THE USE OF SOLUTE-TRANSPORT METHODS TO ESTIMATE TIME-VARYING NITROGEN LOADING RATES TO THE PECONIC ESTUARY RESULTING FROM WASTEWATER AND FERTILIZER INPUTS TO GROUNDWATER IN SUFFOLK COUNTY, NEW YORK

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Problem

The Peconic Estuary of eastern Long Island, New York, is undergoing development as the region transitions from a rural area dependent on agriculture and tourism to a suburban one with a larger year-round population. The glacial and coastal-plain sediments underlying Long Island comprise a sole-source aquifer system that supplies the region's communities with potable water. The area surrounding the Peconic Estuary was intensely farmed prior to suburbanization. Nitrogen loading from past fertilizer use was high as estimated from historical information and the continued detection of legacy effects in the aquifer system. In some areas, the peak or bolus of agricultural nitrogen loading from practices several decades ago may still be present in groundwater that is slowly moving toward the estuary. Likewise, the discharge of wastewater into the environment, primarily through onsite wastewater treatment systems (OWTSs), has adversely affected both water supplies and surface waters. Streams, ponds, and estuaries all receive groundwater discharge, and the terrestrial disposal of wastewater has increased concentrations of nutrients in discharging groundwater. Nitrogen is the nutrient of most concern in the Peconic Estuary with nitrogen-related eutrophication resulting in harmful algae blooms, fish kills, and the loss of critical estuarine habitats such as eel grass beds.

Background

The Peconic Estuary Program (PEP), working with local, State, and Federal governments, citizen and environmental groups, businesses, industries, and academic institutions, is currently (2016) implementing a comprehensive conservation and management plan (CCMP) that includes developing Total Maximum Daily Loads (TMDLs) of nitrogen for the estuary. The purpose of the effort is to establish loading thresholds that local communities will use to evaluate the effectiveness of wastewater

management plans in protecting estuarine habitats. Local communities are currently in various stages of wastewater planning. The regional nature of the flow system, in which the groundwater contributing areas to an estuarine system typically encompass more than one town, indicates that analysis of nitrogen loading rates for a given estuary needs to account for wastewater plans in neighboring towns. The long travel times of groundwater in parts of the aquifer system—decades to a century or more—require that the legacy effects of past agricultural (and wastewater) practices also be considered.

The U.S. Geological Survey (USGS) has assisted the PEP and other entities to better understand the Island's groundwater flow system and to begin to assess how, in the context of the regional flow system, wastewater management plans may affect nitrogen loading rates to the region's estuaries. Similar USGS work on Cape Cod, Massachusetts, contributed to development and implementation of nitrogen TMDLs there (Walter, 2008; Colman and others, 2015). As part of the Cape Cod effort, the USGS developed methods that allow for 1) incorporation of parcel-scale water use data into solute-transport models and 2) hypothetical simulation of time-varying nitrogen loads to estuaries for sequential wastewater management actions (including sewering and centralized wastewater disposal). Currently, the USGS has undertaken a comprehensive assessment of the groundwatersheds and travel times to about 1,000 Long Island fresh and marine surface-water segments using flow-model and particle-tracking (MODFLOW and MODPATH) methods. The USGS proposes to apply the model used to produce comprehensive delineations of Long Island areas contributing water to surface water bodies, and Cape Cod solute-transport methods in support of nitrogen TMDL development for the Peconic Estuary.

The USGS work on Cape Cod demonstrated that the use of a tool that fully integrates parcel-scale water use and three-dimensional solute transport has several advantages over a simpler, mass-balance approach that uses static watersheds to estimate loads and GIS data to estimate (spreadsheet models). These advantages include the ability 1) for groundwatersheds to change dynamically in response to changing hydraulic stresses (as occur from sewering, centralized wastewater disposal, and changes in water-supply withdrawals); 2) to assess time-varying loading rates resulting from temporal changes in water use and complex, sequential wastewater management actions; 3) to represent additional transport processes such as dispersion and sorption; and 4) to estimate loads for any sub-region of an estuary without being limited to predefined groundwatershed delineations.

The comprehensive set of Long Island groundwatersheds to be provided by USGS to the New York State Department of Environmental Conservation (NYSDEC) are useful for evaluating terrestrial nitrogen loads for current stresses (pumping, sewering, and wastewater disposal) and the development of TMDLs. However, computation of nitrogen loading rates resulting from complex, multi-town wastewater management actions needs a dynamic, quantitative, and internally-consistent approach. Also, as communities move forward in the development of individual Wastewater Management Plans, there is a need for a consistent set of technically sound methods and tools to be used in the evaluation of the effects of planned wastewater management actions on shared aquatic resources. The methods used to evaluate nitrogen loading generated by wastewater management actions

need to be consistent between individual towns to avoid differing results that could arise from the application of inconsistent methods.

Objectives

The overall objective of the study is to apply methods that will allow for the quantitative analysis of nitrogen loading rates to the Peconic Estuary resulting from wastewater and fertilizer inputs to groundwater in Suffolk County. Specifically, the objectives of the investigation are to 1) develop data sets representing current and historic land uses relevant to nitrogen loading in coastal watersheds, 2) incorporate these data as source terms in models capable of simulating transport processes to estimate current estuarine loading rates and nutrient concentrations in the aquifer, and 3) use these current-condition models to simulate the response of estuarine loading rates to possible wastewater-management actions.

Relevance and Benefits

This investigation will provide assistance to the PEP and local communities in the analysis of the effects of wastewater and fertilizer inputs on nitrogen loading rates to the region's fresh and marine surface waters. The proposed work would allow communities to make more informed decisions regarding future wastewater management alternatives and would help the PEP assure that those alternatives result in an acceptable level of protection for the region's aquatic ecosystems. The investigation also benefits the USGS, whose work historically has been integral in enhancing knowledge of Long Island hydrology, by furthering our scientific understanding of regional flow and transport processes. This project is also a continuation of the USGS work in nutrient loading to coastal waters, an ongoing and increasing societal concern.

The regional analysis is needed to assure that wastewater management actions undertaken by neighboring towns within the groundwatersheds to critical estuarine systems result in adequate protection of the Peconic Estuary. The work proposed here would represent an additional level of analysis that would augment the technical work routinely done by local communities and their consultants as part of the development of Wastewater Management Plans for each community. The investigation is designed to complement and support, rather than compete with, the private sector activities at the local level. The USGS would interact with local communities and their consultants through State and regional entities.

The proposed investigation aligns with the mission of the USGS, as outlined recently in the USGS Water Science Strategy document (http://pubs.usgs.gov/circ/1383g/).

Approach

This project will be comprised of four general components: 1) assembly of a detailed inventory of time-varying sources of nitrogen within the Peconic Estuary groundwatershed, including those from both historical agriculture and residential development; 2) subregional model development and method refinement, 3) hypothesis

testing of nitrogen loss and attenuation assumptions, and 4) application of the methods to the estimation of waste- and fertilizer-derived nitrogen loading rates.

The first component will utilize data from local communities to compile time-varying nitrogen sources at a multi-decadal time scale. The second component is a method development and evaluation effort that includes a) the development of a subregional solute-transport model of the Peconic Estuary groundwatershed, linked to a regional model currently being developed, in part, to facilitate watershed delineation, and b) refinement of methods that allow for the synthesis of the time-varying nitrogen sources within the Peconic Estuary watershed into the framework of a three-dimensional solute-transport model. The third component will use the subregional model to evaluate how assumptions of nitrogen attenuation and loss affect nitrogen loading into fresh and marine surface waters. The fourth component will apply the models in estimation of nitrogen loading rates resulting from a limited set of representative complex, sequential wastewater-management actions.

Given the size and shape of the Peconic Estuary groundwatershed and the model-discretization limits associated with solute-transport models, it is anticipated that model cells of 100 feet on a side would be needed to fully simulate all of the processes of interest. The pace at which the model could be developed is dependent on the availability of spatial data. These include data on parcel-scale water use throughout the Peconic Estuary groundwatershed. Such data are critical to a detailed assessment of nitrogen loading to the estuary from wastewater-management actions within its groundwatershed. Thus, it is expected that substantial GIS resources will be required early in the project, some of which may be provided by other entities as in-kind services. Possible in-kind services could include assembly of parcel-scale residential use data layers from water-use data (from water suppliers), associated parcel maps (local stakeholders), and quantification of factors related to summer residents, pets, and leaky sewers. Additional services could include compilation of historic aerial photos to determine historic land uses and historic fertilizer use., and sharing and cooperation in data collection by local stakeholders concerning vadose and hyporheic zone denitrification rates. Aquifer nitrogen concentrations within the groundwater contributing area to the Peconic Estuary and nitrogen concentration of surface water samples collected at the USGS Peconic River streamgage (https://nwis.waterdata.usgs.gov/ny/nwis/qwdata/?site_no=01304500) will be compiled.

Evaluation of time-varying nitrogen sources: A variety of data from local and State stakeholders will be used to develop a comprehensive set of time-varying nitrogen sources from the two principal anthropogenic activities: agriculture and residential development, including fertilizer used on residential lawns. Historical land use and fertilizer-use estimates will be used to develop the spatial distribution of agricultural nitrogen sources over a multi-decadal time scale. Parcels from tax-assessor maps will be linked to corresponding water-use data and used to develop current nitrogen sources from OWTSs, incorporating assumptions of effluent concentrations; these data will be augmented with information on historical residential land use to estimate time-varying residential nitrogen sources. Disposal at wastewater-treatment facilities and the corresponding sewered areas also will be compiled to include those additional nitrogen

sources. These two data sets will be combined to produce a comprehensive set of GIS data layers representing sequential nitrogen sources within the watershed of the Peconic Estuary system over a multi-decadal time scale.

This comprehensive data set will allow for 1) a more complete accounting of time-varying loading from past agricultural (and wastewater) practices within the watershed and 2) a more accurate simulation of current nitrogen loading rates and, therefore, a better estimate of the effects of future wastewater-management actions on loading rates to fresh and marine surface waters. The ability to fully account for historic loading will depend on the quality of available data. Assembly of these data layers would be done early in the project and likely would require participation of other partners, possibly as in-kind services, as discussed previously

Model development and method refinement: A subregional groundwater-flow and solute-transport model encompassing the Peconic Estuary groundwatershed will be developed; the model will be linked to an existing USGS regional model of Long Island by hydraulic boundaries. A GIS-based method, previously developed by the USGS, will be used to incorporate the assembled time-varying nitrogen sources into the subregional solute-transport model. Individual polygons representing spatially-variable nitrogen sources (including both agricultural and residential sources) will be mapped to the model grid to estimate a mean loading rate in each model cell; this will be done for sequential data layers representing a time-varying source term. The model will utilize MT3D (Bedekar and others, 2016) to represent the explicit transport of nitrogen from those sources to wells and ecological receptors. The model will simulate steady-state flow and transient transport.

Evaluation of nitrogen loss and attenuation assumptions: Previous USGS solute-transport analyses of nitrogen loading on Long Island have only incorporated advective transport and dispersion. This assumes that nitrogen is transported conservatively (non-reactively) through the aquifer as nitrate and, therefore, loading rates are considered "worst-case" estimates. The assumption of conservative transport may be reasonable given the oxic, carbon-poor conditions in the aquifer and the high permeability of aquifer sediments. However, it is not known explicitly whether loss or attenuating processes, such as denitrification, occur within the aquifer or along its discharge boundaries. Nitrogen attenuation or loss previously has been represented in simple models as a loss factor applied to different nitrogen source areas. Although this approach does not explicitly simulate the attenuation processes, it does implicitly account for the effect of nitrogen loss or attenuation on loading rates at discharge boundaries, assuming the estimated loss factors are reasonable. These loss factors generally are considered to be a function of spatially-variable characteristics such as total subsurface travel time and unsaturated zone thickness. The use of a solute-transport model allows for the incorporation of these spatially-variable characteristics into analyses of possible nitrogen loss in more detail than simpler GIS-based approaches. Nitrogen loss and attenuation as a function of total subsurface travel time, and the effects on loading at the coast, can be incorporated into an analysis at the model-cell scale. Also, other spatial variables, such as unsaturated zone thickness, or hyporheic- (discharge-) zone characteristics, also can be included in the analysis at the same level of detail. Several representative aquifer cross

sections will be drawn with nitrogen species iso-concentration lines as measured in water quality samples, and these sections will be compared qualitatively to model simulations.

The subregional solute-transport model will be used to 1) develop methods to include representations of nitrogen loss or attenuation, either directly or implicitly as a loss factor applied to surficial sources, into the modeling analysis and 2) incorporate a range of nitrogen loss or attenuation assumptions such that a range of loading estimates can be produced that fully encompass possible subsurface transport assumptions. GIS-based methods will be developed to incorporate subsurface travel times and unsaturated zone thicknesses in the model at the model-cell scale. Possible loss factors from published sources as well as PEP researchers will be evaluated.

Model application: The subregional solute-transport model will be used to simulate a 'full-sewering' scenario to evaluate inherent response times of the aquifer to remove all of the nitrogen sources. In addition, the model will be used to evaluate a limited set of complex wastewater management scenarios. The scenarios, either actual or hypothetical, will be determined in consultation with State, regional, and local stakeholders. The model will be used to estimate time-varying nitrogen loading rates throughout the Peconic Estuary. Simulated nitrogen concentrations in supply wells also will be included in the analyses because protection of water supplies is an additional concern to State, regional, and local planners. The scenarios will be of sufficient complexity to fully encompass projected nitrogen-input conditions and could include actions undertaken by neighboring communities, within the capabilities and limitations of the methods.

An initial-conditions scenario will consist of time-varying historic loading, given data availability, to estimate current nitrate levels in the aquifer and loading rates at discharge boundaries. Model-derived concentrations of this scenario will be compared qualitatively to field measurements. The initial-conditions scenario will be followed by a range of wastewater management actions—such as use of innovative/advanced (I/A) OWTSs, sewering and centralized wastewater disposal, and possibly other measures. The incorporation of sequential wastewater management actions into the solute-transport model allows for the simulation of different phases of wastewater management continuously over time. If needed, scenarios will include wastewater management actions at multiple scales Additional complexities that can be included, if needed, are 1) assumptions of nitrogen loss or attenuation, 2) changes in water-supply pumping, and 3)varying levels of nitrogen treatment at current or proposed wastewater treatment plants which discharge to groundwater.

Quality Assurance

Methods used in this study include GIS development, data management, and groundwater flow and transport modeling. Measurements of nitrogen species concentrations are from State and other agency sources and will be compiled in a project excel spreadsheet then published in a USGS Data Release. Solute-transport modeling will be used to represent nitrogen loading to the Peconic Estuary. Methods used in this study are quality assured through the thorough technical review process in placed for all USGS projects that includes review by no less than 2 highly qualified technical experts working

in other USGS locations than Coram, NY. A model archive will be built during the project, according to USGS standards, and a website will be maintained to provide news, publications, and other results as they become available.

Products

A USGS report will document model development as well as analytical results for a limited set of representative wastewater management scenarios. The report will be designed with the dual purposes of 1) documenting the models and methods developed as part of the USGS investigation and 2) providing a detailed description of surface-water loading rates under changing land-based nitrogen-input conditions. Preliminary model results will be transmitted as PDFs to stakeholders as needed during the course of this investigation. The USGS will present progress and results of the investigation at technical meetings and public forums upon request. Modeling will proceed collaboratively with NYSDEC and PEP personnel to ensure that the two projects are complementary. An additional USGS report or journal article may be published near the end of the project to compare the solute-transport methods and results from the Cape Cod and Peconic Estuary investigations. Numerical models and data used to represent nitrogen source terms will be publically disseminated as a separate web-hosted USGS Data Release product, in accordance with USGS policies.

Budget

The proposed USGS project will require a total of $702,000 in cooperative funding to cover the costs for salaries, equipment, travel, and other related expenses. In-kind services will be included in the total cost of the project. The proposed 3-year project is to begin October 1, 2017 and will continue through September 30, 2020.

Category	Fiscal year (October 1 through September 30)			Total
	2018	2019	2020	
GIS preparation	$200,000	$34,000	$0	$234,000
Model construction	$34,000	$150,000	$0	$184,000
Loading rate estimation	$0	$0	$200,000	$200,000
Dissemination	$0	$50,000	$34,000	$84,000
Total	**234,000**	**234,000**	**234,000**	**$702,000**

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