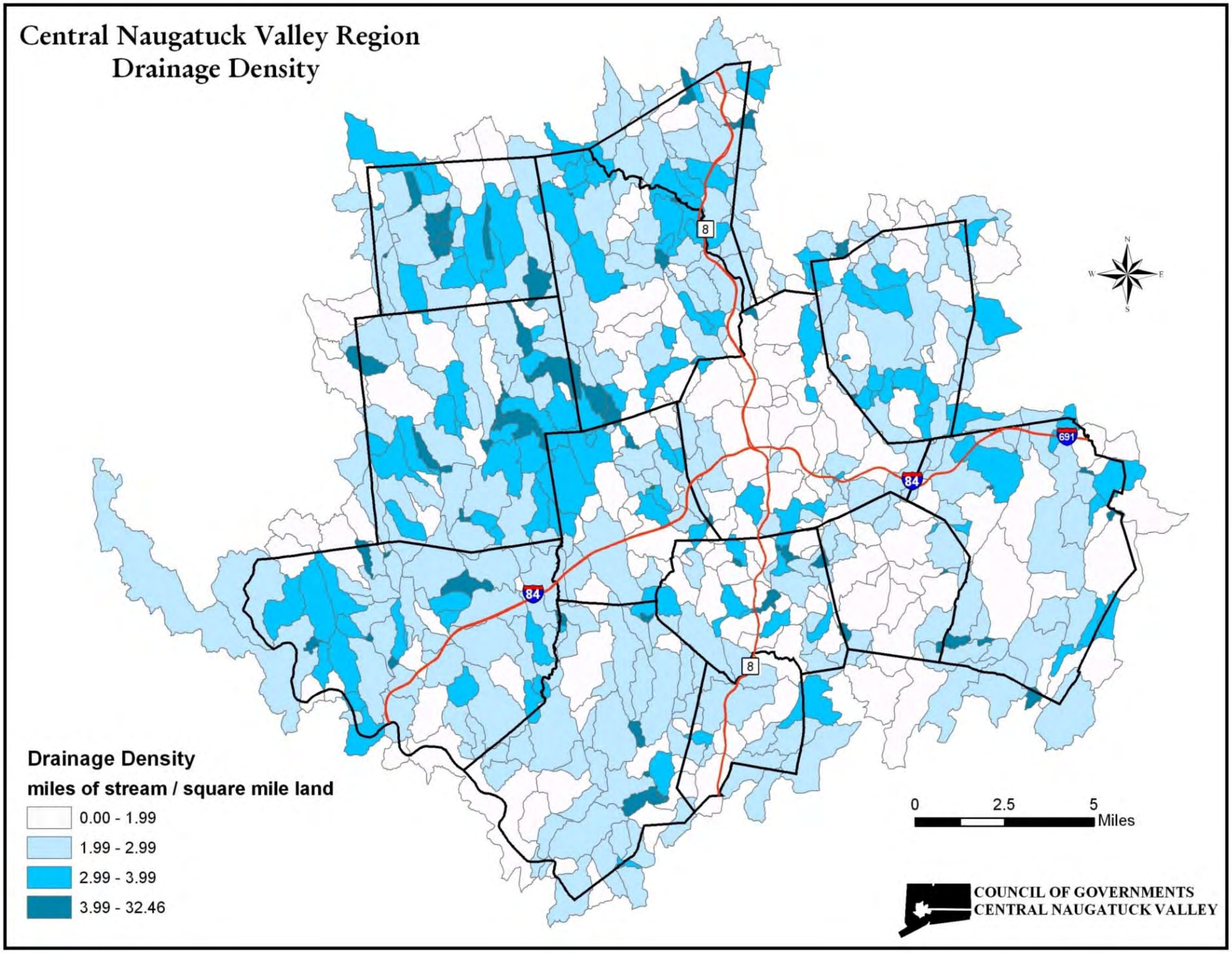
Map 1 – Coarse Stratified Drift, Central Naugatuck Valley Region



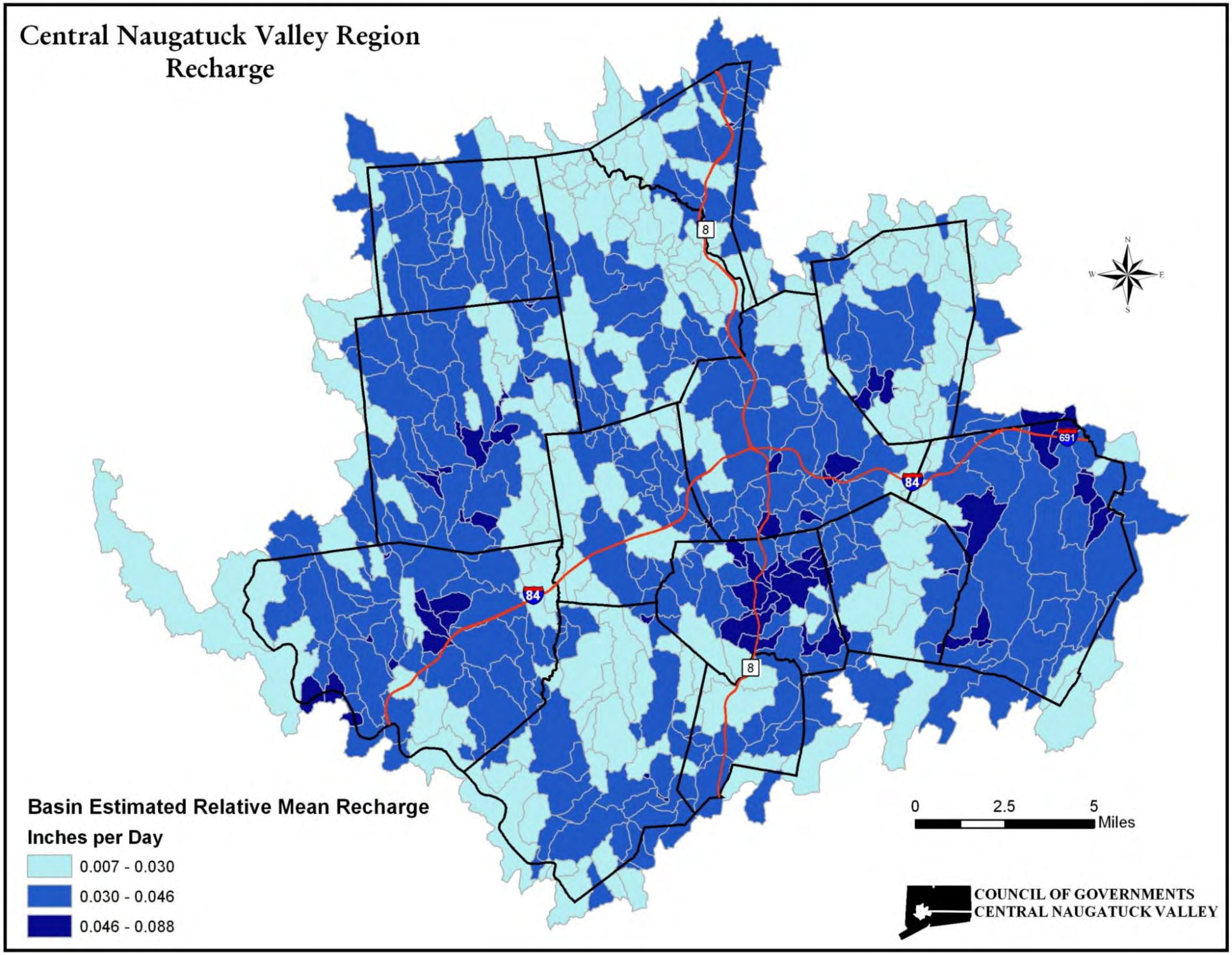
Map 2 – Class D Soils, Central Naugatuck Valley Region



Map 3 – Percent Effective Impervious by Basin, Central Naugatuck Valley Region



Map 4 – Drainage Density, Central Naugatuck Valley Region



Map 5 – Recharge Map, Central Naugatuck Valley Region