APPENDIX

Project Sponser	Project No.	Project Name	Appropriation Amount	Project Description	Program
Atlantic County UA	S340809-23	ACUA Treatment Plant Resiliency Project - Emergency Power	$7,000,000	The proposed project includes several mitigation measures to provide emergency power to the ACUAs Treatment plant.	Clean Water
Atlantic County UA	S340809-25	Seawall	$11,000,000	The proposed project includes construction of a seawall at ACUAs treatment facility.	Clean Water
Atlantic County UA	S340809-26	STP Mitigation Projects	$1,500,000	The ACUA is developing a project to protect certain facilities within the treatment plant site from potential storm surge water from hurricane type events similar to the Super Storm Sandy.	Clean Water
Atlantic County UA	S340809-24	ACUA Pump Station Resiliency Project	$800,000	The proposed project includes several mitigation measures to make the ACUAs pump stations resistant to storm conditions.	Clean Water
Barnegat Township	S344130-01	Jet-Vac Truck for Sanitary and Stormwater Sewer Cleaning/Maintenance	$450,000	The proposed project includes the purchase of a combination Jet-Vac truck for sanitary and stormwater sewer cleaning and maintenance.	Clean Water
Cape May City	0502001-004	Well 5 Replacment for the Sands Aquifer	$2,200,000	Construction of a new 12-inch case well No. 8 into the 800 foot Atlantic City Sands Aquifer	Drinking Water
Carteret Borough	S340939-09	Noe Street Stormwater Pump Station Construction	$10,600,000	The project consists of construction of a new stormwater pump station and detention basin in the Noe Street drainage area. The project includes replacement of stormwater collection piping and inlets a force main an outfall and	Clean Water
Cinnaminson SA	S340170-07	Replace existing surface aerators w/ diffused aeration syst; dissolve oxygen control logic; anoxic zone improvements. Provide odor control equip for sludge handling equip.	$9,000,000	Replace the existing surface aerators with a diffused aeration system and dissolve oxygen control logic. Provide capability to use back third of aeration tanks as anoxic zone to encourage denitrification. Replace the existing Somat presses and dissolved air flotation thickener with a rotating sludge thickener and a rotary fan press. Provide odor control equipment for all sludge handling equipment certain process building interior spaces. Replace pumps and piping and rehabilitate control building where required.	Clean Water
Clinton Town	1005001-008	Well 4 Water Production Facility	$185,300,000	Rehabilitation of treatment plant at well 4	Drinking Water
Cumberland County IA	S342015-03	Landfill Expansion (Phase VI development & Leachate pump station improvements)	$16,100,000	Construction of a 32 acre lateral expansion at the Cumberland County Solid Waste Complex consisting of landfill Cells 7, 8 and 9. The project also includes improvements to three (3) leachate pump stations which provides service to existing landfill Cells 1A,1B and 2A.	Clean Water
Elizabeth City	S340942-18	Progress Street Flood Control Project	$8,200,000	The recommended alternative calls for isolating the flooding area from the CSO outfall by rerouting the existing outfall through an industrial property to Progress Street and reconnecting to the existing outfall on Progress Street.	Clean Water
Ewing Lawrence SA	S340391-10-1	Wastewater Treatment Plant Upgrade	$4,900,000	Supplemental Loan for Project Number S-340391-10 which is currently under construction. Supplemental funding is desired as soon as possible.	Clean Water
Franklin Township SA	S340839-06	Rodney Ave. Pump Station	$17,100,000	The project will consist of the installation of new and replacement of existing gravity sewer totalizing 3,800 LF of 8", 12", 15", 21", and 24" pipe, construction of a pump station and 1,300 LF each of 10" and 16" force main.	Clean Water
Gloucester City	S340958-07	Various Water System Improvements, Phase II	$1,200,000	The Freedom Pier project includes the extension of the existing sanitary sewer system including pipe and appurtenances.	Clean Water
Gloucester City	0414001-020	Water System Improvements, Phase II	$250,000	Replacement of water mains on Water St and looping of mains to Freedom Pier	Drinking Water
Gloucester County UA	S340902-14	Bio-solids handling facility changing from sludge incineration to anaerobic digestion w/ combined heat & pwr generation. Other energy efficient proposals to digestion process.	$45,000,000	The bio-solids handling facility is proposed to change from sludge incineration to anaerobic digestion with combined heat and power generation. Various other wastewater plant improvements are proposed for energy efficiency and to better support the anaerobic digestion process.	Clean Water
Jackson Township	S344050-02	Purchase of a Jet-Vac/Street Sweeper	$1,300,000	The proposed project includes purchase of a Jet-Vac/Street Sweeper.	Clean Water
Jackson Township MUA	1511001-010	Improvements to Manhattan Street Complex: Demolition of field office, abandon water treatment plant, wellhouse #3, storage tanks and associated booster station. Construct storage tank with booster station , new warehouse and miscellaneous safety and energy efficient improvements.	$5,900,000	Replacement of two storage tanks with one 0.2 MG tank with booster station shed and piping, site work and demolish existing tanks and old WTP. Demolition of Field Office and replace with new warehouse that will house the new pumps and chemical feed for well #3.	Drinking Water
Long Beach Township	1517001-500	Beach Haven Terrace Water Plant	$9,200,000	Demolish and replace damaged pump room @ Beach Haven Terrace WTP	Drinking Water
Long Beach Township	1517001-501	Brant Beach Water Plant	$1,900,000	Demolish and replace damaged pump room @ Brant Beach	Drinking Water
Manasquan Borough	S340450-02	Track 1 - Pump Station elec syst & controls, bulkheads undermined, E. Virginia Ave PS elevated using FEMA funds. Proj incl protection & stormwater conveyance measures	$1,800,000	This is a resiliency project for systems adversely impacted by Superstorm Sandy; the pump station electric system and controls were compromised during the storm and bulkheads were undermined. The E Virginia Ave pump station will be elevated using FEMA obligated funds to mitigate impacts of future flooding during high tides and storm events. The proposed project will include infrastructure protection and stormwater conveyance measures; these include an enclosure for the elevated pump station, reconstruction and elevation of bulkheads at Borough property along Perrine Blvd, at the southern-most intersection of Perrine Blvd and Cedar Ave, at the southern terminus of Euclid Ave near Perrine Blvd, and along the 4th Ave parking lot. Improvements will be made to fill in between the reconstructed bulkheads and roads as well as to reinstall water and electric service to the marina.	Clean Water
Middlesex Water Company	1225001-023	Renew 2016-C&L of Water Mains, Replace non-copper services	$8,000,000	C/L of 20,000 LF of water main and replacement of 12,000 LF of undersized water main	Drinking Water
Netcong Borough	1428001-009	Replace old meters with automatic ones	$400,000	Replace custoer meters with automatic meter reading system	Drinking Water
Newark City	0714001-015	Rehabilitation of Water Distribution Mains	$18,200,000	Cleaning & lining of 61,000 LF of 6, 8 & 12-inch water mains	Drinking Water

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New Jersey Environmental Infrastructure Financing Program Projects SFY2017

Project Sponser	Project No.	Project Name	Appropriation Amount	Project Description	Program
North Hudson SA	S340952-19	Combined Sewer Improvements	$4,300,000	1.RepairUpgrade of Combined Sewer Regulators (W1 through W5) - float and gate mechanisms be replaced vortex valves installed to control velocities. 2.RepairUpgrade of Combined Sewer Regulators (H1 through H7 Hillside Road) - all floats and gates within these structures to be replaced in-kind. 3.Sewer Rehabilitation-rehabilitating various sections of deteriorated piping along New York Avenue between 19th Street and 49th Street. Selected sections of piping to be lined with cure-in-place pipe 4.Sewer Main ExtensionSewer Repair - the influent line to the Baldwin Avenue Pump Station to be rerouted to the18th Street Pump Station thus allowing decommissioning of the Baldwin Avenue Pump Station. The piping on Hamilton Ave. will require epaircorrection. 5.Siphon Improvements - Isolate dewater clean and line the entire 3100 linear feet of the 12-inch barrel of one siphon and inspect the other siphon using sonar technology.	Clean Water
North Jersey District WS	1613001-017-1	Wanaque South Pump Station Upgrade: preparation of design and construction of improvements to pumps, motors and drives at pump station, a pump station located on Fairfield Road in Wayne.	$3,600,000	Design/Build Project will involve preparation of detailed design and construction of improvements to pumps, motors and drives at the Commissions Wanaque South Pump Station.	Drinking Water
North Wildwood City	S340663-06	2014 Street & Utility Reconstruction	$18,100,000	Street & Utility Reconstruction as follows Surf Avenue between 1st & 11th Avenues Ocean Avenue between 2 & 18th avenues Beachfront storm sewer between 4th & 15th Avenues 7th 8th & 12th Avenues between Surf Avenue and JFK Blvd. 4th Avenue between Ocean Avenue and JFK Blvd.	Clean Water
Ocean County	**S344080-04**	**Manufactured Treatment Devices**	**$1,100,000**	**Manufactured Treatment Devices will be installed within existing storm water systems immediately upstream of various outfalls along the north side of the Toms River and along lagoons and tributaries to Barnegat Bay.**	**Clean Water**
Ocean County	**S344080-10**	**Camera Pipe Line Inspection Truck System - Equipment**	**$240,000**	**The Camera Pipe Line Inspection System is a piece of equipment that will be used by the Ocean County Road Department to evaluate the condition of the stormwater drainage pipes, locate compromised sections of pipe, and locate blockages, so that sediment and debris can be removed from the stormwater before it outfalls into the tributaries of Barnegat Bay. The equipment is a Cues CCTV Camera Pipe Line Inspection Truck (Ford E-450) with an OZ2 camera and steerable Pipe Ranger Wheeled Transporter.**	**Clean Water**
Ocean County	**S344080-11**	Mechanical Street Sweeper - Equipment	**$336,000**	**The Mechanical Street Sweeper is a piece of equipment that has a six wheel single engine broom street sweeper with a cleated belt conveyor. The Mechanical Street Sweeper is a piece of equipment that will be used by the Ocean County Road Department to remove sediment and debris off of the roads before it enters the stormwater drainage pipes and discharges into the tributaries of Barnegat Bay.**	**Clean Water**
Ocean Township	S340112-07	Replace sanitary sewer main, and make drainage improvements along Maplewood, Teaneck Roads, Englewood Avenue, Dune Lane, Stillwater Road and Harborage Place.	$3,000,000	Replacement of approximately 6000 LF of existing sanitary sewer main as well as drainage improvements along Maplewood Road Teaneck Road Englewood Avenue Dune Lane Stillwater Road and Harborage Place.	Clean Water
Passaic Valley SC	**S340689-31**	**Replace existing Sod Hypochlorite Storage & Feed Tanks to improve & accommodate disinfection for increased wet weather flows**	**$4,000,000**	**This project is one component of PVSCs plant wide improvements to increase its wet weather treatment capacity to reduce the volume of CSO discharges. This project will replace PVSCs existing Sodium Hypochlorite Storage and Feed Facility tanks make improvements to the chemical feed system and if necessary the receiving area containment. The improvements are being designed to accommodate the disinfection for increased wet weather flows.**	**Clean Water**
Passaic Valley SC	**S340689-34**	**Purchase & Install new pumps, valves, piping, flow meters, process control sampling & monitoring equipment**	**$2,900,000**	**The Waste Pump Expansion project is one component of PVSCs Plant Wide Improvements to increase its wet weather treatment capacity to reduce the volume of CSO discharges. The project will be purchasing and installing new pumps valves piping flow meters process control sampling and monitoring equipment and providing electrical improvements as necessary to accommodate the new style pumps. Improvements to address hydraulic issues and improve pump operational characteristics are also being included in the project.**	**Clean Water**
Passaic Valley SC	S340689-22	Yantacaw Pumping Station Rehabilitation	$3,900,000	The project consists of installation of a new flow meter replacement of existing pumps with dry pit submersible pumps with VFD controllers replacement of all suction and discharge piping and valves replacement of sump pumps improvements to the existing communutors and slide gate support system. The work will also include sidewalk repairs leak repairs and miscellaneous electrical and instrumentation upgrades.	Clean Water
Passaic Valley Water Commission	**1605002-025**	**Water Storage Improvements Phase 1 - Standby Emergency Generators**	**$9,100,000**	**Phase 1-Installation of four 2,500 kW diesel generators with buildings and fuel pumps at the Little Falls WTP; storage tanks**	**Drinking Water**
Salem County IA	S342022-01	Cell 11 Construction	$7,700,000	The project includes an 8.3-acre landfill cell, which is one phase of a 31-acre landfill expansion. The landfill design includes a double composite liner system designed and permitted in accordance with NJDEP regulations.	Clean Water

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New Jersey Environmental Infrastructure Financing Program Projects SFY2017

Project Sponsor	Project No.	Project Name	Appropriation Amount	Project Description	Program
Somerset Rar. Valley SA	**S340801-08**	**Rehab of sludge incinerator #2 consists of new secondary heat exchanger, scrubber syst, new assoc instrumentation & elect syst to meet Federal air emmission perf.**	**$5,200,000**	**The proposed rehabilitation of sludge incinerator 2 consists of a new secondary heat exchanger new scrubber system and new associated instrumentation and electrical systems. To meet new Federal air emission performance standards for existing sewage sludge incineration units (40 CFR Part 60 Subpart MMMM) a new mercury control system will be installed which will clean the exhaust from sludge incinerator 2. This proposed project will not involve any changes or an increase to the present wastewater capacity of the WWTP. Additionally no adjustments to the permitted wastewater flow to the treatment plant under the SRVSAs existing NJPDESDSW permit will be necessary.**	**Clean Water**
Stafford Township	**S344100-03**	**Neptune Basin Expansion**	**$5,600,000**	**The proposed project includes the construction andor retrofit of one or more stormwater basins to improve its ability to remove nitrogen.**	**Clean Water**
Trenton City	**1111001-010**	**Rehabilitation of distribution system by C&L of mains**	**$10,500,000**	**Phase 2 of the City of Trenton's cleaning and lining of existing water mains project involves cleaning, lining, replacement of unlined mains with cement-motor lined ductile iron piping and looping of the water mains to avoid dead ends in the Ewington South and Miscellaneous Areas.**	**Drinking Water**
Wanaque Valley RSA	S340780-04-1	STP Improvements	$1,500,000	The proposed Authority capital improvement projects consist of the following: (1) installation of new gas generators at the wastewater treatment facility and at the main pumping station; (2) mechanical aerators and drives with increased aeration capacity for the existing oxidation ditch process system; (3) upgrade of three influent pumps and drives to 40 HP; (4) installation of a rotary drum sludge thickener system; (5) non-potable water pumps, dilution water pumps and drives; (6) mixers on sludge holding tanks; and (8) upgrade of discharge channel ultraviolet disinfection system.	Clean Water
Warren Township SA	S340964-02-1	Supplemental loan for project at Fox Hill West Pump Station and Heather Lane Pump Station. Both have reached end of useful life and require upgrades. Fox Hill will upgrade includes conversion to submersible type pump station and replacement of emergency generator. Heather Lane includes construction of a new valve chamber to replace existing non-functional valve chamber.	$350,000	The Fox Hill West Pump Station was put in operation in 1970 and has reached its useful life. The emergency generator is in a constant state of repair and at the end of its useful life. The Heather Lane Pump Station was put on line in 1985. The current segmented concrete valve pit is subject to groundwater infiltration, and is constantly filled with water. The gate valves are rusted in the open position and cannot be properly accessed or operated to isolate the wet well and pumps from the force m	Clean Water
			$ 448,726,000		

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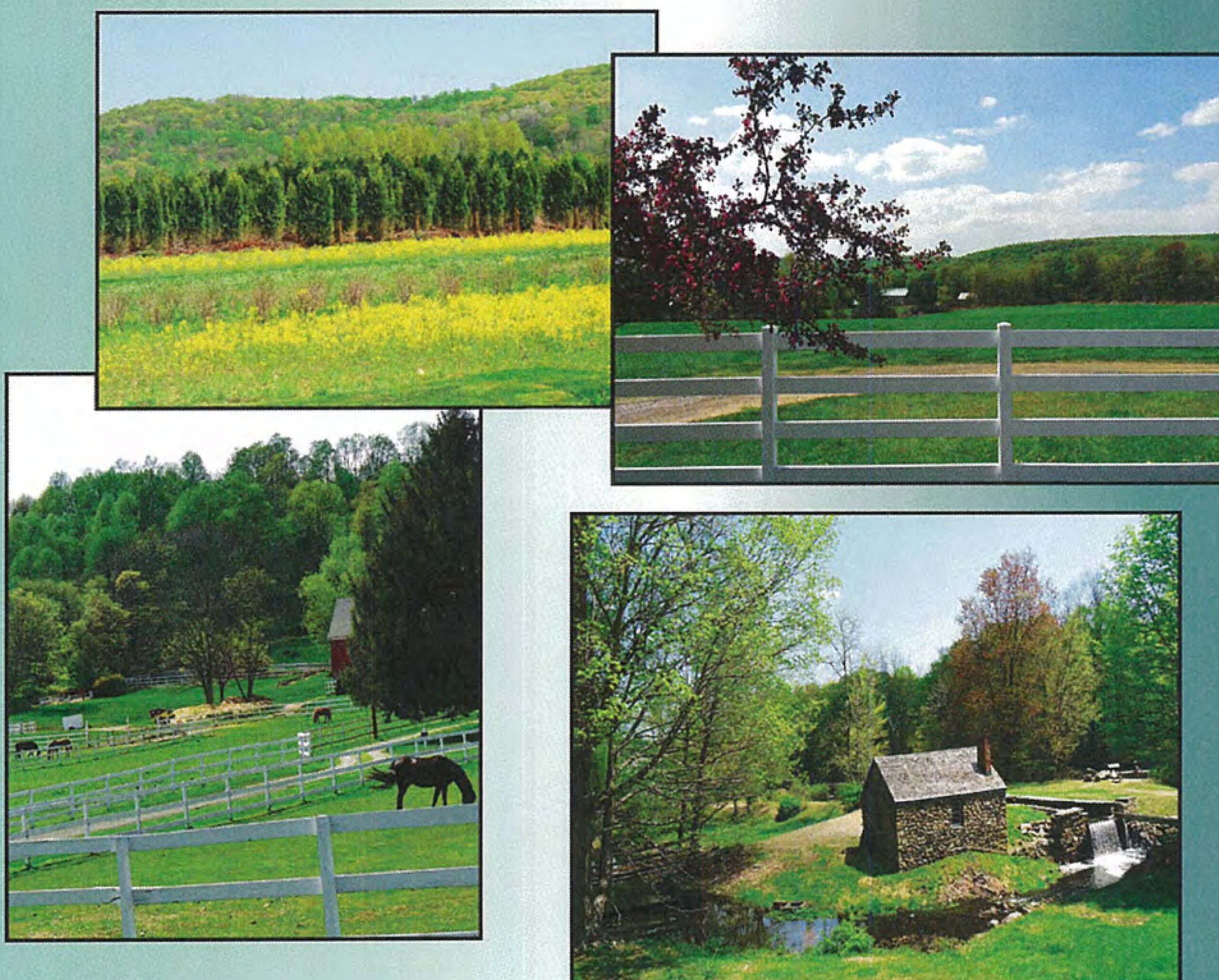
Prepared in cooperation with the
New Jersey Department of Environmental Protection

Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics



Scientific Investigations Report 2015–5075
Version 1.1, August 2015

U.S. Department of the Interior
U.S. Geological Survey

Cover: All photos provided by Ronald J. Baker, U.S. Geological Survey. Upper left, upper right, lower left, show farms in Long Valley, N.J., and lower right a mill in historic Waterloo Village Park, Stanhope, N.J.

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Median Nitrate Concentrations in Ground-water in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics

By Ronald J. Baker, Mary M. Chepiga, and Stephen J. Cauller

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Contents

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Figures

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Tables

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Conversion Factors, Datums

Inch/Pound

Multiply	By	To obtain
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

ANOVA	Analysis of variance
EPA	U.S. Environmental Protection Agency
GPS	Global positioning system
MCL	Maximum contaminant level
MDL	Minimum detection limit
MLE	Maximum likelihood estimate
NJDEP	New Jersey Department of Environmental Protection
NWIS	National Water Information System
PWTA	Private Well Testing Act
USGS	U.S. Geological Survey

Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics

By Ronald J. Baker, Mary M. Chepiga, and Stephen J. Cauller

Abstract

Nitrate-concentration data are used in conjunction with land-use and land-cover data to estimate median nitrate concentrations in groundwater underlying the New Jersey (NJ) Highlands Region. Sources of data on nitrate in 19,670 groundwater samples are from the U.S. Geological Survey (USGS) National Water Information System (NWIS) and the NJ Private Well Testing Act (PWTA).

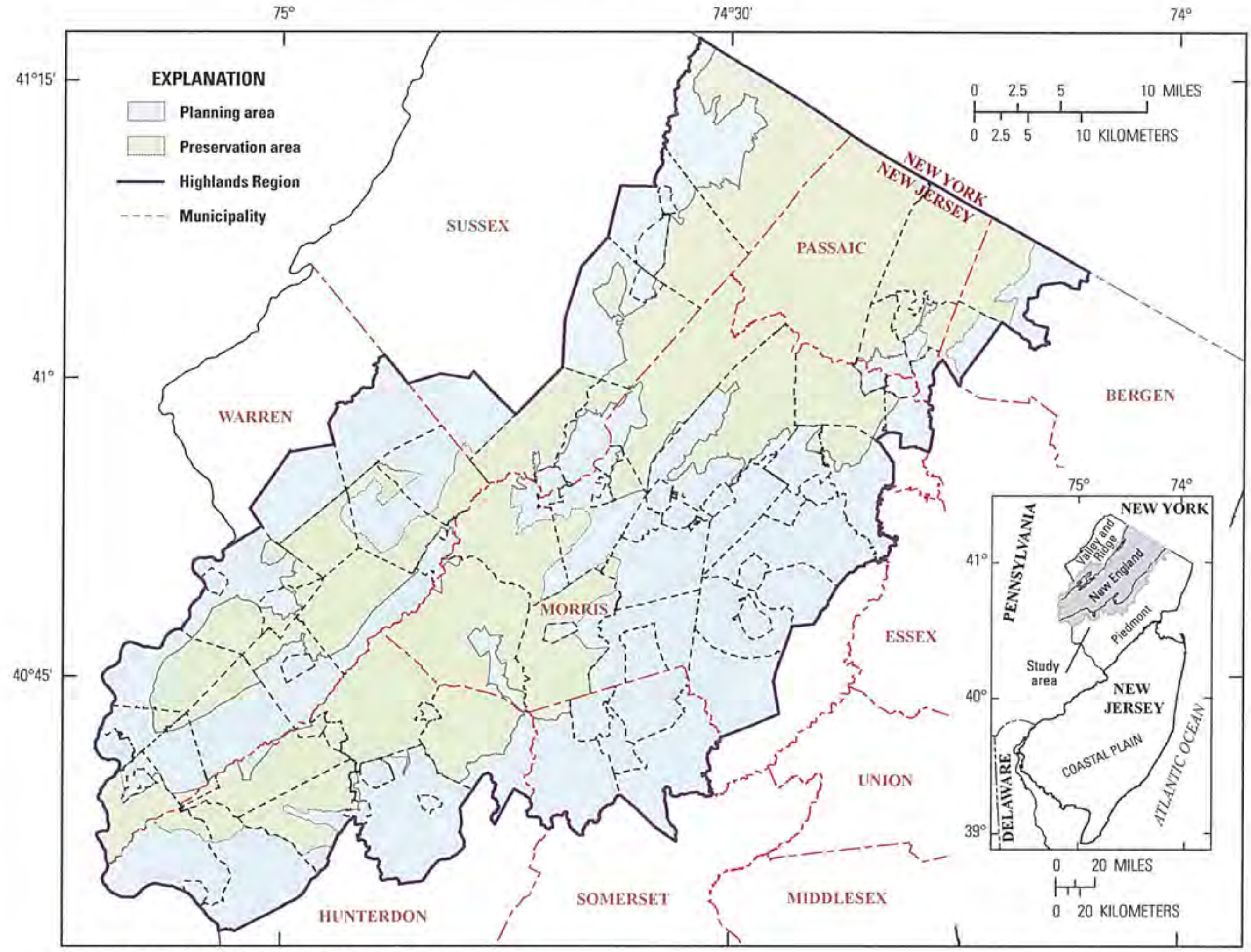
In a study conducted by the USGS, in cooperation with the New Jersey Department of Environmental Protection, logistic regression was used to relate measured nitrate concentrations to five explanatory variables (percent urban and agricultural land use, septic-system density, total length of streams, and number of known contaminated sites) quantified in 610-meter-square grid cells). A method for calculating the median concentrations of nitrate from a series of logistic regression models was developed. Two calibration and two validation procedures showed that the logistic-regression-based method can estimate groundwater-nitrate concentrations in the Highlands Region accurately to within 0.1 milligram per liter as nitrogen (mg/L as N). Limitations of the logistic-regression-based method include the inability to select a logistic model with exactly 0.5 probability of exceeding the threshold value and lack of an algorithm to directly calculate the median value. Quantile regression was evaluated as a suitable alternative and was slightly less accurate than the logistic-regression method in estimating median groundwater nitrate concentrations in the Highlands Region.

Multiple-linear regression with log-transformed nitrate-concentration data and the same five explanatory values was less accurate than either logistic or quantile regression in estimating median nitrate concentrations. On the basis of 4,516 2000 x 2000 foot grid cells that contain wells with data stored in NWIS and the PWTA database, the estimated median nitrate concentration for the entire Highlands Region is about 1.25 mg/L as N, and estimated median concentrations range from about 1.05 to 1.78 mg/L as N among 11 smaller administratively defined areas within the Highlands Region that vary in percentages of urban land use, agricultural land use, and septic-system density.

The Kaplan-Meier method of estimating summary statistics from left-censored data was applied in order to include nondetects (left-censored data) in median nitrate-concentration calculations. Median concentrations also were determined using three alternative methods of handling nondetects. Treatment of the 23 percent of samples that were nondetects had little effect on estimated median nitrate concentrations because method detection limits were mostly less than median values.

Introduction

Monitoring and assessment of groundwater quality is important for the management of groundwater resources from a public health and an ecological perspective. Groundwater quality and anticipated water-quality changes in the New Jersey (NJ) Highlands Region, which is distinct from but overlaps much of the Highlands Physiographic Province (fig. 1), are used by government agencies as regulatory criteria for land-use decisions. Nitrate (NO_3) concentrations are used as an indicator of overall water quality (New Jersey Highlands Water Protection and Planning Council, 2008) One objective of the Highlands Regional Master Plan is "to determine the amount and type of human development and activity which the ecosystem of the Highlands Region can sustain." This objective has zoning and building-restriction implications. The first step in observing changes in groundwater nitrate concentrations is to characterize pre-regulatory (pre-2008) nitrate concentrations, which are used as a "baseline" for comparison with present (2014) and future nitrate concentrations. Although the groundwater nitrate concentration at a location (for example, a single house or public supply well) can be reliably determined by sampling and analyzing the well water, determining the central tendency and range of nitrate concentrations for an entire region such as the Highlands Region is problematic. Therefore, the U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of



Base modified from New Jersey Department of Environmental Protection digital data, 1:24,000 Universal Transverse Mercator projection, Zone 18, NAD83

Figure 1. New Jersey Highlands Region with Planning and Preservation Areas.

Environmental Protection, conducted a study to determine the best method for use in estimating nitrate concentrations in the Highlands Region.

The range of nitrate concentrations in groundwater in an area can be quantified by sampling water from a representative number of randomly distributed wells. The range, however, will be biased if the wells are not uniformly distributed throughout the study area. Public supply, industrial, agricultural, domestic, and observation wells used for groundwater sampling tend to be installed in land-use areas that are urban, suburban, and agricultural. Wells are less frequently installed in forested, barren, and wetlands areas. Previous investigations (Wakida and Lerner, 2005; Nolan and others, 1998; Dubrovsky and Hamilton, 2010) report that nitrate concentrations in groundwater in urbanized, industrialized, and agricultural areas are consistently greater than those in forested and wetland areas. Therefore, median nitrate concentrations determined in samples from wells in urban and other developed areas likely will be higher than the median nitrate concentrations in samples from wells in forested and wetlands areas. One remedy for such bias is to use data from a subset of wells that are uniformly distributed geographically. This would eliminate geographic bias at a cost of decreasing the data density, reducing confidence in the statistical analyses, and possibly introducing additional bias from the well-selection criteria. An alternative method to eliminate bias is to relate nitrate concentrations to explanatory variables such as land use, surface activities, soil characteristics, hydrology, and population, then use these relations to estimate nitrate concentrations for each area of interest. The alternative method was used in this study to estimate baseline groundwater median nitrate concentrations in the NJ Highlands Region and areas within the Highlands Region.

Regression models can be used to relate water-quality characteristics, such as nitrate concentrations, to independent (explanatory) variables, such as percentages of different land-use categories and septic-system density. Logistic-regression models typically are used to relate a set of explanatory variables to the probability of exceeding a threshold value of a water-quality characteristic (Greene and others, 2005; Huang and others, 2013; Tu, 2008; Eckhardt and Stackelberg., 1995; Nolan, 2001; Gardner and Vogel, 2005; Tesoriero and Voss, 2005; Gurdak and Qi, 2012. Typically, the threshold value is a concentration of interest, for example 2 milligrams per liter (mg/L) nitrate as nitrogen (N) in groundwater (Gardner and Vogel, 2005), which was suggested by Mueller and Helsel (1996) as a conservative value to indicate anthropogenic effects. For this study, rather than calculating the probability of exceeding a threshold value, the probability was set in advance (50%, which corresponds to the probability of exceeding the median value), and the logistic-regression model and corresponding threshold concentration (which is the median value) was then determined.

Quantile regression and multiple-linear regression (MLR) were tested as alternatives to the logistic-regression method for estimating median nitrate concentrations in the Highlands Region. Quantile regression (Kroenker and Hallock, 2001) is used to relate one or more independent variables to the value of one dependent variable that corresponds to specified quantiles of the range of dependent-variable values. Multiple linear regression (MLR) is commonly used to relate sets of explanatory variables to water-quality constituents (Helsel and Hirsch, 2002). For example, Sando and others (2014) relate log-transformed concentrations of water-quality constituents to time, streamflow, and season. MLR was similarly applied in this study. Median calculations based on logistic regression, quantile regression, and multiple-linear regression were all subjected to calibration checks and validation by comparing medians of lab-measured nitrate concentrations to calculated concentrations. The best estimates of median nitrate concentrations for the entire New Jersey Highlands Region and smaller administratively defined areas were then calculated.

Purpose and Scope

The purpose of this report is to present the methods used to quantify median groundwater nitrate concentrations in the NJ Highlands Region and to estimate median concentrations for the entire Highlands Region and for selected areas within the Highlands Region. Criteria for selecting explanatory variables and developing logistic-regression models are presented, and statistical tests used to evaluate the logistic regression models also are presented. Benefits and limitations of the methods used are described. Comparisons are made between measured and estimated median values. Nitrate concentrations were less than the method detection limit (MDL) in 23 percent of the groundwater samples tested. Nondetects are water samples in which the constituent of interest, in this case nitrate, was not detected. The Kaplan-Meier method of including nondetects (also referred to as left-censored data) was selected over three other methods (assigning nondetects a value of zero, one-half the MDL, and the MDL), though the estimated median nitrate concentrations determined using the other three nondect methods also are presented. The effect of applying each of these four methods on the estimated median nitrate concentrations is described. The estimated median nitrate concentrations were determined for the entire Highlands Region and selected areas within the Highlands Region, and these values can be used as baseline conditions for comparison with future concentrations as land use and other surface characteristics change over time.

Description of Study Area

New Jersey is divided into four physiographic provinces: the Coastal Plain, Piedmont, Highlands, and Valley and Ridge (Dalton, 2003). The Piedmont, Highlands, and Valley and Ridge consist mostly of a series of discontinuous, rounded ridges separated by deep, narrow valleys and occupy the northern one-third of the area of New Jersey. The NJ Highlands Physiographic Province is part of the Highlands that extends to Connecticut, New York, and Pennsylvania (U.S. Forest Service, 2014).

The NJ Highlands Region is an administratively (not geologically) defined area that overlaps, but is distinct from, the Highlands Physiographic Province. The New York-NJ Highlands Region was first delineated in a study by the U.S. Forest Service (USFS) (Michaels and others, 1992). The USFS described it as an area of national significance that largely consists of forests and farms but needing protection from encroaching urban sprawl. The Highlands Region was later expanded to include areas of Pennsylvania and Connecticut. The NJ Highlands Region encompasses 2,505 square kilometers (km^2) of the Highlands Physiographic Province and also includes 654 km^2 of the Piedmont and 316 km^2 of the Valley and Ridge Physiographic Provinces. The Highlands Region covers 3,474 km^2 and includes parts of Hunterdon, Somerset, Sussex, Warren, Morris, Passaic and Bergen Counties (New Jersey Highlands Council, 2008). The protection of forests and wetlands, preservation of farmland, and permitting of additional urbanization in existing community areas are objectives of the NJ Highlands Water Protection and Planning Council. The Council was formed in 2004 as a provision of the Highlands Water Protection and Planning Act (N.J.S.A. 58:12A-26 et seq.; New Jersey Highlands Water Protection and Planning Council, 2008), which was primarily enacted to protect the drinking-water source for 5.4 million residences of New Jersey and New York. The NJ Highlands Region is divided into the Planning Area, administered by the New Jersey Highlands Council, in which conformance with the Regional Master Plan is voluntary; and the Preservation Area, administered by the New Jersey Department of Environmental Protection, in which conformance with the Regional Master Plan administered by the Highlands Council is mandatory. The Planning and Preservation Areas are each further divided into three Land-Use-Capability Zones: the Conservation Zone, Existing Community Zone, and Preservation Zone (fig. 2, table 1).

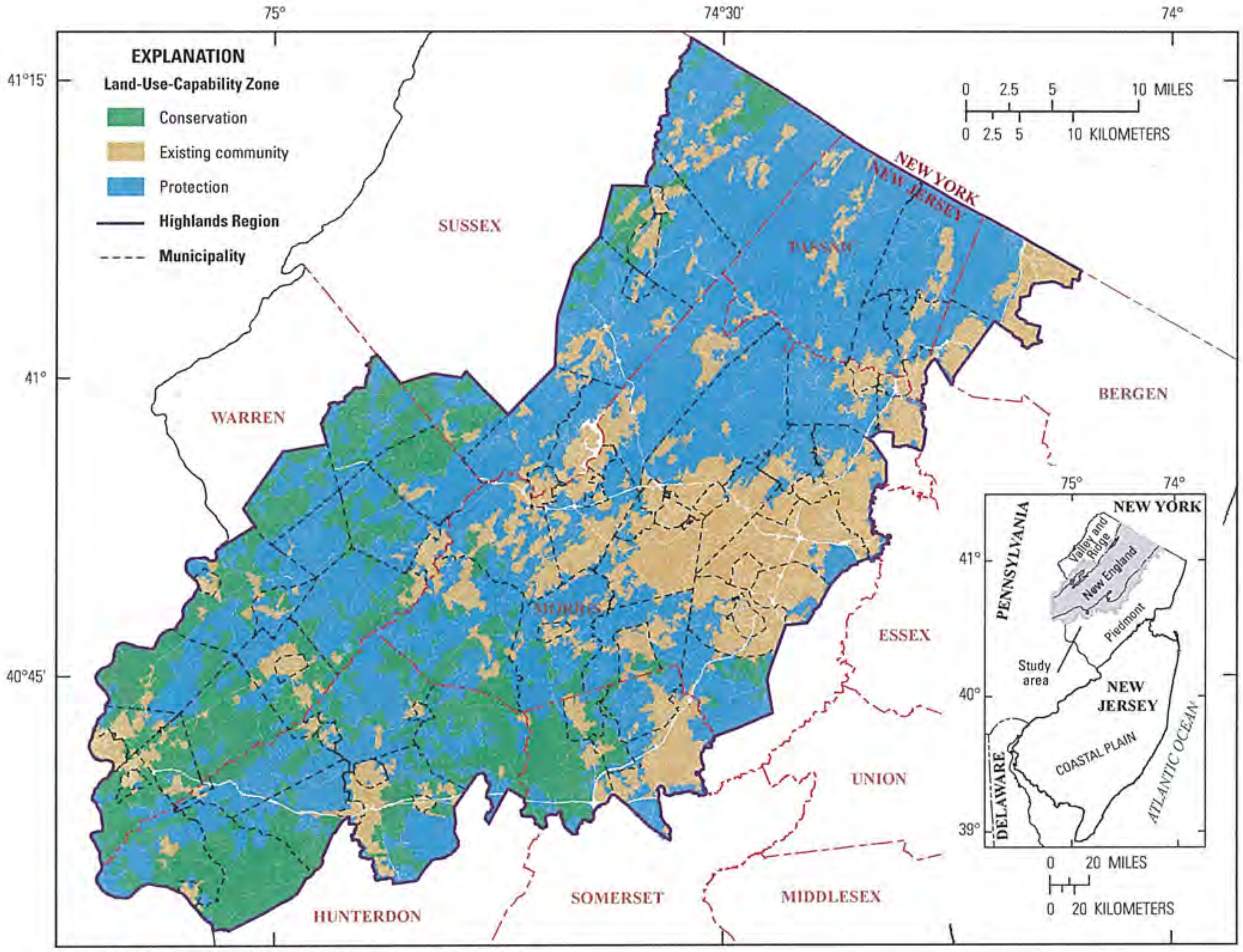


Figure 2. NJ Highlands Region with Land-Use Capability Zones.

Land use in the NJ Highlands Region, as determined from 2007 land use-land cover data (New Jersey Department of Environmental Protection (NJDEP) 2010), consists of about 44 percent of forest land; 12 percent of agricultural land; 26 percent of urban land; and 15 percent of barren, wetlands, and water (fig. 3). Percentages of the six major land-use categories in the Highlands Region vary by Planning Area and Preservation Area and among the three Land-Use-Capability Zones within each Area are shown in table 1.

The Preservation Area consists of 18,000 km^2, and the Planning area is slightly larger, about 19,000 km^2. There is more urban and agriculture land use in the Planning Area than in the Preservation Area (table 1). Urban expansion is limited in the Protection Zones and Conservation Zones. Urban expansion is allowed to a greater extent in the Existing Community Zones but only as is "compatible with the protection and character of the Highlands environment, at levels that are appropriate to maintain the character of established communities," as stated in the Master Plan (New Jersey Highlands Council, 2008). The Conservation Zone consists of highly agricultural land, and urban expansion is limited to protect the resources and character of this Zone (New Jersey Highlands Council, 2008). In the Preservation Area and Planning Area, forest and wetland land uses dominate the Protection Zone, agriculture dominates the Conservation Zone, and urban land use dominates the Existing Community Zone.

Previous Investigations

Previous investigations addressed nitrate in the study area and relations between land-use patterns and nitrate in groundwater. Agricultural and domestic fertilizers and septic systems are acknowledged as substantial sources of nitrate to groundwater (Nolan and others, 2002). Nicholson and others (1996) studied the hydrogeology, groundwater flow, and nitrates in the NJ Highlands. Glacial valley-fill, carbonate

Table 1. Land use in the NJ Highlands Region.

Area and zone	Land use, in percent[1,2]					
	Urban	Agricultural	Forest	Wetlands	Barren	Water
Entire NJ Highlands	27.0	12.3	45.6	10.3	2.1	2.7
Planning Area	37.8	16.9	33.0	11.3	1.0	3.6
Conservation Zone	15.89	44.48	27.46	10.32	0.74	1.11
Existing Community Zone	64.16	2.83	20.97	6.64	1.11	4.29
Protection Zone	22.98	6.54	49.54	15.77	0.92	4.25
Preservation Area	16.9	8.1	60.3	9.6	0.6	4.6
Conservation Zone	16.81	38.12	33.80	10.04	0.35	0.89
Existing Community Zone	54.64	3.56	28.00	7.04	0.77	5.99
Protection Zone	13.56	3.71	67.32	9.82	0.61	4.98
All grid cells with sampled wells	32.92	13.26	41.38	8.82	0.57	2.80
All grid cells with no sampled wells	21.75	11.47	49.61	11.08	0.93	4.89

[1]Calculated from New Jersey Department of Environmental Protection digital data (New Jersey Department of Environmental Protection, 2010)

[2]Percentages do not sum to 100 because of rounding.

rock, and gneissic rock aquifers were identified as the major sources of water. Human activities affected water resources by increasing the concentrations of volatile organic compounds, iron, and nitrate and in groundwater and surface water, and by consumptive use, resulting in decreasing discharge to streams and lower water tables. The maximum nitrate concentration in water samples collected from 73 wells completed in three aquifers was 9.5 milligrams per liter (mg/L) as nitrogen (N), with the highest nitrate concentrations in samples from present or previous agricultural areas and urbanized areas. The distribution of nitrate concentrations in forested and wetland areas indicate that background concentrations are less than 1 mg/L as N. Concentrations varied among three aquifers (table 2); glacial valley-fill aquifers had higher median concentrations of nitrate than carbonate and gneissic aquifers.

Serfes (1994) studied the natural groundwater quality in bedrock aquifers of the Newark Basin. The Newark Basin is synonymous with the Piedmont Physiographic Province and is adjacent to and southeast of the Highlands Physiographic Province. Nitrate concentrations in 55 well-water samples ranged from 0.1 to 7.4 mg/L as N with a median concentration of 1.6 mg/L as N.

Clawges and Vowinkel (1996) evaluated the roles of well construction, hydrogeology, and land use in the susceptibility of groundwater bedrock aquifers in the Newark Basin to nitrate contamination. Nitrate was the dominant form of nitrogen measured in samples from 132 wells. Nitrate concentrations ranged from less than 0.1 to 9.5 mg/L as N with a median concentration of 1.6 mg/L as N, similar to that in the Piedmont Physiographic Province (Serfes, 1994). Shallow wells and wells with shallow open intervals were associated with higher nitrate concentrations, indicating a greater effect from agriculture and urbanization. Groundwater nitrate concentrations were statistically lower in forested areas and wetlands than in agricultural and urban areas. The highest concentration measured was 9.5 mg/L as N in a groundwater sample from an agricultural area.

Serfes (2004) summarized the groundwater quality in the bedrock aquifers of the Highlands and Valley and Ridge Physiographic Provinces in New Jersey (fig. 1 inset) from 97 well-water samples collected from the Middle Proterozoic, Kittatinny Supergroup, and Martinsburg Formations. Nitrate concentrations ranged from less than (<) 0.05 to 5.7 mg/L as

Table 2. Statistical summary of nitrate in groundwater samples from the glacial valley-fill, carbonate-rock, and gneissic-rock aquifer systems in the NJ Highlands Region.

[mg/L, milligrams per liter; N, nitrogen; <, less than]

Aquifer type	Nitrate concentration (mg/L as N)[1]			
	Samples	Minimum	Median	Maximum
Glacial Valley-Fill	27	<0.10	1.40	6.10
Carbonate rock	30	<0.10	1.00	9.50
Gneissic rock	16	<0.10	0.38	2.00

[1] From Nicholson and others, 1996

17x

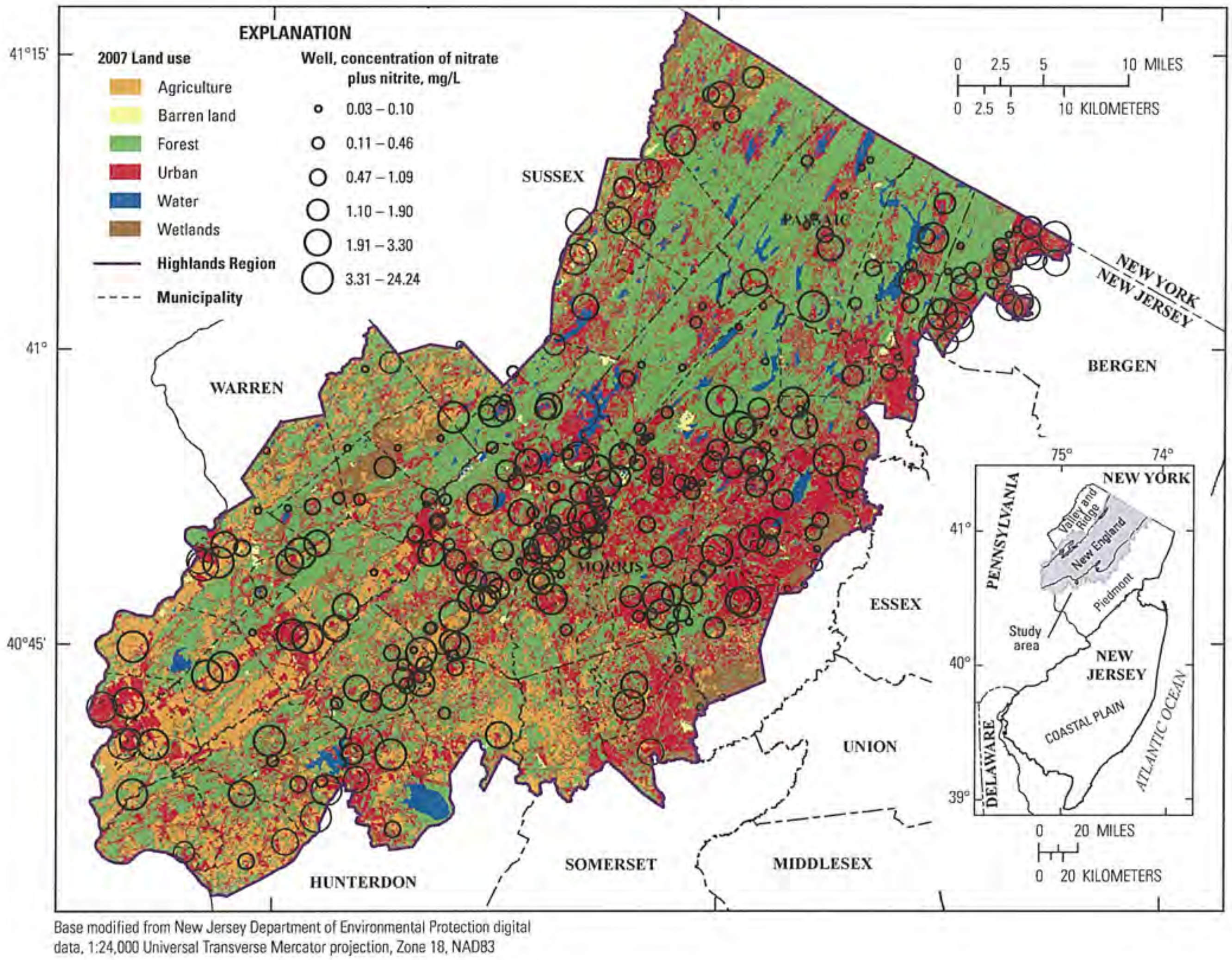


Figure 3. Land-use patterns, locations of wells with data in the U.S. Geological Survey National Water Information System, and nitrate concentrations in groundwater in the New Jersey Highlands Region. (mg/L, milligrams per liter)

N in these samples (table 3). The median nitrate concentration among the 97 samples was 0.41 mg/L as N.

Hoffman and Canace (2004) published a method to estimate nitrate concentrations in groundwater near septic systems and the average land area required to sufficiently dilute nitrate in septic-system effluent to avoid exceeding maximum nitrate concentration goals for potable water supply. The method is based on a mass-dilution model (Trela and Douglas, 1978) and a groundwater-recharge model (Charles and others, 1993). This method is currently (2015) used in the New Jersey Pinelands to protect groundwater resources by limiting the density of new urban construction.

Dubrovsky and others (2010) reviewed water-quality data from 1992 to 2004 for streams and groundwater throughout the United States. Nationally, nitrate concentrations in groundwater appear to be increasing slowly. Data from more than 5,000 wells showed that nitrate concentrations in groundwater in urban and agricultural areas are substantially greater than concentrations in forested and wetland areas and are greater than the estimated 1 mg/L as N that occurs as a natural background level. Among 495 wells that were sampled during 1993–2003, median nitrate concentrations increased from 3.2 to 3.4 mg/L as N, and the exceedance of the Federal and State health-based maximum contaminant level (MCL; 10 mg/L as N) increased from 16 to 21 percent.

18x

Table 3. Statistical summary of nitrate concentrations in groundwater samples from the Middle Proterozoic bedrock, Kittatinny Supergroup, and Martinsburg Formation in the Highlands and Valley and Ridge Physiographic Provinces in NJ.

[mg/L, milligrams per liter; N, nitrogen; <, less than]

Geologic Formation	Nitrate concentration (mg/L as N)[1]		
	Minimum	Median	Maximum
Middle Proterozoic (45 samples)	<0.10	0.76	5.7
Kittatinny Supergroup (26 samples)	<0.05	0.39	5.6
Martinsburg Formation (26 samples)	<0.05	0.16	5.3

[1]From Serfes, 2004

Method of Study

The method for determining the median nitrate concentration in groundwater of the NJ Highlands Region and Areas and Zones within the Highlands Region required the following steps:

1. Obtain available nitrate-concentration data from groundwater samples from the NJ Highlands Region.
2. Develop a method of estimating the median value of a dependent variable from a series of logistic-regression relations and a set of explanatory (independent) variables. In this case, nitrate concentration is the dependent variable, and the independent variables are the land characteristics responsible for, or otherwise related to, nitrate concentrations.
3. Compile a comprehensive set of potential explanatory variables, which may be related to nitrate concentration, to be used in regression models.
4. Quantify the explanatory variables for areas surrounding wells for which nitrate data are available.
5. Identify an optimum set of explanatory variables for a series of logistic-regression equations based on threshold values that represent the range of measured nitrate concentrations in the NJ Highlands Region. Develop logistic-regression models.
6. Estimate median nitrate concentrations for the NJ Highlands Region and the Planning and Preservation Areas; Conservation, Existing Community, and Protection Zones; and each Area:Zone combination.
7. Evaluate logistic-regression model performance.
8. Compare median nitrate concentrations to concentrations obtained using quantile regression and multiple-linear regression.
9. Analyze the effects of using alternative methods that include nondetects in the model development and median nitrate calculations.

Nitrate-Concentration Data

Two independent sources of groundwater nitrate data were used for this study (table 4). The first dataset is a subset consisting of 782 wells in the Highlands Physiographic Province with data available from the USGS National Water Information System (NWIS) (http://waterdata.usgs.gov/nwis). The second dataset consists of 19,369 wells in the Highlands Physiographic Province with data available from the NJ Private Well Testing Act (PWTA; New Jersey Department of Environmental Protection, 2003).

National Water Information System Data

Wells in the NWIS database were installed for diverse purposes, including water supply, observation, and agriculture. The data are of exceptional quality because samples were analyzed by USGS laboratories and extensively reviewed. This dataset was used in a previous study to quantify median nitrate concentrations in the Highlands Region (New Jersey Highlands Council, 2008).

The 782 wells in the NWIS database sampled between 1983 and 2004 were evaluated to identify well clustering and to remove the wells with substantially overlapping 500-meter-radius buffers in order to avoid duplicate representation of areas (Barringer and others, 1990). A subset of 352 wells within the Highlands Region (fig. 3) was identified with minimum buffer overlapping, and nitrate data from this subset were used to identify the five explanatory variables used in all logistic models and for the initial estimates of median nitrate concentrations in Highlands groundwater (New Jersey Highlands Water Protection and Planning Council, 2008). Generally, NWIS wells are clustered in urban land-use areas. Water samples with the highest nitrate concentrations occurred mostly in areas dominated by urban and agricultural land use. Nitrate concentrations ranged from 0.03 to 24.2 mg/L as N with a median value of 0.98 mg/L as N, and 48 values (16 percent) were nondetects.

Circular well buffers are widely used in spatial groundwater-quality investigations. The 500-meter radius was selected on the basis of an evaluation by Koterba (1998), which stated that the best compromise for defining land-use characteristics around wells in a wide variety of hydrogeologic settings across the Nation would be a circular buffer with a 500-meter radius from the well. This was further supported by Johnson and Belitz (2009). In this investigation, it was assumed that the area within the 500-meter circular well buffer represents land use and surface characteristics, such as

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Table 4. Sources of data on nitrate in groundwater in the New Jersey Highlands Region.

[NWIS, U.S. Geological Survey (USGS) National Water Information System; PWTA, New Jersey Private Well Testing Act; mg/L, milligrams per liter; --, no information; <, less than; NO_3, nitrate; QA, quality assurance]

Data source:	NWIS	PWTA	NWIS and PWTA
Number of groundwater samples	300	19,369	19,669
Sampling dates	12/02/1983–06/23/2004	10/14/2001–01/20/2011	12/02/1983–01/20/2011
Nitrate concentration (mg/L)			
Minimum (mg/L)	<0.03	<0.02	<0.02
Median (mg/L)	0.94	1.79	1.80
Maximum (mg/L)	24.20	153	153
Analytical methods, QA	Multiple USGS methods, USGS sampling and QA	As specified by each analytical method	--
Total number of grid cells	9,745	9,745	9,745
Number of grid cells with NO_3 data	284	4,379	4,516

septic-system inputs and fertilizer application, that may affect the local groundwater quality.

Private Well Testing Act Data

The New Jersey PWTA, which became effective in September 2002, requires water-quality sampling of domestic wells at the time of the sale of a home (Atherholt, 2009; NJDEP, 2003). PWTA water-quality data and the global positioning system location data are compiled by the NJDEP. The PWTA data are extensive, but water samples are collected only from domestic supply wells. PWTA data do not contain the information available for NWIS wells, such as well depth and aquifer identification. The PWTA specified a list of 12 approved analytical methods for analysis of nitrate (table 5). All samples were analyzed by NJ State certified laboratories, which are required to follow quality assurance/quality control protocols specified by the published analytical methods. Analysis of variance (ANOVA) and graphical analysis showed no spatial bias in either analytical methods used to analyze PWTA samples or in the nitrate method detection limit (MDL).

PWTA data for 19,369 wells sampled during October 2002–January 2011 within the NJ Highlands Region boundary were used in this study. PWTA rules mandate a level of anonymity associated with well locations. NJDEP's method to obscure the well location is to create a grid of square cells that are 610 m (2,000 ft) per side. Wells in each grid cell are plotted at the center of each grid. Therefore, the location of each well was generalized to within plus or minus 431 m (1,414 ft.) of the actual location. The number of groundwater samples collected in each grid cell is shown on a map of the Highlands Region in fig. 4. As with NWIS wells, PWTA wells are clustered in urban land-use areas.

The grid of 610-m-square cells (total of 9,745 cells) was generated using GIS software for the NJ Highlands Region boundary, and a unique identifier was assigned to each grid cell (Grid ID). Nitrate concentrations from all well samples within a grid cell were compiled, and the median measured nitrate concentration was calculated where grid cells contained more than one well. Of the 9,745 cells that make up the area of the NJ Highlands Region and the 19,369 wells that were sampled, the PWTA dataset provided a median nitrate concentration for each of 4,379 grid cells and no data for 5,366 grid cells. Nitrate concentrations for all PWTA samples ranged from 0.02 to 153 mg/L as N, and the median concentration was 1.79 mg/L.

Combined NWIS and PWTS Data

The NWIS and PWTA water-quality datasets were combined to optimize the use of all available data, which provided measured nitrate concentrations in 4,516 grid cells, and 5,228 grid cells with no nitrate data. The number of samples per cell with nitrate data ranged from 1 to 114 with a median of 3 samples and an average of 4.3 samples. As with the separate NWIS and PWTA data, most sampled wells tended to be situated in areas with urban or agricultural land. The median nitrate concentration in each cell ranges from 0.027

Table 5. Approved methods for nitrate analysis of New Jersey Private Well Testing Act samples.

[EPA, U.S. Environmental Protection Agency; ASTM, American Society for Testing and Materials; Cd, cadmium; --, no information; mg/L, milligrams per liter; N, nitrogen]

Methodology	Typical MDL[1] (mg/L as N)	EPA method	ASTM method	Standard methods	Other methods	Number of samples
Automated Cd reduction	0.05	353.2	D3867-90A	4500-NO3-F	--	1,009
Ion chromatography	0.01	300.0	D4327-91	4110B	B-1011 (Millipore)	9,032
Ion selective electrode	0.14	--	--	4500-NO3-D	601 (ATI Orion)	3,000
Manual Cd reduction	0.01	--	D3867-90B	4500-NO3-E	--	0
Unspecified method	--	--	--	--	--	4,864
Flow Injection/Cd reduction	0.01	--	--	--	10-107-04-1A (Lachat)	977

[1]Method detection limits (MDL) vary among labs and over time in individual labs

to 26.2 mg/L as N with an overall median concentration of 1.50 mg/L as N.

Of the 19,670 PWTA and NWIS samples, 511 (3 percent) had concentrations greater than the State and Federal Maximum Contaminant Level (MCL) for nitrate of 10 mg/L as N. A total of 4,519 (23 percent) samples had concentrations less than the MDL, which ranged from 0.020 to 10.0 mg/L as N, and are categorized as nondetects. The MDL varied among samples because of differences among laboratories and analytical methods used.

Nondetect Data

Among the 23 percent of samples that were nondetects, a disproportionally large percentage occurred in forested land and wetlands. The Preservation Area had a higher percentage of nondetects (25.8 percent) than the Planning Area (19.9 percent). Similarly, the Protection Zone had a higher percentage (27.0 percent) than either the Conservation or Existing Community Zones (18.3 and 19.6 percent, respectively). This result is expected, as groundwater that is not affected by anthropogenic surface activities tends to have lower concentrations of nitrate and therefore more nondetects.

Methods of analyzing data that contain nondetects (left-censored data) include assigning a value such as zero, the MDL, or some fraction (such as one-half) of the MDL. These substitution methods, though prevalent in published literature, have no sound basis because no substituted value between zero and the MDL can be argued to be more valid than any other (Helsel, 2005). An alternative method is to conduct the data analysis without assigning specific values to nondetects, such as the Maximum Likelihood Estimate (MLE), where a distribution (known or assumed) is assigned to the data, and statistics based on that distribution, not on individual data, are calculated. The MLE was not used here to estimated median nitrate concentrations in grid cells because the method does not perform well for sample sizes less than 30, and few grid cells contain 30 or more sampled wells. The Kaplan-Meier method is recommended for estimating summary statistics for censored data (Helsel, 2005). It is nonparametric and therefore does not require information or assumptions about data distribution; also it has no minimum sample-size limitations. Therefore, this method was used to calculate the median nitrate concentration for each grid cell. Although it is the best choice for this dataset and analysis, the Kaplan-Meier method is not without limitation. In grid cells that provided a single value, and that value is a nondetect, the default median value was the MDL. This circumstance applied to 385 nitrate concentrations and affected 8.5 percent of grid cells with a single nitrate concentration value. Only 152 (3.3 percent) of those MDL values were greater than or equal to ($\geq$)0.5 mg/L as N, and only those could affect the median concentration in the entire Highlands Region, Planning and Preservation Land-Use-Capability Zone, or Area:Zone combination. Thus, for at least 96.7 percent of grid cells with nitrate data, either the Kaplan-Meier method was applied as designed or the method detection limit was substantially less than the estimated median nitrate concentration in the Highlands Region.

For comparison, median concentrations also were calculated with nondetects set to zero, one-half the MDL, or the MDL; these are discussed in the section "Four Methods of Including Nondetects." This gives the full range of variability in nitrate concentrations resulting from the choice of methods for handling nondetects.

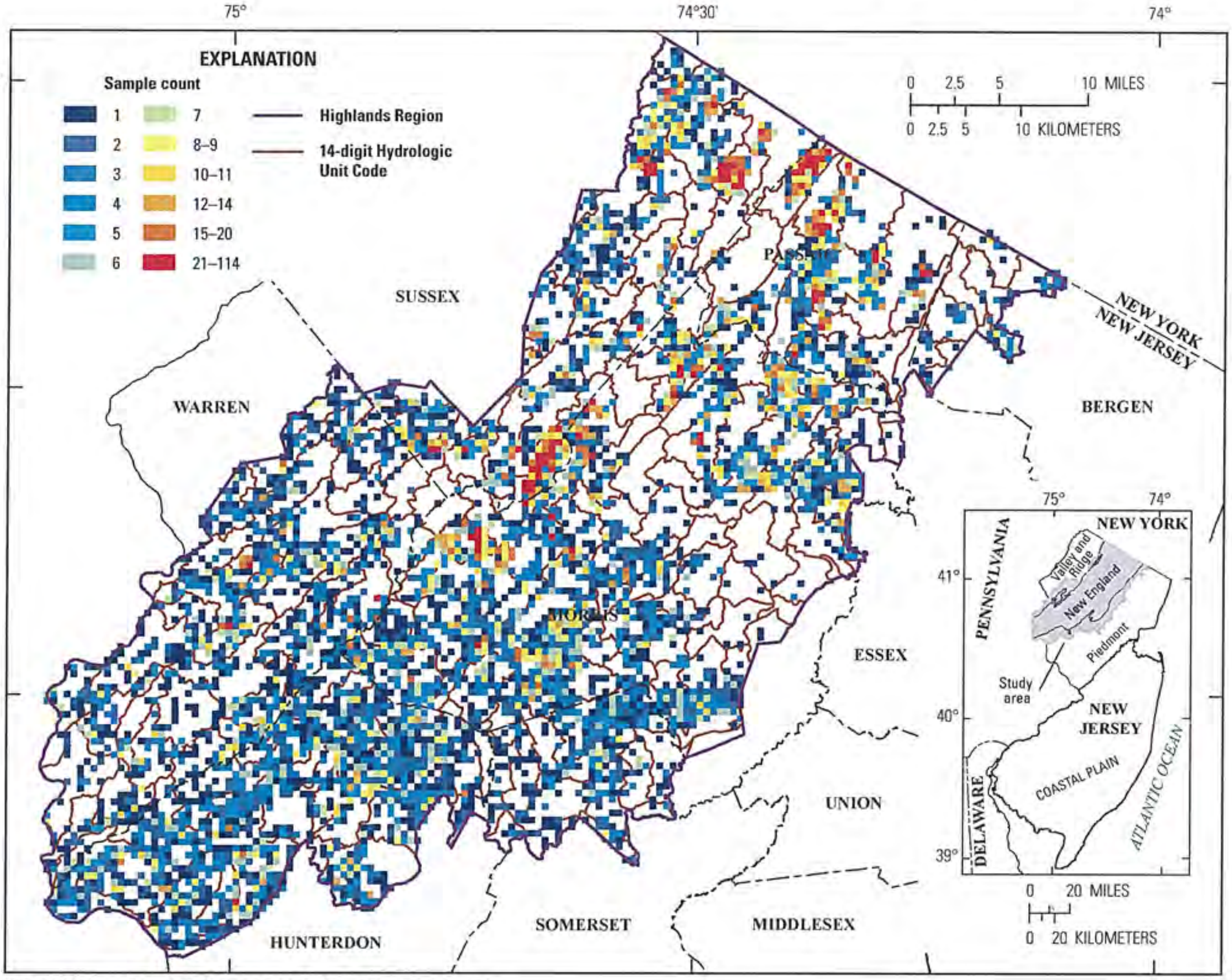

Figure 4. Numbers of groundwater samples collected in each model grid cell for the New Jersey Highlands Region. (Data from the U.S. Geological Survey National Water Information System database and the New Jersey Private Well Testing Act database)

Logistic Regression Model Development

The logistic model, as presented by Greene and others (2005), is of the form

$$p_i = P(Y = 1 \mid X_i) = \frac{\exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ..., + \beta_k x_{ik})}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ..., + \beta_k x_{ik})} \quad (1)$$

or (equivalently, the logit form)

$$\ln\left(\frac{p_i}{1 - p_i}\right) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ..., + \beta_k x_{ik} \quad , \quad (2)$$

where

- p_i is the probability of the binary response variable Y_i (which can only have values of 0 or 1) being equal to 1;
- β_0 is the intercept;
- $\beta_1 \ldots \beta_k$ are regression coefficients for each explanatory variable of the regression equation;
- $x_{i1}, x_{i2}, ..., x_{ik}$ are values of explanatory variables; and
- X_i refers to the set of values of all explanatory variables $(1, x_{i1}, x_{i2}, \ldots, x_{ik})$.

The quantity $\frac{p_i}{1 - p_i}$ is referred to as the "odds ratio" and is equivalent to $\frac{p(Y = 1)}{p(Y = 0)}$; it is used to express the probability that an event will occur. For example, if the

22x

probability of nitrate concentration in a water sample exceeding 2.0 mg/L as N is 0.25, then the odds ratio is $\frac{p(Y=1)=0.25}{p(Y=0)=0.75}$, or 1 to 3. Model coefficients and other parameters were calculated with an iterative maximum-likelihood algorithm by S-Plus (Insightful Corp., 2003). Input scripts for developing multiple logistic-regression models are shown in Appendix 1.

In this investigation, the binary variable Y represents the two cases: Y = 0 where the nitrate concentration of a water sample is less than a threshold concentration C_{Ti}, or Y = 1 where the concentration is greater than or equal to C_{Ti}. Thus, increasing the value of C_{Ti} would increase the probability that Y = 0.

Estimation of Median Nitrate Concentrations

The value of p_i obtained from a logistic-regression model represents a quantile of the range of possible values of the dependent variable. Thus, $p_i = 0.5$ at the 0.5 quantile, which is the median value, of the dependent variable (nitrate concentration). The condition where $p_i = 0.5$ can be expressed as

$$\ln\left(\frac{p_i}{1-p_i}\right) = \ln\left(\frac{0.5}{1-0.5}\right) = \ln(1) = 0$$
$$= \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots, + \beta_k x_{ik} \quad , \quad (3)$$

and the median value of the dependent variable is equal to the threshold value (C_{Ti}) of the logistic regression model shown in equation (3). This is the property of logistic regression that enables it to be used for estimating median values. The method applied here to estimate a median value is basically to identify two logistic models for which p_i is slightly greater than and slightly less than 0.5 and to assign the median value of the dependent variable by using an interpolation process described below.

The threshold value C_{Ti} for $p_i = 0.5$ is not directly calculable but can be selected from a series of logistic equations with a range of C_{Ti} values. In this investigation, logistic models with C_{Ti} = 0.05, 0.1, 0.15…1.0, 1.1, 1.2,…10.0 were developed (a total of 110 models). Ideally, a logistic model for which $p_i = 0.5$ would be identified, and the corresponding C_{Ti} value would be assigned as the median value. In practice, the set of C_{Ti} values is incremental and not continuous, and therefore, identifying the logistic model for which p_i = exactly 0.5 is unlikely. Linear interpolation was used to calculate between C_{T1} and C_{T2} of two logistic models M_1 and M_2 that have values of p_1 and p_2 which are nearest to 0.5, where p_1 is less than 0.5 and p_2 is greater than 0.5:

$$\text{Median } [NO_3 - N] = \frac{C_{T1}(p_2 - 0.5)}{(p_2 - p_1)} + \frac{C_{T2}(0.5 - p_1)}{(p_2 - p_1)} \quad . \quad (4)$$

Thus, the median nitrate concentration in groundwater underlying an area, such as that within a circular well buffer or grid cells, is determined from a set of explanatory variable values, and the two logistic regression equations from which the probability of exceeding the nitrate concentration is 0.5 are determined by interpolation. The median concentration over a larger area, such as the entire Highlands Region or an area within the Highlands Region is then calculated as the median of the median concentrations of all the smaller areas (well buffers or grid cells).

Explanatory Variables

A total of 320 geographic and environmental characteristics are potential explanatory variables (Appendix 2) related to median nitrate concentrations in groundwater and were compiled in a previous investigation (New Jersey Highlands Council, 2008). The variables include land-use/land-cover characteristics as defined by the Anderson system (Anderson and others 1976). Land-use data for 1986 (NJDEP, 1986), 1995 (NJDEP, 2001), 2002 (NJDEP, 2008), and 2007 (NJDEP, 2010) were used in this investigation so that median nitrate concentrations were evaluated with land-use patterns during similar time periods. Land-use characteristics included percentages of each land use within well buffers and distances between the well and the nearest land-use type. Anderson Level 1 land-use categories in New Jersey are urban, agricultural, rangeland, forest, water, wetlands, and barren land. Subcategories (Anderson Level 2) include mixtures of land use such as, but not limited to, urban/residential, urban/industrial, agricultural/cropland, and agricultural/confined feeding operations. Level 2 categories that are in the Highlands Region are included in the list of 320 potential explanatory variables. Other characteristics listed in Appendix 2 include soil properties, transportation (length and number of roads and railroads), population, hydrology, water-quality characteristics (concentrations of chemical species), and well depth.

To relate independent variables to median nitrate concentrations at individual wells, the value of each variable within an area surrounding the well was determined. This was done for wells in the NWIS database by calculating the value of each of the 320 variables within the 500-meter-radius circular buffer of each well. This was not done for the PTWA wells because the exact location of each well is unknown. The explanatory variables that are identified as the best predictors of median nitrate concentrations in water samples from wells in the NWIS database were then used to determine median nitrate concentrations in the grid cells.

The best predictor variables from the list of 320 geographic and environmental characteristics (Appendix 2) were identified by applying a step-wise regression procedure to obtain a series of five-variable models that best fit the measured nitrate concentrations in groundwater samples from the set of wells in the NWIS database, as described in the Highlands Regional Master Plan (New Jersey Highlands Council, 2008). First, Spearman's Rho nonparametric correlation coefficients (Spearman, 1904) were calculated using the value of each variable and nitrate concentration in each well. This procedure, previously used by Kolpin (1997), provided a nonparametric, univariate assessment of the regression relation between nitrate concentration and each potential explanatory variable. Next, univariate logistic regression relations were developed for each potential explanatory variable for C_{Ti} values of 0.1, 0.3, 1.0, 3.0, 5.0, and 10 mg/L as N. Potential variables that had significant Spearman's rho (>0.105 or <-0.105 for p = 0.05) or significant t values in one or more univariate logistic models (>1.96 for p = 0.05) were used in two-variable logistic models. The process was continued for 3-, 4-, and 5-variable models until all possible combinations of variables that were significant in the 4-variable models were used to generate a set of 5-variable models. Selection of the final set of five variables included numerical and subject criteria. Selection was based on the sum of all six t statistic values for the model (including the intercept), minimum of expected colinearity among variables, and maximum spatial representation of the variables. The sum of t statistic values provides an objective, numerical assessment of the overall significance of the logistic model. This metric varies, depending upon the value of the threshold nitrate concentration C_{Ti} associated with the regression equation. C_{Ti} is shown in relation to t value in fig. 5, where t for each of five explanatory variables varies as a function of C_{Ti}. Collinearity occurs between related variables, such as population and percent urban land use, or distance to nearest agriculture and percent agricultural land use. Models with two or more variables that are expected to be collinear were not considered in the selection of the final five variables. Where a choice between two similar or related variables had to be made, the variable with the greatest spatial representation was selected. For example, in selecting between percent urban residential and percent total urban land use, the total urban variable was selected. The final set of explanatory variables consists of urban land use, agricultural land use, septic-system density, total length of streams, and the number of known contaminated sites in the well buffer. The sum of t statistic values for these five variables was large for all six C_{Ti} values. Collinearity was expected to be minimal, and all five variables have greater than or equal spatial representation compared to related variables. This set of variables was used for all future logistic, quantile, and multiple-linear regression model development.

Spreadsheet Design for Estimating Median Nitrate Concentrations

A Microsoft Excel spreadsheet was used to calculate the median nitrate concentration for each area of interest (well buffer, grid cell, or Area:Zone combination). An example of the spreadsheet is shown as Appendix 1. The spreadsheet is arranged in five sections.

1. A list of 110 logistic regression models with model parameters (regression coefficients and intercept), t-statistic values, and standard errors, with documentation of data files used to develop the model.
2. Fields that contain information about the wells and buffer or grid cell. This includes location within Highlands areas and zones, grid or well identification number, lab-measured nitrate concentration (if applicable), and values of the five explanatory variables.
3. Fields in which the probability of exceeding the threshold nitrate concentration is calculated for each well or grid cell for each of the 110 logistic-regression relations.
4. Fields in which the results of (3) are used to estimate the median nitrate concentration for each well or grid cell on the basis of equations 3 and 4.
5. A field in which the overall estimated median nitrate concentration for the area of interest (entire Highlands Region or smaller area within the Highlands) is shown.

Methods Used to Evaluate Logistic Regression Models

Four methods were used to assess the statistical significance of explanatory variables and evaluate the logistic-regression models: the t statistic of each logistic-regression coefficient, which is equivalent to the Wald statistic as calculated by Hosmer and Lemeshow (2000); Press's Q; a test of the correlation between estimated and measured median nitrate; and a test of the overall accuracy of the method to estimate the median values of measured nitrate concentrations.

The t statistic is calculated as the ratio of the maximum likelihood estimate of the slope parameter to an estimate of its standard error:

$$t = W = \beta_i / (\text{standard error of } \beta_i) \quad , \qquad (5)$$

where

β_i represents the coefficient of explanatory variable i in the logistic-regression model.

The value of t for each variable indicates the significance of that variable. Variables with values of t for large samples (where the t distribution is indistinguishable from the standard normal distribution) of greater than 1.96 are significant at the 0.05 level and contribute significantly to the model.

Press's Q statistic is a function of the model's ability to correctly categorize data that were used to develop the model. The two categories are p>0.5 and p<0.5. A value, for example a lab-measured nitrate concentration, is correctly categorized where p>0.5 and the value is greater than the threshold value

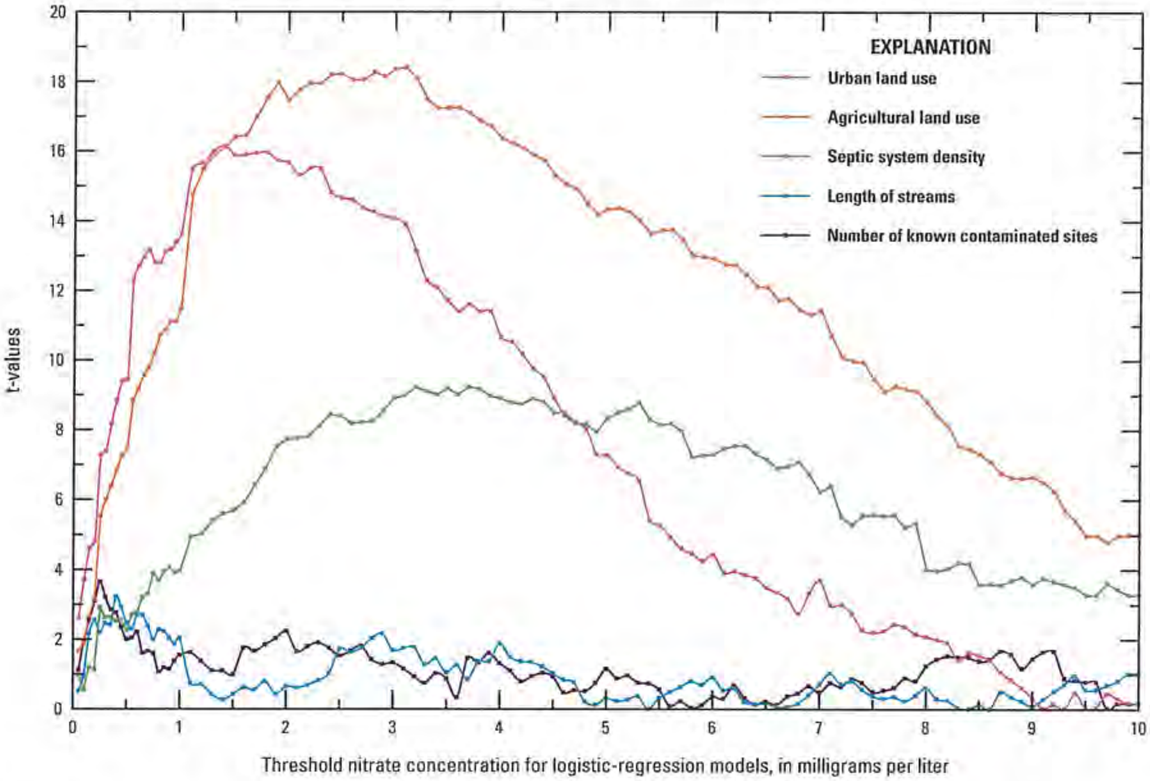

Figure 5. Values of the t statistic for five explanatory variables in logistic-regression equations for nitrate-threshold concentrations 0.05–10.0 milligrams per liter as nitrogen.

or $p<0.5$ and the value is less than the threshold value. The percent of correct classifications is used to calculate Press's Q:

$$Q = [N - (n*K)]\ \text{^}2/N*(K-1) \quad , \qquad (6)$$

where

N is sample size,
n is number of correct classifications, and
K is number of groups (2).

The correlation between deciles of estimated and measured nitrate concentrations also was applied on the basis of methods of Greene and others (2005) and Nolan (2001), where the relation between the calculated probability of exceeding a threshold value and the fraction of measured data that exceeded the threshold value for each quantile of calculated values was determined. Instead of probabilities, the estimated median nitrate concentrations for each quantile were compared to the median measured concentration for the same quantile. This provided an overall assessment of the method's ability to accurately estimate median values and information about the relative magnitude of error over a range of nitrate concentrations.

Two additional model diagnostics were used to evaluate and validate the logistic, quantile, and multiple-linear regression methods of calculating median nitrate concentrations. In the first, the median of measured concentrations was compared to the median concentration determined with the regression methods for the same set of grid cells (all of those with measured nitrate data) as a calibration check. In the second, model validation was conducted by developing regression models using data from half of the grid cells, calculating the median nitrate concentration of the other half with the regression methods, and comparing those estimates to the median of measured nitrate concentration values.

Median Nitrate Concentrations in Groundwater

Median values of lab-measured and estimated nitrate concentrations are discussed in this section (table 6). Medians of lab-measured nitrate concentrations were determined in two ways: as the median of all measured nitrate-concentration values in the combined NWIS-PWTA dataset, and as the median concentration at the grid-cell level. Median nitrate concentrations were determined for the entire Highlands Region, for the

Table 6. Measured and estimated nitrate concentrations in groundwater from the New Jersey Highlands Region.

[mg/L, milligrams per liter; N, nitrogen]

Area within the NJ Highlands	Median nitrate concentration (mg/L as N)		
	Median of measured concentrations		Estimated median concentrations for all grid cells
	Individual water samples	Grid-cell level[1]	
Entire Highlands Region	1.79	1.50	1.25
Planning Area	2.16	1.78	1.55
Preservation Area	1.42	1.25	1.08
Conservation Zone	2.17	2.02	1.76
Existing Community Zone	2.51	2.14	1.78
Protection Zone	1.28	1.10	1.07
Planning Area:Conservation Zone	2.40	2.15	1.78
Planning Area:Existing Community Zone	2.71	2.17	1.78
Planning Area:Protection Zone	1.50	1.27	1.19
Preservation Area:Conservation Zone	1.85	1.93	1.64
Preservation Area:Existing Community Zone	2.26	2.07	1.79
Preservation Area:Protection Zone	1.18	1.02	1.05

[1]For the models, the New Jersey Highlands Region is divided into a grid of 9,745 610-meter-square cells.

Planning and Preservation Areas, for each of the three Land-Use-Capability Zones, and for each Area:Zone combination.

Median of Measured Nitrate Concentrations in the NJ Highlands Region

The median measured nitrate concentration among all water samples in the combined NWIS-PWTA dataset was 1.79 mg/L as N, and concentrations in the 2 Areas, 3 Land-Use Capability Zones, and 6 Area:Zone combinations range from 1.18 to 2.71 mg/L as N (table 6). Concentrations were higher where agricultural or urban land use is more prevalent, such as the Conservation and Existing Community Zones, and lower where land use is predominantly forested land, such as the Protection Zone. There is spatial bias in well locations because many sampled wells are located in urban areas; thus, a bias in median nitrate concentrations was expected. Over-representation of urban and possibly agricultural areas and under-representation of forested areas in the combined NWIS-PWTA database must, therefore, result in higher median nitrate concentrations for all water samples than the actual median concentration for groundwater underlying the entire Highlands Region or any Area, Zone, or Area:Zone combination.

The median nitrate concentrations for the Highlands at the grid-cell level was 1.50, and concentrations in the 2 Areas, 3 Land-Use Capability Zones, and 6 Area:Zone combinations range from 1.02 to 2.17 mg/L as N (table 6). Spatial bias in well locations was reduced by calculating a single nitrate concentration for each grid cell, then calculating the median concentration at the grid-cell level. Each grid cell that contained wells in the combined NWIS-PWTA database received equal

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weight in all calculations. The remaining spatial bias is caused by the lack of nitrate data for about one-half the grid cells; those grid cells tended to have a larger percentage of forested land use (table 1). Therefore, although median concentration at the grid-cell level are subject to less spatial bias than those calculated from individual nitrate concentrations, some spatial bias remains and leads to over-estimation of median nitrate concentrations.

Median of Estimated Nitrate Concentrations

The estimated median nitrate concentration for all grid cells in the entire Highlands Region estimated using the logistic-regression method is 1.25 mg/L as N, and estimated median concentrations range from 1.05 to 1.79 mg/L as N among the Area, Zone, and Area:Zone combinations (table 6). Spatial distribution of estimated nitrate concentrations is shown on a map of the Highlands Region (fig. 6). A comparison of figs. 3 and 6 shows that forested areas correspond to lower median nitrate concentrations, and urban areas correspond to higher median concentrations. Estimated median nitrate concentrations are lower for the entire Highlands Region than the median of measured nitrate concentrations at the individual-sample and grid-cell scales (table 6). This is consistent with lower nitrate concentrations occurring in groundwater underlying grid cells dominated by forested and wetland areas, which are under-represented in the database of nitrate concentrations. Median values of the five explanatory variables used in the logistic models are shown in table 7. Urban and agricultural land uses and septic-system density are greater in the grid cells with sampled wells than in those without. The non-random distribution of wells is apparent when considering that the average percentage of non-urban, non-agricultural land in areas with sampled wells is nearly 15 percent greater than in areas without sampled wells, and there are on average 41 percent more septic systems per unit area in areas with sampled wells than in areas without sampled wells. The average number of known contaminated sites is 21 percent greater in grid cells with sampled wells. It is clear, therefore, that a median nitrate concentration calculated directly from water-sample data would have over-estimated the nitrate concentration of the underlying groundwater for the entire Highlands Region or any Area or Zone.

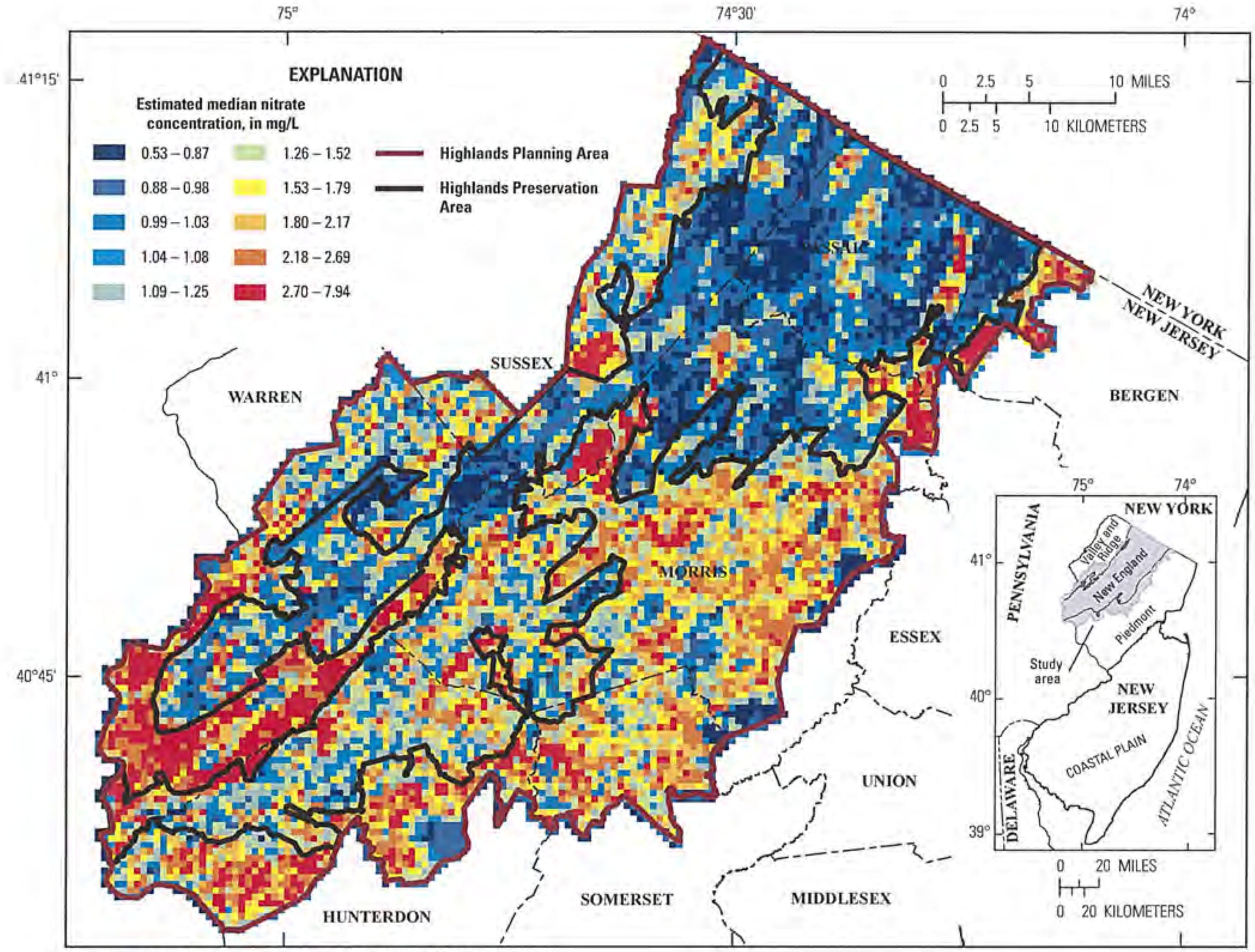
Fit and Validation of Logistic-Regression Models

Four tests demonstrated that the logistic-regression models generally contained significant explanatory variables, had significant predictive power, and can reliably estimate nitrate concentrations for grid cells in which no wells were sampled. Values of the t statistic for the five explanatory variables are shown in fig. 5. Urban and agricultural land use and septic-system density are the most significant variables over most of the range of threshold nitrate concentrations. The 5 variables decline in significance at the low and high extremes of the range of threshold values, though at least 3 variables are significant ($p=0.05$) for the nitrate threshold range of 0.1–8.3 mg/L as N. All five variables are significant for a nitrate-concentration threshold range of 0.25–0.60 mg/L as N, which includes a large portion of the measured nitrate concentrations. A case could be made for discarding the two weakest variables, known contaminated sites and total length of streams. However, these variables were significant at low concentration thresholds where land-use and septic-system-density variables were depressed. Using or not using the less-than-significant variables in the models has little effect on the calculated probability values, and therefore they were retained for the value they add to the models at the low range of the threshold values. Also, the same five explanatory variables were used in all logistic models so that probabilities among threshold values would be comparable.

Press's Q and the percent of correctly classified samples are shown in fig. 7. More than 60 percent of nitrate concentrations at the grid-cell level were correctly classified as greater than or less than the threshold value for the 110 logistic-regression models. Results of this statistical analysis are most meaningful where the median nitrate concentration is near the threshold value and random selection would result in 50 percent of values being incorrect. At the high and low extremes of values, a large fraction of values would be categorized incorrectly only if the model had no predictive power. This is not the case here (fig. 7) because greater than 90 percent of values were categorized correctly. Similarly, values of Press's Q (equation 6, fig. 7) are significantly greater than the critical value for logistic-regression models where the median nitrate concentration is near the threshold value. The "dip" in the curve (fig. 7) occurs because incorrectly expecting a calculated value to be above or below the threshold value is more likely to occur near the threshold value. The large values of Q reflect the large sample size for each model, which enables all models to accurately categorize samples as greater than or less than the critical value on the basis of the values of the explanatory variables.

Comparisons of Median Measured Nitrate Concentrations and Estimated Median Nitrate Concentrations

Two simulation scenarios were developed to assess the accuracy of the logistic regression method for estimating median nitrate concentrations of the entire Highlands Region and Areas and Zones within the Highlands Region (table 8). In scenario 1, the medians of lab-measured concentrations were compared to the estimated nitrate concentrations for 4,516 grid cells. The set of 110 logistic-regression equations were prepared from values of the five explanatory variables and the median of measured nitrate values for those 4,516 cells. The estimated (1.49 mg/L as N) and measured (1.50 mg/L as N) median concentrations were nearly identical.



Base modified from New Jersey Department of Environmental Protection digital data, 1:24,000 Universal Transverse Mercator projection, Zone 18, NAD83

Figure 6. Estimated median nitrate concentration in model grids for the New Jersey Highlands Region. (mg/L, milligrams per liter)

This complements the t (equivalent to the Wald) and Press's Q statistics, which indicate that the selection of explanatory variables was appropriate and that the results of the logistic-regression method are generally significant.

The median estimation method based on logistic regression was further tested by sorting the grid cells in Scenario 1 by estimated concentration (high to low) and dividing the population by 10 quantiles (deciles). The median of estimated nitrate values in each quantile (decile) was then compared to that of the lab-measured values (fig. 8). Median estimated concentrations in the quartiles ranged from 1.01 to 3.24 mg/L as N. The median of estimated nitrate concentrations for the tenth quantile (decile) (3.24 mg/L as N) was the most dissimilar from the median of measured values (3.58 mg/L as N) and was lower by 9.5 percent. The average deviation between quantile (decile) median nitrate concentrations on the basis of estimated versus lab-measured was 4.4 percent. This shows that medians of lab-measured nitrate concentrations were predicted with reasonable accuracy over the range of threshold concentrations.

Model validation was accomplished by developing the set of 110 logistic-regression models using only data associated with half of the grid cells and using those models to estimate median nitrate concentrations for the remaining half of the grid cells, then comparing those median values to the corresponding median concentrations (Scenario 2). As shown in figure 9, the relation between the medians of estimated and lab-measured nitrate concentrations is similar to that for Scenario 1, although the deviation in the 10th decile was slightly higher (10.3 percent) as was the average deviation (5.4 percent).

Figures 8 and 9 show the error trend in the estimated values for Scenarios 1 and 2. Scenario 1 tested the capability of a set of logistic-regression equations to predict the nitrate

Table 7. Summary statistics for explanatory variables used in logistic-regression models to calculate median nitrate concentration in groundwater from in the NJ Highlands Region.

	Grid cells[1] with sampled wells[2]	Grid cells with no sampled wells
Percent urban land use[3]		
Minimum	0	0
Mean	32.9	20.2
Median	27.9	6.6
Maximum	100	100
Percent agricultural land use		
Minimum	0	0
Mean	13.2	11.5
Median	2.3	0
Maximum	97.1	100
Total length of streams		
Minimum	0	0
Mean	1,613	1,628
Median	1,263	1,172
Maximum	13,707	12,942
Septic-system density		
Minimum	0	0
Mean	41.6	29.5
Median	24.2	18.3
Maximum	843	669
Number of known contaminated sites		
Minimum	0	0
Mean	0.17	0.14
Median	0	0
Maximum	7	9

[1]The Highlands Region is divided into a grid of 9,745 610-meter-square cells.

[2]Wells with results inventoried in U.S. Geological Survey National Water Information System or sampled as a requirement of the New Jersey Private Well Testing Act.

[3]Calculated from NJ Department of Environmental Protection digital data (NJ Department of Environmental Protection, 2010).

concentrations at various quantiles, including quartiles for the data used in developing the logistic equations. Scenario 2 was a more realistic test in which median-nitrate-concentration and land-use data from half the grid cells were used to predict the median concentrations in the other half. The analysis of error in the estimated nitrate concentrations (figs. 10 and 11) shows that most estimates were accurate within 10 percent and that the interquartile range of concentrations was estimated accurately. The first and third quantile errors of the estimate for Scenario 2 were 8.3 and 5.5 percent, respectively. The largest errors occurred for the 5th and 10th percentiles (nearly 30% in Scenario 2), indicating that there is greater error, in terms of percent, in the lower concentrations than in the higher concentrations.

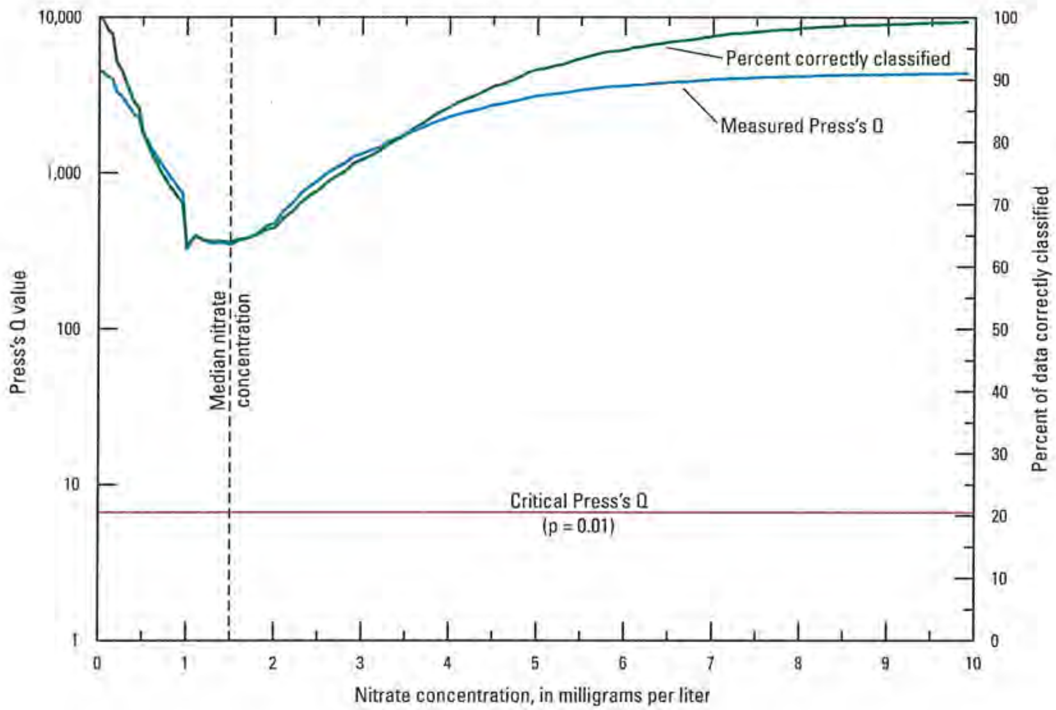


Figure 7. Values of the Press's Q statistic for logistic-regression models with nitrate-threshold concentrations of 0.05–10.0 milligrams per liter of nitrate as nitrogen.

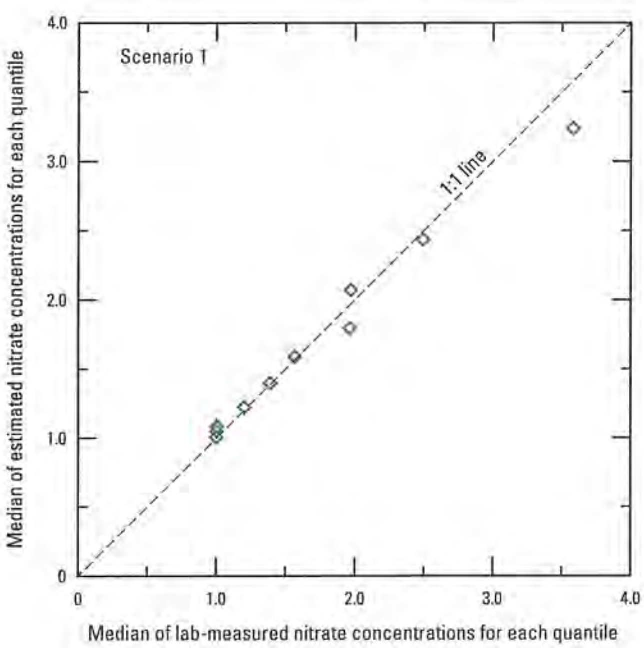


Figure 8. Median measured nitrate concentration in relation to estimated median nitrate concentration for each of 10 quantiles in Scenario 1, in milligrams per liter as nitrogen.

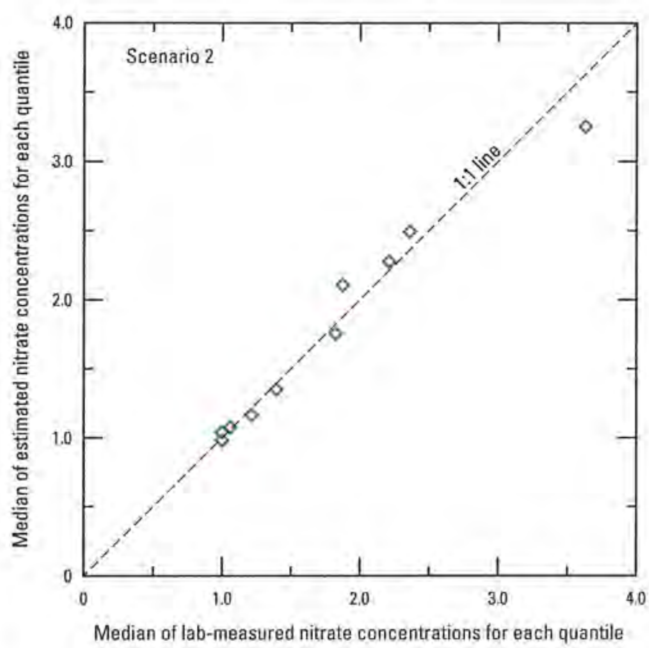


Figure 9. Median measured nitrate concentration in relation to estimated median nitrate concentration for each of 10 quantiles in Scenario 2, in milligrams per liter as nitrogen.

.30x

Table 8. Simulation scenarios for logistic-regression model validation: comparisons between lab-measured and estimated median nitrate concentrations.

[mg/L, milligrams per liter; N, nitrogen]

Validation scenario number and description	Number of grid cells[1]	Median of lab-measured nitrate concentrations (mg/L as N)	Median of estimated nitrate concentrations (mg/L as N)	Percent difference
1. Comparison between medians of lab-measured and estimated nitrate concentrations for the same set of grid cells	4,516	1.50	1.49	0.7
2. Comparison between medians of lab-measured and estimated nitrate concentrations for the same set of grid cells sorted by Highlands Administrative Area and Land-Use Capability Zone[2]				
a. Planning Area	2,300	1.78	1.75	1.7
Conservation Zone	732	2.14	2.04	4.7
Existing Community Zone	759	2.17	2.10	3.0
Protection Zone	809	1.28	1.28	0.0
b. Preservation Area	2,152	1.25	1.25	0.0
Conservation Zone	336	1.90	1.88	1.1
Existing Community Zone	275	2.07	1.95	5.8
Protection Zone	1,541	1.05	1.09	3.8
3. Comparison between median of lab-measured values in 2,258 randomly selected grid cells and estimated values for the remaining cells that have sampled wells	2,258	1.50	1.45	3.3

[1]The Highlands Region is divided into a grid of 9,745 610-meter-square grid cells. Median groundwater-nitrate concentration, land use, and other variables used in logistic regression models are calculated for each grid cell.

[2]The NJ Highlands Region is divided into the Planning Area, administered by the New Jersey Highlands Council, in which conformance with the Regional Master Plan is voluntary; and the Preservation Area, administered by the New Jersey Department of Environmental Protection, in which conformance with the Regional Master Plan administered by the Highlands Council is mandatory.

Comparison among Estimated Median Nitrate Concentrations Obtained with Logistic, Quantile, and Multiple-Linear Regression Methods

Estimated median nitrate concentrations for the Highlands Region, Planning and Preservation Areas, Land-Use-Capability Zones, and Area:Zone combination determined by logistic, quantile, and multiple-linear regressions are shown in table 9. Although validation results showed that the logistic-regression method was able to estimate median nitrate concentrations slightly more accurately than quantile regression and substantially more accurately than MLR, median concentrations determined using the three methods were similar. The average difference between medians determined with logistic and quantile regressions was less than 0.1 mg/L as N, and the average difference between medians from logistic regression and MLR was 0.15 mg/L as N. As these are all regression methods based on minimizing residual error and all were developed using the same five explanatory variables and nitrate data, similarity among the resulting estimated median nitrate concentrations is not surprising. All three methods effectively remove the spatial bias caused by systematically larger percentages of urban land use and higher septic-system density in grid cells that contain NWIS and PWTA wells. The decision about which regression method to select rests on whether a higher priority is placed on the use of a well-established, proven, accepted method (quantile regression or MLR) that is slightly less accurate according to validation results or the unconventional use of logistic regression with slightly more accurate estimates.

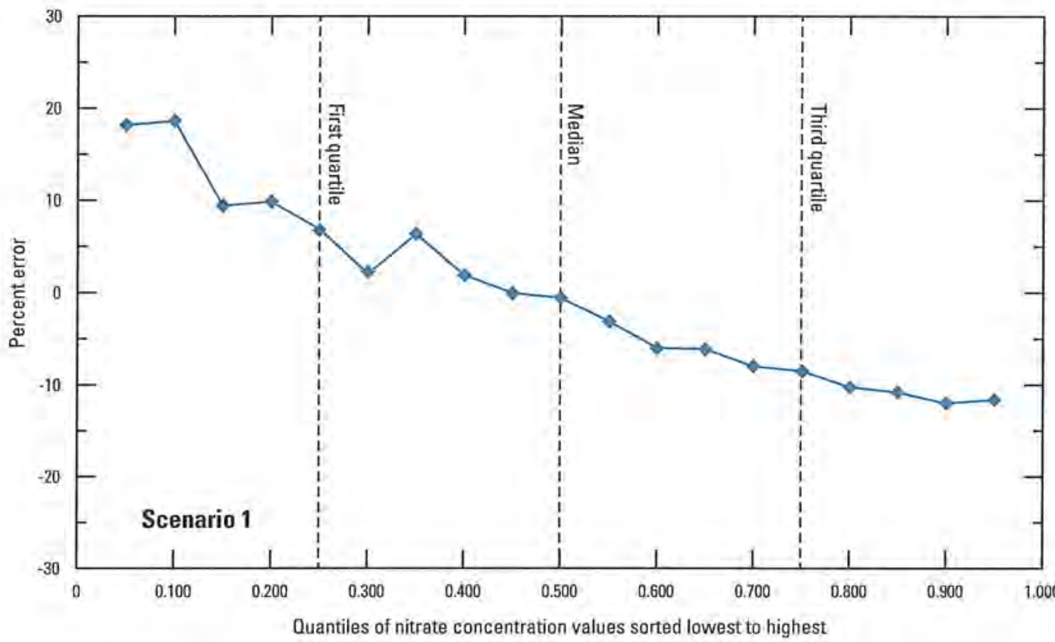


Figure 10. Percent error in estimates of quantiles of nitrate concentration in Scenario 1.

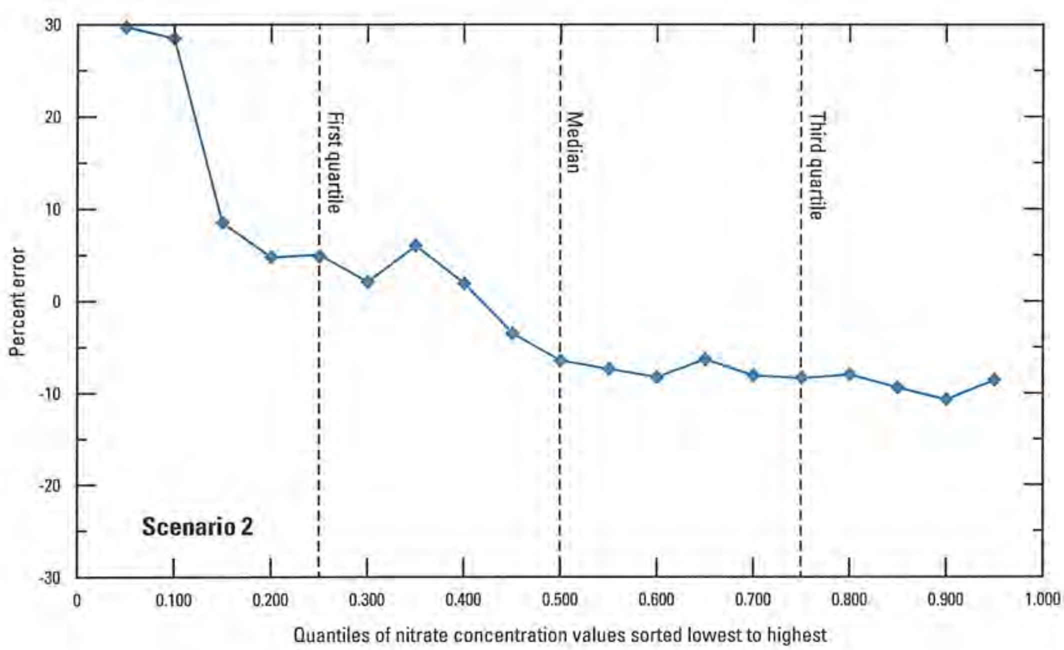


Figure 11. Percent error in estimates of quantiles of nitrate concentration in Scenario 2.

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Table 9. Estimated median nitrate concentrations based on logistic regression, quantile regression, and multiple-linear regression models of the NJ Highlands Region.

[mg/L, milligrams per liter; N, Nitrogen; NJ, New Jersey]

Area within the NJ Highlands	Estimated median nitrate concentrations (mg/L as N) assigned to nondetect samples		
	Method of calculating the median value		
	Logistic regression	Quantile regression	Multiple-linear regression
Entire Highlands Region	1.25	1.37	1.24
Planning Area	1.55	1.67	1.38
Preservation Area	1.08	1.08	1.12
Conservation Zone	1.76	1.94	1.52
Existing Community Zone	1.78	1.83	1.48
Protection	1.07	1.05	1.09
Planning Area:Conservation Zone	1.78	1.97	1.52
Planning Area:Existing Community Zone	1.78	1.83	1.47
Planning Area:Protection Zone	1.19	1.28	1.17
Preservation Area:Conservation Zone	1.64	1.87	1.49
Preservation Area:Existing Community Zone	1.79	1.84	1.50
Preservation Area:Protection Zone	1.05	0.96	1.05

Four Methods of Including Nondetects

The four methods that include nondetects in the median nitrate concentration calculations are (1) simple substitution of zero, (2) substitution of one-half the detection limit, (3) substitution of the detection limit, and (4) estimation based on the Kaplan-Meier method. Although substitution is discouraged in the statistical research literature (Helsel, 2005), there is historical precedent and some conditions under which this approach is recommended (U.S. Environmental Protection Agency, 2009). Substituting zero may be appropriate in cases where nondetects represent an absence of the contaminant being measured. Substituting half the detection limit may be reasonable if it is assumed that the population of nondetects is uniformly distributed along the interval of zero and the detection limit. Substituting the detection limit is the most conservative approach, as it is known that (within the precision of the data-collection methods) the concentration does not exceed that value.

The variability in estimated median nitrate concentrations resulting from the four methods is shown in fig. 12 and table 10. The variability in the Planning Area for each Land-Use-Capability Zone is small. Variability in the Preservation Area, where nitrate concentrations are generally lower, is greater. This is because a greater portion of nitrate concentrations in grid cells are shifted from above the median to below the median when a smaller value is assigned to each nondetect, thus shifting the recalculated median lower to a greater extent. Thus, the median nitrate concentration in the Preservation Area is decreased by 0.11 mg/L as N when the assignment of nondetects is changed from the MDL to zero. This effect is increased when the areas are parsed into the three zones (fig. 12). The choice of nondetect assignment is unimportant for the Conservation Zone within the Planning Area but is significant for the Protection Zone in the Preservation Area where the estimated median nitrate concentration decreases by 0.26 mg/L as N when the nondetect assignment is similarly changed. Other sources of error, which include uncertainty about well location within grid cells and direction and flow rate of groundwater, changing land-use percentages over time, analytical precision, sampling procedures, and the selected set of explanatory variables can add substantially to the error in estimates of median nitrogen concentration.

In summary, the handling of nondetect values is important in estimating median nitrate concentrations where a large fraction of values are nondetects or where the MDL is greater than the median value but has little effect where only a small fraction of values are nondetects or where the MDL is substantially less than the median value. For estimating the median nitrate concentration of groundwater in Highlands Region,

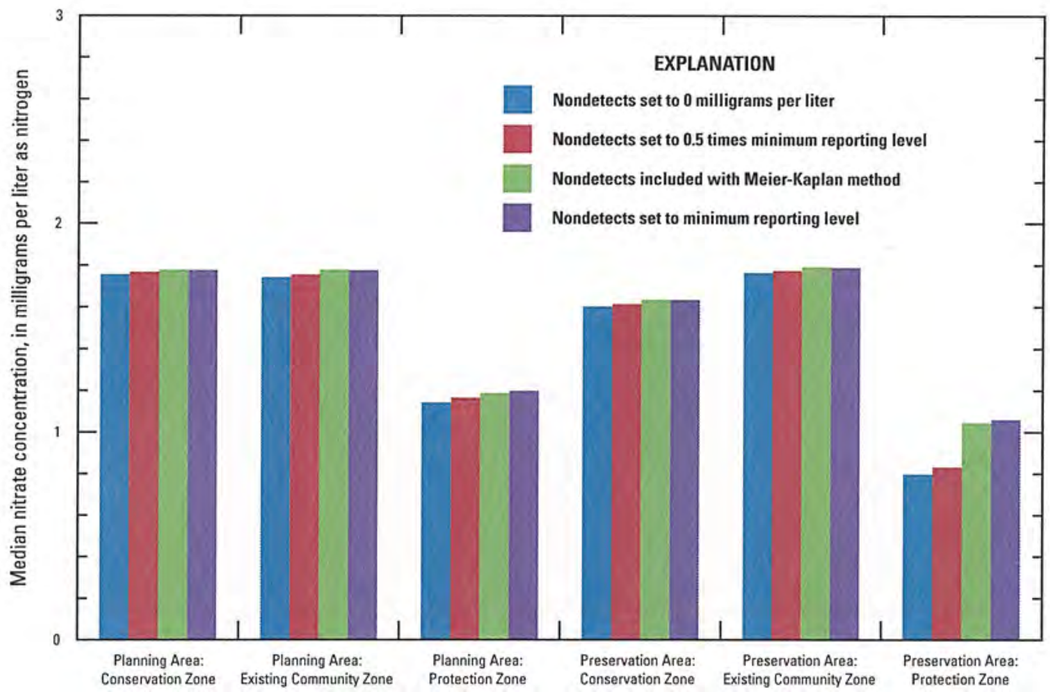

Figure 12. Median estimated groundwater-nitrate concentrations aggregated by grid cell for areas and Land-Use Capability Zones calculated with four methods of including nondetects.

Table 10. Estimated median nitrate concentrations based on logistic-regression models of the NJ Highlands Region calculated with four methods of assigning values to nondetects.

[mg/L, milligrams per liter; MDL, minimum detection limit; N, nitrogen; NJ, New Jersey]

Area within the NJ Highlands	Estimated median nitrate concentrations (mg/L as N)			
	Value assigned to nondetect			
	Zero[1]	0.5 x MDL[2]	Kaplan-Meier[3]	MDL[4]
Entire Highlands	1.21	1.23	1.25	1.25
Planning Area	1.52	1.53	1.55	1.55
Preservation Area	0.95	0.98	1.08	1.09
Conservation Zone	1.74	1.75	1.76	1.76
Existing Community Zone	1.75	1.76	1.78	1.78
Protection	0.89	0.93	1.07	1.08
Planning Area:Conservation Zone	1.76	1.77	1.78	1.78
Planning Area:Existing Community Zone	1.74	1.76	1.78	1.78
Planning Area:Protection Zone	1.14	1.17	1.19	1.20
Preservation Area:Conservation Zone	1.60	1.61	1.64	1.63
Preservation Area:Existing Community Zone	1.77	1.77	1.79	1.79
Preservation Area:Protection Zone	0.80	0.83	1.05	1.06

[1] Values of all nondetect samples set to zero.

[2] Values of all nondetect samples set to ½ the MDL.

[3] Kaplan-Meier method (Helsel, 2005) used to assign values to nondetect samples.

[4] Values of all nondetect samples set to the MDL.

the choice of method to include nondetects in the calculation makes a significant difference only for the Protection Zone within the Preservation Area. Assigning the MDL as the value for all nondetects would produce a "worst-case scenario" median concentration and likely would overstate the median nitrate concentration. Selecting either 0.5 x MDL or applying the Kaplan-Meier method would most likely increase the accuracy of the median estimate, but there is no justification for using 0.5 x MDL and no justification for assigning zero as the concentrations of nondetects. Therefore, Kaplan-Meier method remains the most reasonable choice for handling nondetects.

Summary and Conclusions

Nitrate-concentration data were used in conjunction with variables related to land use and land-surface characteristics to estimate median nitrate concentrations in groundwater underlying the New Jersey (NJ) Highlands Region in a study conducted by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection. Sources of nitrate data were the USGS National Water Information System (NWIS) and the New Jersey Private Well Testing Act (PWTA). Spearman's nonparametric correlation coefficient and a step-wise logistic-regression procedure were used to identify five independent (explanatory) variables that produce highly correlated logistic models that are based on a range of nitrate-concentration thresholds—0.1, .03, 1.0, 3.0, 5.0, and 10 milligrams per liter as nitrogen (mg/L as N). The explanatory variables that were found to be significant in logistic-regression models that used NWIS data are percent urban land use, agricultural land use, length of streams, septic-system density, and number of known contaminated sites. Each explanatory variable was quantified within 610-meter x 610-meter grid cells. A series of 110 logistic models with thresholds ranging from 0.05 to 10 mg/L as N were developed, and the probability of a nitrate concentration exceeding a designated threshold concentration in groundwater underlying a grid cell was calculated. For each grid cell, the median concentration was determined by identifying the two logistic models for which the probability of exceedance was nearest to 50 percent, and the corresponding thresholds were the two nitrate concentrations nearest to the median by definition. Linear interpolation was used to calculate the actual median nitrate concentration for each grid cell. A series of evaluation methods was applied to the logistic models. Twenty-three percent of the nitrate data were left-censored (included nondetect values), and the Kaplan-Meier method of including nondetects in the median calculation was applied to estimate the median nitrate concentration in each grid cell. Three additional methods of assigning values to nondetects were explored. Little difference in median nitrate concentration was noted for the Highlands Region and most areas within the Highlands Region regardless of which method was used to handle nondetects. Median nitrate concentrations within the Highlands Region correlated positively with percentages of urban land use, agricultural land use, and septic-system density. Model validation showed that the logistic-regression approach was able to accurately calculate median concentrations with a maximum error of less than 0.1 mg/L as N. Median estimated nitrate concentrations based on quantile regression were slightly less accurate, and those based on multiple-linear regression were substantially less accurate. Although logistic regression produced accurate estimates of median nitrate concentrations for the NJ Highlands Region, the more conventional quantile regression method would be the favored alternative for future similar studies over the somewhat cumbersome logistic-regression method used here. An additional benefit of quantile regression is that it generates an estimate of the value of the dependent variable (for example, nitrate concentration) for any quantile.

The estimated median nitrate concentration in groundwater in the NJ Highlands Region was 1.25 mg/L as N. The estimated median concentrations were highest in the Preservation Area/Existing Community Zone (1.79 mg/L as N) and lowest in the Preservation Area/Protection Zone (1.05 mg/L as N) using the logistic-regression method.

This application of logistic regression to determine the median value of a dependent variable requires a dataset sufficiently large to represent conditions in the area of study, logistic models that are appropriate for evaluating the phenomenon in question with closely spaced threshold values that bracket the range of expected values for the dependent variable, and explanatory variables that are significant across the range of threshold values. The large database provided by the New Jersey Private Well Testing Act coupled with extensive land-use data and other geo-referenced data was ideal for this application of logistic regression. With the spatial bias of well distribution removed, estimates of median nitrate concentration are more representative of the Highlands Region than are median nitrate concentrations for analyzed water samples.

References Cited

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 41 p.

Atherholt, T.B., Louis, J.B., Shevlin, J., Fell, K., Krietzman, S., 2009, The New Jersey Private Well Testing Act: An overview: New Jersey Department of Environmental Protection, Division of Science, Research and Technology, accessed October 31, 2014, at http://www.state.nj.us/dep/dsr/research/pwta-overview.pdf.

Barringer, T., Dunn, D., Battaglin, W., and Vowinkel, V., 1990, Problems and methods involved in relating land use to groundwater quality: Water Resources Bulletin, American Water Resources Association, v. 26, no. 1, 9 p.

Charles, E.G., Behroozi, Cyrus, Schooley, Jack, and Hoffman, J.L., 1993, A method for evaluating ground-water-recharge areas in New Jersey: Trenton, N.J., New Jersey Geological Survey Report GSR-32, 95 p.

Clawges, R.M., and Vowinkel, E.F., 1996, Variables indicating nitrate contamination in bedrock aquifers, Newark Basin, NJ: Journal of the American Water Resources Association, v. 32 no. 5, p. 1055–1066.

Dalton, 2003, Physiographic provinces of New Jersey: Trenton, N.J., New Jersey Geological Survey Circular, 2 p.

Dubrovsky, N.M., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton, P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., and Wilber, W.G., 2010, The quality of our nation's water—Nutrients in the nation's streams and groundwater, 1992–2004: U.S. Geological Survey Circular 1350, 176 p.

Dubrovsky, N.M., and Hamilton, P.A., 2010, Nutrients in the Nation's streams and groundwater: National findings and implications: U.S. Geological Survey Fact Sheet 2010–3078, 6 p.

Eckhardt, D.A.V., and Stackelberg, P.E., 1995, Relation of ground-water quality to land use on Long Island, New York: Ground Water, v. 33, p. 1019–1033.

Gardner, K.K., and Vogel, R.M., 2005, Predicting groundwater nitrate concentration from land use: Ground Water, v. 43, no. 3, p. 343–352.

Greene, E.A., LaMotte, A.E., and Cullinan, K., 2005, Groundwater vulnerability to nitrate contamination at multiple thresholds in the Mid-Atlantic Region using spatial probability methods: U.S. Geological Survey Scientific Investigation Report 2004–5118. 24 p.

Gurdak, J.J., and Qi., S.L., 2012, Vulnerability of recently recharged groundwater in principle aquifers of the United States to nitrate contamination: Environmental Science and Technology, v. 46, p. 6004–6012.

Helsel, D.R., 2005, Nondetects and data analysis: statistics for censored environmental data: Hoboken, N.J., Wiley-Interscience, 250 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources, *in* U.S. Geological Survey, Techniques of Water-Resources Investigations of the United States Geological Survey, Hydrologic analysis and interpretation, book 4, chap. A3.

Hoffman, J.L., and Canace, R.J., 2004, A recharge-based nitrate-dilution model for New Jersey: New Jersey Geological Survey Open File Report OFR 04–1, 27 p.

Hosmer, D.W., and Lemeshow, S., 2000, Applied logistic regression: Hoboken, N.J., Wiley-Interscience, 373 p.

Huang, J., Zhan, J., Yan, H., Wu, F., and Deng, X, 2013, Evaluation of the impacts of land use on water quality: A case study in the Chaohu Lake Basin: The Scientific World Journal, v. 2013, 7 p.

Insightful Corp., 2003, S-PLUS version 6.2: Seattle, Wash., USA.

Johnson, T.D., and Belitz, K., 2009, Assigning land use to supply wells for the statistical characterization of regional groundwater quality: Correlating urban land use and VOC occurrence: Journal of Hydrology, v. 370, p. 100–108.

Kolpin, D.W., 1997, Agricultural chemicals in groundwater of the Midwestern United States: Relations to land use: Environmental Science and Technology, v. 26, p. 1025–1037.

Koterba, M.T., 1998, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program-Collection, documentation, and compilation of required site, well, subsurface, and landscape data for wells: U.S. Geological Survey Water-Resources Investigations Report 98–4107, 91 p.

Koenker, R., and Hallock, K., 2001, Quantile regression: Journal of Economic Perspectives, v. 15, no. 4, p. 143–156.

Michaels, J.A., Neville, L.R., Edelman, D., Sullivan, T., and DiCola, L.A., 1992. New York–New Jersey Highlands Regional Study: Radnor, Pa., U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry, 130 p.

Mueller, D.K., and D.R. Helsel, 1996, Nutrients in the nations waters—too much of a good thing?: U.S. Geological Survey Circular 1136, 24 p.

New Jersey Department of Environmental Protection (NJDEP), 1986, 1986 Land use/land cover, accessed April 14, 2015, at http://www.nj.gov/dep/gis/lulcshp.html.

New Jersey Department of Environmental Protection (NJDEP), 2001, 1995/97 Land use/land cover by Watershed Management Area (WMA), accessed April 14, 2015, at http://www.state.nj.us/dep/gis/lulc95shp.html.

New Jersey Department of Environmental Protection (NJDEP), 2003, Private well testing act program electronic data deliverable manual: Trenton, N.J., Bureau of Safe Drinking Water, 70 p.

New Jersey Department of Environmental Protection (NJDEP), 2008, 2002 Land use/land cover by Watershed Management Area (WMA), accessed April 14, 2015, at http://www.state.nj.us/dep/gis/lulc02shp.html.

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New Jersey Department of Environmental Protection (NJDEP), 2010, NJDEP 2007 Land use/land cover update, accessed April 16, 2015, at http://www.state.nj.us/dep/gis/lulc07shp.html.

New Jersey Highlands Water Protection and Planning Council, 2008, Highlands Master Plan, Technical report: Water resources volume I, watersheds and water quality, p. 114–173, accessed April 16, 2015, at http://www.highlands.state.nj.us/njhighlands/master/tr_water_res_vol_1.pdf.

Nicholson, R.S., McAuley, S.D., Barringer, J.L., and Gordon, A.D., 1996, Hydrogeology of, and ground-water flow in, a valley-fill and carbonate rock aquifer system near Long Valley in the New Jersey Highlands: U.S. Geological Survey Water-Resources Investigation Report 93–4157, 159 p., 3 pl.

Nolan, B.T., 2001, Relating nitrogen sources and aquifer susceptibility to nitrate in shallow groundwaters of the United States: Ground Water, v. 39, no. 2, p. 290–299.

Nolan, B.T., Ruddy, B.C., Hitt, K.J., and Helsel, D.R., 1998, A national look at nitrate contamination in ground water: Water Conditioning and Purification, v. 39, no. 12, p. 76–79.

Nolan, B.T., Hitt, K.J., and Ruddy, B.C., 2002. Probability of nitrate contamination of recently recharged groundwaters in the conterminous United States: Environmental Science and Technology, v. 36, no. 10, p. 2138–2145.

Sando, S.K., Vecchia, A.V., Lorenz, D.L., and Barnhart, E.P., 2014, Water-quality trends for selected sampling sites in the upper Clark Fork Basin, Montana, water years 1996–2010: U.S. Geological Survey Scientific Investigations Report 2013–5217, 162 p., with appendixes, http://dx.doiorg/10.3133/sir20135217.

Serfes, M.E., 1994, Natural ground-water quality in bedrock of the Newark Basin, New Jersey: New Jersey Geological Survey Report no. 35, 29 p.

Serfes, M.E., 2004, Ground water quality in the bedrock aquifers of the Highlands and Valley and Ridge Physiographic Provinces of New Jersey: New Jersey Geological Survey Report 39, 29 p.

Spearman, C., 1904, The proof and measurement of association between two things: The American Journal of Psychology, v. 15, no. 1, p. 72–101.

Tesoriero, A.J., and Voss, F.D., 2005, Predicting the probability of elevated nitrate concentrations in the Puget Sound Basin: Implications for aquatic susceptibility and vulnerability: Groundwater, v. 35, no. 6, p. 1029–1039.

Trela, J.J., and Douglas, L.A., 1978, Soils, septic systems and carrying capacity in the NJ Pine Barrens: Paper presented at the First Annual Pine Barrens Research Conference, Atlantic City, N.J., May 22, 1978, 34 p.

Tu, J., 2008, Assessing the impact of long-term land use changes on water quality in Eastern Massachusetts: Ann Arbor, Mich., ProQuest, 271 p.

U.S. Forest Service, 2014, The Highlands of Connecticut, New Jersey, New York and Pennsylvania, accessed April 28, 2015, at http://na.fs.fed.us/highlands/about/index.shtm.

U.S. Environmental Protection Agency, 2009, Statistical analysis of groundwater monitoring data at RCRA facilities. Unified guidance, EPA 530/R-09-007, 888 p. accessed April 28, 2015, at http://www.epa.gov/osw/hazard/correctiveaction/resources/guidance/sitechar/gwstats/unified-guid.pdf.

Wakida, F.T., and Lerner, D.N., 2005, Non-agricultural sources of groundwater nitrate: A review and case study: Water Research, v. 39, no.1, p. 3–16.

Appendixes 1 and 2

Appendix 1

Example spreadsheet for calculating median nitrate concentrations with logistic-regression models. (Appendix 1 available at http://dx.doi.org/10.3133/sir20155075)

Appendix 2

Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region. (Appendix 2 available at http://dx.doi.org/10.3133/sir20155075)

Prepared by the West Trenton Publishing Service Center

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Accettola, Alison

From: Smith B., Sen. D.O.
Sent: Wednesday, November 02, 2016 4:10 PM
To: Accettola, Alison; Horowitz, Judith L.
Subject: FW: SCR 39 - clarifications and amendments

Hi Alison & Judy:

The Senator would like your opinions.

Sue Cahn
Legislative Aide & Scheduler
Senator Bob Smith - 17th District
216 Stelton Road
Suite E-5
Piscataway, NJ 08854
732-752-0770

From: Bill [mailto:bill_wolfe@comcast.net]
Sent: Tuesday, November 1, 2016 11:47 AM
To: Smith B., Sen. D.O.; Greenstein, Sen. D.O.
Cc: Lesniak, Sen. D.O.
Subject: SCR 39 - clarifications and amendments

Dear Chairman Smith and Senators Greenstein and Lesniak:

Thank you for sponsoring and posting SCR 36 for Committee hearing. SCR 36 would:

"Amends Constitution to dedicate all State moneys received from settlements and awards in cases of environmental contamination for certain environmental purposes."

I write to suggest amendments to improve the bill and clarify certain issues to prevent unintended consequences.

1. Administrative costs

The SCR would limit the appropriations to State agencies to 5% for administrative costs.

One of the many issues to emerge from the recent Christie DEP Exxon NRD Settlement is that enforcement of these cases is not cheap.

Current DEP staffing levels for the NRD program are not adequate to manage the large backlog of NRD cases. In addition, DEP lacks in house scientific and technical expertise to effectively prosecute many complex contested cases. As a result, DEP often must hire contract consultant experts - or settle for paltry pennies on the dollar settlements.

DEP also lacks promulgated NRD regulations to bolster the legal enforceability of the NRD program (NJ Courts have rejected DEP NRD enforcement efforts due to lack of adopted regulations).

The Kanner law firm that managed the Exxon case - and their expert consultants - were compensated at far more than 5% of the settlement proceeds.

No private law firm in NJ would accept 5% of a civil settlement agreement as adequate compensation.

Finally, DEP and the Department of Law seek "cost recovery" actions to compensate the State for costs incurred as a result of the discharge of hazardous substance and/or natural resource injury. Those efforts must not be limited by the 5% administrative cost cap.

To address these kinds of issues, I suggest the following amendments:

a) define "administrative costs" to exclude DEP professionals and technical and legal consultants.
b) specifically exclude DEP and DoL "cost recovery" efforts from the SCR - or dedicate them to State agencies.

Passage of the SCR in its current form with the 5% cap would starve already under-resourced DEP programs and virtually guarantee that there would never again be anything like a large scale complex Exxon case, that the current limited DEP NRD and enforcement programs would persist, and perhaps they would be further scaled back due to lack of adequate resources.

2. Use of the funds

The first priority of the SCR should be to restore fully the previously CBT dedicated funds diverted by the Open Space Ballot approval, specifically for State parks maintenance, water resources, and hazards site remediation. This money should come off the top.

The public never supported and has been outraged to learn that these funds were diverted by the Open Space Question.

The second priority should be to allocate 50% of remaining revenues (after the above restoration) to the nearby communities that suffered the harms to natural resources and/or public health. This could b done via a requirement for a geographic regional nexus.

Finally, the remaining 50% would be allocated according to the current version, i.e.

"for any of the purposes enumerated in Article VIII, Section II, paragraph 6 of the State Constitution, "

3. Expand the scope to include all enforcement revenues

The SCR is not precise regarding the settlements and revenues covered. For example, would a Water Pollution Control Act or Freshwater Wetlands Act settlement be included within the scope of the SCR? It appears not.

To promote the policy objectives of the SCR, all DEP enforcement revenues could be dedicated.

In conclusion, please keep in mind that the dedication of NRD settlement revenues was included in the introduced version of the Open Space SCR. Mysteriously, that provision was deleted instead of being expanded to include all enforcement and settlement revenues.

I appreciate your consideration of these amendments and would be glad to respond to your questions.

Respectfully,

Bill Wolfe

Horowitz, Judith L.

From:	Bill <bill_wolfe@comcast.net>
Sent:	Friday, November 04, 2016 11:43 AM
To:	Smith B., Sen. D.O.
Cc:	Horowitz, Judith L.; Greenstein, Sen. D.O.; Bateman, Sen. D.O.; Codey, Sen. D.O.; Lesniak, Sen. D.O.; wolfe, bill
Subject:	Highlands hearing record - USGS Data Quality Complaint

Dear Chairman Smith:

Per your request during yesterday's Senate Environment Committee's hearing, I would like to submit the following documents for your information and incorporation in the record regarding the Legislature's pending review of the NJ DEP's proposed revisions to the Highlands "septic density standards" mandated by the Highlands Act.

1. USGS Data Quality Act complaint

As you may know, on May 18, 2016, Public Employees for Environmental Responsibility (PEER) filed a complaint with the USGS pursuant to the federal Data Quality Act regarding the USGS's Highlands nitrate study.

The PEER complaint requests that the USGS withdraw the study, which forms the exclusive scientific basis of the NJ DEP rule proposal. The USGS review of this complaint is still pending. A decision is over-due under USGS policy, which provides a 90 day period to review Data Quality Act complaints.

The PEER complaint, which I wrote, goes into great detail regarding significant bias (geographical, statistical, and scientific), flaws, and limitations in the USGS study.

In addition to those scientific and technical flaws, the USGS methodology is in blatant conflict with the Legislative standards established by the Highlands Act that govern regulatory derivation of the DEP's "septic density standards". Most basically, the septic density standards apply only in the Preservation Area. In contrast, USGS relied on data from the Planning Area.

The Legislature, in the Highlands Act, established a non-degradation water quality policy as well as specified with precision - and thereby limited - the factors DEP could consider in promulgating "septic density standards".

NJ DEP septic density standards are authorized by the Highlands Act in order to **prevent the degradation of water quality.** The applicable provision provides:

"*... a septic system density standard established at a level* ***to prevent the degradation of water quality****, or to require the restoration of water quality, and to protect ecological uses from individual, secondary, and cumulative impacts,* ***in consideration of deep aquifer recharge available for dilution****...*"[18] (Emphasis added)

The current septic density standards DEP adopted were derived based on an ambient groundwater nitrate concentration of 0.21 mg/L for forested lands in the Preservation Area. This concentration was found to be the "natural condition" or natural background concentration.

In contrast, the USGS study and NJ DEP proposed revisions are based explicitly on groundwater degraded by anthropogenic loadings of nitrogen from septics and agriculture practices. This methodology conflicts with the legislative standard in the Highlands Act to prevent degradation of surface and groundwater.

The USGS attempted to derive the median value of nitrate in groundwater in the Preservation Area, based on samples taken outside the Preservation Area. That is simply not authorized by and conflicts with the Highlands Act.

I would like to submit the PEER complaint for the record, see:

http://www.peer.org/assets/docs/nj/5_18_16_Highlands-USGS_DQA_complaint.pdf

2. NJ DEP Private Well Testing Act Reports

There were serious substantive omissions in the testimony by NJ DEP and USGS regarding the Private Web Testing Act data.

These omissions reflect bias and may lead to misleading interpretations of the science by Legislators.

Accordingly, I would like to submit a Report by NJ DEP's Division of Science and Research and two other official program Reports on the PWTA data.

The PEER USGS complaint goes into some detail, based on NJ DEP's now PWTA Reports, about why that data is flawed, limited, and inappropriate for purposes of deriving the "septic density standards".

The NJDEP prepared three distinct Reports on the PWTA data, all of which documented serious limitations in PWTA data.

Specifically, DEP issued a preliminary PWTA Report in 2004, see especially page 6 fo**r "limitations of the data":**
http://www.nj.gov/dep/watersupply/pwta/pdf/pwta_report.pdf

NJ DEP issued a more detailed PWTA Report in July 2008

The **DEP's 2008 Private Well Testing Act Report** warns about lack of QA/QC and other limitations and flaws in the PWTA data (see page 5, "Limitations of the Data")
http://www.nj.gov/dep/watersupply/pwta/pdf/pwta_report_final.pdf

Analysis and Data Reporting - The PWTA Program testing data are submitted electronically and are automatically entered into the database **without any quality control or quality assurance reviews**. It is assumed that the certified laboratory properly met all required protocols and the data are accurate. The PWTA Program relies on the reporting laboratory to catch and correct any data entry errors.

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In addition to the NJ DEP's programmatic PWTA Reports released in 2004 and 2008, an April 2009 Report by the DEP's Division of Science and Research, titled: ***The New Jersey Private Well Testing Act: An Overview* (April 2009) goes into great detail about flaws in PWTA data. The DEP Report found:** (boldface emphases are mine): http://www.state.nj.us/dep/dsr/research/pwta-overview.pdf

Data limitations

The quality of NJDEP's PWTA database is adversely affected to an unknown extent by several factors. There is no agency responsible for verifying that the data from all real estate transactions (sales and leases) subject to the PWTA are reported to the NJDEP. Therefore, some data is likely missing. Some data that were initially rejected by the E2/COMPASS quality control system were not resubmitted, despite NJDEP efforts to have these data resubmitted. One laboratory failed to submit data over a 3-year period, although this is believed to be an isolated case.

There are errors in the reported data as well. The PWTA relies on the sampling and testing laboratories for proper conduct of sampling, testing, and data accuracy. As previously stated, all laboratories performing PWTA analysis must be certified. That is, they are required to successfully complete periodic performance evaluations. Certification presumably reduces sampling and analysis errors. Nevertheless, **there is no ongoing quality control of the data, either following sample collection, during or after testing, or in reporting results to the client or during electronic entry to the NJDEP database. It is not known how many errors exist in the non-location aspects of the data**. As one example, it is suspected that, contrary to PWTA regulations, collection of lead samples from unflushed water tanks or spigots is the primary reason why many elevated lead results were reported. NJDEP personnel periodically evaluate the data and, through contact with the submitting laboratories, correct data submissions. This process also reduces the amount of errors.

There is no GPS certification program for samplers who collect GPS coordinate information. As a result, there were numerous GPS errors, especially during the first year of sample collection. For example, many GPS coordinates were not located in the correct municipality let alone the correct property. Because much of the data analysis relied on accurate well location information, the NJDEP spent approximately one man-year (full time equivalent) correcting well location errors, including address, municipality, county, block and lot and GPS coordinate information for wells sampled from PWTA inception (September 2002) through April 5, 2007. This was done using an electronic, subscription-based, tax parcel website, eTaxmaps.com, to correct block and lot as well as address information errors. Once those errors were corrected, the data for each municipality was organized by block and lot to look for GPS errors. GPS errors were corrected using ArcMap® 9.2 software (ESRI Inc., Redlands, CA) and the following data layers: county and municipal boundaries, county tax parcel boundaries (available for 17 of the 21 counties), NJ roads (from Tele Atlas North America, Inc., v 9.1, April, 2007), and 2002 high-resolution infrared orthophotography (1 foot Ground Resolution Distance). For repeat samples of the same well, identical GPS coordinates were offset 1 foot to distinguish these samples on high resolution maps and to enable certain geospatial statistical analyses. A copy of the database with the correct well location information was created in Microsoft Access®. Because of the extensive location errors, the NJDEP subsequently provided GPS training to all PWTA-certified laboratories.

The PWTA requires just one sample and test during a real estate transaction. No confirmatory sampling and testing that might verify the accuracy of the results from the initial sample is required. However, as of April 5, 2007, 9 % of the tested wells have been tested more than once due to multiple real estate transactions and other reasons.
Wells may be contaminated with pathogens or chemicals that were not among the tested parameters. The list of tested parameters was selected based on known or potential broad-based contamination concerns in NJ, but the list is by no means comprehensive in terms of contaminants that have been identified in ground water in NJ or elsewhere. However, the presence of some of the parameters in excess of the standard may be considered as an indicator of the possible presence of other non-tested contaminants.
For example, if fecal coliform or E. coli are detected, the well is considered to be contaminated with fecal wastes from either humans or animals. Such wastes may include one or more of a variety of potentially pathogenic microorganisms such as Salmonella, Shigella, enteric viruses, Giardia or Cryptosporidium. The presence of VOCs may indicate a higher likelihood that some other man-made chemical contaminants may be present.

Information on well depth was not collected in the PWTA database in most cases. This information would have been helpful to more accurately assess the impact of specific geologic formations on ground water quality. Well construction information, specifically permit application information and, in some cases, well drilling record information, is available for many of the wells in NJDEP's other electronic databases (NJEMS and Hiview). These databases include well identification numbers and well depth information, but it was not possible to transfer this information into the PWTA database (over 50,000 wells) on a well-by-well basis.

Having the well drilling record information or at least the permit application information for all wells rather than for just 5 % in the PWTA database would have assisted data analysis in many cases where there were multiple data records for the same address, block and lot. In some of these cases, it was not certain whether a single well was tested more than once, or there was more than one well at that location, with each well tested just once.
The PWTA addresses NJ ground water quality but not quantity concerns. However, statewide water quantity concerns are addressed through other NJDEP Division of Water Supply programs and through implementation of the NJ Statewide Water Supply Master Plan.

In addition to the reasons set forth in the PEER USGS complaint, the PWTA data are inherently biased, flawed, and limited, as well as an ultra vires basis and inappropriate for use in deriving Highlands Preservation Area septic density standards.

The PWTA data were available when NJ DEP deceived and adopted the current septic density standards. However, due to bias, flaws, and limitations, the NJ DEP chose not to incorporate the PWTA data into the dataset used to derive the current septic density standards.

For DEP now to use USGS to bring those contaminated PWTA data into the regulatory basis for weakening current standards is totally unacceptable scientific practice and it conflicts with the policies, standards and authorized regulatory basis of the Highlands Act.

I appreciate your consideration of this information and incorporation in the hearing record.

I will be submitting additional information and would be glad to respond to any questions..

Respectfully,

Bill Wolfe

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Documents Submitted in Support of Testimony at the Senate Environment Committee Hearing on November 3, 2016
By
John A. Thonet, PE, PP, President, Thonet Associates, Inc.
Environmental Planning and Engineering Design Consultants

1. Professional CV of John Thonet, PE, PP;
2. Scientific Investigations Report 2015-5075, *Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics*, prepared by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection (NJDEP), prepared in 2015;
3. Memorandum dated September 1, 2015 to Jeffrey L. Hoffman, NJ State Geologist, NJDEP, from John A. Thonet, Thonet Associates, Inc., providing Preliminary Comments Regarding Scientific Investigations Report 2015-5075, *Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics*, prepared by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection (NJDEP);
4. New Jersey Geological & Water Survey Technical Memorandum 14-1 entitled, *Nitrate Concentrations in Ground water of New Jersey's Highlands Region*, prepared by Jeffrey L. Hoffman and Alexandra Petriman, NJDEP, Water Resources Management, Division of Water Supply and Geosciences, New Jersey Geological and Water Survey, dated 2014;
5. Letter from Jeffrey L. Hoffman, State Geologist, NJDEP, New Jersey Geological and Water Survey, to John A. Thonet, Thonet Associates, Inc., dated December 18, 2015, responding to Thonet Associates' above-listed Memorandum to Jeffrey L. Hoffman dated September 1, 2015;
6. Letter from Richard H. Kropp, Center Director, US Geological Survey, NJ Water Science Center, to Jeffrey L. Hoffman, P.G., Acting State Geologist, NJDEP/Div. of Water Supply & Geosciences, New Jersey Geological & Water Survey, undated;
7. Memorandum dated January 16, 2016 to Jeffrey L. Hoffman, NJ State Geologist, NJDEP, from John A. Thonet, Thonet Associates, Inc., providing Continuing Comments Regarding Scientific Investigations Report 2015-5075, *Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics*, prepared by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection (NJDEP); and
8. A revision to the originally prepared New Jersey Geological & Water Survey Technical Memorandum 14-1 entitled, *Nitrate Concentrations in Ground water of New Jersey's Highlands Region*, prepared by Jeffrey L. Hoffman and Alexandra Petriman, NJDEP, Water Resources Management, Division of Water Supply and Geosciences, New Jersey Geological and Water Survey, dated 2014, Revised 2015, and bearing a stamp-marking stating, "PRELIMINARY SUBJECT TO REVISION).

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John A. Thonet, PE, PP

Professional History

Thonet Associates, Inc.
Environmental Planning and Engineering Design

Founder and President
1980-2009 and 2011-Present

Thonet Associates, Inc. is Mr. Thonet's private consulting practice. Mr. Thonet applies his expertise in environmental sciences, engineering and land use planning to the design of land development projects and the development and implementation of land use planning programs.

Education:

- B.S. in Forest Engineering, State University of New York (SUNY) College of Environmental Science and Forestry (ES&F) at Syracuse, 1972. Concurrent diploma issued by Syracuse University.
- M.S. in Forest Engineering, State University of New York (SUNY) College of Environmental Science and Forestry (ES&F) at Syracuse, 1975. Concurrent diploma issued by Syracuse University.

Mr. Thonet's professional education in the environmental sciences, engineering and planning also includes professional development certificates from the following universities and professional development programs:

- Hydrology, Hydraulics, Flood Plain Management and Stormwater Management:
    - Graduate study in hydraulic design of structures, Polytechnic Institute of New York
    - Continuing education certificate in Urban Hydrology, Penn State University
    - NRCS Unit Hydrograph Peak Rate Factors for New Jersey, The Practicing Institute of Engineering, Inc.
    - Vegetated Roof Design and Construction, HalfMoon Education, Inc.
    - Designing and Constructing Flood-Resistant Buildings, HalfMoon Education, Inc.
    - Low Impact Development, HalfMoon Education, Inc.

- Environmental Science, Impacts and Restoration:
  - Methodologies of delineating wetlands based on vegetation, soils, and hydrology, Continuing Education, Rutgers University
  - Threatened and endangered species, Continuing Education, Rutgers University
  - Glacial deposits in New Jersey, Continuing Education, Rutgers University
  - Impact of Plants on Earthen Dams, Failure & Damage Analysis, Inc.
  - Stream restoration, Continuing Education, Rutgers University

- Environmental Planning and Regulation:
  - NJ/NY Environmental Regulations & Due Diligence, New Jersey Institute of Technology
  - Preparing Site Plans and Subdivisions for Municipal Completeness, Engineering Education – a division of RBZ Enterprises, Inc.

- Alternative Energy:
  - Geothermal Heating and Cooling; HalfMoon Education, Inc.
  - Solar Power Design Worshop, HalfMoon Education, Inc.

- Underground Facilities and Infrastructure:
  - On-site wastewater treatment and disposal systems, Continuing Education, Rutgers University
  - Underground storage tanks, Continuing Education, Rutgers University
  - Management of Underground Infrastructure; National Water Main Cleaning Company

- Desktop mapping with ArcView, Continuing Education, Rutgers University

Professional Licenses, Registrations and Certificates: Mr. Thonet holds the following professional licenses, registrations and certificates related to his work with Thonet Associates, Inc.:

- Professional Engineer (PE) in New Jersey, Massachusetts, Pennsylvania, and Michigan
- Professional Engineer (Retired) in West Virginia
- Professional Planner (PP) in New Jersey
- Certificate of Training - Wetland Delineation Certification Program Rutgers University – US Army Corps of Engineers

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Professional Societies:

- American Planning Association (APA)
- Urban Land Institute (ULI)
- American Society of Civil Engineers (ASCE)
- National Society of Professional Engineers (NSPE)
- New Jersey Society of Professional Engineers
- Society of American Foresters (SAF)

Professional Services:

Thonet Associates' Services include the preparation of environmental assessments and impact statements, wetland studies, threatened and endangered (T&E) species investigations, natural resources inventories, flood plain and flood control studies, storm water management, development feasibility studies, environmentally-based community master plans, and environmental zoning and land development ordinances. Mr. Thonet also facilitates environmental permitting for land development projects and provides expert testimony in the fields of environmental science, engineering and land use planning.

Professional History:

Established in 1980, Thonet Associates has provided consulting services for more than 35 years on behalf of over 1,000 public and private clients in over 100 municipalities in New Jersey, Pennsylvania, New York, Massachusetts, Michigan, West Virginia, Georgia and North Carolina.

Prior to founding Thonet Associates, Mr. Thonet worked for the Power Authority of the State of New York (PASNY) as an environmental engineer (1973-1974), for an international engineering/architecture company, Tippetts-Abbett-McCarthy-Stratton (TAMS), as a hydrologist/hydraulic engineer (1974-1979), and as an environmental planner and engineer for an environmental land use planning firm, Dresdner Associates (1979-1980). Mr. Thonet has over 40 years of professional experience in the fields of environmental science, land use planning and civil engineering.

Thonet Associates' size has varied from a maximum of ten (10) full-time and part-time employees to a minimum of two (2) employees, depending on economic conditions and Mr. Thonet's professional objectives at any given time. At the present time, the firm is comprised of Mr. Thonet, one Senior Environmental Planner, and an administrative assistant.

Mr. Thonet is best known for his work relating to flood plain and storm water management, freshwater wetlands delineations and protection, and environmentally based land use planning and design. He regularly collaborates with other environmental, engineering, and planning professionals, as needed to fulfill the needs of his clients.

Mr. Thonet has continuously provided consulting services as Thonet Associates from 1980 to the present except for 2010 and a portion of 2011 when he accepted a fulltime position as Chairman of Herley Industries, Inc. in order to assist Herley during a critical period in it's history.

THONET Associates Inc
Environmental Planning and Engineering Design

Herley Industries, Inc.

1991-2011
Chairman of the Board of Directors (2010-2011)
Member of the Board of Directors (1991-2011)

Concurrently with running Thonet Associates, Inc., Mr. Thonet served for 20 years as a corporate director on the Board of Directors of Herley Industries, Inc. (NASDAQ: HRLY). Herley Industries, Inc. is a leading supplier of microwave products and systems to defense and aerospace entities worldwide. In January of 2010, Mr. Thonet became Herley's fulltime executive Chairman.

At that time, Herley employed just over 1,000 employees worldwide, with domestic manufacturing facilities in Pennsylvania, Massachusetts, Florida, and New Jersey and overseas facilities in the United Kingdom and Israel. Despite possessing an experienced and competent work force, Herley's revenues had been declining and the firm had suffered significant losses during the preceding two years.

The Board of Directors decided the situation called for new leadership and made significant management changes including naming a new CEO, COO, and CFO. Mr. Thonet was subsequently hired to serve as Herley's executive Chairman, the company's highest-ranking executive officer.

In fiscal 2010, under Herley's new management, the company recorded revenues of over $188 million, the highest revenues ever achieved in Herley's 45-year history. In addition, Herley negotiated successful resolutions to complex litigation matters that had resulted in significant uncertainty regarding the company's long-term financial condition.

With revenues recovered and increasing, resulting in significantly reduced uncertainty regarding the company's financial condition, Mr. Thonet publicly announced to shareholders that, going forward, Herley would simultaneously "look in two directions" in formulating its future…looking to grow the company through acquisitions, while at the same time, looking to merge the company with another defense company of similar or larger size. The message was well received by the street and Herley's stock price began to realize its true potential.

In the first half of fiscal 2011, as a result of improved internal efficiencies orchestrated by Herley's new management team, Herley's financial performance continued to improve, reporting both record revenues and record earnings for the first and second quarters.

In the third quarter of fiscal 2011, Mr. Thonet directed the company's CFO to use the company's available cash resources to pay down virtually all of the company's long-term debt while simultaneously orchestrating the merger of Herley with another defense company in March of 2011 for a sales price of $270 million, approximately 44% more than the company's street value when Mr. Thonet assumed the position of Chairman 15 months earlier. On April 16, 2011, having completed his work at Herley, Mr. Thonet returned to his private consulting practice, Thonet Associates, Inc.

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Other Professional Activities:

New Jersey Highlands Coalition

October 2012-February 2016
President of the Board of Trustees, Chairman of Executive Committee, Member of Finance Committee and Policy Committee

2006-2010, Member of the Board of Trustees, Chairman of the Finance Committee, Member of the Executive Committee

Association of New Jersey Environmental Commissions (ANJEC)

2014-Present
Member of the Board of Trustees

New Jersey Environmental Lobby (NJEL)

2002-Present
Member of Board of Trustees

Syracuse University

2005-Present
Member, Advisory Board to the Department of Civil & Environmental Engineering within the L.C. Smith College of Engineering and Computer Science

State University of New York (SUNY) College of Environmental Science and Forestry (ESF) at Syracuse

1998-Present
Founding Chairman and Member, Environmental Resources and Forest Engineering Group (ERFEG) Advisory Council

South Orange Environmental Commission

1999-2003
Founding Chairman

Main Street South Orange, Inc. (MSSO)

A not-for-profit, volunteer-based downtown revitalization program
1991-1998
Co-Chairman of the Board of Trustees (1993 - 1998)
Chairman – Economic Development Committee (1992-1993)
Founding Chairman – Public Improvements Subcommittee (1991-1992)

Environmental Planning and Engineering Design

Professional Publications

- Co-author, *When the Best Laid Plans Fail to Protect*, ANJEC Report, Summer 2014
- Author, Chapter 13, "Floodplains" and Section 17.3, "New Jersey's Stream Encroachment Regulations", *Environmental Permitting Handbook*, McGraw Hill, 2000
- Author, *Storm Water Control Ordinance for Lands Within the Great Swamp Watershed Overlay Zone*, a "model" storm water ordinance prepared under contract to the Great Swamp Watershed Association, 1996
- Author, No Net Increase – A Storm Water Management Philosophy, ANJEC Report, 1996
- Co-author, *Environmental Land Use Regulations vs. Discriminatory Zoning Practices*, ASCE International Convention and Exposition, NYC, 1981
- Author, *Floodplain and Storm Water Management Regulations – Their Relationship to Each Other and to the Environmental Zoning Aspects of Land Use Planning*, Proceedings, International Symposium on Urban Hydrology, Hydraulics and Sediment Control, 1981
- Co-author, Technical Report, Development Suitability – St. Lawrence-Eastern Ontario Shoreline Study, Applied Forestry Research Institute (AFRI), Syracuse, NY, 1977
- Author, *Drainage Basin Characteristics and Energy Losses in the Rainfall-Runoff Process*, A thesis submitted in partial fulfillment of the requirements for a Master of Science degree from the SUNY College of Environmental Science and Forestry, Syracuse, NY, April 1975

Speaking Engagements

- *Mandatory Training Program for New Board Members*, Planning Instructor, New Jersey Planning Officials, Hillsborough Township Municipal Building, April 30, 2016 and October 22, 2016
- *Honing Skills: Assessing Development Proposals*, Workshop at ANJEC's 41st Annual Environmental Congress, Raritan Valley Community College, Branchburg, NJ, October 24, 2014
- *Municipal Planning Incorporating Natural Systems*, Hunterdon County Green Table, South Branch Watershed Association, Echo Hill Environmental Center, Stanton Station, NJ 2008
- *An Example of the Precautionary Principle in New Jersey – The Highlands Water Planning & Protection Act – Will the Regional Master Plan Reflect the Intent? -* Conference on The Precautionary Principle, sponsored by the Environmental Education Fund, The Environmental Studies Program of Seton Hall University, The Science and Environmental Health Network, and Public Employees for Environmental Responsibility, 2008
- *Storm Water in Development Review and Zoning*, Session I Workshop, ANJEC 32nd Annual Environmental Congress, 2005

- *New Jersey's New Storm Water Management Rules,* Burlington County Board of Chosen Freeholders and the Rancocas Creek Watershed Management Area Public Advisory Committee's Third Annual Storm Water Management Conference, New Jersey EcoComplex, Columbus, NJ, 2004
- *New Jersey's New Storm Water Management Rules in Relation to Stream and Riparian Corridor Protection,* Sussex & Warren County Farmland & Open Space Roundtable, Waterloo Village Meeting House, Stanhope, NJ, 2004
- *New Jersey's Storm Water Management Regulations,* ANJEC Environmental Commission Training to Protect Natural Resources, East Amwell, NJ 2004
- *New Jersey's Proposed/Adopted Storm Water Regulations,* the New Jersey Chapter of the American Society of Landscape Architects, Atlantic City, NJ 2004
- *The Importance of Infiltration in New Jersey's New Storm Water Management Regulations,* Soil and Water Conservation Society, Firman E. Bear Chapter, Forest Resource Education Center, Jackson, NJ, 2004
- *New Jersey's Newly Proposed Storm Water Management Regulations,* ANJEC Environmental Commission Training to Protect Natural Resources, Vineland, NJ 2003
- *New Jersey's Newly Proposed Storm Water Management Rules,* ANJEC presentation to Medford Township in association with the Woodford Cedar Run Wildlife Refuge, 2003
- *Planning for BMPs: A new Approach to Storm Water Management in Your Towns,* ANJEC's New Jersey Environmental Congress, 1999
- *Storm Water Management – What Can We Do Other Than Detention Basins?* - A presentation to the Tinton Falls Mayor and Council, Planning Board, Environmental Commission and Storm Water Work Group, Tinton Falls Municipal Building, Council Chambers, 1999
- *No Net Increase – A Storm Water Management Philosophy for the Highlands,* Highlands Research Symposium II, Applying Ecological Knowledge to Land Use Decision-Making, Workshop of Wetlands and Storm Water Management, 1996
- *Planning for and with Natural Systems,* ANJEC's New Jersey Environmental Congress, 1993
- *The Art of Managing Non-Point Source Pollution,* ANJEC Environmental Commissioners' Course, 1991
- *Storm Water Management and Hydrology in the Great Swamp Watershed,* NJDEP's Great Swamp Watershed Advisory Committee, 1990
- *Taking the Mystery out of Storm Water Management,* Monmouth County Water Resources Associates Public Workshop of Storm Water Management, 1990
- *Environmental Aspects of the Site Plan/Subdivision Review Process,* NJ Federation of Planning Officials, Educational Meeting at the Northern Area NJFPO, 1989
- *Storm Water and Groundwater Management with Respect to NPS Pollution,* ANJEC Commissioners' Course, 1989
- *Storm Water Management in New Jersey,* ANJEC Commissioners' Course, 1982 and 1983

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THONET Associates Inc

Environmental Planning and Engineering Design

Selected Projects and Programs:

Main Street South Orange, Inc.

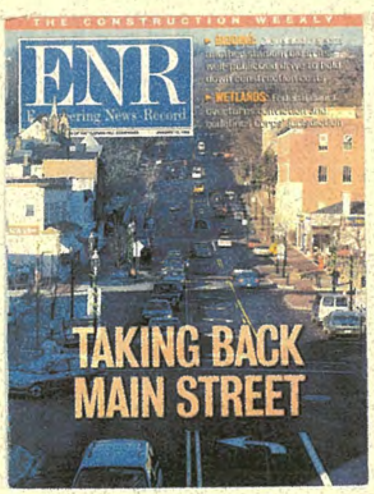
A downtown revitalization organization
1991-1998
Co-Chairman of the Board of Trustees (1993 - 1998)
Chairman – Economic Development Committee (1992-1993)
Founding Chairman – Public Improvements Subcommittee (1991-1992)

Mr. Thonet and his family resided in South Orange, NJ from 1980 through 2003 and in 1989, he and his wife acquired a small office building in the center of town from which Thonet Associates, Inc. operated until 2003.

South Orange Train Station Improvements

In 1991, Main Street South Orange, Inc. (MSSO) was formed as a not-for-profit, volunteer-based organization whose goal was to revitalize downtown South Orange by stimulating business opportunity, historic preservation, and community growth.

In the process of professionally guiding the MSSO program, Mr. Thonet utilized the well-respected "Main Street Four Point Approach" to downtown revitalization as well as his many years of experience as a small business owner and as a professional accustomed to dealing with governmental agencies and process. South Orange went on to become one of New Jersey's "success stories" in downtown revitalization.



In January of 1998, Mr. Thonet's last year as Co-Chairman, South Orange's revitalized streetscape and traffic-calming design was featured on the cover of Engineering News Record (ENR) with the headline, "Taking Back Main Street."

Mr. Thonet is particularly proud of South Oranges' success and the role he played in helping South Orange to realize that success, both as a professional and as a volunteer.

Septic Management vs. Sewers, Lake Lackawanna Study for Byram Township, Sussex County, New Jersey

1998-1999

In 1998, Byram Township received a grant from the New Jersey Department of Environmental Protection (NJDEP), Office for the Watershed Management Public Education and Outreach Grant Program, to study whether it would be better to control nonpoint source pollution in Lake Lackawanna caused by numerous septic systems located around the lake by extending Byram's sewer system to service the area or by establishing a septic management plan. Thonet Associates was selected by Byram Township to conduct the study.

The study concluded that implementation of a septic management plan would yield immediate and long-term water quality benefits at low cost and would not preclude further investigating and pursuing approvals for adding Lake Lackawanna to the sewer service area.

The study recommended prompt implementation of a septic management plan and further investigation into the feasibility, cost and practicality of a "limited" sewer system to serve just existing homes and infill lots within the Lake Lackawanna community.

Storm Water Treatment BMP Demonstration Project for Interstate Highway Route 287's Harding Rest Stop

1998-2001

In 1998, Harding Township authorized Thonet Associates to assist the Harding Township Environmental Commission with a storm water treatment demonstration project for the Harding Rest Stop on Interstate Highway Route 287 (I-287). The storm water treatment system tested was a Vortech Storm Water Treatment System manufactured by Vortechnic Inc., followed by discharge to a sand filter.

The study, completed in 2001, concluded that Vortech Storm Water Treatment System, followed by a sand filter, provided a very effective method of removing total petroleum hydrocarbons (TPHs) and total suspended solids, with removal efficiencies of 86% and 98% achieved respectively.

The study was one of the earlier demonstration projects in New Jersey aimed at documenting that storm water from highly trafficked areas could be effectively treated for water quality prior to discharge to local streams.

Model "No Net" Storm Water Management Ordinance for Great Swamp Watershed Association (GSWA)

1995-1996

In 1995, the Great Swamp Watershed Association (GSWA) hired Thonet Associates, Inc. to prepare a model "no net" storm water ordinance, meaning one that would result in no net increase in storm water rates and volumes, no net increase in soil erosion and stream channel erosion, and no increase in nonpoint source pollution associated with storm water runoff. This was significantly different from New Jersey's storm water regulations at that time, and mimicked by most New Jersey municipalities, that simply required no increase in peak rates of runoff.

The ordinance was a precursor to New Jersey's new storm water management regulations promulgated eight years later, in 2004, and the ordinance incorporates many of the same and similar provisions to New Jersey's new regulations.

Mr. Thonet and the GSWA voluntarily contributed their knowledge gained in developing the "no net" model ordinance to the NJDEP during its long process of preparing and adopting New Jersey's new Storm Water Management regulations and Best Management Practices (BMP) manual. Mr. Thonet received a letter from the NJDEP in 2004 thanking him for his input to this process. In pertinent part, the thank you letter states,

> "Thank you for you input in the development of the New Jersey Storm Water Best Management Practices Manual. Your experience, expertise, and commitment of time an energy were instrumental in the successful completion of this task..." [Lawrence J. Baier, Director, NJDEP, Division of Watershed Management, June 28, 2004]

The New Jersey Storm Water Best Management Practices Manual includes Mr. Thonet in its "Acknowledgements" section as one of the individuals that the NJDEP thanks "...for their technical input and assistance during the development of the manual."

Harding Township Affordable Housing Study within the Great Swamp Watershed

1994

In 1994, the New Jersey Department of Environmental Protection (NJDEP) entered into a Grant Agreement with Harding Township's Environmental Commission to provide matching funds for conceptual planning and design of a low and moderate income, multifamily housing project to be located within the environmentally sensitive watershed of Great Swamp.

The study demonstrated the feasibility of constructing 23 low/moderate income-housing units and one superintendent's unit, without significant environmental impacts, on 3.3 acres of land located within the Great Swamp watershed. The conceptual project had a gross density of 2.9 dwelling units/acre and a net density of 7.3 dwelling units per acres, and could be designed to meet Harding Township's "no net increase" storm water management goals.

The study documented the feasibility of building multifamily housing at moderate densities within the environmentally important Great Swamp watershed without increasing storm water runoff rates, volumes or nonpoint pollution.

Lafayette Township's Environmentally Based Wastewater Management Plan and Land Use Element of Master Plan

1989

In the late 1980s, Thonet Associates was retained by Lafayette Township in Sussex County, New Jersey, to serve as it's environmental planning consultant for purposes of preparing a Wastewater Management Plan (WWMP) utilizing environmentally-based "carrying capacity" principles, including application of the "nitrate dilution model" as a planning tool for areas not served by public sewerage systems.

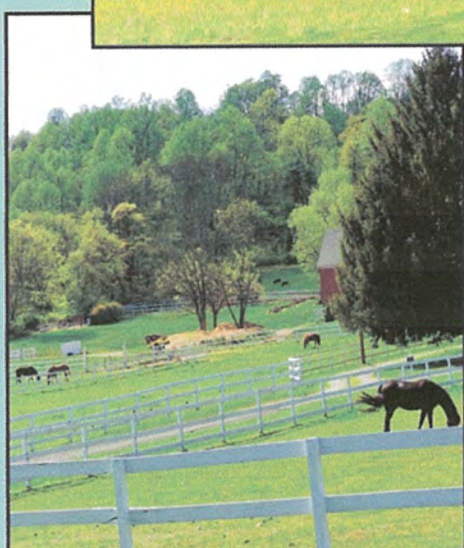
In addition, following the preparation and adoption of the WWMP, the township retained Thonet Associates, together with Planning Consultant, Peter Steck, to revise the Township's master plan, zoning ordinance and land use regulations to follow the same environmentally-based "carrying capacity" principles on which the WWWP was based.

Lafayette Township's updated Master Plan was subsequently recognized by the New Jersey State League of Municipalities for its unique contribution to environmental land use planning in the State of New Jersey.

USGS
science for a changing world

Prepared in cooperation with the
New Jersey Department of Environmental Protection

Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics



Scientific Investigations Report 2015–5075

U.S. Department of the Interior
U.S. Geological Survey

Cover: All photos provided by Ronald J. Baker, U.S. Geological Survey. Upper left, upper right, lower left, show farms in Long Valley, NJ, and lower right a mill in historic Waterloo Village Park, Stanhope, NJ

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Median Nitrate Concentrations in Ground-water in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics

By Ronald J. Baker, Mary M. Chepiga, and Stephen J. Cauller

Prepared in cooperation with the
New Jersey Department of Environmental Protection

Scientific Investigations Report 2015–5075

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

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ISSN 2328-0328 (online)

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Acknowledgments

The authors gratefully acknowledge the New Jersey Highlands Council for their interest and participation in this work; and Jeff Hoffman, Nick Procopio, and Sandra Goodrow of the New Jersey Department of Environmental Protection for their many contributions and constructive suggestions during report development and review.

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Contents

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Figures

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Tables

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Conversion Factors, Datums

Inch/Pound

Multiply	By	To obtain
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

ANOVA	Analysis of variance
EPA	U.S. Environmental Protection Agency
GPS	Global positioning system
MCL	Maximum contaminant level
MDL	Minimum detection limit
MLE	Maximum likelihood estimate
NJDEP	New Jersey Department of Environmental Protection
NWIS	National Water Information System
PWTA	Private Well Testing Act
USGS	U.S. Geological Survey

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Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics

By Ronald J. Baker, Mary M. Chepiga, and Stephen J. Cauller

Abstract

Nitrate-concentration data are used in conjunction with land-use and land-cover data to estimate median nitrate concentrations in groundwater underlying the New Jersey (NJ) Highlands Region. Sources of data on nitrate in 19,670 groundwater samples are from the U.S. Geological Survey (USGS) National Water Information System (NWIS) and the NJ Private Well Testing Act (PWTA).

In a study conducted by the USGS, in cooperation with the New Jersey Department of Environmental Protection, logistic regression was used to relate measured nitrate concentrations to five explanatory variables (percent urban and agricultural land use, septic-system density, total length of streams, and number of known contaminated sites) quantified in 610-meter-square grid cells. A method for calculating the median concentrations of nitrate from a series of logistic regression models was developed. Two calibration and two validation procedures showed that the logistic-regression-based method can estimate groundwater-nitrate concentrations in the Highlands Region accurately to within 0.1 milligram per liter as nitrogen (mg/L as N). Limitations of the logistic-regression-based method include the inability to select a logistic model with exactly 0.5 probability of exceeding the threshold value and lack of an algorithm to directly calculate the median value. Quantile regression was evaluated as a suitable alternative and was slightly less accurate than the logistic-regression method in estimating median groundwater nitrate concentrations in the Highlands Region.

Multiple-linear regression with log-transformed nitrate-concentration data and the same five explanatory values was less accurate than either logistic or quantile regression in estimating median nitrate concentrations. On the basis of 4,516 2000 x 2000 foot grid cells that contain wells with data stored in NWIS and the PWTA database, the estimated median nitrate concentration for the entire Highlands Region is about 1.25 mg/L as N, and estimated median concentrations range from about 1.05 to 1.78 mg/L as N among 11 smaller administratively defined areas within the Highlands Region that vary in percentages of urban land use, agricultural land use, and septic-system density.

The Kaplan-Meier method of estimating summary statistics from left-censored data was applied in order to include nondetects (left-censored data) in median nitrate-concentration calculations. Median concentrations also were determined using three alternative methods of handling nondetects. Treatment of the 23 percent of samples that were nondetects had little effect on estimated median nitrate concentrations because method detection limits were mostly less than median values.

Introduction

Monitoring and assessment of groundwater quality is important for the management of groundwater resources from a public health and an ecological perspective. Groundwater quality and anticipated water-quality changes in the New Jersey (NJ) Highlands Region, which is distinct from but overlaps much of the Highlands Physiographic Province (fig. 1), are used by government agencies as regulatory criteria for land-use decisions. Nitrate (NO_3) concentrations are used as an indicator of overall water quality (New Jersey Highlands Water Protection and Planning Council, 2008) One objective of the Highlands Regional Master Plan is "to determine the amount and type of human development and activity which the ecosystem of the Highlands Region can sustain." This objective has zoning and building-restriction implications. The first step in observing changes in groundwater nitrate concentrations is to characterize pre-regulatory (pre-2008) nitrate concentrations, which are used as a "baseline" for comparison with present (2014) and future nitrate concentrations. Although the groundwater nitrate concentration at a location (for example, a single house or public supply well) can be reliably determined by sampling and analyzing the well water, determining the central tendency and range of nitrate concentrations for an entire region such as the Highlands Region is problematic. Therefore, the U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of

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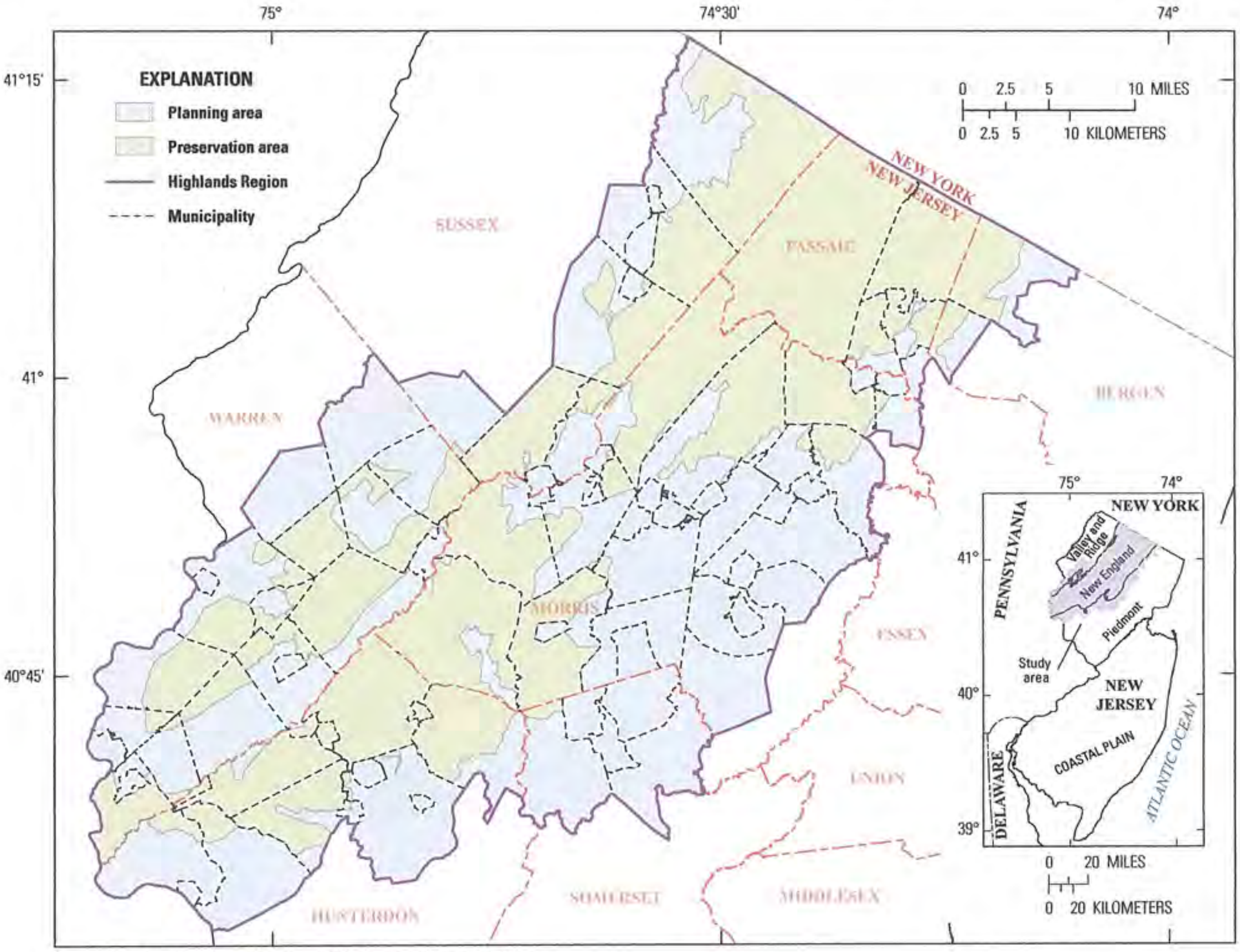

Base modified from New Jersey Department of Environmental Protection digital data, 1:24,000 Universal Transverse Mercator projection, Zone 18, NAD83

Figure 1. New Jersey Highlands Region with Planning and Preservation Areas.

Environmental Protection, conducted a study to determine the best method for use in estimating nitrate concentrations in the Highlands Region.

The range of nitrate concentrations in groundwater in an area can be quantified by sampling water from a representative number of randomly distributed wells. The range, however, will be biased if the wells are not uniformly distributed throughout the study area. Public supply, industrial, agricultural, domestic, and observation wells used for groundwater sampling tend to be installed in land-use areas that are urban, suburban, and agricultural. Wells are less frequently installed in forested, barren, and wetlands areas. Previous investigations (Wakida and Lerner, 2005; Nolan and others, 1998; Dubrovsky and Hamilton, 2010) report that nitrate concentrations in groundwater in urbanized, industrialized, and agricultural areas are consistently greater than those in forested and wetland areas. Therefore, median nitrate concentrations determined in samples from wells in urban and other developed areas likely will be higher than the median nitrate concentrations in samples from wells in forested and wetlands areas. One remedy for such bias is to use data from a subset of wells that are uniformly distributed geographically. This would eliminate geographic bias at a cost of decreasing the data density, reducing confidence in the statistical analyses, and possibly introducing additional bias from the well-selection criteria. An alternative method to eliminate bias is to relate nitrate concentrations to explanatory variables such as land use, surface activities, soil characteristics, hydrology, and population, then use these relations to estimate nitrate concentrations for each area of interest. The alternative method was used in this study to estimate baseline groundwater median nitrate concentrations in the NJ Highlands Region and areas within the Highlands Region.

Regression models can be used to relate water-quality characteristics, such as nitrate concentrations, to independent (explanatory) variables, such as percentages of different

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land-use categories and septic-system density. Logistic-regression models typically are used to relate a set of explanatory variables to the probability of exceeding a threshold value of a water-quality characteristic (Greene and others, 2005; Huang and others, 2013; Tu, 2008; Eckhardt and Stackelberg., 1995; Nolan, 2001; Gardner and Vogel, 2005; Tesoriero and Voss, 2005; Gurdak and Qi, 2012. Typically, the threshold value is a concentration of interest, for example 2 milligrams per liter (mg/L) nitrate as nitrogen (N) in groundwater (Gardner and Vogel, 2005), which was suggested by Mueller and Helsel (1996) as a conservative value to indicate anthropogenic effects. For this study, rather than calculating the probability of exceeding a threshold value, the probability was set in advance (50%, which corresponds to the probability of exceeding the median value), and the logistic-regression model and corresponding threshold concentration (which is the median value) was then determined.

Quantile regression and multiple-linear regression (MLR) were tested as alternatives to the logistic-regression method for estimating median nitrate concentrations in the Highlands Region. Quantile regression (Kroenker and Hallock, 2001) is used to relate one or more independent variables to the value of one dependent variable that corresponds to specified quantiles of the range of dependent-variable values. Multiple linear regression (MLR) is commonly used to relate sets of explanatory variables to water-quality constituents (Helsel and Hirsch, 2002). For example, Sando and others (2014) relate log-transformed concentrations of water-quality constituents to time, streamflow, and season. MLR was similarly applied in this study. Median calculations based on logistic regression, quantile regression, and multiple-linear regression were all subjected to calibration checks and validation by comparing medians of lab-measured nitrate concentrations to calculated concentrations. The best estimates of median nitrate concentrations for the entire New Jersey Highlands Region and smaller administratively defined areas were then calculated.

Purpose and Scope

The purpose of this report is to present the methods used to quantify median groundwater nitrate concentrations in the NJ Highlands Region and to estimate median concentrations for the entire Highlands Region and for selected areas within the Highlands Region. Criteria for selecting explanatory variables and developing logistic-regression models are presented, and statistical tests used to evaluate the logistic regression models also are presented. Benefits and limitations of the methods used are described. Comparisons are made between measured and estimated median values. Nitrate concentrations were less than the method detection limit (MDL) in 23 percent of the groundwater samples tested. Nondetects are water samples in which the constituent of interest, in this case nitrate, was not detected. The Kaplan-Meier method of including nondetects (also referred to as left-censored data) was selected over three other methods (assigning nondetects a value of zero, one-half the MDL, and the MDL), though the estimated median nitrate concentrations determined using the other three nondect methods also are presented. The effect of applying each of these four methods on the estimated median nitrate concentrations is described. The estimated median nitrate concentrations were determined for the entire Highlands Region and selected areas within the Highlands Region, and these values can be used as baseline conditions for comparison with future concentrations as land use and other surface characteristics change over time.

Description of Study Area

New Jersey is divided into four physiographic provinces: the Coastal Plain, Piedmont, Highlands, and Valley and Ridge (Dalton, 2003). The Piedmont, Highlands, and Valley and Ridge consist mostly of a series of discontinuous, rounded ridges separated by deep, narrow valleys and occupy the northern one-third of the area of New Jersey. The NJ Highlands Physiographic Province is part of the Highlands that extends to Connecticut, New York, and Pennsylvania (U.S. Forest Service, 2014).

The NJ Highlands Region is an administratively (not geologically) defined area that overlaps, but is distinct from, the Highlands Physiographic Province. The New York-NJ Highlands Region was first delineated in a study by the U.S. Forest Service (USFS) (Michaels and others, 1992). The USFS described it as an area of national significance that largely consists of forests and farms but needing protection from encroaching urban sprawl. The Highlands Region was later expanded to include areas of Pennsylvania and Connecticut. The NJ Highlands Region encompasses 2,505 square kilometers (km^2) of the Highlands Physiographic Province and also includes 654 km^2 of the Piedmont and 316 km^2 of the Valley and Ridge Physiographic Provinces. The Highlands Region covers 3,474 km^2 and includes parts of Hunterdon, Somerset, Sussex, Warren, Morris, Passaic and Bergen Counties (New Jersey Highlands Council, 2008). The protection of forests and wetlands, preservation of farmland, and permitting of additional urbanization in existing community areas are objectives of the NJ Highlands Water Protection and Planning Council. The Council was formed in 2004 as a provision of the Highlands Water Protection and Planning Act (N.J.S.A. 58:12A-26 et seq.; New Jersey Highlands Water Protection and Planning Council, 2008), which was primarily enacted to protect the drinking-water source for 5.4 million residences of New Jersey and New York. The NJ Highlands Region is divided into the Planning Area, administered by the New Jersey Department of Environmental Protection, in which conformance with the Regional Master Plan is voluntary, and the Preservation Area, administered by the New Jersey Highlands Council, in which conformance with the Plan is mandatory. The Planning and Preservation Areas are each further divided into three Land-Use-Capability Zones: the Conservation Zone, Existing Community Zone, and Preservation Zone (fig. 2, table 1).

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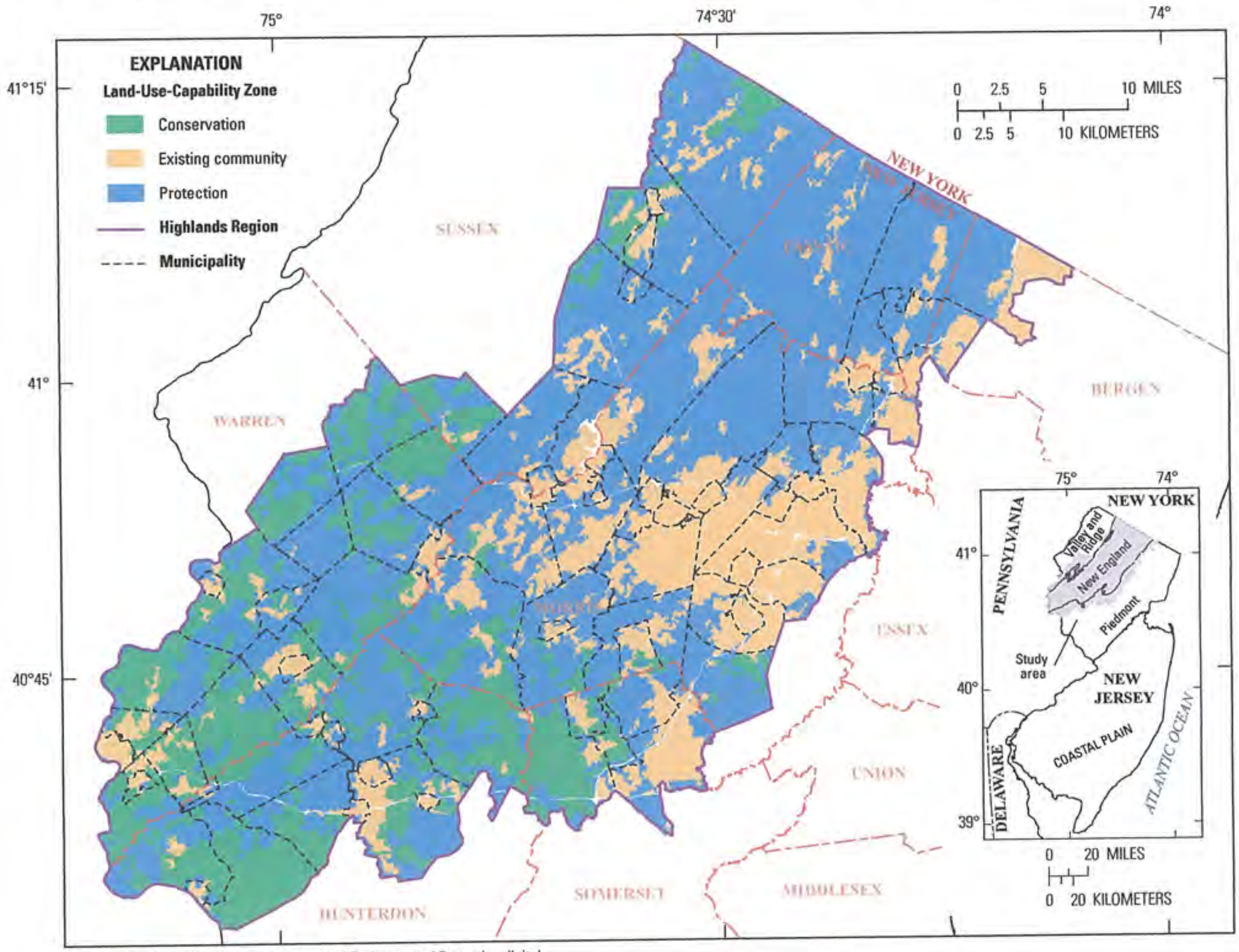

Base modified from New Jersey Department of Environmental Protection digital data, 1:24,000 Universal Transverse Mercator projection, Zone 18, NAD83

Figure 2. NJ Highlands Region with Land-Use Capability Zones.

Land use in the NJ Highlands Region, as determined from 2007 land use-land cover data (New Jersey Department of Environmental Protection (NJDEP) 2010), consists of about 44 percent of forest land; 12 percent of agricultural land; 26 percent of urban land; and 15 percent of barren, wetlands, and water (fig. 3). Percentages of the six major land-use categories in the Highlands Region vary by Planning Area and Preservation Area and among the three Land-Use-Capability Zones within each Area are shown in table 1.

The Preservation Area consists of 18,000 km^2, and the Planning area is slightly larger, about 19,000 km^2. There is more urban and agriculture land use in the Planning Area than in the Preservation Area (table 1). Urban expansion is limited in the Protection Zones and Conservation Zones. Urban expansion is allowed to a greater extent in the Existing Community Zones but only as is "compatible with the protection and character of the Highlands environment, at levels that are appropriate to maintain the character of established communities," as stated in the Master Plan (New Jersey Highlands Council, 2008). The Conservation Zone consists of highly agricultural land, and urban expansion is limited to protect the resources and character of this Zone (New Jersey Highlands Council, 2008). In the Preservation Area and Planning Area, forest and wetland land uses dominate the Protection Zone, agriculture dominates the Conservation Zone, and urban land use dominates the Existing Community Zone.

Previous Investigations

Previous investigations addressed nitrate in the study area and relations between land-use patterns and nitrate in groundwater. Agricultural and domestic fertilizers and septic systems are acknowledged as substantial sources of nitrate to groundwater (Nolan and others, 2002). Nicholson and others (1996) studied the hydrogeology, groundwater flow, and nitrates in the NJ Highlands. Glacial valley-fill, carbonate

68x

Table 1. Land use in the NJ Highlands Region.

Area and zone	Land use, in percent[1,2]					
	Urban	Agricultural	Forest	Wetlands	Barren	Water
Entire NJ Highlands	27.0	12.3	45.6	10.3	2.1	2.7
Planning Area	37.8	16.9	33.0	11.3	1.0	3.6
Conservation Zone	15.89	44.48	27.46	10.32	0.74	1.11
Existing Community Zone	64.16	2.83	20.97	6.64	1.11	4.29
Protection Zone	22.98	6.54	49.54	15.77	0.92	4.25
Preservation Area	16.9	8.1	60.3	9.6	0.6	4.6
Conservation Zone	16.81	38.12	33.80	10.04	0.35	0.89
Existing Community Zone	54.64	3.56	28.00	7.04	0.77	5.99
Protection Zone	13.56	3.71	67.32	9.82	0.61	4.98
All grid cells with sampled wells	32.92	13.26	41.38	8.82	0.57	2.80
All grid cells with no sampled wells	21.75	11.47	49.61	11.08	0.93	4.89

[1]Calculated from New Jersey Department of Environmental Protection digital data (New Jersey Department of Environmental Protection, 2010)

[2]Percentages do not sum to 100 because of rounding.

rock, and gneissic rock aquifers were identified as the major sources of water. Human activities affected water resources by increasing the concentrations of volatile organic compounds, iron, and nitrate and in groundwater and surface water, and by consumptive use, resulting in decreasing discharge to streams and lower water tables. The maximum nitrate concentration in water samples collected from 73 wells completed in three aquifers was 9.5 milligrams per liter (mg/L) as nitrogen (N), with the highest nitrate concentrations in samples from present or previous agricultural areas and urbanized areas. The distribution of nitrate concentrations in forested and wetland areas indicate that background concentrations are less than 1 mg/L as N. Concentrations varied among three aquifers (table 2); glacial valley-fill aquifers had higher median concentrations of nitrate than carbonate and gneissic aquifers.

Serfes (1994) studied the natural groundwater quality in bedrock aquifers of the Newark Basin. The Newark Basin is synonymous with the Piedmont Physiographic Province and is adjacent to and southeast of the Highlands Physiographic Province. Nitrate concentrations in 55 well-water samples ranged from 0.1 to 7.4 mg/L as N with a median concentration of 1.6 mg/L as N.

Clawges and Vowinkel (1996) evaluated the roles of well construction, hydrogeology, and land use in the susceptibility of groundwater bedrock aquifers in the Newark Basin to nitrate contamination. Nitrate was the dominant form of nitrogen measured in samples from 132 wells. Nitrate concentrations ranged from less than 0.1 to 9.5 mg/L as N with a median concentration of 1.6 mg/L as N, similar to that in the Piedmont Physiographic Province (Serfes, 1994). Shallow wells and wells with shallow open intervals were associated with higher nitrate concentrations, indicating a greater effect from agriculture and urbanization. Groundwater nitrate concentrations were statistically lower in forested areas and wetlands than in agricultural and urban areas. The highest concentration measured was 9.5 mg/L as N in a groundwater sample from an agricultural area.

Serfes (2004) summarized the groundwater quality in the bedrock aquifers of the Highlands and Valley and Ridge Physiographic Provinces in New Jersey (fig. 1 inset) from 97 well-water samples collected from the Middle Proterozoic, Kittatinny Supergroup, and Martinsburg Formations. Nitrate concentrations ranged from less than (<) 0.05 to 5.7 mg/L as

Table 2. Statistical summary of nitrate in groundwater samples from the glacial valley-fill, carbonate-rock, and gneissic-rock aquifer systems in the NJ Highlands Region.

[mg/L, milligrams per liter; N, nitrogen; <, less than]

Aquifer type	Nitrate concentration (mg/L as N)[1]			
	Samples	Minimum	Median	Maximum
Glacial Valley-Fill	27	<0.10	1.40	6.10
Carbonate rock	30	<0.10	1.00	9.50
Gneissic rock	16	<0.10	0.38	2.00

[1] From Nicholson and others, 1996

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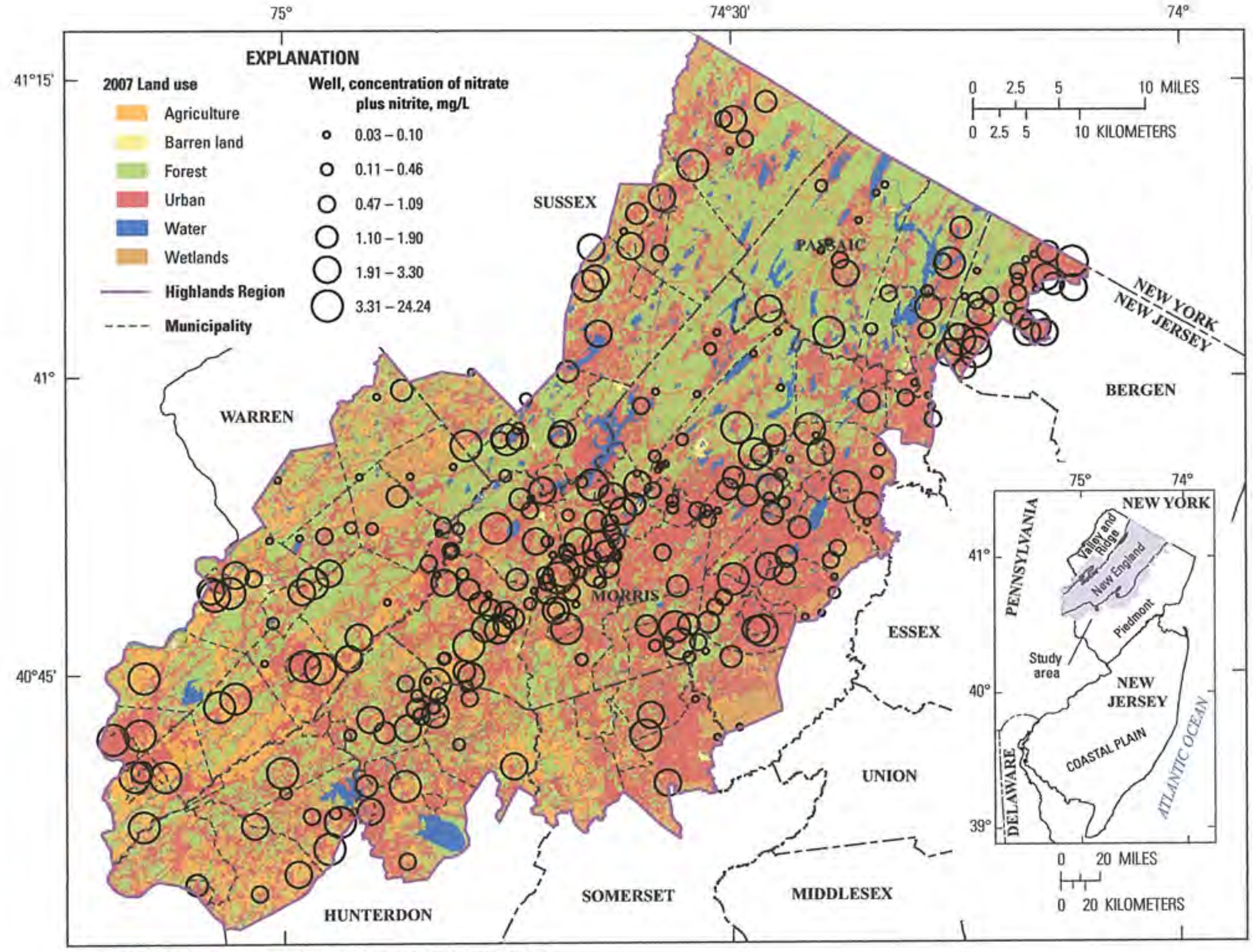

Base modified from New Jersey Department of Environmental Protection digital data, 1:24,000 Universal Transverse Mercator projection, Zone 18, NAD83

Figure 3. Land-use patterns, locations of wells with data in the U.S. Geological Survey National Water Information System, and nitrate concentrations in groundwater in the New Jersey Highlands Region. (mg/L, milligrams per liter)

N in these samples (table 3). The median nitrate concentration among the 97 samples was 0.41 mg/L as N.

Hoffman and Canace (2004) published a method to estimate nitrate concentrations in groundwater near septic systems and the average land area required to sufficiently dilute nitrate in septic-system effluent to avoid exceeding maximum nitrate concentration goals for potable water supply. The method is based on a mass-dilution model (Trela and Douglas, 1978) and a groundwater-recharge model (Charles and others, 1993). This method is currently (2015) used in the New Jersey Pinelands to protect groundwater resources by limiting the density of new urban construction.

Dubrovsky and others (2010) reviewed water-quality data from 1992 to 2004 for streams and groundwater throughout the United States. Nationally, nitrate concentrations in groundwater appear to be increasing slowly. Data from more than 5,000 wells showed that nitrate concentrations in groundwater in urban and agricultural areas are substantially greater than concentrations in forested and wetland areas and are greater than the estimated 1 mg/L as N that occurs as a natural background level. Among 495 wells that were sampled during 1993–2003, median nitrate concentrations increased from 3.2 to 3.4 mg/L as N, and the exceedance of the Federal and State health-based maximum contaminant level (MCL; 10 mg/L as N) increased from 16 to 21 percent.

Table 3. Statistical summary of nitrate concentrations in groundwater samples from the Middle Proterozoic bedrock, Kittatinny Supergroup, and Martinsburg Formation in the Highlands and Valley and Ridge Physiographic Provinces in NJ.

[mg/L, milligrams per liter; N, nitrogen; <, less than]

Geologic Formation	Nitrate concentration (mg/L as N)[1]		
	Minimum	Median	Maximum
Middle Proterozoic (45 samples)	<0.10	0.76	5.7
Kittatinny Supergroup (26 samples)	<0.05	0.39	5.6
Martinsburg Formation (26 samples)	<0.05	0.16	5.3

[1]From Serfes, 2004

Method of Study

The method for determining the median nitrate concentration in groundwater of the NJ Highlands Region and Areas and Zones within the Highlands Region required the following steps:

1. Obtain available nitrate-concentration data from groundwater samples from the NJ Highlands Region.
2. Develop a method of estimating the median value of a dependent variable from a series of logistic-regression relations and a set of explanatory (independent) variables. In this case, nitrate concentration is the dependent variable, and the independent variables are the land characteristics responsible for, or otherwise related to, nitrate concentrations.
3. Compile a comprehensive set of potential explanatory variables, which may be related to nitrate concentration, to be used in regression models.
4. Quantify the explanatory variables for areas surrounding wells for which nitrate data are available.
5. Identify an optimum set of explanatory variables for a series of logistic-regression equations based on threshold values that represent the range of measured nitrate concentrations in the NJ Highlands Region. Develop logistic-regression models.
6. Estimate median nitrate concentrations for the NJ Highlands Region and the Planning and Preservation Areas; Conservation, Existing Community, and Protection Zones; and each Area:Zone combination.
7. Evaluate logistic-regression model performance.
8. Compare median nitrate concentrations to concentrations obtained using quantile regression and multiple-linear regression.
9. Analyze the effects of using alternative methods that include nondetects in the model development and median nitrate calculations.

Nitrate-Concentration Data

Two independent sources of groundwater nitrate data were used for this study (table 4). The first dataset is a subset consisting of 782 wells in the Highlands Physiographic Province with data available from the USGS National Water Information System (NWIS) (http://waterdata.usgs.gov/nwis). The second dataset consists of 19,369 wells in the Highlands Physiographic Province with data available from the NJ Private Well Testing Act (PWTA; New Jersey Department of Environmental Protection, 2003).

National Water Information System Data

Wells in the NWIS database were installed for diverse purposes, including water supply, observation, and agriculture. The data are of exceptional quality because samples were analyzed by USGS laboratories and extensively reviewed. This dataset was used in a previous study to quantify median nitrate concentrations in the Highlands Region (New Jersey Highlands Council, 2008).

The 782 wells in the NWIS database sampled between 1983 and 2004 were evaluated to identify well clustering and to remove the wells with substantially overlapping 500-meter-radius buffers in order to avoid duplicate representation of areas (Barringer and others, 1990). A subset of 352 wells within the Highlands Region (fig. 3) was identified with minimum buffer overlapping, and nitrate data from this subset were used to identify the five explanatory variables used in all logistic models and for the initial estimates of median nitrate concentrations in Highlands groundwater (New Jersey Highlands Water Protection and Planning Council, 2008). Generally, NWIS wells are clustered in urban land-use areas. Water samples with the highest nitrate concentrations occurred mostly in areas dominated by urban and agricultural land use. Nitrate concentrations ranged from 0.03 to 24.2 mg/L as N with a median value of 0.98 mg/L as N, and 48 values (16 percent) were nondetects.

Circular well buffers are widely used in spatial groundwater-quality investigations. The 500-meter radius was selected on the basis of an evaluation by Koterba (1998), which stated that the best compromise for defining land-use characteristics around wells in a wide variety of hydrogeologic settings across the Nation would be a circular buffer with a 500-meter radius from the well. This was further supported by Johnson and Belitz (2009). In this investigation, it was assumed that the area within the 500-meter circular well buffer represents land use and surface characteristics, such as

Table 4. Sources of data on nitrate in groundwater in the New Jersey Highlands Region.

[NWIS, U.S. Geological Survey (USGS) National Water Information System; PWTA, New Jersey Private Well Testing Act; mg/L, milligrams per liter; --, no information; <, less than; NO_3, nitrate; QA, quality assurance]

Data source:	NWIS	PWTA	NWIS and PWTA
Number of groundwater samples	300	19,369	19,669
Sampling dates	12/02/1983–06/23/2004	10/14/2001–01/20/2011	12/02/1983–01/20/2011
Nitrate concentration (mg/L)			
Minimum (mg/L)	<0.03	<0.02	<0.02
Median (mg/L)	0.94	1.79	1.80
Maximum (mg/L)	24.20	153	153
Analytical methods, QA	Multiple USGS methods, USGS sampling and QA	As specified by each analytical method	--
Total number of grid cells	9,745	9,745	9,745
Number of grid cells with NO_3 data	284	4,379	4,516

septic-system inputs and fertilizer application, that may affect the local groundwater quality.

Private Well Testing Act Data

The New Jersey PWTA, which became effective in September 2002, requires water-quality sampling of domestic wells at the time of the sale of a home (Atherholt, 2009; NJDEP, 2003). PWTA water-quality data and the global positioning system location data are compiled by the NJDEP. The PWTA data are extensive, but water samples are collected only from domestic supply wells. PWTA data do not contain the information available for NWIS wells, such as well depth and aquifer identification. The PWTA specified a list of 12 approved analytical methods for analysis of nitrate (table 5). All samples were analyzed by NJ State certified laboratories, which are required to follow quality assurance/quality control protocols specified by the published analytical methods. Analysis of variance (ANOVA) and graphical analysis showed no spatial bias in either analytical methods used to analyze PWTA samples or in the nitrate method detection limit (MDL).

PWTA data for 19,369 wells sampled during October 2002–January 2011 within the NJ Highlands Region boundary were used in this study. PWTA rules mandate a level of anonymity associated with well locations. NJDEP's method to obscure the well location is to create a grid of square cells that are 610 m (2,000 ft) per side. Wells in each grid cell are plotted at the center of each grid. Therefore, the location of each well was generalized to within plus or minus 431 m (1,414 ft.) of the actual location. The number of groundwater samples collected in each grid cell is shown on a map of the Highlands Region in fig. 4. As with NWIS wells, PWTA wells are clustered in urban land-use areas.

The grid of 610-m-square cells (total of 9,745 cells) was generated using GIS software for the NJ Highlands Region boundary, and a unique identifier was assigned to each grid cell (Grid ID). Nitrate concentrations from all well samples within a grid cell were compiled, and the median measured nitrate concentration was calculated where grid cells contained more than one well. Of the 9,745 cells that make up the area of the NJ Highlands Region and the 19,369 wells that were sampled, the PWTA dataset provided a median nitrate concentration for each of 4,379 grid cells and no data for 5,366 grid cells. Nitrate concentrations for all PWTA samples ranged from 0.02 to 153 mg/L as N, and the median concentration was 1.79 mg/L.

Combined NWIS and PWTS Data

The NWIS and PWTA water-quality datasets were combined to optimize the use of all available data, which provided measured nitrate concentrations in 4,516 grid cells, and 5,228 grid cells with no nitrate data. The number of samples per cell with nitrate data ranged from 1 to 114 with a median of 3 samples and an average of 4.3 samples. As with the separate NWIS and PWTA data, most sampled wells tended to be situated in areas with urban or agricultural land. The median nitrate concentration in each cell ranges from 0.027

Table 5. Approved methods for nitrate analysis of New Jersey Private Well Testing Act samples.

[EPA, U.S. Environmental Protection Agency; ASTM, American Society for Testing and Materials; Cd, cadmium; --, no information; mg/L, milligrams per liter; N, nitrogen]

Methodology	Typical MDL[1] (mg/L as N)	EPA method	ASTM method	Standard methods	Other methods	Number of samples
Automated Cd reduction	0.05	353.2	D3867-90A	4500-NO3-F	--	1,009
Ion chromatography	0.01	300.0	D4327-91	4110B	B-1011 (Millipore)	9,032
Ion selective electrode	0.14	--	--	4500-NO3-D	601 (ATI Orion)	3,000
Manual Cd reduction	0.01	--	D3867-90B	4500-NO3-E	--	0
Unspecified method	--	--	--	--	--	4,864
Flow Injection/Cd reduction	0.01	--	--	--	10-107-04-1A (Lachat)	977

[1]Method detection limits (MDL) vary among labs and over time in individual labs

to 26.2 mg/L as N with an overall median concentration of 1.50 mg/L as N.

Of the 19,670 PWTA and NWIS samples, 511 (3 percent) had concentrations greater than the State and Federal Maximum Contaminant Level (MCL) for nitrate of 10 mg/L as N. A total of 4,519 (23 percent) samples had concentrations less than the MDL, which ranged from 0.020 to 10.0 mg/L as N, and are categorized as nondetects. The MDL varied among samples because of differences among laboratories and analytical methods used.

Nondetect Data

Among the 23 percent of samples that were nondetects, a disproportionally large percentage occurred in forested land and wetlands. The Preservation Area had a higher percentage of nondetects (25.8 percent) than the Planning Area (19.9 percent). Similarly, the Protection Zone had a higher percentage (27.0 percent) than either the Conservation or Existing Community Zones (18.3 and 19.6 percent, respectively). This result is expected, as groundwater that is not affected by anthropogenic surface activities tends to have lower concentrations of nitrate and therefore more nondetects.

Methods of analyzing data that contain nondetects (left-censored data) include assigning a value such as zero, the MDL, or some fraction (such as one-half) of the MDL. These substitution methods, though prevalent in published literature, have no sound basis because no substituted value between zero and the MDL can be argued to be more valid than any other (Helsel, 2005). An alternative method is to conduct the data analysis without assigning specific values to nondetects, such as the Maximum Likelihood Estimate (MLE), where a distribution (known or assumed) is assigned to the data, and statistics based on that distribution, not on individual data, are calculated. The MLE was not used here to estimated median nitrate concentrations in grid cells because the method does not perform well for sample sizes less than 30, and few grid cells contain 30 or more sampled wells. The Kaplan-Meier method is recommended for estimating summary statistics for censored data (Helsel, 2005). It is nonparametric and therefore does not require information or assumptions about data distribution; also it has no minimum sample-size limitations. Therefore, this method was used to calculate the median nitrate concentration for each grid cell. Although it is the best choice for this dataset and analysis, the Kaplan-Meier method is not without limitation. In grid cells that provided a single value, and that value is a nondetect, the default median value was the MDL. This circumstance applied to 385 nitrate concentrations and affected 8.5 percent of grid cells with a single nitrate concentration value. Only 152 (3.3 percent) of those MDL values were greater than or equal to (≥)0.5 mg/L as N, and only those could affect the median concentration in the entire Highlands Region, Planning and Preservation Land-Use-Capability Zone, or Area:Zone combination. Thus, for at least 96.7 percent of grid cells with nitrate data, either the Kaplan-Meier method was applied as designed or the method detection limit was substantially less than the estimated median nitrate concentration in the Highlands Region.

For comparison, median concentrations also were calculated with nondetects set to zero, one-half the MDL, or the MDL; these are discussed in the section "Four Methods of Including Nondetects." This gives the full range of variability in nitrate concentrations resulting from the choice of methods for handling nondetects.

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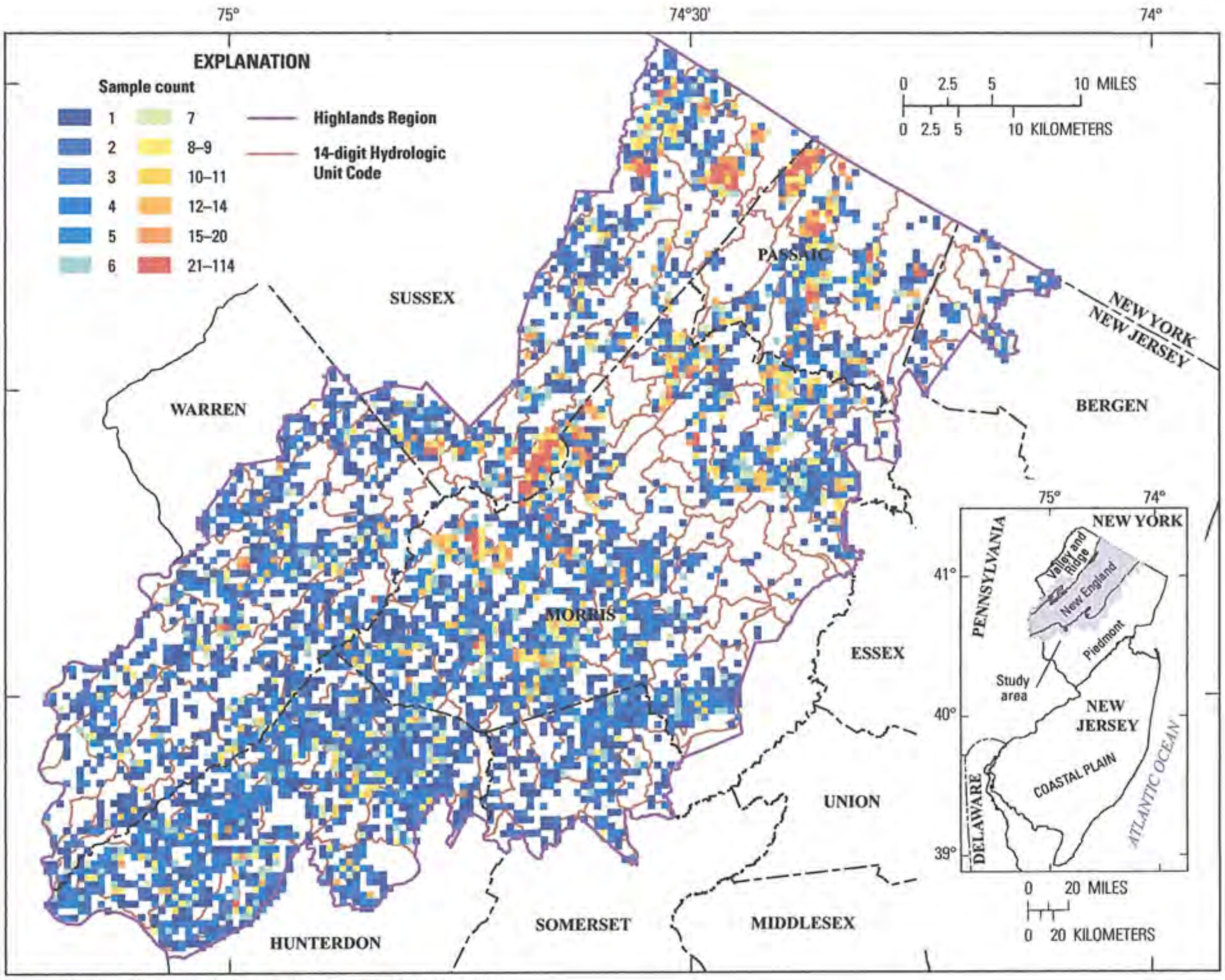

Figure 4. Numbers of groundwater samples collected in each model grid cell for the New Jersey Highlands Region. (Data from the U.S. Geological Survey National Water Information System database and the New Jersey Private Well Testing Act database)

Logistic Regression Model Development

The logistic model, as presented by Greene and others (2005), is of the form

$$p_i = P(Y=1 \mid X_i) = \frac{\exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ..., + \beta_k x_{ik})}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ..., + \beta_k x_{ik})} \quad (1)$$

or (equivalently, the logit form)

$$\ln\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ..., + \beta_k x_{ik} \quad , \quad (2)$$

where

p_i is the probability of the binary response variable Y_i (which can only have values of 0 or 1) being equal to 1;

β_0 is the intercept;

$\beta_1 \ldots \beta_k$ are regression coefficients for each explanatory variable of the regression equation;

$x_{i1}, x_{i2}, ..., x_{ik}$ are values of explanatory variables; and X_i refers to the set of values of all explanatory variables $(1, x_{i1}, x_{i2}, \ldots, x_{ik})$.

The quantity $\frac{p_i}{1-p_i}$ is referred to as the "odds ratio" and is equivalent to $\frac{p(Y=1)}{p(Y=0)}$; it is used to express the probability that an event will occur. For example, if the

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probability of nitrate concentration in a water sample exceeding 2.0 mg/L as N is 0.25, then the odds ratio is $\frac{p(Y=1)=0.25}{p(Y=0)=0.75}$, or 1 to 3. Model coefficients and other parameters were calculated with an iterative maximum-likelihood algorithm by S-Plus (Insightful Corp., 2003). Input scripts for developing multiple logistic-regression models are shown in Appendix 1.

In this investigation, the binary variable Y represents the two cases: Y = 0 where the nitrate concentration of a water sample is less than a threshold concentration C_{Ti}, or Y = 1 where the concentration is greater than or equal to C_{Ti}. Thus, increasing the value of C_{Ti} would increase the probability that Y = 0.

Estimation of Median Nitrate Concentrations

The value of p_i obtained from a logistic-regression model represents a quantile of the range of possible values of the dependent variable. Thus, $p_i = 0.5$ at the 0.5 quantile, which is the median value, of the dependent variable (nitrate concentration). The condition where $p_i = 0.5$ can be expressed as

$$\begin{aligned}\ln\left(\frac{p_i}{1-p_i}\right) &= \ln\left(\frac{0.5}{1-0.5}\right) = \ln(1) = 0 \\ &= \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots, + \beta_k x_{ik}\end{aligned} \quad , \quad (3)$$

and the median value of the dependent variable is equal to the threshold value (C_{Ti}) of the logistic regression model shown in equation (3). This is the property of logistic regression that enables it to be used for estimating median values. The method applied here to estimate a median value is basically to identify two logistic models for which p_i is slightly greater than and slightly less than 0.5 and to assign the median value of the dependent variable by using an interpolation process described below.

The threshold value C_{Ti} for $p_i = 0.5$ is not directly calculable but can be selected from a series of logistic equations with a range of C_{Ti} values. In this investigation, logistic models with C_{Ti} = 0.05, 0.1, 0.15…1.0, 1.1, 1.2,…10.0 were developed (a total of 110 models). Ideally, a logistic model for which $p_i = 0.5$ would be identified, and the corresponding C_{Ti} value would be assigned as the median value. In practice, the set of C_{Ti} values is incremental and not continuous, and therefore, identifying the logistic model for which p_i = exactly 0.5 is unlikely. Linear interpolation was used to calculate between C_{T1} and C_{T2} of two logistic models M_1 and M_2 that have values of p_1 and p_2 which are nearest to 0.5, where p_1 is less than 0.5 and p_2 is greater than 0.5:

$$\text{Median } [NO_3 - N] = \frac{C_{T1}(p_2 - 0.5)}{(p_2 - p_1)} + \frac{C_{T2}(0.5 - p_1)}{(p_2 - p_1)} \quad . \quad (4)$$

Thus, the median nitrate concentration in groundwater underlying an area, such as that within a circular well buffer or grid cells, is determined from a set of explanatory variable values, and the two logistic regression equations from which the probability of exceeding the nitrate concentration is 0.5 are determined by interpolation. The median concentration over a larger area, such as the entire Highlands Region or an area within the Highlands Region is then calculated as the median of the median concentrations of all the smaller areas (well buffers or grid cells).

Explanatory Variables

A total of 320 geographic and environmental characteristics are potential explanatory variables (Appendix 2) related to median nitrate concentrations in groundwater and were compiled in a previous investigation (New Jersey Highlands Council, 2008). The variables include land-use/land-cover characteristics as defined by the Anderson system (Anderson and others 1976). Land-use data for 1986 (NJDEP, 1986), 1995 (NJDEP, 2001), 2002 (NJDEP, 2008), and 2007 (NJDEP, 2010) were used in this investigation so that median nitrate concentrations were evaluated with land-use patterns during similar time periods. Land-use characteristics included percentages of each land use within well buffers and distances between the well and the nearest land-use type. Anderson Level 1 land-use categories in New Jersey are urban, agricultural, rangeland, forest, water, wetlands, and barren land. Subcategories (Anderson Level 2) include mixtures of land use such as, but not limited to, urban/residential, urban/industrial, agricultural/cropland, and agricultural/confined feeding operations. Level 2 categories that are in the Highlands Region are included in the list of 320 potential explanatory variables. Other characteristics listed in Appendix 2 include soil properties, transportation (length and number of roads and railroads), population, hydrology, water-quality characteristics (concentrations of chemical species), and well depth.

To relate independent variables to median nitrate concentrations at individual wells, the value of each variable within an area surrounding the well was determined. This was done for wells in the NWIS database by calculating the value of each of the 320 variables within the 500-meter-radius circular buffer of each well. This was not done for the PTWA wells because the exact location of each well is unknown. The explanatory variables that are identified as the best predictors of median nitrate concentrations in water samples from wells in the NWIS database were then used to determine median nitrate concentrations in the grid cells.

The best predictor variables from the list of 320 geographic and environmental characteristics (Appendix 2) were identified by applying a step-wise regression procedure to obtain a series of five-variable models that best fit the measured nitrate concentrations in groundwater samples from the set of wells in the NWIS database, as described in the Highlands Regional Master Plan (New Jersey Highlands Council, 2008). First, Spearman's Rho nonparametric correlation coefficients (Spearman, 1904) were calculated using the

75x

value of each variable and nitrate concentration in each well. This procedure, previously used by Kolpin (1997), provided a nonparametric, univariate assessment of the regression relation between nitrate concentration and each potential explanatory variable. Next, univariate logistic regression relations were developed for each potential explanatory variable for C_{Ti} values of 0.1, 0.3, 1.0, 3.0, 5.0, and 10 mg/L as N. Potential variables that had significant Spearman's rho (>0.105 or <-0.105 for $p = 0.05$) or significant t values in one or more univariate logistic models (>1.96 for $p = 0.05$) were used in two-variable logistic models. The process was continued for 3-, 4-, and 5-variable models until all possible combinations of variables that were significant in the 4-variable models were used to generate a set of 5-variable models. Selection of the final set of five variables included numerical and subject criteria. Selection was based on the sum of all six t statistic values for the model (including the intercept), minimum of expected colinearity among variables, and maximum spatial representation of the variables. The sum of t statistic values provides an objective, numerical assessment of the overall significance of the logistic model. This metric varies, depending upon the value of the threshold nitrate concentration C_{Ti} associated with the regression equation. C_{Ti} is shown in relation to t value in fig. 5, where t for each of five explanatory variables varies as a function of C_{Ti}. Collinearity occurs between related variables, such as population and percent urban land use, or distance to nearest agriculture and percent agricultural land use. Models with two or more variables that are expected to be collinear were not considered in the selection of the final five variables. Where a choice between two similar or related variables had to be made, the variable with the greatest spatial representation was selected. For example, in selecting between percent urban residential and percent total urban land use, the total urban variable was selected. The final set of explanatory variables consists of urban land use, agricultural land use, septic-system density, total length of streams, and the number of known contaminated sites in the well buffer. The sum of t statistic values for these five variables was large for all six C_{Ti} values. Collinearity was expected to be minimal, and all five variables have greater than or equal spatial representation compared to related variables. This set of variables was used for all future logistic, quantile, and multiple-linear regression model development.

Spreadsheet Design for Estimating Median Nitrate Concentrations

A Microsoft Excel spreadsheet was used to calculate the median nitrate concentration for each area of interest (well buffer, grid cell, or Area:Zone combination). An example of the spreadsheet is shown as Appendix 1. The spreadsheet is arranged in five sections.

1. A list of 110 logistic regression models with model parameters (regression coefficients and intercept), t-statistic values, and standard errors, with documentation of data files used to develop the model.
2. Fields that contain information about the wells and buffer or grid cell. This includes location within Highlands areas and zones, grid or well identification number, lab-measured nitrate concentration (if applicable), and values of the five explanatory variables.
3. Fields in which the probability of exceeding the threshold nitrate concentration is calculated for each well or grid cell for each of the 110 logistic-regression relations.
4. Fields in which the results of (3) are used to estimate the median nitrate concentration for each well or grid cell on the basis of equations 3 and 4.
5. A field in which the overall estimated median nitrate concentration for the area of interest (entire Highlands Region or smaller area within the Highlands) is shown.

Methods Used to Evaluate Logistic Regression Models

Four methods were used to assess the statistical significance of explanatory variables and evaluate the logistic-regression models: the t statistic of each logistic-regression coefficient, which is equivalent to the Wald statistic as calculated by Hosmer and Lemeshow (2000); Press's Q; a test of the correlation between estimated and measured median nitrate; and a test of the overall accuracy of the method to estimate the median values of measured nitrate concentrations.

The t statistic is calculated as the ratio of the maximum likelihood estimate of the slope parameter to an estimate of its standard error:

$$t = W = \beta_i / (\text{standard error of } \beta_i) \quad , \qquad (5)$$

where

β_i represents the coefficient of explanatory variable i in the logistic-regression model.

The value of t for each variable indicates the significance of that variable. Variables with values of t for large samples (where the t distribution is indistinguishable from the standard normal distribution) of greater than 1.96 are significant at the 0.05 level and contribute significantly to the model.

Press's Q statistic is a function of the model's ability to correctly categorize data that were used to develop the model. The two categories are $p>0.5$ and $p<0.5$. A value, for example a lab-measured nitrate concentration, is correctly categorized where $p>0.5$ and the value is greater than the threshold value

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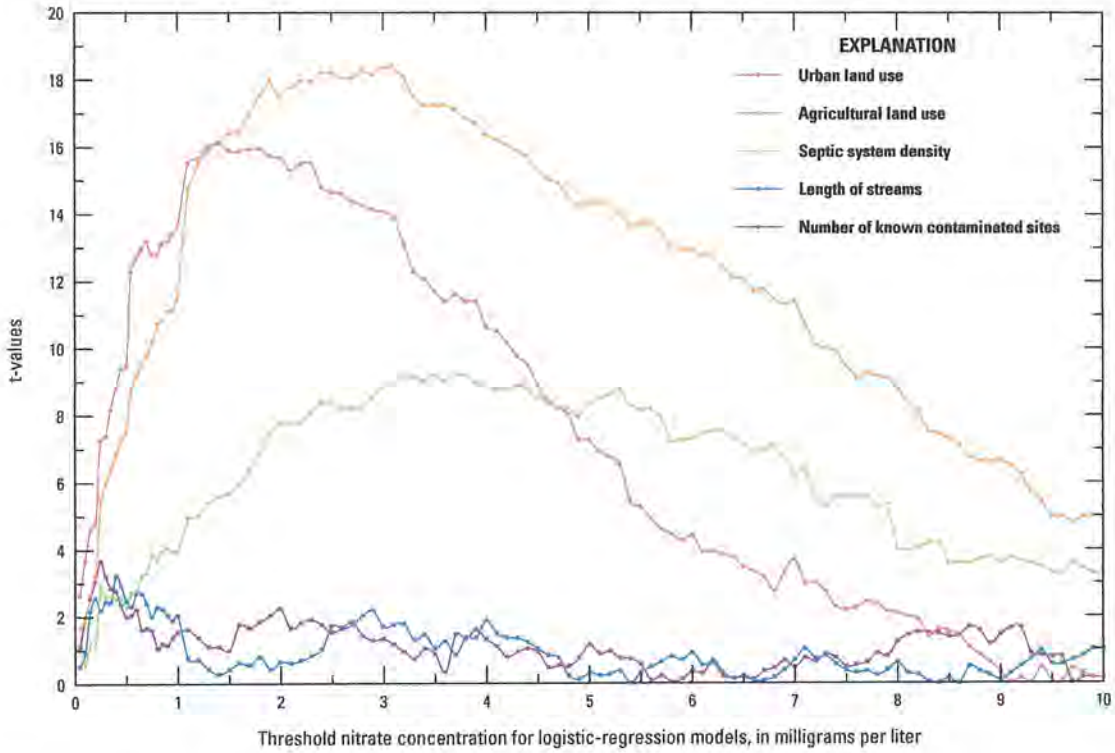

Figure 5. Values of the t statistic for five explanatory variables in logistic-regression equations for nitrate-threshold concentrations 0.05–10.0 milligrams per liter as nitrogen.

or p<0.5 and the value is less than the threshold value. The percent of correct classifications is used to calculate Press's Q:

$$Q = [N - (n^*K)]\ \hat{}2/N^*(K-1) \quad , \qquad (6)$$

where

N is sample size,
n is number of correct classifications, and
K is number of groups (2).

The correlation between deciles of estimated and measured nitrate concentrations also was applied on the basis of methods of Greene and others (2005) and Nolan (2001), where the relation between the calculated probability of exceeding a threshold value and the fraction of measured data that exceeded the threshold value for each quantile of calculated values was determined. Instead of probabilities, the estimated median nitrate concentrations for each quantile were compared to the median measured concentration for the same quantile. This provided an overall assessment of the method's ability to accurately estimate median values and information about the relative magnitude of error over a range of nitrate concentrations.

Two additional model diagnostics were used to evaluate and validate the logistic, quantile, and multiple-linear regression methods of calculating median nitrate concentrations. In the first, the median of measured concentrations was compared to the median concentration determined with the regression methods for the same set of grid cells (all of those with measured nitrate data) as a calibration check. In the second, model validation was conducted by developing regression models using data from half of the grid cells, calculating the median nitrate concentration of the other half with the regression methods, and comparing those estimates to the median of measured nitrate concentration values.

Median Nitrate Concentrations in Groundwater

Median values of lab-measured and estimated nitrate concentrations are discussed in this section (table 6). Medians of lab-measured nitrate concentrations were determined in two ways: as the median of all measured nitrate-concentration values in the combined NWIS-PWTA dataset, and as the median concentration at the grid-cell level. Median nitrate concentrations were determined for the entire Highlands Region, for the

77x

Table 6. Measured and estimated nitrate concentrations in groundwater from the New Jersey Highlands Region.

[mg/L, milligrams per liter; N, nitrogen]

Area within the NJ Highlands	Median nitrate concentration (mg/L as N)		
	Median of measured concentrations		Estimated median concentrations for all grid cells
	Individual water samples	Grid-cell level[1]	
Entire Highlands Region	1.79	1.50	1.25
Planning Area	2.16	1.78	1.55
Preservation Area	1.42	1.25	1.08
Conservation Zone	2.17	2.02	1.76
Existing Community Zone	2.51	2.14	1.78
Protection Zone	1.28	1.10	1.07
Planning Area:Conservation Zone	2.40	2.15	1.78
Planning Area:Existing Community Zone	2.71	2.17	1.78
Planning Area:Protection Zone	1.50	1.27	1.19
Preservation Area:Conservation Zone	1.85	1.93	1.64
Preservation Area:Existing Community Zone	2.26	2.07	1.79
Preservation Area:Protection Zone	1.18	1.02	1.05

[1]For the models, the New Jersey Highlands Region is divided into a grid of 9,745 610-meter-square cells.

Planning and Preservation Areas, for each of the three Land-Use-Capability Zones, and for each Area:Zone combination.

Median of Measured Nitrate Concentrations in the NJ Highlands Region

The median measured nitrate concentration among all water samples in the combined NWIS-PWTA dataset was 1.79 mg/L as N, and concentrations in the 2 Areas, 3 Land-Use Capability Zones, and 6 Area:Zone combinations range from 1.18 to 2.71 mg/L as N (table 6). Concentrations were higher where agricultural or urban land use is more prevalent, such as the Conservation and Existing Community Zones, and lower where land use is predominantly forested land, such as the Protection Zone. There is spatial bias in well locations because many sampled wells are located in urban areas; thus, a bias in median nitrate concentrations was expected. Over-representation of urban and possibly agricultural areas and under-representation of forested areas in the combined NWIS-PWTA database must, therefore, result in higher median nitrate concentrations for all water samples than the actual median concentration for groundwater underlying the entire Highlands Region or any Area, Zone, or Area:Zone combination.

The median nitrate concentrations for the Highlands at the grid-cell level was 1.50, and concentrations in the 2 Areas, 3 Land-Use Capability Zones, and 6 Area:Zone combinations range from 1.02 to 2.17 mg/L as N (table 6). Spatial bias in well locations was reduced by calculating a single nitrate concentration for each grid cell, then calculating the median concentration at the grid-cell level. Each grid cell that contained wells in the combined NWIS-PWTA database received equal

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weight in all calculations. The remaining spatial bias is caused by the lack of nitrate data for about one-half the grid cells; those grid cells tended to have a larger percentage of forested land use (table 1). Therefore, although median concentration at the grid-cell level are subject to less spatial bias than those calculated from individual nitrate concentrations, some spatial bias remains and leads to over-estimation of median nitrate concentrations.

Median of Estimated Nitrate Concentrations

The estimated median nitrate concentration for all grid cells in the entire Highlands Region estimated using the logistic-regression method is 1.25 mg/L as N, and estimated median concentrations range from 1.05 to 1.79 mg/L as N among the Area, Zone, and Area:Zone combinations (table 6). Spatial distribution of estimated nitrate concentrations is shown on a map of the Highlands Region (fig. 6). A comparison of figs. 3 and 6 shows that forested areas correspond to lower median nitrate concentrations, and urban areas correspond to higher median concentrations. Estimated median nitrate concentrations are lower for the entire Highlands Region than the median of measured nitrate concentrations at the individual-sample and grid-cell scales (table 6). This is consistent with lower nitrate concentrations occurring in groundwater underlying grid cells dominated by forested and wetland areas, which are under-represented in the database of nitrate concentrations. Median values of the five explanatory variables used in the logistic models are shown in table 7. Urban and agricultural land uses and septic-system density are greater in the grid cells with sampled wells than in those without. The non-random distribution of wells is apparent when considering that the average percentage of non-urban, non-agricultural land in areas with sampled wells is nearly 15 percent greater than in areas without sampled wells, and there are on average 41 percent more septic systems per unit area in areas with sampled wells than in areas without sampled wells. The average number of known contaminated sites is 21 percent greater in grid cells with sampled wells. It is clear, therefore, that a median nitrate concentration calculated directly from water-sample data would have over-estimated the nitrate concentration of the underlying groundwater for the entire Highlands Region or any Area or Zone.

Fit and Validation of Logistic-Regression Models

Four tests demonstrated that the logistic-regression models generally contained significant explanatory variables, had significant predictive power, and can reliably estimate nitrate concentrations for grid cells in which no wells were sampled. Values of the t statistic for the five explanatory variables are shown in fig. 5. Urban and agricultural land use and septic-system density are the most significant variables over most of the range of threshold nitrate concentrations. The 5 variables decline in significance at the low and high extremes of the range of threshold values, though at least 3 variables are significant ($p=0.05$) for the nitrate threshold range of 0.1–8.3 mg/L as N. All five variables are significant for a nitrate-concentration threshold range of 0.25–0.60 mg/L as N, which includes a large portion of the measured nitrate concentrations. A case could be made for discarding the two weakest variables, known contaminated sites and total length of streams. However, these variables were significant at low concentration thresholds where land-use and septic-system-density variables were depressed. Using or not using the less-than-significant variables in the models has little effect on the calculated probability values, and therefore they were retained for the value they add to the models at the low range of the threshold values. Also, the same five explanatory variables were used in all logistic models so that probabilities among threshold values would be comparable.

Press's Q and the percent of correctly classified samples are shown in fig. 7. More than 60 percent of nitrate concentrations at the grid-cell level were correctly classified as greater than or less than the threshold value for the 110 logistic-regression models. Results of this statistical analysis are most meaningful where the median nitrate concentration is near the threshold value and random selection would result in 50 percent of values being incorrect. At the high and low extremes of values, a large fraction of values would be categorized incorrectly only if the model had no predictive power. This is not the case here (fig. 7) because greater than 90 percent of values were categorized correctly. Similarly, values of Press's Q (equation 6, fig. 7) are significantly greater than the critical value for logistic-regression models where the median nitrate concentration is near the threshold value. The "dip" in the curve (fig. 7) occurs because incorrectly expecting a calculated value to be above or below the threshold value is more likely to occur near the threshold value. The large values of Q reflect the large sample size for each model, which enables all models to accurately categorize samples as greater than or less than the critical value on the basis of the values of the explanatory variables.

Comparisons of Median Measured Nitrate Concentrations and Estimated Median Nitrate Concentrations

Two simulation scenarios were developed to assess the accuracy of the logistic regression method for estimating median nitrate concentrations of the entire Highlands Region and Areas and Zones within the Highlands Region (table 8). In scenario 1, the medians of lab-measured concentrations were compared to the estimated nitrate concentrations for 4,516 grid cells. The set of 110 logistic-regression equations were prepared from values of the five explanatory variables and the median of measured nitrate values for those 4,516 cells. The estimated (1.49 mg/L as N) and measured (1.50 mg/L as N) median concentrations were nearly identical.

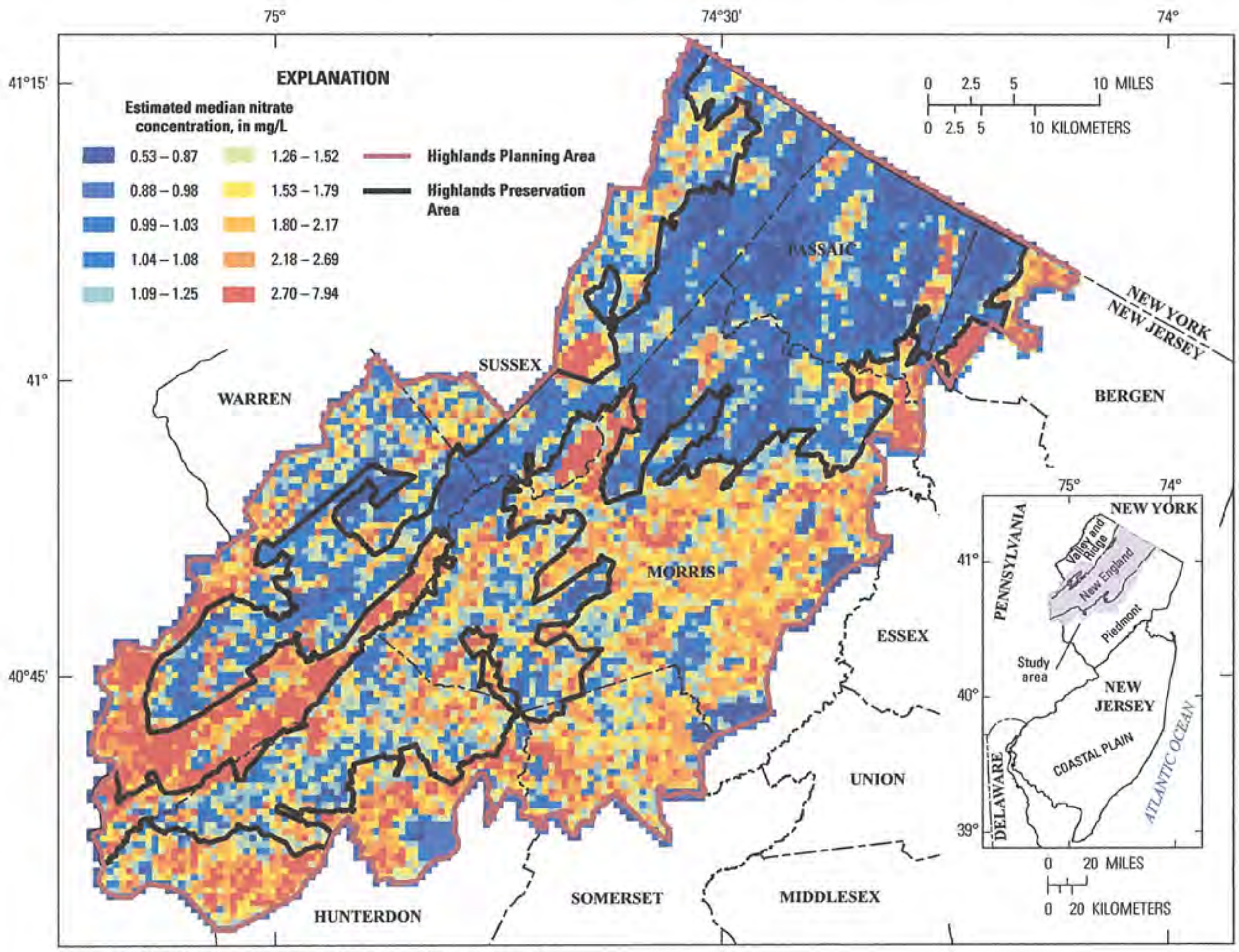

Figure 6. Estimated median nitrate concentration in model grids for the New Jersey Highlands Region. (mg/L, milligrams per liter)

This complements the t (equivalent to the Wald) and Press's Q statistics, which indicate that the selection of explanatory variables was appropriate and that the results of the logistic-regression method are generally significant.

The median estimation method based on logistic regression was further tested by sorting the grid cells in Scenario 1 by estimated concentration (high to low) and dividing the population by 10 quantiles (deciles). The median of estimated nitrate values in each quantile (decile) was then compared to that of the lab-measured values (fig. 8). Median estimated concentrations in the quartiles ranged from 1.01 to 3.24 mg/L as N. The median of estimated nitrate concentrations for the tenth quantile (decile) (3.24 mg/L as N) was the most dissimilar from the median of measured values (3.58 mg/L as N) and was lower by 9.5 percent. The average deviation between quantile (decile) median nitrate concentrations on the basis of estimated versus lab-measured was 4.4 percent. This shows that medians of lab-measured nitrate concentrations were predicted with reasonable accuracy over the range of threshold concentrations.

Model validation was accomplished by developing the set of 110 logistic-regression models using only data associated with half of the grid cells and using those models to estimate median nitrate concentrations for the remaining half of the grid cells, then comparing those median values to the corresponding median concentrations (Scenario 2). As shown in figure 9, the relation between the medians of estimated and lab-measured nitrate concentrations is similar to that for Scenario 1, although the deviation in the 10th decile was slightly higher (10.3 percent) as was the average deviation (5.4 percent).

Figures 8 and 9 show the error trend in the estimated values for Scenarios 1 and 2. Scenario 1 tested the capability of a set of logistic-regression equations to predict the nitrate

80x

Table 7. Summary statistics for explanatory variables used in logistic-regression models to calculate median nitrate concentration in groundwater from in the NJ Highlands Region.

	Grid cells[1] with sampled wells[2]	Grid cells with no sampled wells
Percent urban land use[3]		
Minimum	0	0
Mean	32.9	20.2
Median	27.9	6.6
Maximum	100	100
Percent agricultural land use		
Minimum	0	0
Mean	13.2	11.5
Median	2.3	0
Maximum	97.1	100
Total length of streams		
Minimum	0	0
Mean	1,613	1,628
Median	1,263	1,172
Maximum	13,707	12,942
Septic-system density		
Minimum	0	0
Mean	41.6	29.5
Median	24.2	18.3
Maximum	843	669
Number of known contaminated sites		
Minimum	0	0
Mean	0.17	0.14
Median	0	0
Maximum	7	9

[1]The Highlands Region is divided into a grid of 9,745 610-meter-square cells.

[2]Wells with results inventoried in U.S. Geological Survey National Water Information System or sampled as a requirement of the New Jersey Private Well Testing Act.

[3]Calculated from NJ Department of Environmental Protection digital data (NJ Department of Environmental Protection, 2010).

concentrations at various quantiles, including quartiles for the data used in developing the logistic equations. Scenario 2 was a more realistic test in which median-nitrate-concentration and land-use data from half the grid cells were used to predict the median concentrations in the other half. The analysis of error in the estimated nitrate concentrations (figs. 10 and 11) shows that most estimates were accurate within 10 percent and that the interquartile range of concentrations was estimated accurately. The first and third quantile errors of the estimate for Scenario 2 were 8.3 and 5.5 percent, respectively. The largest errors occurred for the 5th and 10th percentiles (nearly 30% in Scenario 2), indicating that there is greater error, in terms of percent, in the lower concentrations than in the higher concentrations.

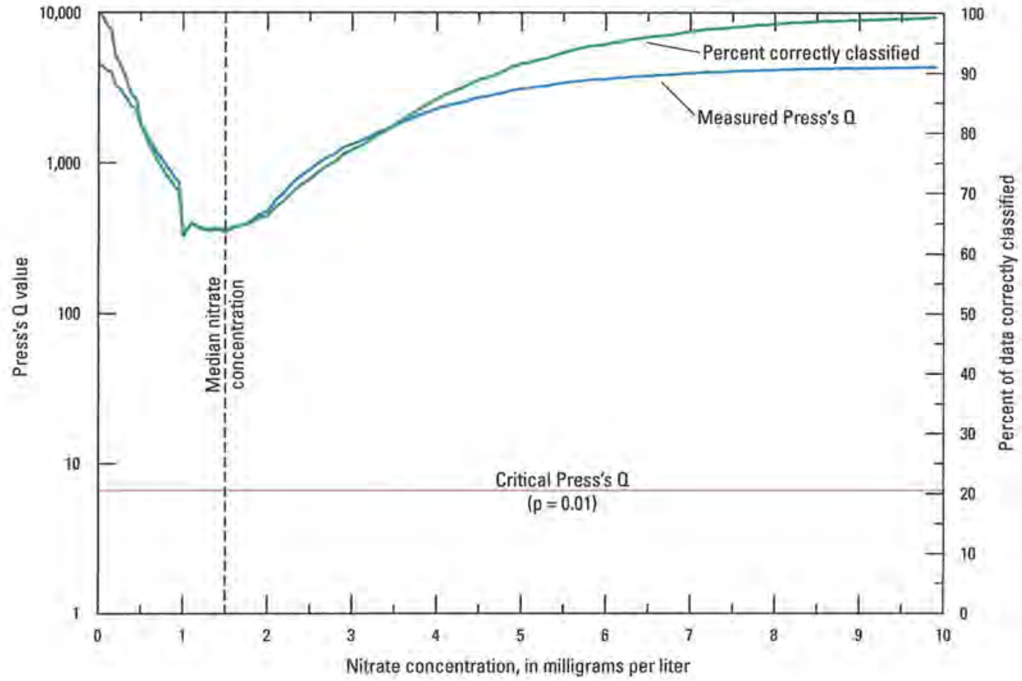

Figure 7. Values of the Press's Q statistic for logistic-regression models with nitrate-threshold concentrations of 0.05–10.0 milligrams per liter of nitrate as nitrogen.

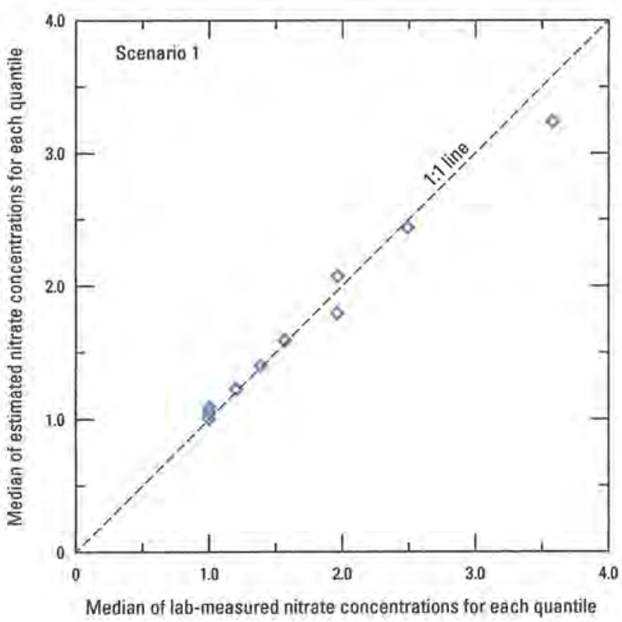

Figure 8. Median measured nitrate concentration in relation to estimated median nitrate concentration for each of 10 quantiles in Scenario 1, in milligrams per liter as nitrogen.

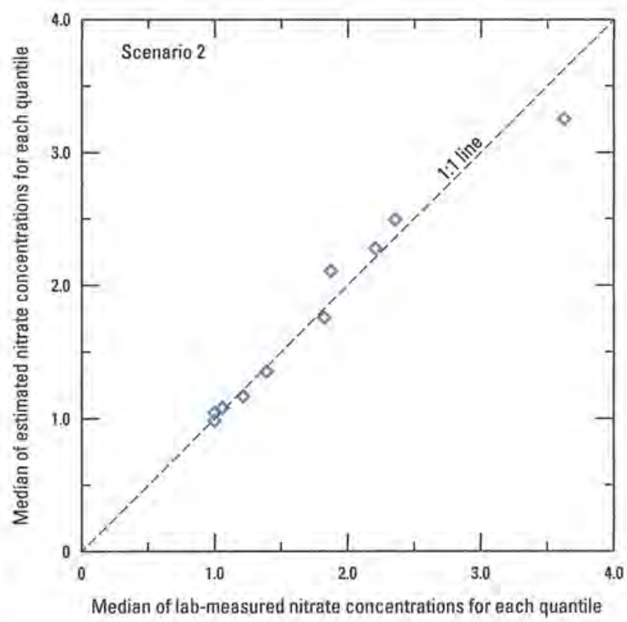

Figure 9. Median measured nitrate concentration in relation to estimated median nitrate concentration for each of 10 quantiles in Scenario 2, in milligrams per liter as nitrogen.

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Table 8. Simulation scenarios for logistic-regression model validation: comparisons between lab-measured and estimated median nitrate concentrations.

[mg/L, milligrams per liter; N, nitrogen]

Validation scenario number and description	Number of grid cells[1]	Median of lab-measured nitrate concentrations (mg/L as N)	Median of estimated nitrate concentrations (mg/L as N)	Percent difference
1. Comparison between medians of lab-measured and estimated nitrate concentrations for the same set of grid cells	4,516	1.50	1.49	0.7
2. Comparison between medians of lab-measured and estimated nitrate concentrations for the same set of grid cells sorted by Highlands Administrative Area and Land-Use Capability Zone[2]				
a. Planning Area	2,300	1.78	1.75	1.7
Conservation Zone	732	2.14	2.04	4.7
Existing Community Zone	759	2.17	2.10	3.0
Protection Zone	809	1.28	1.28	0.0
b. Preservation Area	2,152	1.25	1.25	0.0
Conservation Zone	336	1.90	1.88	1.1
Existing Community Zone	275	2.07	1.95	5.8
Protection Zone	1,541	1.05	1.09	3.8
3. Comparison between median of lab-measured values in 2,258 randomly selected grid cells and estimated values for the remaining cells that have sampled wells	2,258	1.50	1.45	3.3

[1]The Highlands Region is divided into a grid of 9,745 610-meter-square grid cells. Median groundwater-nitrate concentration, land use, and other variables used in logistic regression models are calculated for each grid cell.

[2]The Highlands Area consists of the Planning Area, administered by the New Jersey Department of Environmental Protection, and the Preservation Area, administered by the New Jersey Highlands Council. Each Area includes three Land-Use Capability Zones: the Conservation Zone, Existing Community Zone, and Protection Zone.

Comparison among Estimated Median Nitrate Concentrations Obtained with Logistic, Quantile, and Multiple-Linear Regression Methods

Estimated median nitrate concentrations for the Highlands Region, Planning and Preservation Areas, Land-Use-Capability Zones, and Area:Zone combination determined by logistic, quantile, and multiple-linear regressions are shown in table 9. Although validation results showed that the logistic-regression method was able to estimate median nitrate concentrations slightly more accurately than quantile regression and substantially more accurately than MLR, median concentrations determined using the three methods were similar. The average difference between medians determined with logistic and quantile regressions was less than 0.1 mg/L as N, and the average difference between medians from logistic regression and MLR was 0.15 mg/L as N. As these are all regression methods based on minimizing residual error and all were developed using the same five explanatory variables and nitrate data, similarity among the resulting estimated median nitrate concentrations is not surprising. All three methods effectively remove the spatial bias caused by systematically larger percentages of urban land use and higher septic-system density in grid cells that contain NWIS and PWTA wells. The decision about which regression method to select rests on whether a higher priority is placed on the use of a well-established, proven, accepted method (quantile regression or MLR) that is slightly less accurate according to validation results or the unconventional use of logistic regression with slightly more accurate estimates.

83x

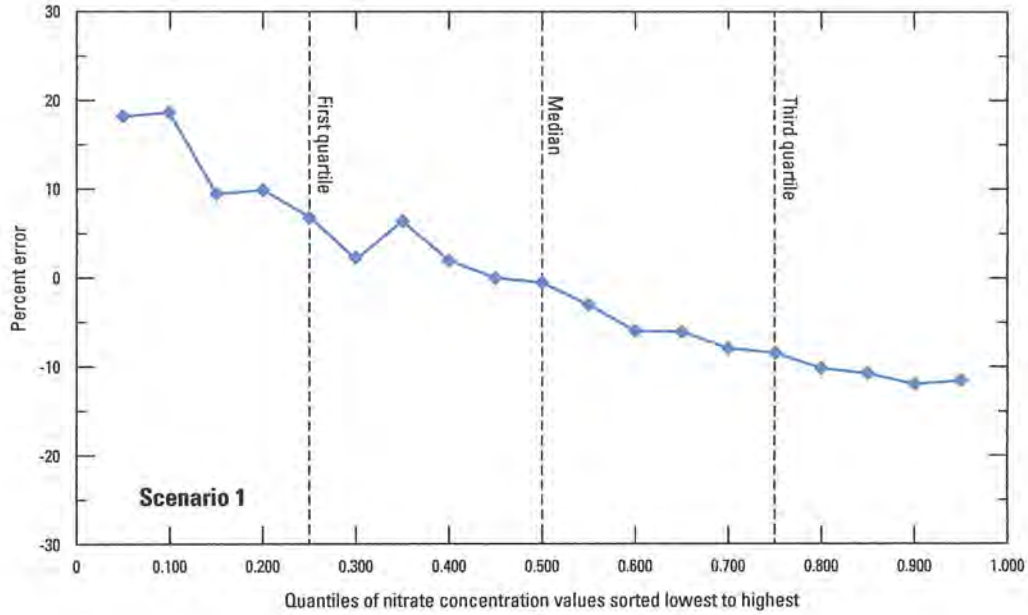

Figure 10. Percent error in estimates of quantiles of nitrate concentration in Scenario 1.

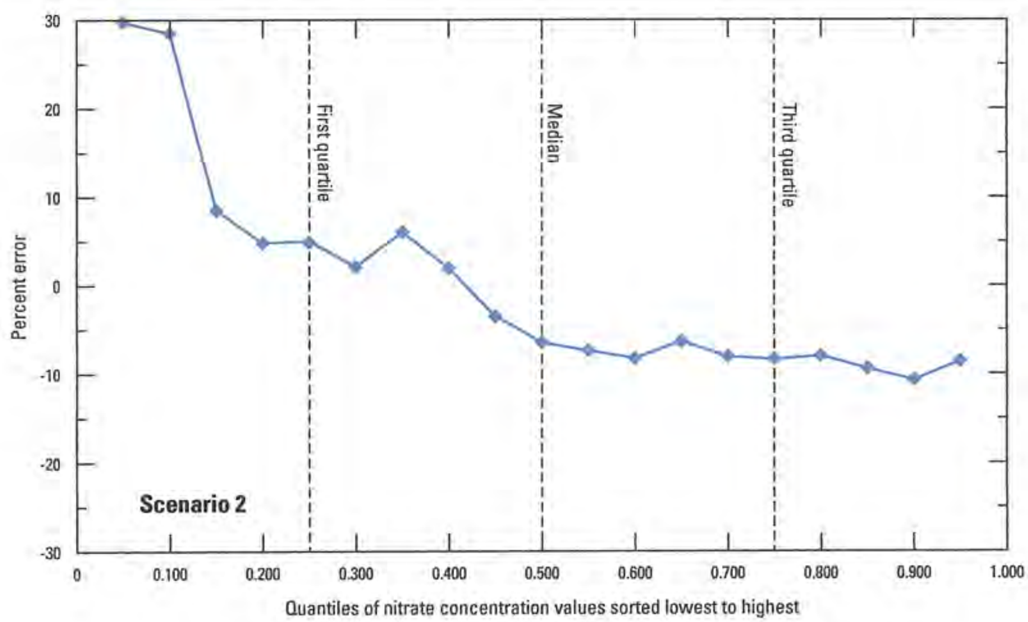

Figure 11. Percent error in estimates of quantiles of nitrate concentration in Scenario 2.

84x

Table 9. Estimated median nitrate concentrations based on logistic regression, quantile regression, and multiple-linear regression models of the NJ Highlands Region.

[mg/L, milligrams per liter; N, Nitrogen; NJ, New Jersey]

Area within the NJ Highlands	Estimated median nitrate concentrations (mg/L as N) assigned to nondetect samples — Method of calculating the median value		
	Logistic regression	Quantile regression	Multiple-linear regression
Entire Highlands Region	1.25	1.37	1.24
Planning Area	1.55	1.67	1.38
Preservation Area	1.08	1.08	1.12
Conservation Zone	1.76	1.94	1.52
Existing Community Zone	1.78	1.83	1.48
Protection	1.07	1.05	1.09
Planning Area:Conservation Zone	1.78	1.97	1.52
Planning Area:Existing Community Zone	1.78	1.83	1.47
Planning Area:Protection Zone	1.19	1.28	1.17
Preservation Area:Conservation Zone	1.64	1.87	1.49
Preservation Area:Existing Community Zone	1.79	1.84	1.50
Preservation Area:Protection Zone	1.05	0.96	1.05

Four Methods of Including Nondetects

The four methods that include nondetects in the median nitrate concentration calculations are (1) simple substitution of zero, (2) substitution of one-half the detection limit, (3) substitution of the detection limit, and (4) estimation based on the Kaplan-Meier method. Although substitution is discouraged in the statistical research literature (Helsel, 2005), there is historical precedent and some conditions under which this approach is recommended (U.S. Environmental Protection Agency, 2009). Substituting zero may be appropriate in cases where nondetects represent an absence of the contaminant being measured. Substituting half the detection limit may be reasonable if it is assumed that the population of nondetects is uniformly distributed along the interval of zero and the detection limit. Substituting the detection limit is the most conservative approach, as it is known that (within the precision of the data-collection methods) the concentration does not exceed that value.

The variability in estimated median nitrate concentrations resulting from the four methods is shown in fig. 12 and table 10. The variability in the Planning Area for each Land-Use-Capability Zone is small. Variability in the Preservation Area, where nitrate concentrations are generally lower, is greater. This is because a greater portion of nitrate concentrations in grid cells are shifted from above the median to below the median when a smaller value is assigned to each nondetect, thus shifting the recalculated median lower to a greater extent. Thus, the median nitrate concentration in the Preservation Area is decreased by 0.11 mg/L as N when the assignment of nondetects is changed from the MDL to zero. This effect is increased when the areas are parsed into the three zones (fig. 12). The choice of nondetect assignment is unimportant for the Conservation Zone within the Planning Area but is significant for the Protection Zone in the Preservation Area where the estimated median nitrate concentration decreases by 0.26 mg/L as N when the nondetect assignment is similarly changed. Other sources of error, which include uncertainty about well location within grid cells and direction and flow rate of groundwater, changing land-use percentages over time, analytical precision, sampling procedures, and the selected set of explanatory variables can add substantially to the error in estimates of median nitrogen concentration.

In summary, the handling of nondetect values is important in estimating median nitrate concentrations where a large fraction of values are nondetects or where the MDL is greater than the median value but has little effect where only a small fraction of values are nondetects or where the MDL is substantially less than the median value. For estimating the median nitrate concentration of groundwater in Highlands Region,

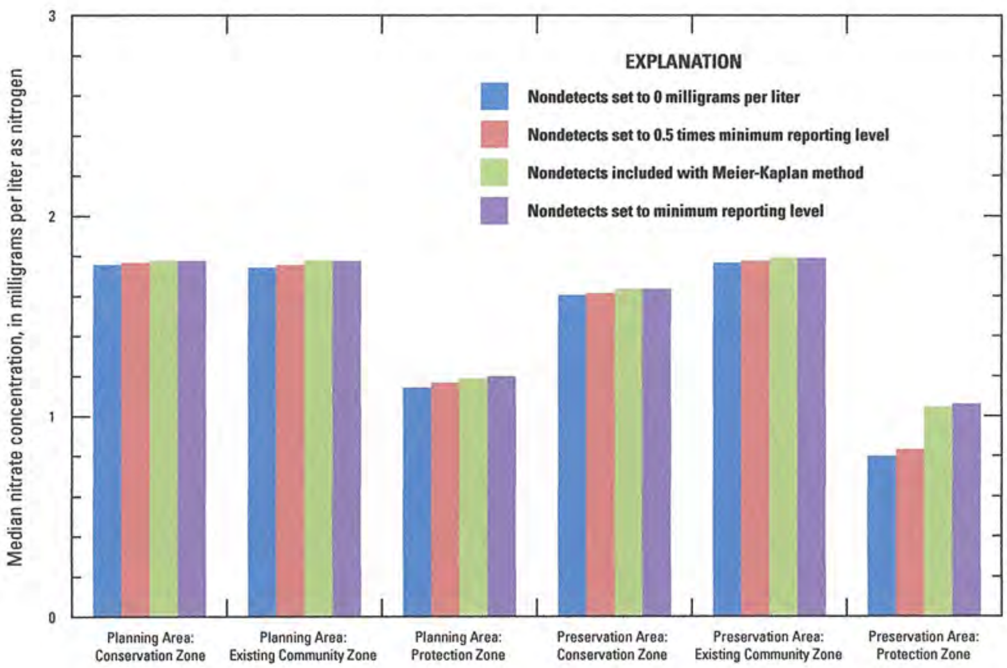

Figure 12. Median estimated groundwater-nitrate concentrations aggregated by grid cell for areas and Land-Use Capability Zones calculated with four methods of including nondetects.

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Table 10. Estimated median nitrate concentrations based on logistic-regression models of the NJ Highlands Region calculated with four methods of assigning values to nondetects.

[mg/L, milligrams per liter; MDL, minimum detection limit; N, nitrogen; NJ, New Jersey]

Area within the NJ Highlands	Estimated median nitrate concentrations (mg/L as N)			
	Value assigned to nondetect			
	Zero[1]	0.5 x MDL[2]	Kaplan-Meier[3]	MDL[4]
Entire Highlands	1.21	1.23	1.25	1.25
Planning Area	1.52	1.53	1.55	1.55
Preservation Area	0.95	0.98	1.08	1.09
Conservation Zone	1.74	1.75	1.76	1.76
Existing Community Zone	1.75	1.76	1.78	1.78
Protection	0.89	0.93	1.07	1.08
Planning Area:Conservation Zone	1.76	1.77	1.78	1.78
Planning Area:Existing Community Zone	1.74	1.76	1.78	1.78
Planning Area:Protection Zone	1.14	1.17	1.19	1.20
Preservation Area:Conservation Zone	1.60	1.61	1.64	1.63
Preservation Area:Existing Community Zone	1.77	1.77	1.79	1.79
Preservation Area:Protection Zone	0.80	0.83	1.05	1.06

[1] Values of all nondetect samples set to zero.

[2] Values of all nondetect samples set to ½ the MDL.

[3] Kaplan-Meier method (Helsel, 2005) used to assign values to nondetect samples.

[4] Values of all nondetect samples set to the MDL.

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the choice of method to include nondetects in the calculation makes a significant difference only for the Protection Zone within the Preservation Area. Assigning the MDL as the value for all nondetects would produce a "worst-case scenario" median concentration and likely would overstate the median nitrate concentration. Selecting either 0.5 x MDL or applying the Kaplan-Meier method would most likely increase the accuracy of the median estimate, but there is no justification for using 0.5 x MDL and no justification for assigning zero as the concentrations of nondetects. Therefore, Kaplan-Meier method remains the most reasonable choice for handling nondetects.

Summary and Conclusions

Nitrate-concentration data were used in conjunction with variables related to land use and land-surface characteristics to estimate median nitrate concentrations in groundwater underlying the New Jersey (NJ) Highlands Region in a study conducted by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection. Sources of nitrate data were the USGS National Water Information System (NWIS) and the New Jersey Private Well Testing Act (PWTA). Spearman's nonparametric correlation coefficient and a step-wise logistic-regression procedure were used to identify five independent (explanatory) variables that produce highly correlated logistic models that are based on a range of nitrate-concentration thresholds—0.1, .03, 1.0, 3.0, 5.0, and 10 milligrams per liter as nitrogen (mg/L as N). The explanatory variables that were found to be significant in logistic-regression models that used NWIS data are percent urban land use, agricultural land use, length of streams, septic-system density, and number of known contaminated sites. Each explanatory variable was quantified within 610-meter x 610-meter grid cells. A series of 110 logistic models with thresholds ranging from 0.05 to 10 mg/L as N were developed, and the probability of a nitrate concentration exceeding a designated threshold concentration in groundwater underlying a grid cell was calculated. For each grid cell, the median concentration was determined by identifying the two logistic models for which the probability of exceedance was nearest to 50 percent, and the corresponding thresholds were the two nitrate concentrations nearest to the median by definition. Linear interpolation was used to calculate the actual median nitrate concentration for each grid cell. A series of evaluation methods was applied to the logistic models. Twenty-three percent of the nitrate data were left-censored (included nondetect values), and the Kaplan-Meier method of including nondetects in the median calculation was applied to estimate the median nitrate concentration in each grid cell. Three additional methods of assigning values to nondetects were explored. Little difference in median nitrate concentration was noted for the Highlands Region and most areas within the Highlands Region regardless of which method was used to handle nondetects. Median nitrate concentrations within the Highlands Region correlated positively with percentages of urban land use, agricultural land use, and septic-system density. Model validation showed that the logistic-regression approach was able to accurately calculate median concentrations with a maximum error of less than 0.1 mg/L as N. Median estimated nitrate concentrations based on quantile regression were slightly less accurate, and those based on multiple-linear regression were substantially less accurate. Although logistic regression produced accurate estimates of median nitrate concentrations for the NJ Highlands Region, the more conventional quantile regression method would be the favored alternative for future similar studies over the somewhat cumbersome logistic-regression method used here. An additional benefit of quantile regression is that it generates an estimate of the value of the dependent variable (for example, nitrate concentration) for any quantile.

The estimated median nitrate concentration in groundwater in the NJ Highlands Region was 1.25 mg/L as N. The estimated median concentrations were highest in the Preservation Area/Existing Community Zone (1.79 mg/L as N) and lowest in the Preservation Area/Protection Zone (1.05 mg/L as N) using the logistic-regression method.

This application of logistic regression to determine the median value of a dependent variable requires a dataset sufficiently large to represent conditions in the area of study, logistic models that are appropriate for evaluating the phenomenon in question with closely spaced threshold values that bracket the range of expected values for the dependent variable, and explanatory variables that are significant across the range of threshold values. The large database provided by the New Jersey Private Well Testing Act coupled with extensive land-use data and other geo-referenced data was ideal for this application of logistic regression. With the spatial bias of well distribution removed, estimates of median nitrate concentration are more representative of the Highlands Region than are median nitrate concentrations for analyzed water samples.

References Cited

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 41 p.

Atherholt, T.B., Louis, J.B., Shevlin, J., Fell, K., Krietzman, S., 2009, The New Jersey Private Well Testing Act: An overview: New Jersey Department of Environmental Protection, Division of Science, Research and Technology, accessed October 31, 2014, at http://www.state.nj.us/dep/dsr/research/pwta-overview.pdf.

Barringer, T., Dunn, D., Battaglin, W., and Vowinkel, V., 1990, Problems and methods involved in relating land use to groundwater quality: Water Resources Bulletin, American Water Resources Association, v. 26, no. 1, 9 p.

88x

Charles, E.G., Behroozi, Cyrus, Schooley, Jack, and Hoffman, J.L., 1993, A method for evaluating ground-water-recharge areas in New Jersey: Trenton, N.J., New Jersey Geological Survey Report GSR-32, 95 p.

Clawges, R.M., and Vowinkel, E.F., 1996, Variables indicating nitrate contamination in bedrock aquifers, Newark Basin, NJ: Journal of the American Water Resources Association, v. 32 no. 5, p. 1055–1066.

Dalton, 2003, Physiographic provinces of New Jersey: Trenton, N.J., New Jersey Geological Survey Circular, 2 p.

Dubrovsky, N.M., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton, P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., and Wilber, W.G., 2010, The quality of our nation's water—Nutrients in the nation's streams and groundwater, 1992–2004: U.S. Geological Survey Circular 1350, 176 p.

Dubrovsky, N.M., and Hamilton, P.A., 2010, Nutrients in the Nation's streams and groundwater: National findings and implications: U.S. Geological Survey Fact Sheet 2010–3078, 6 p.

Eckhardt, D.A.V., and Stackelberg, P.E., 1995, Relation of ground-water quality to land use on Long Island, New York: Ground Water, v. 33, p. 1019–1033.

Gardner, K.K., and Vogel, R.M., 2005, Predicting groundwater nitrate concentration from land use: Ground Water, v. 43, no. 3, p. 343–352.

Greene, E.A., LaMotte, A.E., and Cullinan, K., 2005, Groundwater vulnerability to nitrate contamination at multiple thresholds in the Mid-Atlantic Region using spatial probability methods: U.S. Geological Survey Scientific Investigation Report 2004–5118. 24 p.

Gurdak, J.J., and Qi., S.L., 2012, Vulnerability of recently recharged groundwater in principle aquifers of the United States to nitrate contamination: Environmental Science and Technology, v. 46, p. 6004–6012.

Helsel, D.R., 2005, Nondetects and data analysis: statistics for censored environmental data: Hoboken, N.J., Wiley-Interscience, 250 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources, *in* U.S. Geological Survey, Techniques of Water-Resources Investigations of the United States Geological Survey, Hydrologic analysis and interpretation, book 4, chap. A3.

Hoffman, J.L., and Canace, R.J., 2004, A recharge-based nitrate-dilution model for New Jersey: New Jersey Geological Survey Open File Report OFR 04–1, 27 p.

Hosmer, D.W., and Lemeshow, S., 2000, Applied logistic regression: Hoboken, N.J., Wiley-Interscience, 373 p.

Huang, J., Zhan, J., Yan, H., Wu, F., and Deng, X, 2013, Evaluation of the impacts of land use on water quality: A case study in the Chaohu Lake Basin: The Scientific World Journal, v. 2013, 7 p.

Insightful Corp., 2003, S-PLUS version 6.2: Seattle, Wash., USA.

Johnson, T.D., and Belitz, K., 2009, Assigning land use to supply wells for the statistical characterization of regional groundwater quality: Correlating urban land use and VOC occurrence: Journal of Hydrology, v. 370, p. 100–108.

Kolpin, D.W., 1997, Agricultural chemicals in groundwater of the Midwestern United States: Relations to land use: Environmental Science and Technology, v. 26, p. 1025–1037.

Koterba, M.T., 1998, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program-Collection, documentation, and compilation of required site, well, subsurface, and landscape data for wells: U.S. Geological Survey Water-Resources Investigations Report 98–4107, 91 p.

Koenker, R., and Hallock, K., 2001, Quantile regression: Journal of Economic Perspectives, v. 15, no. 4, p. 143–156.

Michaels, J.A., Neville, L.R., Edelman, D., Sullivan, T., and DiCola, L.A., 1992, New York–New Jersey Highlands Regional Study: Radnor, Pa., U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry, 130 p.

Mueller, D.K., and D.R. Helsel, 1996, Nutrients in the nations waters—too much of a good thing?: U.S. Geological Survey Circular 1136, 24 p.

New Jersey Department of Environmental Protection (NJDEP), 1986, 1986 Land use/land cover, accessed April 14, 2015, at http://www.nj.gov/dep/gis/lulcshp.html.

New Jersey Department of Environmental Protection (NJDEP), 2001, 1995/97 Land use/land cover by Watershed Management Area (WMA), accessed April 14, 2015, at http://www.state.nj.us/dep/gis/lulc95shp.html.

New Jersey Department of Environmental Protection (NJDEP), 2003, Private well testing act program electronic data deliverable manual: Trenton, N.J., Bureau of Safe Drinking Water, 70 p.

New Jersey Department of Environmental Protection (NJDEP), 2008, 2002 Land use/land cover by Watershed Management Area (WMA), accessed April 14, 2015, at http://www.state.nj.us/dep/gis/lulc02shp.html.

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New Jersey Department of Environmental Protection (NJDEP), 2010, NJDEP 2007 Land use/land cover update, accessed April 16, 2015, at http://www.state.nj.us/dep/gis/lulc07shp.html.

New Jersey Highlands Water Protection and Planning Council, 2008, Highlands Master Plan, Technical report: Water resources volume I, watersheds and water quality, p. 114–173, accessed April 16, 2015, at http://www.highlands.state.nj.us/njhighlands/master/tr_water_res_vol_1.pdf.

Nicholson, R.S., McAuley, S.D., Barringer, J.L., and Gordon, A.D., 1996, Hydrogeology of, and ground-water flow in, a valley-fill and carbonate rock aquifer system near Long Valley in the New Jersey Highlands: U.S. Geological Survey Water-Resources Investigation Report 93–4157, 159 p., 3 pl.

Nolan, B.T., 2001, Relating nitrogen sources and aquifer susceptibility to nitrate in shallow groundwaters of the United States: Ground Water, v. 39, no. 2, p. 290–299.

Nolan, B.T., Ruddy, B.C., Hitt, K.J., and Helsel, D.R., 1998, A national look at nitrate contamination in ground water: Water Conditioning and Purification, v. 39, no. 12, p. 76–79.

Nolan, B.T., Hitt, K.J., and Ruddy, B.C., 2002. Probability of nitrate contamination of recently recharged groundwaters in the conterminous United States: Environmental Science and Technology, v. 36, no. 10, p. 2138–2145.

Sando, S.K., Vecchia, A.V., Lorenz, D.L., and Barnhart, E.P., 2014, Water-quality trends for selected sampling sites in the upper Clark Fork Basin, Montana, water years 1996–2010: U.S. Geological Survey Scientific Investigations Report 2013–5217, 162 p., with appendixes, http://dx.doiorg/10.3133/sir20135217.

Serfes, M.E., 1994, Natural ground-water quality in bedrock of the Newark Basin, New Jersey: New Jersey Geological Survey Report no. 35, 29 p.

Serfes, M.E., 2004, Ground water quality in the bedrock aquifers of the Highlands and Valley and Ridge Physiographic Provinces of New Jersey: New Jersey Geological Survey Report 39, 29 p.

Spearman, C., 1904, The proof and measurement of association between two things: The American Journal of Psychology, v. 15, no. 1, p. 72–101.

Tesoriero, A.J., and Voss, F.D., 2005, Predicting the probability of elevated nitrate concentrations in the Puget Sound Basin: Implications for aquatic susceptibility and vulnerability: Groundwater, v. 35, no. 6, p. 1029–1039.

Trela, J.J., and Douglas, L.A., 1978, Soils, septic systems and carrying capacity in the NJ Pine Barrens: Paper presented at the First Annual Pine Barrens Research Conference, Atlantic City, N.J., May 22, 1978, 34 p.

Tu, J., 2008, Assessing the impact of long-term land use changes on water quality in Eastern Massachusetts: Ann Arbor, Mich., ProQuest, 271 p.

U.S. Forest Service, 2014, The Highlands of Connecticut, New Jersey, New York and Pennsylvania, accessed April 28, 2015, at http://na.fs.fed.us/highlands/about/index.shtm.

U.S. Environmental Protection Agency, 2009, Statistical analysis of groundwater monitoring data at RCRA facilities. Unified guidance, EPA 530/R-09-007, 888 p. accessed April 28, 2015, at http://www.epa.gov/osw/hazard/correctiveaction/resources/guidance/sitechar/gwstats/unified-guid.pdf.

Wakida, F.T., and Lerner, D.N., 2005, Non-agricultural sources of groundwater nitrate: A review and case study: Water Research, v. 39, no.1, p. 3–16.

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Appendixes 1 and 2

Appendix 1

Example spreadsheet for calculating median nitrate concentrations with logistic-regression models. (Appendix 1 available at http://dx.doi.org/10.3133/sir20155075)

Appendix 2

Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region. (Appendix 2 available at http://dx.doi.org/10.3133/sir20155075)

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Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
SLOP	Slope of land (percent)	0.000	x	x			
SOILPH	Soil pH (standard units)	-0.103	x	x	x		
THICK	Soil thickness (cm)	-0.144	x	x			
Top	Depth to top of well screen (feet)	0.141	x				
WellDepth	Depth of well (feet)	0.225	x	x	x	x	x

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Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
P6 (1995)	Percent wetlands	-0.224	x	x	x	x	x
P6 (2002)	Percent wetlands	-0.223	x	x	x	x	x
P61 (1972)	Percent marshes and vegetated dunes	-0.228	x				
P61 (2002)	Percent marshes and vegetated dunes	0.081	x				
P62 (1972)	Percent non-forested wetlands	-0.004	x				
P62 (1986)	Percent non-forested wetlands	-0.226	x				
P62 (1995)	Percent non-forested wetlands	-0.224	x				
P62 (2002)	Percent non-forested wetlands	-0.224	x				
P7 (1972)	Percent barren land	-0.001	x		x	x	x
P7 (1986)	Percent barren land	-0.215	x		x	x	x
P7 (1995)	Percent barren land	-0.177	x		x	x	x
P7 (2002)	Percent barren land	0.072	x		x	x	x
P71890	Mercury, dissolved (µg/L as Hg)	-0.076	x				
P72 (1995)	Percent bare exposed rock and rock slides	0.081	x				
P72 (2002)	Percent bare exposed rock and rock slides	0.081	x				
P73 (1986)	Percent extractive mining land use	0.074	x				
P73 (1995)	Percent extractive mining land use	0.033	x				
P73 (2002)	Percent extractive mining land use	0.015	x				
P74 (1986)	Percent altered barren lands	-0.263	x				
P74 (1995)	Percent altered barren lands	-0.273	x				
P74 (2002)	Percent altered barren lands	-0.045	x				
P75 (1972)	Percent of transitional areas of barren land	0.024	x				
P75 (1986)	Percent of transitional areas of barren land	0.033	x				
P75 (1995)	Percent of transitional areas of barren land	0.170	x				
P75 (2002)	Percent of transitional areas of barren land	0.150	x				
P76 (1972)	Percent undifferentiated barren land	-0.014	x				
P76 (1986)	Percent undifferentiated barren land	-0.053	x				
P76 (1995)	Percent undifferentiated barren land	-0.126	x				
P76 (2002)	Percent undifferentiated barren land	0.002	x				
P82084	Nitrogen $^{15}N/^{14}N$ ratio (per mil)	0.117	x				
P90095	Specific conductance (microsiemens per cm)	0.008	x				
P90410	Acid neutralizing capacity, water (mg/L as $CaCO_3$)	0.003	x				
PERM	Soil permeability	0.075	x	x	x	x	x
POPDEN	Population density (2000 census, per square kilometer)	0.407	x	x	x	x	x
SEPDEN	Septic density (1990 census, per square kilometer)	0.216	x	x	x		

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Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
P4 (2002)	Percent forested land	0.051	x	x	x	x	x
P41 (1972)	Percent deciduous forest	-0.267	x	x			
P41 (1986)	Percent deciduous forest	-0.008	x	x			
P41 (1995)	Percent deciduous forest	0.072	x	x			
P41 (2002)	Percent deciduous forest	0.033	x	x			
P42 (1972)	Percent coniferous forests	-0.102	x	x			
P42 (1986)	Percent coniferous forests	0.009	x	x			
P42 (1995)	Percent coniferous forests	0.058	x	x			
P42 (2002)	Percent coniferous forests	0.088	x	x			
P43 (1972)	Percent mixed forest	-0.031	x	x			
P43 (1986)	Percent mixed forest	-0.213	x	x			
P43 (1995)	Percent mixed forest	-0.138	x	x			
P43 (2002)	Percent mixed forest	-0.006	x	x			
P44 (1986)	Percent brush land and shrub land	0.203	x				
P44 (1995)	Percent brush land and shrub land	0.153	x				
P44 (2002)	Percent brush land and shrub land	0.123	x				
P45 (2002)	Percent severe burned upland vegetation	-0.059	x				
P5 (1972)	Percent water	-0.051	x	x	x	x	x
P5 (1986)	Percent water	-0.107	x	x	x	x	x
P5 (1995)	Percent water	-0.081	x	x	x	x	x
P5 (2002)	Percent water	-0.093	x	x	x	x	x
P51 (1972)	Percent streams and canals	0.041	x				
P51 (1986)	Percent streams and canals	-0.332	x				
P51 (1995)	Percent streams and canals	-0.307	x				
P51 (2002)	Percent streams and canals	-0.307	x				
P52 (1972)	Percent natural lakes	-0.012	x				
P52 (1986)	Percent natural lakes	0.080	x				
P52 (1995)	Percent natural lakes	0.056	x				
P52 (2002)	Percent natural lakes	0.074	x				
P53 (1972)	Artificial lakes and reservoirs	-0.074	x				
P53 (1986)	Artificial lakes and reservoirs	0.139	x				
P53 (1995)	Artificial lakes and reservoirs	0.145	x				
P53 (2002)	Artificial lakes and reservoirs	0.128	x				
P6 (1972)	Percent wetlands	-0.230	x	x	x	x	x
P6 (1986)	Percent wetlands	-0.226	x	x	x	x	x

Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
P16 (1986)	Percent mixed urban or built-up land	0.008	x				
P16 (1995)	Percent mixed urban or built-up land	0.114	x				
P16 (2002)	Percent mixed urban or built-up land	0.114	x				
P17 (1972)	Percent other urban or built-up land	-0.021	x	x			
P17 (1986)	Percent other urban or built-up land	0.173	x	x			
P17 (1995)	Percent other urban or built-up land	-0.093	x	x			
P17 (2002)	Percent other urban or built-up land	-0.066	x	x			
P18 (1986)	Percent recreational land	-0.255	x				
P18 (1995)	Percent recreational land	-0.229	x				
P18 (2002)	Percent recreational land	-0.224	x				
P2 (1972)	Percent agricultural land use	0.223	x	x	x	x	x
P2 (1986)	Percent agricultural land use	0.313	x	x	x	x	x
P2 (1995)	Percent agricultural land use	0.312	x	x	x	x	x
P2 (2002)	Percent agricultural land use	0.315	x	x	x	x	x
P21 (1972)	Percent of cropland and pastureland	0.237	x	x			
P21 (1986)	Percent of cropland and pastureland	0.304	x	x			
P21 (1995)	Percent of cropland and pastureland	0.308	x	x			
P21 (2002)	Percent of cropland and pastureland	0.300	x	x			
P22 (1972)	Percent orchards, vineyards, nurseries and horticultural areas	-0.056	x	x			
P22 (1986)	Percent orchards, vineyards, nurseries and horticultural areas	0.108	x	x			
P22 (1995)	Percent orchards, vineyards, nurseries and horticultural areas	0.139	x	x			
P22 (2002)	Percent orchards, vineyards, nurseries and horticultural areas	0.118	x	x			
P23 (1972)	Percent confined feeding operations land use	-0.068	x	x			
P23 (1986)	Percent confined feeding operations land use	0.004	x	x			
P23 (1995)	Percent confined feeding operations land use	0.009	x	x			
P23 (2002)	Percent confined feeding operations land use	0.009	x	x			
P24 (1972)	Percent confined feeding operations land use	0.118	x	x			
P24 (1986)	Percent agricultural land use other than cropland and pastureland	0.193	x	x			
P24 (1995)	Percent confined feeding operations land use	0.238	x	x			
P24 (2002)	Percent agricultural land use other than cropland and pastureland	0.228	x	x			
P38260	Methylene blue active substance (mg/L)	-0.012	x				
P39086	Alkalinity, water, dissolved, total, (mg/L as $CaCO_3$)	-0.109	x				
P4 (1972)	Percent forested land	-0.299	x	x	x	x	x
P4 (1986)	Percent forested land	0.035	x	x	x	x	x
P4 (1995)	Percent forested land	0.089	x	x	x	x	x

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Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
P00930	Sodium, dissolved (mg/L as Na)	-0.057	x				
P00935	Potassium, dissolved (mg/L as K)	0.006	x				
P00940	Chloride, dissolved (mg/L as Cl)	0.081	x				
P00945	Sulfate, dissolved (mg/L as SO_4)	-0.115	x				
P00950	Fluoride, dissolved (mg/L as F)	-0.201	x				
P00955	Silica, dissolved (mg/L as SiO_2)	0.041	x				
P01000	Arsenic, dissolved (µg/L as As)	-0.463	x				
P01022	Boron, total (µg/L as B)	-0.376	x				
P01046	Iron, dissolved (µg/L as Fe)	-0.431	x				
P01056	Manganese, dissolved (µg/L as Mn)	-0.555	x				
P1 (1972)	Percent urban land	0.088	x	x	x	x	x
P1 (1986)	Percent urban land	0.075	x	x	x	x	x
P1 (1995)	Percent urban land	-0.006	x	x	x	x	x
P1 (2002)	Percent urban land	0.035	x	x	x	x	x
P11 (1972)	Percent of residential land use	0.145	x	x	x	x	x
P11 (1986)	Percent of residential land use	0.445	x	x	x	x	x
P11 (1995)	Percent of residential land use	0.453	x	x	x	x	x
P11 (2002)	Percent of residential land use	0.464	x	x	x	x	x
P12 (1972)	Percent commercial services land use	0.053	x	x	x		
P12 (1986)	Percent commercial services land use	-0.230	x	x	x		
P12 (1995)	Percent commercial services land use	-0.245	x	x	x		
P12 (2002)	Percent commercial services land use	-0.247	x	x	x		
P13 (1972)	Percent industrial land	-0.061	x	x			
P13 (1986)	Percent industrial land	0.097	x	x			
P13 (1995)	Percent industrial land	0.092	x	x			
P13 (2002)	Percent industrial land	0.100	x	x			
P14 (1972)	Percent transportation, communication and utilities land use	-0.092	x	x			
P14 (1986)	Percent transportation, communication and utilities land use	-0.009	x	x			
P14 (1995)	Percent transportation, communication and utilities land use	0.119	x	x			
P14 (2002)	Percent transportation, communication and utilities land use	0.147	x	x			
P15 (1972)	Percent of industrial plus commercial land	-0.038	x	x			
P15 (1986)	Percent of industrial plus commercial land	0.013	x	x			
P15 (1995)	Percent of industrial plus commercial land	-0.089	x	x			
P15 (2002)	Percent of industrial plus commercial land	-0.089	x	x			
P16 (1972)	Percent mixed urban or built-up land	-0.007	x				

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Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
LMajrds	Length of major roads (meters)	0.159	x				
Lrail	Length of railroads (meters)	-0.067	x				
LStrm24	Length of streams (meters)	-0.172	x	x	x	x	x
Nallrds	Total number of roads	0.444	x				
Nallrec	Number of recreational areas	-0.198	x	x			
Ncem	Number of cemeteries	0.106	x				
Ndams	Number of dams	0.086	x				
Nkcsl01	Number of known contamination site locations, 2001 inventory	0.196	x	x	x	x	x
Nlocalrds	Number of local roads	0.450	x				
Nmajrds	Number of major roads	0.157	x				
Nnjgolf	Number of golf courses	-0.266	x	x	x		
Nnjpdesgw	Number of permitted ground-water-discharge sites	0.058	x	x			
Nnjpdesstorm	Number of permitted storm discharge sites	-0.015	x	x			
Nnjpdessw	Number of permitted surface-water-discharge sites	-0.144	x	x			
Nrail	Number of railroads	-0.074	x				
Nstploc	Number of sewage treatment plant locations	-0.021	x	x	x		
Nstrm24k	Number of streams	-0.108	x	x			
Nswl	Number of solid waste locations	0.037	x	x			
OI	Well length of open interval (feet)	0.129	x	x	x	x	x
ORGPCT	Percent organic material in soil	-0.244	x	x	x		
P00010	Temperature, water (degrees Centigrade)	-0.071	x				
P00076	Turbidity (NTU)	-0.067	x				
P00095	Specific conductance (microsiemens per cm)	0.027	x				
P00300	Dissolved oxygen (mg/L)	0.493	x				
P00400	pH, water, whole, field (standard units)	-0.203	x				
P00403	pH, water, whole, laboratory (standard units)	-0.235	x				
P00608	Nitrogen, ammonia, dissolved (mg/L as N)	-0.406	x				
P00613	Nitrogen, nitrite, dissolved, (mg/L as N)	-0.046	x				
P00623	Nitrogen, ammonia plus organic, dissolved (mg/L as N)	-0.172	x				
P00631	Nitrate plus nitrite, dissolved (mg/L as N)	1.000	x				
P00666	Phosphorus, dissolved (mg/L as P)	-0.124	x				
P00671	Phosphorus, orthophosphate, dissolved (mg/L as P)	-0.127	x				
P00681	Carbon, organic, dissolved (mg/L as C)	-0.147	x				
P00915	Calcium, dissolved (mg/L as Ca)	0.000	x				
P00925	Magnesium, dissolved (mg/L as Mg)	0.070	x				

99x

Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
D7 (1995)	Distance to barren land (meters)	0.184	x				
D7 (2002)	Distance to barren land (meters)	-0.059	x				
D72 (1995)	Distance to bare exposed rock (meters)	-0.078	x				
D72 (2002)	Distance to bare exposed rock (meters)	-0.077	x				
D73 (1986)	Distance to extractive mining (meters)	-0.073	x				
D73 (1995)	Distance to extractive mining (meters)	-0.033	x				
D73 (2002)	Distance to extractive mining (meters)	-0.014	x				
D74 (1986)	Distance to altered or disturbed lands or wetlands (meters)	0.253	x				
D74 (1995)	Distance to altered or disturbed lands or wetlands (meters)	0.273	x				
D74 (2002)	Distance to altered or disturbed lands or wetlands (meters)	0.052	x				
D75 (1972)	Distance to transitional areas of barren land (meters)	-0.023	x				
D75 (1986)	Distance to transitional areas of barren land (meters)	-0.033	x				
D75 (1995)	Distance to transitional areas of barren land (meters)	-0.168	x				
D75 (2002)	Distance to transitional areas of barren land (meters)	-0.151	x				
D76 (1972)	Distance to undifferentiated barren land (meters)	0.015	x				
D76 (1986)	Distance to undifferentiated barren land (meters)	0.053	x				
D76 (1995)	Distance to undifferentiated barren land (meters)	0.146	x				
D76 (2002)	Distance to undifferentiated barren land (meters)	-0.002	x				
Dallrds	Distance to nearest road (meters)	-0.436	x				
Dallrec	Distance to all recreational areas (meters)	0.116	x				
Dcem	Distance to nearest cemetery (meters)	-0.106	x				
Ddams	Distance to nearest dam (meters)	-0.081	x				
Dkcsl01	Distance to nearest known contamination site, 2001 inventory (meters)	-0.192	x				
Dpdesgw	Distance to nearest permitted ground-water discharge site (meters)	-0.057	x				
Dpdesstorm	Distance to nearest permitted storm discharge location (meters)	0.015	x				
Dpdessw	Distance to permitted surface-water discharges (meters)	0.126	x				
Drail	Distance to the nearest railroad (meters)	0.075	x				
Dstploc	Distance to nearest sewage-treatment-plant location (meters)	0.021	x				
Dstrm24k	Distance to nearest stream (meters)	0.136	x				
Dswl	Distance to nearest surface water discharge location (meters)	-0.038	x				
HoleDepth	Hole depth (feet)	0.218	x				
IMPSURF95PCT	Percent impervious surface	-0.062	x	x	x	x	x
KFACT	Soil erodibility factor, whole soil	0.307	x	x			
KFFACT	Soil erodibility factor, particles less than 2 mm diameter	0.307	x	x	x	x	x
Llocalrds	Length of local roads (meters)	0.468	x	x	x	x	x

100x

Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
D43 (1986)	Distance to mixed forest (meters)	0.212	x				
D43 (1995)	Distance to mixed forest (meters)	0.107	x				
D43 (2002)	Distance to mixed forest (meters)	-0.009	x				
D44 (1986)	Distance to mixed deciduous or coniferous brush or shrub land (meters)	-0.186	x				
D44 (1995)	Distance to mixed deciduous or coniferous brush or shrub land (meters)	-0.060	x				
D44 (2002)	Distance to mixed deciduous or coniferous brush or shrub land (meters)	-0.122	x				
D45 (2002)	Distance to severe burned upland vegetation (meters)	0.059	x				
D5 (1972)	Distance to water (meters)	0.048	x				
D5 (1986)	Distance to water (meters)	0.157	x				
D5 (1995)	Distance to water (meters)	0.140	x				
D5 (2002)	Distance to water (meters)	0.146	x				
D51 (1972)	Distance to streams and canals (meters)	-0.041	x				
D51 (1986)	Distance to streams and canals (meters)	0.335	x				
D51 (1995)	Distance to streams and canals (meters)	0.298	x				
D51 (2002)	Distance to streams and canals (meters)	0.299	x				
D52 (1972)	Distance to nearest lake (meters)	0.011	x				
D52 (1986)	Distance to nearest lake (meters)	-0.082	x				
D52 (1995)	Distance to nearest lake (meters)	-0.057	x				
D52 (2002)	Distance to nearest lake (meters)	-0.075	x				
D53 (1972)	Distance to nearest reservoir (meters)	0.072	x				
D53 (1986)	Distance to nearest reservoir (meters)	-0.139	x				
D53 (1995)	Distance to nearest reservoir (meters)	-0.145	x				
D53 (2002)	Distance to nearest reservoir (meters)	-0.129	x				
D6 (1972)	Distance to wetlands (meters)	0.228	x				
D6 (1986)	Distance to wetlands (meters)	0.161	x				
D6 (1995)	Distance to wetlands (meters)	0.144	x				
D6 (2002)	Distance to wetlands (meters)	0.158	x				
D61 (1972)	Distance to forested wetlands (meters)	0.226	x				
D61 (2002)	Distance to forested wetlands (meters)	-0.081	x				
D62 (1972)	Distance to non-forested wetlands (meters)	0.004	x				
D62 (1986)	Distance to non-forested wetlands (meters)	0.161	x				
D62 (1995)	Distance to non-forested wetlands (meters)	0.144	x				
D62 (2002)	Distance to non-forested wetlands (meters)	0.158	x				
D7 (1972)	Distance to barren land (meters)	0.003	x				
D7 (1986)	Distance to barren land (meters)	0.223	x				

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Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.—Continued

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
D17 (2002)	Distance to other or built-up land use (meters)	0.140	x				
D18 (1995)	Distance to recreational land (meters)	0.129	x				
D18 (2002)	Distance to recreational land (meters)	0.120	x				
D2 (1972)	Distance to agricultural land use (meters)	-0.192	x				
D2 (1995)	Distance to agricultural land use (meters)	-0.313	x				
D2 (2002)	Distance to agricultural land use (meters)	-0.308	x				
D21 (1972)	Distance to cropland and pastureland (meters)	-0.210	x				
D21 (1986)	Distance to cropland and pastureland (meters)	-0.300	x				
D21 (1995)	Distance to cropland and pastureland (meters)	-0.308	x				
D21 (2002)	Distance to cropland and pastureland (meters)	-0.296	x				
D22 (1972)	Distance to orchards, groves, vineyards or nurseries (meters)	0.056	x				
D22 (1986)	Distance to orchards, groves, vineyards or nurseries (meters)	-0.107	x				
D22 (1995)	Distance to orchards, groves, vineyards or nurseries (meters)	-0.136	x				
D22 (2002)	Distance to orchards, groves, vineyards or nurseries (meters)	-0.114	x				
D23 (1972)	Distance to confined feeding operations land use (meters)	0.068	x				
D23 (1986)	Distance to confined feeding operations land use (meters)	-0.004	x				
D23 (1995)	Distance to confined feeding operations land use (meters)	-0.009	x				
D23 (2002)	Distance to confined feeding operations land use (meters)	-0.009	x				
D24 (1972)	Distance to other agricultural land (meters)	-0.118	x				
D24 (1986)	Distance to other agricultural land (meters)	-0.192	x				
D24 (1995)	Distance to other agricultural land (meters)	-0.247	x				
D24 (2002)	Distance to other agricultural land (meters)	-0.237	x				
D4 (1972)	Distance to forested wetlands (meters)	0.293	x				
D4 (1986)	Distance to forested wetlands (meters)	0.008	x				
D4 (1995)	Distance to forested wetlands (meters)	-0.063	x				
D4 (2002)	Distance to forested wetlands (meters)	-0.161	x				
D41 (1972)	Distance to deciduous forest land (meters)	0.262	x				
D41 (1986)	Distance to deciduous forest land (meters)	0.037	x				
D41 (1995)	Distance to deciduous forest land (meters)	-0.237	x				
D41 (2002)	Distance to deciduous forest land (meters)	-0.205	x				
D42 (1972)	Distance to evergreen forest (meters)	0.102	x				
D42 (1986)	Distance to evergreen forest (meters)	-0.014	x				
D42 (1995)	Distance to evergreen forest (meters)	-0.057	x				
D42 (2002)	Distance to evergreen forest (meters)	-0.095	x				
D43 (1972)	Distance to mixed forest (meters)	0.037	x				

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Appendix 2. Geographic and environmental characteristics evaluated as possible explanatory variables in models of median nitrate concentrations in groundwater in the NJ Highlands Region.

Variable name	Variable description	Spearman's rho	logistic egression				
			1 variable	2 variables	3 variables	4 variables	5 variables
AWC	Available water capacity	0.285	x	x			
Bot	Depth to bottom of well (feet)	0.227	x				
BotCasing	Depth to bottom of casing (feet)	0.046	x				
CLAYPCT	Percent clay in soil	0.260	x	x	x	x	x
D1 (1972)	Distance to urban land use (meters)	-0.091	x				
D1 (1986)	Distance to urban land use (meters)	-0.091	x				
D1 (1995)	Distance to urban land use (meters)	-0.065	x				
D1 (2002)	Distance to urban land use (meters)	-0.104	x				
D11 (1972)	Distance to residential land use (meters)	-0.140	x				
D11 (1986)	Distance to residential land use (meters)	-0.417	x				
D11 (1995)	Distance to residential land use (meters)	-0.427	x				
D11 (2002)	Distance to residential land use (meters)	-0.439	x				
D12 (1972)	Distance to commercial and services land use (meters)	-0.058	x				
D12 (1986)	Distance to commercial and services land use (meters)	0.180	x				
D12 (1995)	Distance to commercial and services land use (meters)	0.179	x				
D12 (2002)	Distance to commercial and services land use (meters)	0.185	x				
D13 (1972)	Distance to industrial land use (meters)	0.061	x				
D13 (1986)	Distance to industrial land use (meters)	-0.095	x				
D13 (1995)	Distance to industrial land use (meters)	-0.092	x				
D13 (2002)	Distance to industrial land use (meters)	-0.101	x				
D14 (1972)	Distance to transportation or communication land use (meters)	0.078	x				
D14 (1986)	Distance to transportation or communication land use (meters)	0.004	x				
D14 (1995)	Distance to transportation or communication land use (meters)	-0.137	x				
D14 (2002)	Distance to transportation or communication land use (meters)	-0.162	x				
D15 (1972)	Distance to industrial and commercial complexes (meters)	0.038	x				
D15 (1986)	Distance to industrial and commercial complexes (meters)	-0.014	x				
D15 (1995)	Distance to industrial and commercial complexes (meters)	0.089	x				
D15 (2002)	Distance to industrial and commercial complexes (meters)	0.089	x				
D16 (1972)	Distance to mixed urban or built-up land (meters)	0.006	x				
D16 (1986)	Distance to mixed urban or built-up land (meters)	-0.008	x				
D16 (1995)	Distance to mixed urban or built-up land (meters)	-0.114	x				
D16 (2002)	Distance to mixed urban or built-up land (meters)	-0.114	x				
D17 (1972)	Distance to other or built-up land use (meters)	0.022	x				
D17 (1986)	Distance to other or built-up land use (meters)	-0.167	x				
D17 (1995)	Distance to other or built-up land use (meters)	0.129	x				

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Memorandum

To: Jeffrey L. Hoffman, NJ State Geologist, New Jersey Department of Environmental Protection (NJDEP), by email: Jeffrey.L.Hoffman@dep.nj.us

From: John A. Thonet, Thonet Associates, Inc., *Environmental Planning and Engineering Design Consultants*

Date: September 1, 2015

Re: Preliminary Comments Regarding Scientific Investigations Report 2015-5075: *Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics*
Prepared by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection (NJDEP)

cc: Julia Somers, Executive Director, New Jersey Highlands Coalition
Elliott Ruga, Policy Director, New Jersey Highlands Coalition

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On July 30, 2015, I had the pleasure of accompanying representatives of the New Jersey Highlands Coalition at a briefing by you and Ray Cantor of the NJDEP regarding the above-referenced study, recently prepared by the USGS, in cooperation with the NJDEP. As I believe you know, in addition to currently serving as the President of the Board of Trustees for the New Jersey Highlands Coalition, my firm, Thonet Associates, Inc., *Environmental Planning and Engineering Design Consultants*, has been providing environmental consulting services for land development projects and land use planning programs here in New Jersey for over 35 years.

During our meeting, you and Ray indicated that the newly prepared regression model was intended to provide a method of estimating median nitrate concentrations in groundwater in the NJ Highlands Region using regression models and various land-surface characteristics. Following the briefing, I promised to review the 2015 report and provide the Department with my comments.

This memorandum provides my preliminary comments, based on my initial reading of the report. I hope these comments will be helpful to the Department in deciding how best to proceed, recognizing its jurisdictional responsibilities within the Preservation Area of the New Jersey Highlands.

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Thonet Associates' Preliminary Comments

1. The 2015 study analyzes the entire NJ Highlands Region as a single study area, rather than analyzing the Preservation Area and Planning Area separately. This approach is inadvisable for following reasons:

   a. The NJDEP has the primary responsibility for overseeing future development within the Preservation Area, whereas, it is the Highlands Council, that has the primary responsibility within the Planning Area.

   In order to fulfill its regulatory responsibilities with regard to the Preservation Area, the Department should first focus its efforts on accurately measuring nitrate concentrations at sufficient numbers of locations within the Preservation Area to permit the development of a regression model that can be used to accurately predict median nitrate concentrations solely within the Preservation Area. This effort could require the establishment of additional observation wells within the Preservation Area's forest lands and wetlands, which constitute nearly 70 percent of all land within the Preservation Area and which I believe are currently under-represented in the available well records.

   The 2015 study failed to accomplish this important "first step" toward establishing a representative well record for the Preservation Area. Hence, the regression model developed, absent that well record, cannot be expected to provide estimates of median nitrate concentrations that are truly representative of the Preservation Area. This is a critical and fatal flaw in the 2015 study, if it is proposed to use that model to estimate median nitrate concentrations within the Preservation Area.

   b. The Preservation Area and Planning Area are markedly different in their land-surface characteristics and hence, it is both improper and illogical to combine these two distinctly different areas into one study area for the purposes of developing a "predictive model" for nitrate concentrations. Specifically, the below-table documents these significant differences:

Location within NJ Highlands Region	Land Use, in percent					
	Urban	Agricultural	Forest	Wetlands	Barren	Water
Preservation Area	16.9	8.1	60.3	9.6	0.6	4.6
Planning Area	37.8	16.9	33.0	11.3	1.0	3.7

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As can be seen, almost 75 percent of the Preservation Area consists of undeveloped forested lands, wetlands and water areas, with a scant 8.1 percent disturbed for agricultural purposes and only 16.9 percent characterized as "urban." In contrast, nearly 55 percent of the Planning Area is already disturbed and/or developed, including 37.8 percent "urban" uses and 16.9 percent agricultural uses.

It is counterintuitive, and poor experimental design, to expect that a regression model developed for the NJ Highlands Region as a whole to be able to accurately predict median nitrate concentration levels, based on "land surface characteristics" when, (i) the land surface characteristics of the Planning Area and Preservation Area are so significantly different, and (ii) the well database used overwhelmingly includes wells that are not representative of the majority of the Preservation Area.

c. The Preservation Area is a "nondegradation" area with regard to water quality, unlike the Planning Area within which the water quality standards are not so stringent. Accordingly, it is particularly important to correctly establish median nitrate concentrations within the Preservation Area itself, independent of the NJ Highlands Region as a whole.

   This requires an independent study of the Preservation Area itself, one that preferably includes the establishment and monitoring of additional wells to obtain the best "measurement" of existing nitrate concentrations within the Preservation Area. An accurate regression model for the Preservation Area cannot be developed without an adequate well database within the Preservation Area.

   This has been a deficiency in the Preservation Area's well database since the Highlands Water Protection and Planning Act was enacted but now that 11 years have passed since Act was passed, it is extremely disappointing that the Department has failed to use that time to correct this data deficiency. In my opinion, the Department's jurisdictional responsibilities in the Preservation Area required nothing less.

d. The logistical regression model that was recently developed relates measured nitrate concentrations to five explanatory variables, including:

   1) Percent urban land use;
   2) Percent of agricultural land use;

3) Septic system density;
4) Total length of streams; and
5) Number of known contaminated sites.

The percent urban and agricultural land uses, as well as the existing septic system density are factors that Thonet Associates agrees would be expected to be significant "explanatory" variables that would be helpful in predicting median nitrate levels within the Planning Area which has substantial urban land uses, agricultural land uses and lands utilizing septic systems.

However, as documented above, about 75 percent of the Preservation Area is undeveloped land that has no urban land uses, no agricultural land uses, no septic systems and little to no well data. Accordingly, three (3) of the five (5) "explanatory variables" used in the regression model are really not found in 75 percent of the Preservation Area and hence can't be expected to "explain" median nitrate concentrations within the Preservation Area.

Preliminary Conclusion No. 1:

For the above reasons, it is Thonet Associates' preliminary opinion that the regression model developed as part of the 2015 study, which analyzes the entire NJ Highlands Region as a single study area, rather than analyzing the Preservation Area and Planning Area separately, is not likely to be representative of the Preservation Area. Accordingly, utilizing the 2015 regression model to predict median nitrate concentrations within the Preservation Area would be unreliable and thus inconsistent with the purposes of the New Jersey Highlands Water Protection and Planning Act at N.J.S.A. 13:20-1 et seq. ("the Act").

2. The median nitrate concentration results presented in the 2015 report are significantly inconsistent with the 2014 USGS/NJDEP model results, which appear to utilize the same databases.

   Thonet Associates is familiar with the results of a similar study prepared by USGS and the NJDEP in 2014. The publication presenting these results is New Jersey Geological & Water Survey Technical Memorandum 14-1, authored by you and Alexandra Petriman, and entitled, *Nitrate Concentrations in Groundwater of New Jersey's Highlands Region*.

In that study, the Preservation Area and Planning Areas were considered individually, utilizing well data from 352 observation wells provided by the USGS, supplemented by well data from 19,360 domestic wells tested under New Jersey's Private ell Testing Act.

The following table presents the 2014 study's reported results.

2014 Study Results		
Land Use Capability Zone	**Median Nitrate Concentration**	
	With Only the Preservation Area Considered	With Only the Planning Area Considered
Protection Zone	0.1 mg/l	0.6 mg/l
Conservation Zone	2.15 mg/l	2.8 mg/l
Existing Community Zone	2.36 mg/l	3.55 mg/l

The 2014 study's results are significantly different from the 2015 study's results, both of which were prepared by both USGS and the NJDEP just one year earlier using the identical database. For example, the 2015 study reports a median nitrate concentration of 1.05 mg/l for the Protection Zone within the Preservation Area, which is more than ten (10) times greater than the median concentration reported in 2014.

The 2015 study also reported the Preservation Area's median nitrate concentrations at 1.64 mg/l and 1.79 mg/l for the Conservation Zone and Existing Community Zone, respectively, which are both only 76 percent of the 2014 values.

For the Planning Area, the 2015 study reports a median nitrate concentration of 1.19 mg/l within the Protection Zone, which is nearly double the 0.6 mg/l concentration reported just one year ago in 2014.

The 2015 study also reported the Planning Area's median nitrate concentrations at 1.78 mg/l for both the Conservation Zone and the Existing Community Zone. For the Conservation Zone, this 2015 value is about 64 percent of the 2014 value and for Existing Community Zone the 2015 value is only one-half of the 2014 value.

Conclusion No. 2: The significant differences in the 2015 and 2014 study results would appear to conclusively document the effect of studying the NJ Highlands Region as a whole vs. studying the Preservation Area and Planning Areas as separate study areas.

These differences, together with our previous comments regarding how, in the 2015 study, the Preservation Area is not adequately represented by the available well data and not adequately represented by the "explanatory variables" selected, lead Thonet Associates' to a preliminary conclusion that the 2015 study's analyses is invalid in its construction and inaccurate in its results.

Request for Additional Information

Some additional information would be helpful to me as I continue to evaluate the 2015 study. In this regard, I request that the Department provide me with some additional information and answers to the following questions:

1. How many wells were located within the undeveloped forested lands and wetlands within the Preservation Area? Within the Planning Area?
2. How many wells were located within agricultural lands within the Preservation Area? Within the Planning Area?
3. How many wells were located within urban lands within the Preservation Area? Within the Planning Area?
4. Were the number of contaminated sites and the total length of streams really determined to be significant "explanatory variables?"

   These variables would not appear to be directly related to nitrate concentrations in groundwater. What is the Department's explanation of the relationship that exists between nitrate concentrations and these two variables?
5. Did the 2014 study utilize essentially the same well database as the 2015 study?
6. Why did the Department abandon the 2014 study's results in favor of the 2015 study results? Why does the Department believe that the 2015 study more accurately predicts median nitrate concentrations within the Preservation Area than the 2014 study does?
7. Would the Department be willing to provide me with all of the raw data for the grid cells within just the Preservation Area including:
   a. The measured median nitrate concentrations for all cells for which well data was available and a map showing the locations of those cells;
   b. The land use characteristics of each grid cell within the Preservation Area (i.e. septic density; percentages of forest lands, wetlands, water areas, barren

lands, urban areas and agricultural lands; number of contaminated sites; and total length of streams); and

c. A map showing the locations of all grid cells within the Preservation Area.

If the Department is willing to provide me with the above information, please contact me to discuss the best way that this data transfer could be accomplished.

I thank you and the Department in advance for responding to my above questions and requests for additional information.

NEW JERSEY GEOLOGICAL &

WATER SURVEY

Technical Memorandum 14-1

Nitrate Concentrations in Groundwater of New Jersey's Highlands Region

New Jersey Department of Environmental Protection
Water Resources Management
Division of Water Supply and Geosciences
New Jersey Geological and Water Survey
2014

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NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

NJDEP's core mission is and will continue to be the protection of the air, waters, land and natural and historic resources of the State to ensure continued public benefit. The Department's mission is advanced through effective and balanced implementation and enforcement of environmental laws to protect these resources and the health and safety of our residents.

At the same time, it is crucial to understand how actions of this agency can impact the State's economic growth, to recognize the interconnection of the health of New Jersey's environment and its economy, and to appreciate that environmental stewardship and positive economic growth are not mutually exclusive goals: we will continue to protect the environment while playing a key role in positively impacting the economic growth of the state.

NEW JERSEY GEOLOGICAL AND WATER SURVEY

The mission of the New Jersey Geological and Water Survey is to map, research, interpret and provide scientific information regarding the state's geology and groundwater resources. This information supports the regulatory and planning functions of DEP and other governmental agencies and provides the business community and public with information necessary to address environmental concerns and make economic decisions.

for more information contact:
New Jersey Department of Environmental Protection
New Jersey Geological and Water Survey
P.O. Box 420, Mail Stop 29-01
Trenton, NJ 08625-0420
(609) 984-6587
http://www.njgeology.org/

On the cover: Kitchell Lake, West Milford Township, Passaic County. Homes in the area are served by individual domestic wells and individual subsurface sewage-disposal systems. All of the shown area is in the Highlands preservation area and also in the protection Land Use Capability Zone
Left- Aerial photograph taken in 2007.
Right – Photointerpretation of 2007 land use.
Aerial photograph and land use interpretation are from NJDEP's Geographical Information System datasets. See Appendix A of this report for links to the datasets.

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Nitrate Concentrations in Groundwater of New Jersey's Highlands Region

by

Jeffrey L. Hoffman and Alexandra Petriman

2014

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Epigram

"A nation that fails to plan intelligently for the development and protection of its precious waters will be condemned to wither because of its shortsightedness."

--- President Lyndon B. Johnson, writing in a letter dated November 18, 1968, to the President of the Senate and to the Speaker of the House, transmitting "An Assessment of the Nation's Water Resources." (Johnson, 1968)

Nitrate Concentrations in Groundwater of New Jersey's Highlands Region

by

Jeffrey L. Hoffman and Alexandra Petriman

2014

I. ABSTRACT

The Highlands Water Protection and Planning Act of 2004 called for the protection of one of New Jersey's most important sources of drinking water, the Highlands Region. This region, which includes 17 percent of the State, provided 34 percent of the potable water consumed in New Jersey in 1999 (Hoffman and Domber, 2004). One component of this protection is limiting the impact of human activities on groundwater quality. This impact is measured, in part, by increases in groundwater nitrate concentrations.

Nitrate concentrations in groundwater are summarized using three overlapping subdivisions of the Highlands Region:

(1) Underlying legislation distinguishes a Preservation Area (with stricter environmental controls) and a Planning Area (with more development permitted). The NJDEP has major responsibility for overseeing additional development in the Preservation Area whereas the Highlands Council has primacy in the Planning Area.

(2) The N.J. Department of Environmental Protection (NJDEP) provides records of observed land use based on interpretation of aerial photographs using an Anderson classification system. NJDEP assigns land use to one of six categories. Agricultural, barren land and urban uses are grouped as 'mixed-use' lands. Forest, water, and wetlands are grouped as 'pristine' lands.

(3) The Highlands Council uses a model of resource constraints and development opportunity at a regional scale to define three Land Use Capability Zones. They are the Protection, Conservation, and Existing-Community Zones.

This report also summarizes observed and estimated groundwater nitrate concentrations in the Highlands Region. The background groundwater nitrate concentration helps set the maximum allowable density of homes with individual subsurface sewage-disposal systems. Three studies provide information on background nitrate concentrations:

(1) NJDEP used water-quality data from observation wells in the Preservation Area to calculate median nitrate concentrations (NJDEP, 2008a) The median nitrate value in mixed-

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use lands, based on 45 observation wells, is 0.76 mg/l. The median nitrate value in pristine lands, based on seven observation wells, is 0.21 mg/l.

(2) The U. S. Geological Survey (USGS) modeled background nitrate concentration in groundwater based on water-quality data from 352 observation wells correlated to land-use characteristics (Highlands Council, 2008c). The model was then used to estimated median nitrate values where water-quality data were not available. Estimated median nitrate values in the Protection, Conservation, and Existing-Community Land Use Capability Zones are 0.72, 1.87 and 1.17 mg/l, respectively.

(3) The USGS improved the background nitrate model by adding nitrate data from 19,369 domestic wells tested under the Private Well Testing Act (Atherholt and others, 2009). Based on this expanded data set for the entire Highlands Region, estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community Land Use Capability Zones are 0.20, 2.55, and 3.35 mg/l, respectively (USGS, 2012). If only the Preservation Area is considered then estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community Zones are 0.10, 2.15, and 2.36 mg/l, respectively. If only the Planning Area is considered then estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community zones are 0.60, 2.80, and 3.55 mg/l, respectively.

II. INTRODUCTION

Since the 19th century, the New Jersey Highlands have been recognized as an important source of drinking water. In 1894, the New Jersey Geological Survey noted:

> Our Highlands water-sheds, to which we call attention more fully hereafter, must be the first source from which this demand [*for additional water*] is to be met. They lie convenient to the metropolitan district, at a sufficient elevation for the delivery of their waters by gravity, are not populous, have just the right amount of forest, geological and topographical conditions favorable to purity and if they could be preserved in their present favorable condition would form in all respects an ideal gathering-ground. They have already begun to be utilized, and every succeeding decade must see a more rapid advance in their development. They are also threatened at points with pollution. Their protection and conservation for the future needs of the State seem to be merited by their unusual excellence. (Vermeule, 1894)

The recognition of the Highlands as a source of high-quality water, and a call for its protection, was repeated in 1907:

> The Highland watersheds are the best in the State in respect to ease of collection, in scantiness of population, with consequent absence of contamination; in elevation, giving opportunity for gravity delivery, and in softness as shown by chemical analysis. These watersheds should be preserved from pollution at all hazards, for upon them the most populous portions of the State must depend for water supplies. There has been too much laxness in the past regarding this important matter. (New Jersey Potable Water Commission, 1907)

In 1999, the Highlands Region supplied 34 percent of the potable water in New Jersey (Hoffman and Domber, 2004). The region wholly or partially supplied potable water to 292 municipalities in 16 counties. These municipalities are home to 64 percent of the State's population. The New Jersey Legislature formally recognized the special qualities and importance of the region with the passage the Highlands Water Protection and Planning Act of 2004:

> The Legislature further finds and declares that the New Jersey Highlands is an essential source of drinking water, providing clean and plentiful drinking water for one-half of the State's population, including communities beyond the New Jersey Highlands, from only 13 percent of the State's land area; ... (P.L. 2004, Chapter 120, approved August 10, 2004).

The Act also set up the New Jersey Highlands Water Protection and Planning Council ('Highlands Council') to oversee implementation of the Act.

In order to focus preservation efforts and channel additional development to appropriate areas, the Highlands Region is subdivided on the basis of current land use. However, this land use can be analyzed different ways. This report summarizes three ways the Highlands Region is divided:

- by the Act into Planning and Preservation Area;
- by the NJDEP using an Anderson land-use classification scheme; and
- by the Highlands Council based on an evaluation of resource constraints and development opportunities.

One step in protecting the Highlands Region's water resources is to prohibit excessive nitrate loading by individual subsurface sewage-disposal systems (also known as septic systems). Hoffman and Canace (2004) present a model of permissible densities of septic systems if a number of input parameters are specified. One necessary parameter is the allowable nitrate concentration in the groundwater. If the allowable nitrate concentration is set equal to the background nitrate concentration then the septic systems should not create an appreciable increase in groundwater nitrate concentration. Thus, defining the background nitrate concentration in the Highlands Region is an important step in protecting water resources. This report provides a summary of three approaches to defining the background nitrate values:

- an original analysis of available observation-well water-quality data only;
- a model relating available observation-well water-quality data to appropriate land-use characteristics; and
- an update of the model adding water-quality data from the private well testing act.

II.A. Data Sources

This analysis relies on Geographic Information System (GIS) coverages of the Highlands Region and its geographic subdivisions provided by the Highlands Council and NJDEP (Appendix A). In the analysis process minor errors occur when two coverages don't exactly coincide. These errors are on the order of 270 acres. The total area of the Highlands is about 859,000 acres. This report considers this error, about .03%, to be de minimus.

II.B. Acknowledgements

Many thanks to Otto Zapecza of the U.S. Geological Survey who provided a technical review. Also thanks to the N.J. Geological and Water Survey reviewers and publications staff.

III. LOCATION

The Highlands Water Protection and Planning Act of 2004 defines the Highlands Region in northern New Jersey (fig. 1). It consists of over 850,000 acres in this part of the state.

The Highlands Region consists of almost all of its eponymous physiographic province and parts of the neighboring Valley and Ridge and Piedmont physiographic provinces. The Highlands physiographic province is generally marked by a series of rounded ridges and narrow valleys that trend in a northeast-southwest direction (Lewis and Kummel, 1940). The ridges are about 400 to 600 feet higher than the neighboring valley floors (Hoffman and French, 2008).

Figure 1. New Jersey's Highlands Region and Physiographic Provinces.

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IV. GEOGRAPHICAL DIVISIONS

The Highlands Region is subdivided based on three different methods. Each is for a specific purpose and has its own benefits.

IV.A. Planning and Preservation Areas

The Highlands Water Protection and Planning Act determined that:

> … it is in the public interest of all the citizens of the State of New Jersey to enact legislation setting forth a comprehensive approach to the protection of the water and other natural resources of the New Jersey Highlands; that this comprehensive approach should consist of the identification of a preservation area of the New Jersey Highlands that would be subjected to stringent water and natural resource protection standards, policies, planning, and regulation… (P.L. 2004, Chapter 120, approved August 2004).

The Act provides a detailed spatial description of the Preservation Area (fig. 2). All land in the Highlands Region outside of the Preservation Area is defined as the Planning Area. The areas are about equal in size: the Planning Area totals 444,276 acres, and the Preservation Area 414,992 acres.

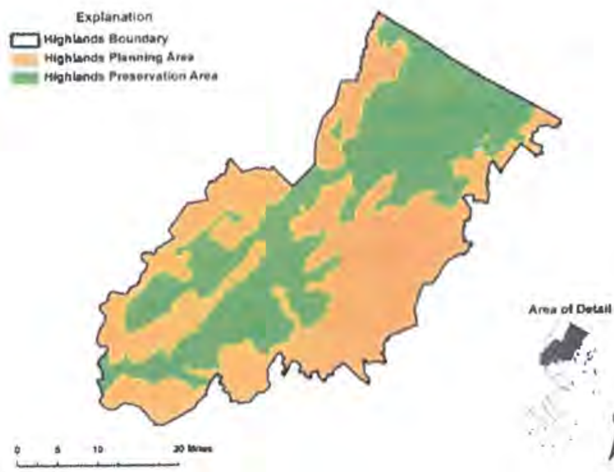

Figure 2. Planning and Preservation Areas in the Highlands Region of New Jersey.

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IV.B. Pristine and Mixed-Use Land-Use Groups

NJDEP provides analysis of land use in New Jersey based on aerial photography (NJDEP, 2010). This analysis is available for 1995/97, 2002, and 2007. The 2007 coverage is based on aerial photographs with a pixel size of 1 foot (NJDEP, 2012).

Each mapped unit is assigned a land use utilizing a modified Anderson approach (Anderson and others, 1976). Land uses are grouped into six general categories - agricultural, barren land, urban, forest, water and wetlands. Figure 3 shows mapped land use in the Highlands Region based on the 2007 aerial photographs.

Figure 2. Land use in the Highlands Region of New Jersey, 2007.

Figure 3. Mixed-use and pristine land use groups in the Highlands Region.

For analysis purposes, NJDEP defined two land-use groups. The mixed-use group consists of the agricultural, barren-land, and urban-land uses and is 357,591 acres in size. The pristine group consists of the forest, water and wetlands land uses and covers 525,471 acres. Figure 4 shows these two land-use groups. Table 1 lists the area of each land use and group in the Highlands Region.

Table 1. Acreage of land uses and groups in the Highlands Region of New Jersey

Group	Land Use	Acres
Mixed-Use	agriculture	112,107
	barren land	6,679
	urban	238,805
	subtotal	357,591
Pristine	forest	400,338
	water	35,232
	wetlands	89,901
	subtotal	525,471
Total Acreage:		883,062

IV.C. Land Use Capability Zones

Another way of classifying land use in the Highlands Region is by Land Use Capability Zones (Highlands Council, 2008b). This approach is based on the Land use Analysis Decision Support (LANDS) model:

> The LANDS model provides for a comprehensive evaluation of both resource constraints and development opportunity at a regional scale. It addresses the potential for conflict between natural resource protection and economic growth by identifying environmental constraints and capacity limitations of land and infrastructure, and identifying those areas within the Highlands Region that can best support appropriate and varying levels of economic and development activity. (Highlands Council, 2008b).

The Land Use Capability Zones consist of three zones and four sub-zones. They are: the Protection Zone (which includes the wildlife management sub-zone), the Conservation Zone (which includes the conservation environmentally constrained sub-zone), and the Existing-Community Zone (which contains the existing-community environmentally-constrained sub-zone and the lake-community subzone). The summary tables and figures in this report consider only the three zones (fig. 5). Table 2 lists the areas of the three zones in the Highlands Region.

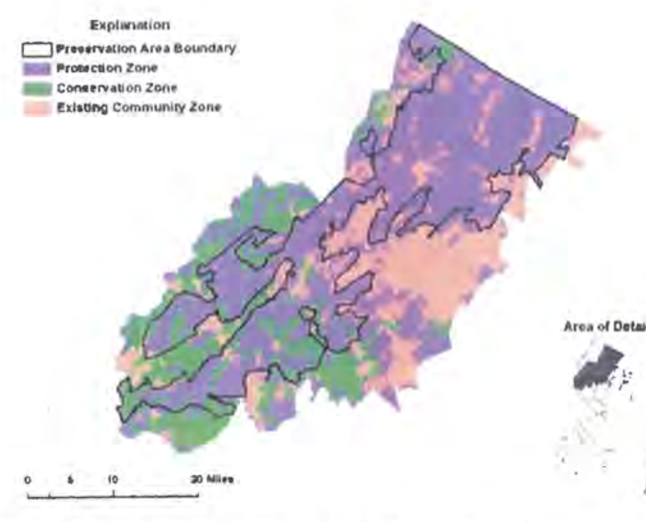

Figure 4. Land Use Capability Zones in the Highlands Region.

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IV.D. Overlay Analysis

The three methodologies for subdividing the Highlands Region may be overlain to ascertain their areas of intersection. Table 3 lists the area of intersection of Highlands Areas with land-use types and groups. Table 4 lists the area of intersection of Highlands Areas with Land Use Capability Zones. Table 5 lists the area of intersection of Land Use Capability Zones with land-use types and groups.

Table 2. Acreage of Land Use Capability Zones in the Highlands Region of New Jersey.

Land Use Capability Zone	Acres
protection	476,661
conservation	184,280
existing community	198,417
Total Acreage	859,358

Table 5 is further subdivided to determine the intersection of Land Use Capability Zones and land-use types and groups: first the Planning Area (table 6) and then the Preservation Area (table 7).

Table 3. Acreage of intersection of Highlands Areas with land-use types and groups.

Highlands Area	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-Total	Land Use			Sub-Total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Planning	72,387	4,200	162,083	238,671	141,895	15,137	48,491	205,523	444,194
Preservation	33,592	2,424	70,043	106,058	249,860	19,014	39,965	308,838	414,897
Total Acreage	105,979	6,624	232,126	344,729	391,755	34,151	88,456	514,361	859,091

Table 4. Acreage of intersection of Highlands Areas and Land Use Capability Zones.

Highlands Area	Land Use Capability Zone			Total Acreage
	Protection	Conservation	Existing community	
Planning	148,868	129,673	165,488	444,028
Preservation	327,449	54,555	32,896	414,900
Total Acreage	476,317	184,228	198,384	858,928

Table 5. Acreage of intersection of Land Use Capability Zones and land-use types and groups in the Highlands Region.

Land Use Capability Zone	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-total	Land Use			Sub-total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Protection	15,375	3,392	59,768	78,534	313,781	23,840	60,027	397,648	476,182
Conservation	91,281	1,175	21,550	114,006	49,379	1,701	19,140	70,220	184,227
Existing Community	3,100	3,569	137,879	144,549	35,992	7,923	9,921	53,836	198,384
Total Acreage	109,756	8,136	219,197	337,089	399,152	33,464	89,088	521,704	858,793

Table 6. Acreage of intersection of Land Use Capability Zones and land-use types and groups in the Planning Area.

Land Use Capability Zone	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-total	Land Use			Sub-total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Protection	6,886	1,293	27,364	35,543	79,885	7,024	26,363	113,272	148,815
Conservation	63,147	1,003	17,413	81,563	33,189	1,291	13,630	48,110	129,673
Existing Community	2,341	1,904	117,278	121,523	28,763	6,723	8,479	43,965	165,488
Total Acreage	72,374	4,200	162,055	238,629	141,837	15,038	48,472	205,347	443,976

Table 7. Acreage of intersection of Land Use Capability Zones and land-use types and groups in the Preservation Area.

Land Use Capability Zone	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-total	Land Use			Sub-total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Protection	8,259	1,974	38,013	48,246	228,583	17,189	33,348	279,121	327,367
Conservation	24,911	177	7,533	32,621	16,037	510	5,386	21,933	54,554
Existing Community	417	273	24,491	25,181	5,188	1,308	1,219	7,715	32,896
Total Acreage	33,587	2,424	70,037	106,048	249,808	19,007	39,953	308,769	414,817

V. NITRATE CONCENTRATIONS IN GROUNDWATER

Estimates of background nitrate concentrations are based on the type of data used and the geographic area from which the data were gathered. To date there have been three slightly different approaches, the first two based on water quality in observation wells and third adding data from domestic wells. Each approach, and the estimated background nitrate values, are summarized below.

V.A. Observation Well Data, NJDEP 2008

NJDEP (2008a) estimated background nitrate data based on water-quality data from observation wells. Serfes (2004) provided an estimate of 0.76 mg/l of median ambient nitrate concentration in noncarbonate bedrock of northern New Jersey. This value is based on data from 45 observation wells. NJDEP assumed this value applied to land used in the mixed-use group.

In order to estimate background nitrate concentration in the groundwater of pristine land-use group NJDEP analyzed land use near observation wells in the Highlands Region. The land-use classification was based on 2002 aerial photos interpreted using the modified Anderson classification scheme (NJDEP, 2012). If the land use within 500 meters of an observation well was 90 percent or more forest, wetlands and water then NJDEP assumed groundwater in that well represented a pristine situation (NJDEP, 2008a). Of 388 wells in and near the Highlands Region only 7 were both in the Highlands Region and in a pristine area. The median nitrate value of these 7 wells was 0.21 mg/l nitrate. NJDEP assumed this value was appropriate for use as a background groundwater nitrate value in areas not impacted by human activities (NJDEP, 2008a).

V.B. Modeling of Observation Well Data, Highlands Council 2008

The Highlands Council commissioned the U.S. Geological Survey (USGS) to develop a model of groundwater nitrate concentrations that could be used to estimate nitrate concentrations in 183 HUC14 subwatersheds in the Highlands Region (fig. 7). To do this, the USGS correlated nitrate values in 352 observation wells with land-use characteristics within 500 meters of each well (Highlands Council, 2008c). USGS used the correlation to project median nitrate concentration in each of the 183 HUC14 subwatersheds in the Highlands Region (Ellis and Price, 1995). Based on the median value of each watershed, the Highlands Region-wide median concentration was estimated to be 0.83 mg/l. Each subwatershed was also assigned to either the

Table 8. Estimated median background groundwater nitrate in the Planning Area, Highlands Council 2008 estimates

Land Use Capability Zone	Nitrate Concentration (mg/l)
Protection	0.72
Conservation	1.87
Existing Community	1.17

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Planning or Preservation Area. The subwatersheds in the Planning Area were broken out by Land Use Capability Zone. In the Planning Area the median nitrate concentration was estimated to be 0.72 mg/l in the Protection Land Use Capability Zone, 1.87 mg/l in the Conservation Zone, and 1.17 in the Existing-Community Zone (table 8).

V.C. Modeling of Observation Well and PWTA Data, USGS 2012

The USGS 2008 approach (detailed in Highlands Council, 2008c) was based on groundwater-quality data from observation wells. An additional data set became subsequently available because of the Private Well Testing Act.

The Private Well Testing Act became effective in 2002. It requires sellers of homes with domestic wells to test untreated groundwater prior to selling the property (Atherholt and others, 2009). The results must be shared with potential buyers. The Act requires water from domestic wells to be tested for pH, presence of total coliform bacteria, concentration of nitrates, lead, 26 volatile organic chemicals, iron and manganese. These results are submitted to NJDEP and are used to conduct regional analyses (such as NJDEP, 2008b). The Act also requires that the submitted water-quality data be kept confidential.

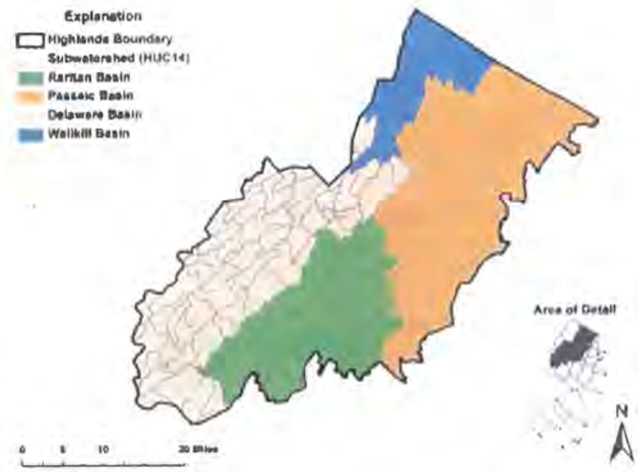

Figure 6. Major drainage basins and subwatersheds in the Highlands Region of New Jersey.

Analysis of groundwater quality data generated by the Private Well Testing Act must be done with several caveats in mind:

- Most of the wells are located in rural and low-density suburban areas. Information is not available for all areas of the state.
- Coastal communities, parks, preserved forests, and wildlife preserves have very few or no wells.
- NJDEP does not enforce the data submission requirement. It is unknown if any data are missing from the NJDEP data base.
- NJDEP has observed errors in laboratory reporting. Although laboratories must be certified to perform PWTA analysis there is no quality control of the data to ensure that collection, testing and analysis are done properly and consistently.

USGS divided the Highlands Region into a grid of 9,745 cells, each measuring 2,000 feet by 2,000 feet. NJDEP queried the PWTA data base and found 19,369 data points in the Highlands Region. NJDEP provided USGS with the observed groundwater nitrate values grouped by grid cell.

125x

Of the 9,745 cells, 1,417 contained one or more nitrate values. For cells in which the reported nitrate value was at or less than the detection limit; that limit was assumed to be the nitrate concentration. USGS subsequently calculated the median nitrate value for the 1,417 cells containing one or more reported nitrate measurements. The median nitrate concentration of the cell medians was 1.5 mg/l (U. S, Geological Survey, 2012).

In order to compile nitrate levels for the remaining 5,228 cells lacking observed nitrate data, USGS developed a logistic-regression model. The model took into consideration the land use appropriate for each cell:

- percentage of urban land use
- percentage of agricultural land use
- number of contaminated sites
- stream length
- average size of properties using septic tanks

The model development process correlated the estimated median nitrate value in 1,417 cells with land use in those cells. After calibration, USGS ran the model to estimate the median nitrate concentration in all cells lacking observed water-quality data.

Each of the cells was assigned to a subwatershed, Highlands Area, and Land Use Capability Zone based on location of the cell centroid. USGS then estimated the median of all values in each of these subdivisions. Table 9 lists the number of cells in each Land Use Capability Zone in the entire Highlands Region, and in the Preservation and Planning Areas. This table lists the number of cells in each subdivision, the minimum and maximum of the observed and the estimated median nitrate value of the cells, and the median nitrate value of all cells in that subdivision. Figure 7 shows medi-

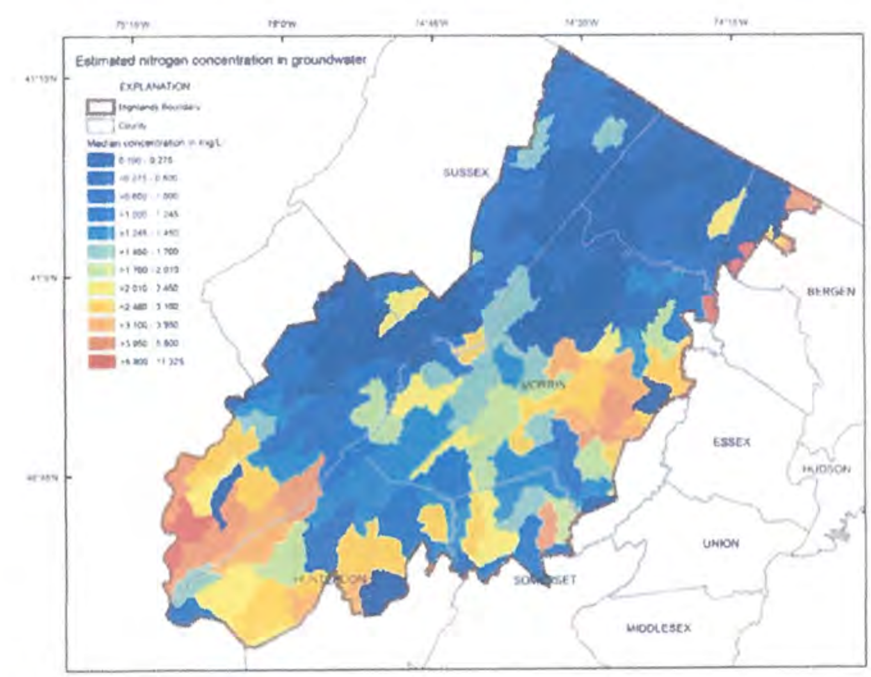

Figure 7. Median nitrate values in Highlands Region subwatershed (image copied from USGS, 2012).

an nitrate value in each subwatershed.

Based on this expanded data set for the entire Highlands Region, estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community Land Use Capability Zones are 0.20, 2.55, and 3.35 mg/l, respectively (USGS, 2012). If only the Preservation Area is considered then estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community Zones are 0.10, 2.15, and 2.36 mg/l, respectively. If only the Planning Area is considered then estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community zones are 0.60, 2.80, and 3.55 mg/l, respectively.

Table 9. Estimated median background groundwater nitrate, USGS 2012 estimates

Land Use Capability Zone	Highlands Region				Preservation Area				Planning Area			
	No. of cells	Nitrate (mg/l)			# of cells	Nitrate (mg/l)			# of cells	Nitrate (mg/l)		
		min	max	med-ian		min	max	med-ian		min	max	med-ian
Protection	5,191	0.027	24.24	0.20	3,578	0.03	18.00	0.10	1,613	0.029	24.21	0.60
Conservation	2,003	0.029	26.20	2.55	595	0.06	26.20	2.15	1,408	0.029	18.95	2.80
Existing Community	2,158	0.029	27.95	3.35	358	0.10	18.95	2.36	1,800	0.029	27.95	3.55

VI. REFERENCES

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer. R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 41 p., available at http://landcover.usgs.gov/pdf/anderson.pdf.

Atherholt, T.B., Louis, J.B., Shevlin, J., Fell, K., and Krietzman, S., 2009, The New Jersey private well testing act, an overview: N.J. Dept. of Environmental Protection, Division of Science, Research and Technology, technical report, 8 p., available at http://www.state.nj.us/dep/dsr/research/pwta-overview.pdf.

Ellis, W.H. and Price, C.V., 1995, Development of a 14-digit hydrologic coding scheme and boundary data set for New Jersey: U.S. Geological Survey Water-Resources Investigation Report 95-4134, 1 plate, scale 1:250,000.

Highlands Council, 2008a, Highlands regional master plan: New Jersey Highlands Water Protection and Planning Council, Chester, NJ, 490 p., available at http://www.highlands.state.nj.us/njhighlands/master/index.html.

Highlands Council, 2008b, Land Use Capability Zone map: New Jersey Highlands Water Protection and Planning Council, Chester, NJ, technical report, 27 p., available at http://www.highlands.state.nj.us/njhighlands/master/index.html.

Highlands Council, 2008c, Water resources volume I, watersheds and water quality: New Jersey Highlands Water Protection and Planning Council, Chester, NJ, technical report, 324 p., available at http://www.highlands.state.nj.us/njhighlands/master/index.html.

Hoffman, J.L. and Canace, R.J., 2004, A recharge-based nitrate-dilution model for New Jersey: N.J. Geological Survey Open-File Report 04-1, 27 p., available at http://www.njgeology.org/pricelst/ofreport/ofr04-1.pdf.

Hoffman, J.L., and Domber, S.E., 2004, Potable water supplied in 1999 by New Jersey's Highlands: N.J. Geological Survey technical report, 8 p., available at www.state.nj.us/dep/njgs/enviroed/freedwn/highpotwater.pdf.

Hoffman, J.L. and French, M.A., 2008, Ground-water recharge in the New Jersey Highlands Region: N.J. Geological Survey Open-File Report 08-1, 18 p., available at http://www.njgeology.org/pricelst/ofreport/ofr08-1.pdf.

Johnson, L. B., 1968, Letter to the President of the Senate and to the Speaker of the House transmitting an assessment of the nation's water resources: *in* Lyndon B. Johnson: 1968-1969 (in two books): containing the public messages, speeches, and statements of the president. [Book 2] , Office of the Federal Register, National Archives and Records Ser-

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vice, General Services Administration, available at http://quod.lib.umich.edu/p/ppotpus/4731573.1968.002.

Lewis, J.V. and Kummel, H.B., 1940, The geology of New Jersey: New Jersey Geological Survey Bulletin 50, Trenton, N.J., 203 p., available at http://www.njgeology.org/enviroed/oldpubs/bulletin50.pdf.

New Jersey Department of Environmental Protection, 2008a, Basis and background of the septic density standard of the Highlands Water Protection and Planning Act Rule at N.J.A.C 7:38-3.4: technical report, 39 p., available at www.nj.gov/dep/highlands/docs/septicdensity.pdf.

New Jersey Department of Environmental Protection, 2008b, Private well testing act program well test results for September 2002 – April 2007: Division of Water Supply, Bureau of Safe Drinking Water and Division of Science, Research and Technology, technical report, 75 p., available at http://www.state.nj.us/dep/pwta/pwta_report_final.pdf.

New Jersey Department of Environmental Protection, 2010, Frequently asked questions about digital imagery: web page available at http://www.state.nj.us/dep/gis/faqdigimg.htm.

New Jersey Department of Environmental Protection, 2012, Land Use/Land Cover 2007 Update: Office of Information Resources Management, Bureau of Geographic Information Systems, metadata for New Jersey's 2007 land use/land cover, edition 20100712, available at http://www.nj.gov/dep/gis/listall.html.

New Jersey Potable Water Commission, 1907, To investigate the practicability and probable cost of the acquisition by the State of the title to the potable waters of the state: Trenton, NJ, 101 p., available at http://hdl.handle.net/10929/28751.

Serfes, M.E., 2004, Ground-water quality in the bedrock aquifers of the Highlands and Valley and Ridge Physiographic Provinces of New Jersey, New Jersey Geological Survey Report GSR 39, 28 p., available at http://www.state.nj.us/dep/njgs/pricelst/gsreport/gsr39.pdf.

U. S. Geological Survey, 2012, New Jersey Highlands median nitrate concentration in subwatersheds and Land Use Capability Zones, an assessment using results of the New Jersey Private Well Testing Act, documentation of methods and results: technical correspondence provided to the New Jersey Highlands Water Protection and Planning Council, 7/12/2012, 20 p.

Vermule, C.C., 1894, Report on water supply, water-power, the flow of streams, and attendant phenomena: New Jersey Geological Survey, vol. III of the Final Report of the State Geologist, John L. Murphy Publishing Co., Trenton, NJ, 448 p., available at http://www.njgeology.org/enviroed/oldpubs/SG-FINAL-REPORT-VOL-III.PDF.

Appendix A. Relevant Internet Links

Programs	
New Jersey Dept. of Environmental Protection	http://www.state.nj.us/dep/
NJDEP Highlands Act and Rule	http://www.state.nj.us/dep/highlands/
New Jersey Geological and Water Survey	http://www.njgeology.org
New Jersey Highlands Council	http://www.state.nj.us/njhighlands/
General Data Repositories	
NJDEP GIS coverages	http://www.nj.gov/dep/gis/lists.html
N.J. Highlands Council GIS coverages	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data.html
N.J. Geographical Information Network	https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp
Specific GIS Data Sets	
Highlands Boundary	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data/HL_Boundary.zip
Preservation and Planning areas	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data/HL_Preservation_and_Planning_Area.zip
Land Use Capability Zones	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data/LUCZ.zip

Note: All Internet links active January, 2014.

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United States Department of the Interior
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TAKE PRIDE IN AMERICA

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Subject: "*Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and land-Surface Characteristics*" by R.J. Baker, M.M. Chepiga and S.J.Cauller, USGS Scientific Investigations Report 2015-5075

Dear Mr. Hoffman:

The U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection (NJ DEP) has released the subject publication. The report is the USGS's official report for its investigation from 2008 - 2015 to estimate median nitrate concentrations in the Highlands Region. The subject report has passed through all USGS technical, policy, and editorial reviews and supersedes previous written communication and data requests fulfilled by the USGS to various stakeholders interested in the groundwater nitrate issues of the New Jersey Highlands. This report is available at
http://pubs.er.usgs.gov/publication/sir20155075

During the course of the investigation and prior to the release of the final report, the USGS provided preliminary or draft written communications and data to various stakeholders, including the Highlands Council. The objective of this letter is to resolve any questions about the documents and communications associated with this investigation.

In 2008, the USGS submitted a draft report to the NJ Highlands Council which included estimates of median nitrate concentrations consistent with available nitrate data from the USGS National Water Information System (NWIS). At that time there were only 352 wells with nitrate concentrations in the NWIS database for the Highlands that were appropriate for this study. The Highlands Council then submitted the USGS's draft report to the New Jersey Department of

Environmental Protection (Barbara Hirst and Fred Bowers) for technical peer review. The NJDEP reviewer comments were sent to the USGS and the USGS in turn addressed each comment to the satisfaction of the Highlands Council.

The draft report was not a formal USGS Scientific Investigation Report (SIR). The Highlands Council adopted and edited specific sections of the USGS draft report and included them in one section of their Highlands Master Plan Technical Report published in 2008. http://www.highlands.state.nj.us/njhighlands/master/tr_water_res_vol_1.pdf.

By 2012, a large number of domestic supply wells had been sampled as a result of the Private Well Testing Act (PWTA, http://www.nj.gov/dep/pwta/) of 2001. The USGS, NJDEP, and Highlands Council recognized that using the additional nitrate values from the PWTA data set could be used to improve nitrate estimates for the Highlands that were developed in 2008. In 2012 the USGS and NJDEP began a statistical analysis of the PWTA nitrate data from the Highlands Region to improve the estimates of median nitrate concentrations for the area.

In May, 2012, the USGS prepared and sent to the New Jersey Highlands Council a preliminary written communication titled "*New Jersey Highlands median nitrate concentrations in sub watersheds and land use capability zones, an assessment using results of the New Jersey Private Well Testing Act, documentation of methods and results*". The purpose of the 2012 communication was to describe preliminary results for the Council's review. The 2012 communication presented nitrate concentrations in groundwater from the data in NWIS and PWTA sources.

In both the 2008 and 2012 study, nitrate-concentration data are related to land-use, hydrologic, septic-density and other data sets. The median nitrate concentrations for the Highlands Region and for subareas within the Highlands were estimated using similar logistic-regression analysis in both the 2008 and 2012 analyses of the data. Differences between the 2008 and 2012 nitrate estimates were noted and possible reasons for those differences were highlighted. Such reasons include: a) lack of information on well location, construction and use in the PWTA data set; b) aquifers sample; c) quality of the PWTA data; d) differences in number of PWTA samples (more than 19,000 samples) vs NWIS samples (352 samples), and e) uncertainty about land use around each well due to lack of locational information.

In 2014, the NJDEP requested the USGS to publish the findings of the 2012 investigation as a formal USGS Scientific Investigation Report (SIR). This process includes peer review and USGS technical review.

During that review it was determined that a statistical correction was incorrectly applied in calculating the 2012 estimated quantile median nitrate values. The correction was determined to be unnecessary and is not part of the quantile model estimates of the median nitrate concentrations documented in the USGS 2015 report.

The statistical method that was used for the 2008 and 2012 investigations were identical, however, the data sets were different, in that the 2008 data set included only NWIS data and the 2012 analysis included NWIS and PWTA data. All of the statistical detail is described in the published 2015USGS report.

It is important to acknowledge the distinction between unpublished 2008 and 2012 documents and the approved USGS 2015 report. The 2008 draft report was written by the USGS with substantial input from the Highlands Council and was extensively peer and technically reviewed by the NJDEP, but was never published as a formal USGS SIR. The 2012 communication was written by the USGS to provide preliminary information. The communication was not peer or technically reviewed, as it was a preliminary analyses being shared with the Council staff. The 2015 report was thoroughly reviewed for technical merit, policy and editorial issues, and it was formally approved for publication by the USGS as a Scientific Investigation Report.

Publication of the 2015 report with the appropriate technical, policy, and editorial reviews is intended to provide the data and interpretation needed by the NJDEP, NJ Highlands Council and the many stakeholders to address the groundwater quality issues of the Highland Region.

If you have any questions, please feel free to contact me.

Kind Regards

Richard H. Kropp

Richard H. Kropp
Center Director
USGS NJ Water Science Center

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Lt. Governor

BOB MARTIN
Commissioner

December 18, 2015

Mr. John A. Thonet
Thonet Associates, Inc.
14 Upper Kingtown Road
Pittstown, New Jersey 08867

Dear Mr. Thonet:

I am responding to your memorandum of September 1, 2015 titled "Preliminary Comments Regarding Scientific Investigation Report 2015-5075 *Median Nitrate Concentrations In Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics*." Thank you very much for taking the time to review this report.

Your memorandum makes a number of points. I believe your comments fall into three primary categories which I summarize below. Each is followed by my response.

Comment 1. You claim it is inappropriate to model background nitrate in the Highlands Preservation area. Instead, DEP should take direct measurements of nitrate in groundwater.

Reply 1. The new study used more than 19,000 directly measured groundwater samples compared with only 52 sample results available for the initial study. Installing additional wells and collecting samples from new wells would impose prohibitive costs on the Department. Obtaining direct measurements by installing wells in pristine areas of the Highlands in the manner you propose would also entail additional ecological disruption in those areas. DEP's original approach to estimating nitrate in the Highlands was an average of 45 samples in nonforested areas and 7 samples in forested areas. This approach was criticized as depending on too small a sample set. But it used the best data available at the time and led to nitrate estimates that were used in the septic density model. The current approach is a dramatic improvement, incorporating thousands of additional data points not available at the time the rules were first adopted. The U.S. Geological Survey (USGS) study also correlates observed values to existing land use in order to predict median nitrate in areas without samples. Not only is this approach based on a much larger data set, it is a much more sophisticated approach to estimating nitrate values. Calibrating a model to observed data and then using that model to estimate values where no observed data are available is a well-established scientific approach. DEP considers the modeling done by the USGS and reported in SIR 2015-5075 an appropriate approach to estimating median nitrate in the New Jersey Highlands.

Comment 2. You claim the USGS model is based primarily on nitrate data from the Highlands Planning Area. Therefor it is inappropriate to apply it to the Preservation Area.

Reply 2. This assertion is incorrect. Most of the additional data is actually from the Preservation area. The combined NWIS and PWTA data base contains 19,670 samples. Of this total 8,977 were from the

Planning area. 10,437 were taken from wells in the Preservation area. and 240 were taken from wells just outside but close enough to be used in the USGS analysis.

Comment 3. You state a previously published report submits significantly different values for the Preservation area.

Reply 3. This statement refers to a report which was based on preliminary results from the USGS that have been corrected. This discrepancy which led to the withdrawal and correction of the report is attributable to a chain of two errors which are expanded in detail below.

I wrote a report, TM 14-1. titled "Nitrate Concentrations in Groundwater of New Jersey's Highlands Region " This was published online on September 8, 2014. The 2014 version of TM14-1 inappropriately referenced 2012 preliminary USGS modeling results of median nitrate values in the Highland. This modeling study added nitrate values from the domestic wells reported under the private well testing act to the previously available data. However the 2012 USGS study results were not fully vetted and reviewed. The preliminary USGS study was not released to the public and should not have been reported on in TM 14-1.

In 2014 DEP contracted with USGS allowing them to formally review and publish their modeling report on median nitrate values in the Highlands. This review found a statistical correlation that was incorrectly applied in the 2012 modeling study. On September 10, 2014 I was informed of this error in the 2012 preliminary results. TM14-1 was removed from the New Jersey Geological and Water Survey's web site that day. USGS has provided an explanation of the numerical mistake made in the preliminary report.

The USGS corrected the mistake, finalized their review, and subsequently published the modeling report on Highlands' median nitrate as SIR 2015-5075. Once SIR 2015-5075 was published I revised my report, TM14-1, to include the corrected, referenceable, estimates of median nitrate in the Highlands. TM 14-1 is available online at:
http://www.njgeology.org/pricelst/tmemo/tm14-1.pdf

In summary, I believe the modeling work by the United States Geological Survey is an appropriate approach to estimating nitrate in groundwater in the New Jersey Highlands. Installation of new wells and sampling of those wells would be prohibitively expensive. Additionally, installation of new monitoring wells and the mobilization and demobilization of sampling equipment would create environmental disruption that accompanies the drilling and sampling process in remote, pristine locations.

Please contact me at (609) 292-1185 or Jeffrey.L.Hoffman@dep.nj.gov if you have any questions.

Sincerely,

Jeffrey L. Hoffman
State Geologist
New Jersey Geological and Water Survey

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MEMORANDUM

To: Jeffrey L. Hoffman, NJ State Geologist, New Jersey Department of Environmental Protection (NJDEP), by email: Jeffrey.L.Hoffman@dep.nj.us

From: John A. Thonet, Thonet Associates, Inc.,
Environmental Planning and Engineering Design Consultants

Date: January 16, 2016

Re: Continuing Comments Regarding USGS Scientific Investigations Report 2015-5075, entitled:
Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics
Prepared by the U.S. Geological Survey (USGS) in cooperation with the New Jersey Department of Environmental Protection (NJDEP or the Department)

cc: Julia Somers, Executive Director, New Jersey Highlands Coalition
Elliott Ruga, Policy Director, New Jersey Highlands Coalition

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First and foremost, I thank you and the Department, , both personally and on behalf of the New Jersey Highlands Coalition, for responding to my September 1, 2015 memorandum, which provided Thonet Associates' preliminary comments on the USGS Scientific Investigations Report (SIR) 2015-5075. This memorandum provides some additional comments based on the additional information that you have recently provided.

As you will recall, New Jersey Highlands Coalition representatives first met with you and other NJDEP representatives on July 30, 2015 at which time we were briefed on the findings contained within USGS SIR 2015-5075. In that meeting, the you and the Department explained that the NJDEP intends to rely on this recently prepared report as the basis for modifying its previous estimates of the "existing conditions" nitrate concentrations within the ground water of the New Jersey Highlands Region, presumably as of August 10, 2004, when the New Jersey's Highlands Water Protection and Planning Act was signed into law, or perhaps, as of 2008 when the USGS first submitted is original report to the Highlands Council.

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As per your briefing, the modified estimates of the "existing conditions" nitrate concentrations would result in changes to permitted septic densities within the Highlands Region and those changes would be significant, particularly within the designated Preservation Area.

In my memorandum to you dated September 1, 2015, I provided some preliminary comments regarding USGS SIR 2015-5075, which you kindly responded to by letter dated December 18, 2015.

Prior to receiving your December 18, 2015 letter, however, you also kindly accepted the New Jersey Highland Coalition's invitation to attend its October 21, 2015 Policy Committee Meeting and addressed that committee regarding USGS SIR 2015-5075, which we very much appreciated. During that meeting, you presented the Policy Committee with some additional information regarding that USGS SIR 2015-5075 and subsequent/y also provided the Coalition with some of the additional information that I had requested in my September 1, 2015 memorandum.

This memorandum addresses the additional information that you have provided to us since our initial briefing of July 30, 2015 and thus supplements our September 1, 2015 comments, for your information and consideration.

Additional Information Provided by the Department

The additional information that was recently provided to the Coalition's Policy Committee includes the following:

1. You informed the Policy Committee that the USGS had apparently made a mistake in its previous analyses for determining estimates of "existing conditions" nitrate concentrations in the groundwater of the New Jersey Highlands.

   You also provided the following two (2) documents to assist in our understanding of the apparent mistake:

   a. An undated letter from Richard H. Kropp, Center Director of the USGS NJ Water Science Center, to you, as Acting State Geologist, New Jersey Geologic and Water Survey, NJDEP, Division of Water Supply & Geosciences; and

   b. New Jersey Geological & Water Survey Technical Memorandum (TM) 14-1, entitled *Nitrate Concentrations in Groundwater of New Jersey's Highlands Region,* prepared by the NJDEP, Water Resources Management, Division of Water Supply and Geosciences, New Jersey Geological Survey, dated 2014, Revised 2015, and marked *"Preliminary, Subject to Revision."*

2. A table from an unspecified document, entitled, *Table 1: Number of NO_3 readings relative to detection limits by area and zone in the combined NWIS+PWTA data base*; and
3. Your letter, dated December 18, 2015, responding to Thonet Associates' preliminary comments of September 1, 2015.

Each of the above documents is discussed on the following pages, with Thonet Associates' comments, questions, and requests for additional information or clarification following in *italics*. Requested additional information is shown in ***bold italics.***

Comments on the Additional Information Provided by the Department

1. **Letter (undated) from Richard H. Kropp, Center Director of the USGS NJ Water Science Center, Jeffrey L. Hoffman, P.G., Acting State Geologist, New Jersey Geologic & Water Survey, NJDEP Division of Water Supply & Geosciences.**
   a. *The letter from Mr. Kropp explains the letter's purpose as follows:*

      "During the course of the (USGS') investigations and prior to the release of the final report, the USGS provided preliminary or draft written communications and data to various stakeholders, including the Highlands Council. The objective of this letter is to resolve any questions about the documents and communications associated with this investigation." [Page 1, undated letter from Kropp to Hoffman]

      This statement documents that "preliminary" or "draft" results of the USGS' investigations into the existing nitrate levels were made available to the New Jersey Highlands Council (the "Council") and various stakeholders (i.e. the "public").

      Please note that the New Jersey Highlands Coalition has been an actively participating "stakeholder" in the NJ Highlands Region since the Highlands Water Protection and Planning Act was enacted on August 10, 2004 and Thonet Associates was working with the Coalition early on to provide comments regarding the water resources aspects of the Regional Master Plan.

      As such, the Coalition and Thonet Associates reviewed every document related to the NJ Highlands' water resources, including every document related to the region's existing nitrate levels, which were made available to *the public. While we recall reviewing various draft documents issued by the NJ Highlands Council, we recall no such "preliminary or draft written communications" from the USGS ever being provided to the public. Even Mr. Kropp's letter that you just recently provided to us is undated.*

Thus, it would be helpful to us if your office could provide us with the titles and dates of the "preliminary or draft communications" to which the USGS is referring.

b. *Mr. Kropp's letter goes on to explain that,*

"In 2008, the USGS submitted a draft report to the NJ Highlands Council which included estimates of median nitrate concentrations consistent with available nitrate data from the USGS National Water Information System data base for the Highlands that were appropriate for this study. The Highlands Council then submitted the USGS' draft report to the New Jersey Department of Environmental Protection (Barbara Hunt and Fred Bowers) for technical peer review. The NJDEP reviewer comments were sent to the USGS and the USGS in turn addressed each comment to the satisfaction of the Highlands Council.

The draft report was not a formal USGS Scientific Investigation Report (SIR). The Highlands Council adopted and edited specific sections of the USGS draft report and included them in one section of their Highlands Master Plan Technical Report published in 2008.

http://www.highlands.state.nj.us/njhighlands/master/tr_water_res_vol_1.pdf." [Pages 1 and 2, undated letter from Kropp to Hoffman]

In 2007, Thonet Associates reviewed and submitted detailed comments on the January 2007 draft of "Water Resources Technical Report, Volume I – Watersheds and Water Quality," including the chapter, entitled, "Nitrates in Ground Water of the Highlands Region." This draft report was subsequently finalized by the Council in 2008 with the same title, but with the chapter on nitrates changed to "Nitrates Concentrations and Septic Density of the Highlands Region." This finalized 2008 report is the same report referenced in the Mr. Kropp's undated letter, which Mr. Kropp indicates "included adopted and edited sections of the USGS' draft 2008 report" that had been subject to technical peer review by the NJDEP.

The January 2007 draft of "Volume I-Water Resources Technical Report" did, indeed, indicate that the Highlands Council's efforts with respect to nitrate management and septic suitability were not yet completed and further indicated that the Council,

> "…would be taking action in the near future to complete this task to ensure that the background nitrate and soil suitability results are utilized to make land use decisions that are protective of water quality and quantity at the local level." [Page 110, January 2007 draft "Water Resources Technical Report, Volume I – Watersheds and Water Quality," prepared by the New Jersey Highlands Council]

However, the 2008, finalized version of Volume 1, does not indicate the nitrate studies were still in "preliminary or draft" form. Indeed, the finalized Volume I states, in pertinent part, that,

> "…the Highlands Council used the most recent and reliable data available to perform these analyses." [Page 132, Final, 2008 "Water Resources Technical Report, Volume I – Watersheds and Water Quality," prepared by the New Jersey Highlands Council]

Accordingly, it would be helpful if your office could provide us with copies of the actual "preliminary" or "draft" USGS report(s) used in the preparation of the 2008 Volume 1 Water Resources Technical Report, which I would expect would be in your files and/or on file with the Council. In particular, we would be interested in seeing how the USGS labeled that report as "draft" or "preliminary," since Mr. Kropp's undated letter is the first we are hearing about the USGS disavowing that its 2008 analyses "final" or "official."

c. *The letter from Mr. Kropp further states that,*

> "In May 2012, a large number of domestic supply wells had been sampled as a result of the Private Well testing Act (PWTA…) of 2001. The USGS, NJDEP, and Highlands Council recognized that using the additional nitrate values from the PWRA data set could be used to improve nitrate estimates for the Highlands that were developed in 2008. In 2012 the USGS and NJDEP began a statistical analysis of the PWTA nitrate data from the Highlands Region to improve the estimates of median nitrate concentrations for the area…"
>
> And that,
>
> "In May, 2012, the USGS prepared and sent to the New Jersey Highlands Council a preliminary written communication titled *"New*

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Jersey Highlands median nitrate concentration in subwatersheds and land use capability zones, an assessment using results of the New Jersey Private Well Testing Act, documentation of methods and results." The purpose of the 2012 communication was to describe preliminary results for the Council's review. The 2012 communication presented nitrate concentrations in groundwater from the data in NWIS and PWTA sources." [Page 2, undated letter from Kropp to Hoffman]

It would be most helpful if your office could provide us with the May 2012 "communication" in which the USGS and the Department presented the NJ Highlands Council with nitrate concentrations in the groundwater from this expanded database, as this information clearly was never made available to the public.

In addition, it would be helpful if your office could clarify how the 2012 "existing conditions" nitrate levels could be estimated using well data that post-dated 2004, the date the Act was signed and 2008, the date the RMP was adopted. This is very relevant to what constitutes "existing condition" well data for purposes of compliance with the Highlands Water Protection and Planning Act.

d. *The letter from Mr. Kropp further states that,*

"In both the 2008 and 2012 study, nitrate-concentration data are related to land-use, hydrologic, septic-density and other data sets. The median nitrate concentrations for the Highlands Region and for subareas within the Highlands were estimated using similar logistic-regression analysis in both the 2008 and 2012 analyses of the data..."

And that,

"Differences between the 2008 and 2012 nitrate estimates were noted and possible reasons for those differences were highlighted. Such reasons include: a) lack of information on well location, construction and use in the PWTA data set; b) aquifers sample; c) quality of the PWTA data; d) differences in number of PWTA samples (more than 19,000 samples) vs. NWIS samples (353 samples), and e) uncertainty about land use around each well due to lack of locational information." [Page 2, undated letter from Kropp to Hoffman]

Accordingly, Mr. Kropp identifies what appear to be some significant deficiencies in the PWTA data set used in the 2012 analysis, including uncertainty about the land use around each well due to the lack of locational information, and uncertainty about the "quality" of that data. This seems to bring into question the validity of any analysis that utilizes the PWTA data set.

In addition, clearly the 2012 analysis, which utilized the PWTA data set, presumably included well data obtained after 2004, when the Highlands Protection and Planning Act (the "Act") was signed and after 2008, when the USGS provided its initial estimates of "existing conditions" nitrate concentrations, which have been used for years to regulate land use in the Highlands.

Obviously, "existing conditions" nitrate levels should not be a "moving target," but rather should be the nitrate levels that existed in the Highlands Region at a specific point in time, presumably as of 2004 when the Act was signed or perhaps, 2008, when the Highlands Regional Master Plan (RMP) was adopted, using the USGS 2008 estimates.

Accordingly, it would be helpful if your office could arrange to have the USGS prepare a letter explaining, in greater detail, the PWTA data limitations that Mr. Kropp's letter already acknowledges exist, why those data limitations would not negatively impact the reliability of the estimates generated by the use of that data, and why the USGS believes that it is appropriate to utilize well data from years after the Act was signed into law, to represent "existing conditions."

e. *Mr. Kropp's letter goes on to explain that,*

"In 2014, the NJDEP requested the USGS to publish the findings of the 2012 investigation as a formal USGS Scientific Investigation Report (SIR)…" and, that during the peer review process and USGS technical review, it was determined that, "…a statistical correction was incorrectly applied in calculating the 2012 estimated quantile median nitrate values. The correction was determined to be unnecessary and is not part of the quantile model estimates of the median nitrate concentrations documented in the USGS 2015 report. [Page 2, undated letter from Kropp to Hoffman]

Accordingly, this statement documents that the "mistake" made by the USGS was made, not in the 2008 analysis, originally used by the Highlands Council in 2008, but in the totally different 2012 analysis, and that the "mistake," was in incorrectly applying an undefined "statistical correction," that was "unnecessary." Therefore, this "statistical correction" was not used in the 2015 report. What is also clear is that some sort of "peer review" was conducted, in addition to an internal "USGS technical review."

It would be helpful if your office could provide us with a description of what this 2014 "peer review" consisted of and who the "peer groups" were that conducted that review.

f. *Mr. Kropp's letter also states that,*

"The statistical method that was used for the 2008 and 2012 investigations were identical, however, the data sets were different, in that the 2008 data set included only NWIS data and the 2012 analysis included NWIS and PWRA data..." [Page 2, undated letter from Kropp to Hoffman]

Actually, based on the documents available for Thonet Associates' review, it is clear that the 2008 and 2012 statistical analyses <u>were clearly not the same</u>. This is evident by simply comparing the Highlands Council's finalized 2008 "Water Resources Report, Volume I – Watersheds and Water Quality," to the information provided in Mr. Kropp's undated letter.

This comparison documents that,

1) *The 2008 analysis analyzed nitrate concentrations in ground water measured in NWIS wells throughout the region, with consideration given to:*
   a) *Well location;*
   b) *Construction;*
   c) *Water use;*
   d) *Land use; and*
   e) *Available water quality data.*

   [Page 115, the Highlands Council's finalized 2008 "Water Resources Report, Volume I – Watersheds and Water Quality"]

As you personally wrote in your 2015 version of New Jersey Geological & Water Survey Technical Memorandum 14-1,

> "Data from the NWIS data base are considered to be of "exceptional quality" (Baker and others, 2015)"
>
> [Page11, New Jersey Geological & Water Survey Technical Memorandum 14-1, *Nitrate Concentrations in Groundwater of New Jersey's Highlands Region*, dated 2014, Revised 2015, and stamped "Preliminary, Subject to Revision]

The 2012 analysis however, according to Mr. Kropp's letter, also included the utilization of PWTA wells which apparently,

a) Lacked accurate information regarding the exact location of the PWTA wells;

b) Lacked accurate information for regarding the land uses surrounding the PWTA wells, due to the lack of certainty regarding the exact locations of those wells;

c) Lacked accurate information regarding the construction of the PWTA wells;

d) Lacked accurate information regarding the water use of the PWTA wells; and

e) Were of uncertainty "quality."

Thus, the most apparent difference in the two statistical analyses performed is that the information available with regard to well location, land use, water use, construction, and water quality, for the 2008 NWIS data set was "of exceptional quality," whereas the accuracy of the 2012 PWTA data set was clearly of lesser quality and subject to greater uncertainty. This fact is formally acknowledged by Mr. Kropp and in Thonet Associates' opinion, this fact renders the results of the 2012 (and, now the 2015) analysis, of uncertain accuracy.

An additional difference between the 2008 and 2012 analyses is that, presumably, the 2012 analysis included well data collected after 2004, the date of the Act was signed into law, and after 2008, the date the RMP was adopted, hence raising a legitimate question as to whether or not all of this new data really represented "existing conditions" as related to the intent and purposes of the Highlands Water Protection and Planning Act.

In Thonet Associates opinion, this is a significant, and possibly "fatal" flaw in the 2012 analysis. Simply put, "existing conditions" cannot be a "moving target."

2. **New Jersey Geological & Water Survey Technical Memorandum 14-1, entitled *Nitrate Concentrations in Groundwater of New Jersey's Highlands Region,* prepared by the NJDEP, Water Resources Management, Division of Water Supply and Geosciences, New Jersey Geological Survey, dated 2014, Revised 2015, and marked *"Preliminary, Subject to Revision".***

Thonet Associates reviewed the original 2014 version of "New Jersey Geological & Water Survey Technical Memorandum 14-1," which bears the identical title but is <u>not</u> marked "Preliminary, Subject to Revision."

The 2014 version, unlike the 2015 revision that you recently provided to us, was, in fact, "officially available" to the public on the web site for NJDEP, Water Resources Management, Division of Supply and Geosciences. I have just recently checked the Department's website and find that this 2015 version is now present, but without the "Preliminary, Subject to Revision" stamp, which was on the copy that you provided to us.

I would appreciate it if you could advise me as to when the 2015 version of TM-41 was posted on the website, because the copy that you provided to us in October was marked "Preliminary, Subject to Revision."

The 2014 version of this report, which you and Alexandra Petriman co-authored, provides significantly different estimates of median nitrate concentrations in ground water within the Highlands Region, than presented by the USGS' 2015 Scientific Investigations Report 2015-5075. Thus it would appear that, as of 2014, neither you nor Ms. Petriman had been notified that the USGS had "made a mistake" and had revised its 2012 statistical analysis.

In any event, it can be concluded that it was not until sometime in 2014 that the USGS discovered the "statistical correction" mistake and eliminated that "correction," apparently resulting in significantly different estimates of the Highlands Region's "existing conditions" median nitrate concentrations.

According to Mr. Kropp's letter, the USGS explanation for eliminating this "statistical correction" was simply that it "...was determined to be unnecessary."

[Page 3, Mr. Kropp's undated letter]. In other words, the USGS really provided no explanation whatsoever.

We would very much appreciate it if you (or the USGS) could provide a comprehensive explanation of what the "statistical correction" was for, why it was originally applied to the 2012 analysis, why the USGS determined it to be unnecessary, and how an "unnecessary" correction factor could result in such a significant change in the estimated existing median nitrate concentrations within the Highlands Region.

<u>Some additional comments and observations</u> - Below please find some additional comments and observations, based on Thonet Associates comparison of the Department's 2014 and 2015 versions of "New Jersey Geological & Water Survey Technical Memorandum 14-1, Nitrate Concentrations in Groundwater of New Jersey's Highlands Region:

a. On page iii, the date of the 2015 report is still shown as "2014."

b. Unlike the 2014 version, Department's 2015 version eliminates any mention of the "USGS" in the "Abstract" portion of the report. *Why is that?*

c. Under "Acknowledgements," we note that the technical reviews of the 2014 and 2015 versions were both provided by Otto Zapecza of the US Geological Survey, but for the 2015 version, Mr. Zapecza is listed as U.S. Geological Survey (retired).

   Does this mean that at the time Mr. Zapecza reviewed the 2015 version, he was no longer reviewing the study on behalf of the USGS? Did Mr. Zapecza actually review the 2015 version? Please advise.

d. The 2015 version's report section, *V.B. Modeling of Observation Well Data, Highlands Council 2008*, revises the 2014 version's description of the 2008 modeling work and also revises the estimated median background groundwater nitrate concentrations for the Existing Community Zone, as documented below:

   1) In the 2014 version, it states that,

      "The Highlands Council commissioned the U.S. Geological Survey (USGS) to develop a model of groundwater nitrate concentrations that could be used to estimate nitrate concentrations in 193 HUC14 subwatersheds in the Highlands Region (fig. 7). To do this, the USGS correlated nitrate values in 352 observation wells with land-use characteristics within 500 meters of each well (Highlands Council, 2008c). USGS used the correlation to project median nitrate concentration in each of the 183 HUC14 subwatersheds in

> the Highlands Region…In the Planning Area the median nitrate concentration was estimated to be 0.72 mg/l in the Protection Land Use Capability Zone, 1.87 mg/l in the Conservation Zone, and 1.17 in the Existing Community Zone [emphasis added] (table 8)." [Pages 10 and 11, 2014 version of *New Jersey Geological & Water Survey Technical Memorandum 14-1*]

This description in the 2014 version makes it clear that, in 2008, it was the USGS that developed the model of groundwater nitrate concentrations that were used by the Highlands Council. There is no mention that the USGS' analyses at that time were "not final" and "not official" as Mr. Kropp is now claiming.

2) In the 2015 version, it states that,

> "The Highlands Council in 2008 reported on a logistic-regression water-quality model of median groundwater nitrate concentrations based on land-use characteristics (Highlands Council, 2008c). Nitrate values are from 353 observation wells in the U.S. Geological Survey's National Water Information System (NWIS) database that cover the Highlands but minimize overlap between wells. Data from the NWIS database are considered to be of "excellent quality" (Baker and others, 2015). The logistic water-quality model correlates observed nitrate in the NWIS wells to five land use characteristics (percent of urban land use, percent of agricultural land use, number of contaminated sites, stream length, and average size of properties using septic tanks) within 500 meters of each well head to estimate median nitrate in areas with no observation wells…The Highlands Council estimated median concentrations in the Planning area to be 0.72 mg/l in the Protection Land Use Capability Zone and 1.87 mg/l in the Conservation Zone. The model was not used to predict a median nitrate value in the Existing Community Zone but rater the Highlands Council selected a value of 2.0 mg/l as this is consistent with the statewide groundwater quality standard (Highlands Council, 2008c)" [emphasis added].

This description in the 2015 version seems to downplay the involvement of the USGS, referring to the USGS' NWIS database, but not identifying USGS as the agency that actually prepared the regression analysis.

In this 2015 version, it also states that the Highlands Council did not use the model to predict the median nitrate value for the Existing Community Zone, but rather just selected a value of 2.0 mg/l, based on no analysis whatsoever, a value that is 71 percent higher than the median nitrate concentration predicted by the model.

It would seem to me that the description of the 2008 analyses, as described in both the 2014 and 2015 versions of your Technical memorandum 14-1, should be identical, and should indicate identical results, since only one 2008 study was conducted. ***Please explain the reason for these changes.***

e. Estimates of median nitrate concentrations presented in the 2014 and 2015 versions of *New Jersey Geological & Water Survey Technical Memorandum 14-1, Nitrate Concentrations in Groundwater of New Jersey's Highlands Region* are different. These different results are presented below:

1) Table 9, in the 2014 version, provides the estimated median background groundwater nitrate concentrations, based on the USGS 2012 estimates. I have reproduced these 2012 results in the below table:

USGS 2012 Study Results		
Land Use Capability Zone	**Median Nitrate Concentration**	
	With Only the Preservation Area Considered	With Only the Planning Area Considered
Protection Zone	0.1 mg/l	0.6 mg/l
Conservation Zone	2.15 mg/l	2.8 mg/l
Existing Community Zone	2.36 mg/l	3.55 mg/l

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2) Table 11 in the 2015 version, provides the estimated median background groundwater nitrate concentrations, based on the USGS 2015 estimates. I have reproduced these 2015 results in the below table:

USGS 2015 Study Results		
Land Use Capability Zone	**Median Nitrate Concentration**	
	With Only the Preservation Area Considered	With Only the Planning Area Considered
Protection Zone	1.05 mg/l (10.5 times the 2012 USGS estimate)	1.19 mg/l (71.4% higher than the 2012 USGS estimate)
Conservation Zone	1.64 mg/l (23.7% lower than the 2012 USGS estimate)	1.78 mg/l (36.4% lower than 2012 USGS estimate)
Existing Community Zone	1.79 mg/l (30.5% lower than 2012 USGS estimate)	1.78 mg/l (49.9% lower than 2012 USGS estimate)

As can be seen, the USGS' 2015 results are significantly different from its 2012 results. Mr. Kropp's letter simply does not provide an adequate explanation of how these significant differences occurred by simply eliminating an "unnecessary statistical correction."

3. **Table 1: Number of NO_3 readings relative to detection limits by area and zone in the combined NWIS+PWTA data base, from an unspecified document.**

   Table 1 documents, among other things, the distribution of the wells that were sampled within the Preservation and Protection Areas, and shows that:

   a. *53% of all of the wells sampled (10,437 wells) are located within the Preservation Area, with about:*
      1) *63% of those wells located within the Protection Zone;*
      2) *28% of those wells located within the Existing Community Zone; and*
      3) *9% of those wells located within the Conservation Zone.*

b. 45.6% of all of the wells sampled (8,977 wells) are located within the Planning Area, with about:

1) 45% of those wells located within the Existing Community zone;

2) 34% of those wells located within the Protection Zone; and

3) 21% of those wells located within the Conservation Zone.

The distribution of the wells strongly suggests that there are sufficient wells available in both the Preservation Area and the Planning Area, to permit the preparation of two (2) separate regression models – one for the Preservation Area and One for the Planning Area. I would nonetheless opine that few of those wells are actually located within the Preservation Area's undeveloped forest lands and wetlands, which constitute the majority of the existing land uses within the Preservation Area.

As I opined in my September 1, 2015 comments, given (i) the distinct differences in the existing conditions and land uses within these two separate areas, and (ii) given the fact that the Preservation Area is subject to more stringent regulation due to its location within an "non-degradation area," and (iii) further given that the NJDEP is responsible only for regulating the Preservation Area, it remains Thonet Associates' opinion that it would be more scientifically appropriate to develop a separate model for each of these two very different areas, with the expectation that each model would then provide better estimates of median nitrate concentrations for each of these two distinctly different study areas. Any such model would, however, almost certainly require additional, new sampling wells within the Preservation Area's undeveloped forest lands and wetlands.

Thonet Associates' opinion in this regard remains unchanged.

4. **Letter Jeffrey L. Hoffman, State Geologist, New Jersey Geological and Water Survey, NJDEP to Thonet Associates, dated December 18, 2015, responding to Thonet Associates' *Preliminary Comments* regarding USGS SIR 2015-5075.**

   Your December 18, 2015 letter indicates that Thonet Associates; September 1, 2015 comments fall into three (3) primary categories, for which you then provide your replies. Each of these comment categories and your responses are discussed below:

a. Thonet's Comment Category No. 1: Thonet Associates claims that it is inappropriate to model background nitrate in the Highlands Preservation area and that instead, DEP should take direct measurements of nitrate in groundwater.

Your Reply: Your reply indicates the following in justifying the NJDEP's decision not to take direct measurements of nitrate concentration in groundwater within the Highlands Preservation Area:

1) "Installing additional wells and collecting samples from new wells would impose prohibitive costs on the Department." *[Page 1, Hoffman letter to Thonet, December 18, 2015]*

Thonet Associates acknowledges that collecting samples from new wells would be costly. However, wells are rarely installed in environmentally important areas such as undeveloped forested areas and wetlands, and thus no existing well data, from developed or farmed areas, can be reliably used to estimate nitrate concentrations in such undeveloped forested areas and wetlands.

The Highlands Preservation Area is 60.3% forest, 9.6% wetland and 4.6% water areas. Hence, 74.6% of the Highlands Preservation Area consists of undeveloped forested/wetland/water areas where one would be unlikely to find existing wells. Absent sufficient and reliable estimates of nitrate concentrations within the undeveloped forested and wetland/water areas of the Preservation Area, no reliable prediction model can be developed.

Developing a nitrate model based on insufficient data from undeveloped forest lands and wetlands/water areas would result in unreliable estimates of "existing conditions" nitrate concentrations, which in turn would be contrary to the intent, purposes, and requirements of the Highlands Water Protection and Planning Act.

2) "Obtaining direct measurements by installing wells in pristine areas of the Highlands in the manner you proposed would also entail additional ecological disruption in those areas." *[Page 1, Hoffman letter to Thonet, December 18, 2015]*

Acknowledged. However, the impact of some ecological disruption resulting from obtaining the well data needed to accurately estimate nitrate *concentrations within undeveloped forest lands and wetlands/water areas within the Highlands Preservation Area would be a small price to pay compared to the environmental impact associated with neglecting to collect the data necessary to accurately estimate and protect existing nitrate levels within the Preservation Area.*

In addition, your reply goes on to further to explain the reasons why the Department believes that the current USGS approach to estimating nitrate concentrations in the Highlands Region, including both the Preservation Area and the Planning Area, is better than the NJDEP's original approach. While this explanation is not really responsive to the original comment, the information provided is nonetheless appreciated.

Your explanations as to why the new approach is better than the original approach include the following claims:

1) "The current approach, is a dramatic improvement..." over the "...DEP's original approach to estimating nitrates in the Highlands..." which "was an average of 45 samples in nonforested areas and 7 samples in forested areas..." and which was "criticized as depending on too small a sample set. But it used the best data available at the time and led to nitrate estimates that were used in the septic density model..." *[Page 1, Hoffman letter to Thonet, December 18, 2015]*

   Thonet Associates agrees that, as a general rule, more data is better than less data when developing a prediction model. However, as indicated above, in order to develop an accurate nitrate concentration prediction model in the Highlands Preservation Area, one must first obtain sufficient samples in undeveloped forest lands and wetlands/ water areas, which make up the overwhelming majority of the Preservation Area. Otherwise, the model is just "garbage in, garbage out."

2) "The current approach is a dramatic improvement because it incorporates "...thousands of additional data points not available at the time the rules were first adopted..." *[Page 1, Hoffman letter to Thonet, December 18, 2015]*

   Same comment as immediately above.

3) "The U.S. Geological Survey (USGS) study also correlates observed values to existing land use in order to predict median nitrate in areas without samples. Not only is this approach based on a much larger data

set, it is a much more sophisticated approach to estimating nitrate values." *[Page 1, Hoffman letter to Thonet, December 18, 2015]*

Same comment as immediately above.

4) "Calibrating a model to observed data and then using that model to estimate values where not observed data are available is a well-established scientific approach." *[Page 1, Hoffman letter to Thonet, December 18, 2015]*

Same comment as immediately above.

b. Thonet's Comment 2: Thonet Associates claims the USGS model is based primarily on nitrate data from the Highlands Planning Area. Therefore it is inappropriate to apply it to the Preservation area.

Your Reply: "This assertion is incorrect. Most of the additional data is actually from the Preservation Area. The combined NWIS and PWTA data base contains 19,670 samples. Of this total 8,977 were from the Planning area, 10,437 were taken from wells in the Preservation area, and 240 were taken from wells just outside but close enough to be used in the USGS analysis." *[Pages 1 and 2, Hoffman letter to Thonet, December 18, 2015]*

Acknowledged. I received a copy of "Table 1," discussed earlier in this memorandum, which provided the number of NO3 readings relative to detection limits by area and zone in the combined NWIS + PWTA data base.

Repeating my comment regarding the well distribution information that you provided in Table 1, it is my finding that the distribution of wells strongly suggests that there are sufficient wells available in both the Preservation Area and the Planning Area, to permit the preparation of two (2) separate regression models – one for the Preservation Area and One for the Planning Area. I would nonetheless opine that few of those wells are actually located within the Preservation Area's undeveloped forest lands and wetlands, which constitute the majority of the existing land uses within the Preservation Area.

As I opined in my September 1, 2015 comments, given (i) the distinct differences in the existing conditions and land uses within these two separate areas, and (ii) given the fact that the Preservation Area is subject to more stringent regulation due to its location within an "non-degradation area," and *(iii) further given that the NJDEP is responsible only for regulating the Preservation Area, it remains Thonet Associates' opinion that it would be more scientifically appropriate to develop a separate model for each of these two very different areas, with the expectation that each model would then provide better estimates of median nitrate concentrations for each of these two distinctly different study areas. Any such model would, however, almost certainly require additional, new sampling wells within the Preservation Area's undeveloped forest lands and wetlands.*

c. Comment 3: Thonet Associates states that a previously published report submits significantly different values for the Preservation area.

Your Reply: "This statement refers to a report which was based on preliminary results from the USGS that have been corrected…" *[Page 2, Hoffman letter to Thonet, December 18, 2015]*

Acknowledged. See the Thonet Associates' Comments 1 and 2, on pages 3 through 14 in this memorandum, for my full response.

I hope that you will find my comments helpful and thank you and the Department in advance for responding to my above questions and requests for additional information and/or clarification.

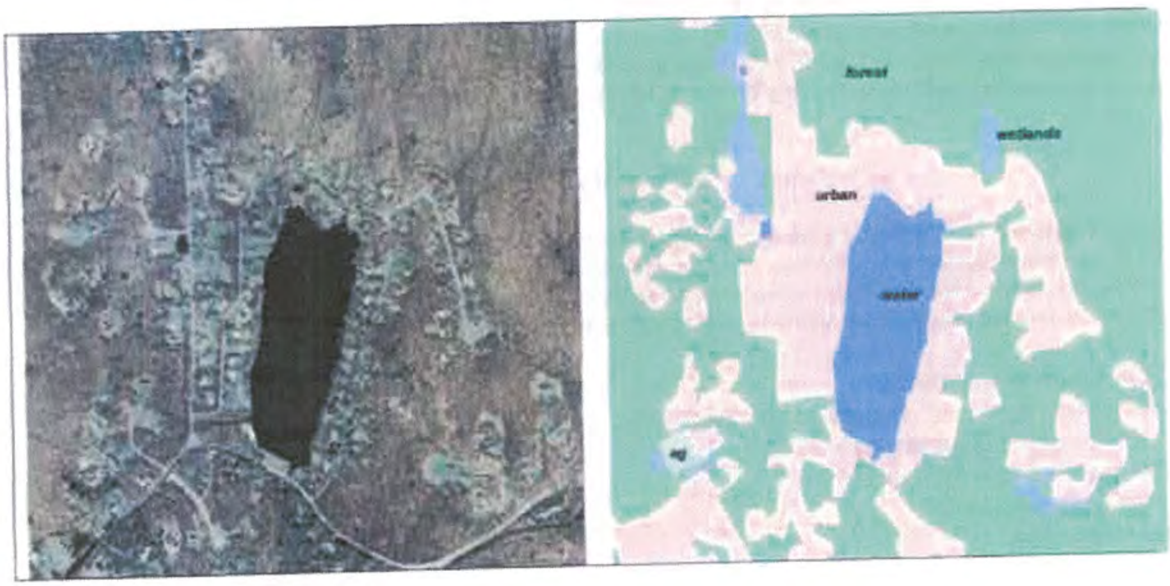
J.A.T.

NEW JERSEY GEOLOGICAL &

WATER SURVEY

Technical Memorandum 14-1

Nitrate Concentrations in Groundwater of New Jersey's Highlands Region



New Jersey Department of Environmental Protection
Water Resources Management
Division of Water Supply and Geosciences
New Jersey Geological and Water Survey
2014
Revised 2015

PRELIMINARY
SUBJECT TO REVISION

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STATE OF NEW JERSEY
Chris Christie, *Governor*
Kim Guadagno, *Lieutenant Governor*

Department of Environmental Protection
Bob Martin, *Commissioner*

Water Resources Management
Dan Kennedy, *Assistant Commissioner*

New Jersey Geological and Water Survey
Karl Muessig, *State Geologist*

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

NJDEP's core mission is and will continue to be the protection of the air, waters, land and natural and historic resources of the State to ensure continued public benefit. The Department's mission is advanced through effective and balanced implementation and enforcement of environmental laws to protect these resources and the health and safety of our residents.

At the same time, it is crucial to understand how actions of this agency can impact the State's economic growth, to recognize the interconnection of the health of New Jersey's environment and its economy, and to appreciate that environmental stewardship and positive economic growth are not mutually exclusive goals: we will continue to protect the environment while playing a key role in positively impacting the economic growth of the state.

NEW JERSEY GEOLOGICAL AND WATER SURVEY

The mission of the New Jersey Geological and Water Survey is to map, research, interpret and provide scientific information regarding the state's geology and groundwater resources. This information supports the regulatory and planning functions of DEP and other governmental agencies and provides the business community and public with information necessary to address environmental concerns and make economic decisions.

for more information contact:
New Jersey Department of Environmental Protection
New Jersey Geological and Water Survey
P.O. Box 420, Mail Stop 29-01
Trenton, NJ 08625-0420
(609) 984-6587
http://www.njgeology.org/

On the cover: Kitchell Lake, West Milford Township, Passaic County. Homes in the area are served by individual domestic wells and individual subsurface sewage-disposal systems. All of the shown area is in the Highlands preservation area and also in the protection Land Use Capability Zone
Left- Aerial photograph taken in 2007.
Right – Photointerpretation of 2007 land use.
Aerial photograph and land use interpretation are from NJDEP's Geographic Information System datasets. See Appendix A of this report for links to the datasets.

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Nitrate Concentrations in Groundwater of New Jersey's Highlands Region

by

Jeffrey L. Hoffman and Alexandra Petriman

2014

PRELIMINARY SUBJECT TO REVISION

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Epigram

"A nation that fails to plan intelligently for the development and protection of its precious waters will be condemned to wither because of its shortsightedness."
--- President Lyndon B. Johnson, writing in a letter dated November 18, 1968, to the President of the Senate and to the Speaker of the House, transmitting "An Assessment of the Nation's Water Resources." (Johnson, 1968)

Nitrate Concentrations in Groundwater of New Jersey's Highlands Region

by
Jeffrey L. Hoffman and Alexandra Petriman
2014 (revised 2015)

PRELIMINARY
SUBJECT TO REVISION

I. ABSTRACT

The Highlands Water Protection and Planning Act of 2004 called for the protection of one of New Jersey's most important sources of drinking water, the Highlands Region. This region, which includes 17 percent of the State, provided 34 percent of the potable water consumed in New Jersey in 1999 (Hoffman and Domber, 2004). One component of this protection is limiting the impact of human activities on groundwater quality. This impact is measured, in part, by increases in groundwater nitrate concentrations.

Nitrate concentrations in groundwater are summarized using three overlapping subdivisions of the Highlands Region:

(1) Underlying legislation distinguishes a Preservation Area (with stricter environmental controls) and a Planning Area (with more development permitted). The The N.J. Department of Environmental Protection (NJDEP) has major responsibility for overseeing additional development in the Preservation Area whereas the Highlands Council has primacy in the Planning Area (Highlands Council, 2008a).

(2) NJDEP provides records of observed land use based on interpretation of aerial photographs using an Anderson classification system. NJDEP assigns land use to one of six categories. Agricultural, barren land and urban uses are grouped as 'mixed-use' lands. Forest, water, and wetlands are grouped as 'pristine' lands.

(3) The Highlands Council (2008b) uses a model of natural resource assessment and development opportunity at a regional scale to define three major Land Use Capability Zones. They are the Protection, Conservation, and Existing-Community Zones.

This report also summarizes observed and estimated groundwater nitrate concentrations in the Highlands Region. The background groundwater nitrate concentration helps establish appropriate allowable density of dwellings utilizing individual subsurface sewage-disposal systems. Three studies provide information on background nitrate concentrations:

(1) NJDEP used water-quality data from observation wells in the Preservation Area to calculate median nitrate concentrations (NJDEP, 2008a). The median nitrate value in mixed-use lands, based on 45 observation wells, was estimated to be 0.76 mg/l. The median ni-

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trate value in pristine lands, based on seven observation wells, was estimated to be 0.21 mg/l.

(2) The Highlands Council (2008c) commissioned a study that correlated background nitrate concentration observed in 352 National Well Inventory System (NWIS) observation wells to land-use characteristics (Highlands Council, 2008c). This correlation was then used to estimate median nitrate values in subwatersheds and Land Use Capability Zones based on overall land-use characteristics. Estimated median nitrate values in the Protection, Conservation, and Existing-Community Land Use Capability Zones was estimated to be 0.72, 1.87 and 1.17 mg/l, respectively.

(3) Baker and others (2015) added nitrate data from 19,369 domestic wells tested under the Private Well Testing Act (PWTA) to the NWIS data set. All data were assigned to grid cells. They used a logistic regression model to estimate median nitrate concentration based on land-use characteristics. They also researched different methods of handling samples with no observed nitrate (non-detect values). Highlands-wide, the estimated median nitrate value is 1.23 mg/l. If only the Preservation Area is considered then estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community Land Use Capability Zones are 0.83, 1.61, and 1.77 mg/l, respectively. If only the Planning Area is considered then estimated median nitrate concentrations in the Protection, Conservation, and Existing-Community Land Use Capability zones are 1.17, 1.77, and 1.76 mg/l, respectively. All of these results are based on replacing non-detect values with one half of the sample-specific nitrate detection limit. This is the NJDEP's preferred approach to handling non-detect values (NJDEP, 2014).

II. INTRODUCTION

Since the 19th century, the New Jersey Highlands have been recognized as an important source of drinking water. In 1894, the New Jersey Geological Survey noted:

> Our Highlands water-sheds, to which we call attention more fully hereafter, must be the first source from which this demand [*for additional water*] is to be met. They lie convenient to the metropolitan district, at a sufficient elevation for the delivery of their waters by gravity, are not populous, have just the right amount of forest, geological and topographical conditions favorable to purity and if they could be preserved in their present favorable condition would form in all respects an ideal gathering-ground. They have already begun to be utilized, and every succeeding decade must see a more rapid advance in their development. They are also threatened at points with pollution. Their protection and conservation for the future needs of the State seem to be merited by their unusual excellence. (Vermeule, 1894)

The recognition of the Highlands as a source of high-quality water, and a call for its protection, was repeated in 1907:

> The Highland watersheds are the best in the State in respect to ease of collection, in scantiness of population, with consequent absence of contamination; in elevation, giving opportunity for gravity delivery, and in softness as shown by chemical analysis. These watersheds should be preserved from pollution at all hazards, for upon them the most populous portions of the State must depend for water supplies. There has been too much laxness in the past regarding this important matter. (New Jersey Potable Water Commission, 1907)

In 1999, the Highlands Region supplied 34 percent of the potable water in New Jersey (Hoffman and Domber, 2004). The region wholly or partially supplied potable water to 292 municipalities in 16 counties. These municipalities are home to 64 percent of the State's population. The New Jersey Legislature formally recognized the special qualities and importance of the region with the passage the Highlands Water Protection and Planning Act of 2004:

> The Legislature further finds and declares that the New Jersey Highlands is an essential source of drinking water, providing clean and plentiful drinking water for one-half of the State's population, including communities beyond the New Jersey Highlands, from only 13 percent of the State's land area; ... (P.L. 2004, Chapter 120, approved August 10, 2004).

The Act also established the New Jersey Highlands Water Protection and Planning Council ('Highlands Council') to oversee implementation of the Act.

In order to focus protection efforts and channel additional development to appropriate areas, the Highlands Region is subdivided on the basis of current land use. However, this land use can be analyzed different ways. This report summarizes three ways the Highlands Region is divided:

- by the Act into a Planning Area and a Preservation Area;
- by the NJDEP using an Anderson land-use classification scheme; and
- by the Highlands Council's Regional Master Plan (RMP), which established a Land Use Capability Zone map based on an evaluation of resource assessments and development opportunities.

One step in protecting the Highlands Region's water resources is to protect water quality through assigning appropriate regional densities of individual subsurface sewage-disposal systems (also known as septic systems). In this approach, specific pollutants discharged by domestic septic systems are used as a surrogate for overall ground water quality. Hoffman and Canace (2004) present a model of permissible densities of septic systems if a number of input parameters are specified. One necessary parameter is the allowable nitrate concentration in the groundwater. If the allowable nitrate concentration is set equal to the background nitrate concentration then the septic systems should not create an appreciable increase in groundwater nitrate concentration. Thus, defining the background nitrate concentration in the Highlands

Region is an important step in protecting water resources. This report provides a summary of three approaches to defining the background nitrate values:

- an original analysis of available observation-well water-quality data only;
- a model relating available observation-well water-quality data to appropriate land-use characteristics; and
- an update of the model adding water-quality data from the Private Well Testing Act.

II.A. Data Sources

This analysis relies on Geographic Information System (GIS) coverages of the Highlands Region and its geographic subdivisions provided by the Highlands Council and NJDEP (Appendix A). In the analysis process minor errors occur when coverages don't exactly coincide. This is the reason totals of the area of subdivision areas do not agree on overall area of the Highlands. However, these errors are a very small percentage of total area and are not significant in this analysis.

II.B. Acknowledgements

Many thanks to Otto Zapecza of the U.S. Geological Survey (retired) who provided a technical review. Also thanks to the many reviewers of this report.

III. LOCATION

The Highlands Water Protection and Planning Act of 2004 defines the Highlands Region in northern New Jersey (fig. 1). It consists of over 850,000 acres in this part of the state.

The Highlands Region consists of almost all of its eponymous physiographic province and parts of the neighboring Valley and Ridge and Piedmont physiographic provinces. The Highlands physiographic province is generally marked by a series of rounded ridges and narrow valleys that trend in a northeast-southwest direction (Lewis and Kummel, 1940). The ridges are about 400 to 600 feet higher than the neighboring valley floors (Hoffman and French, 2008).

Figure 1. New Jersey's Highlands Region and Physiographic Provinces.

IV. GEOGRAPHICAL DIVISIONS

The Highlands Region is subdivided based on three different methods. Each is for a specific purpose and has its own benefits.

IV.A. Planning and Preservation Areas

The Highlands Water Protection and Planning Act determined that:

> … it is in the public interest of all the citizens of the State of New Jersey to enact legislation setting forth a comprehensive approach to the protection of the water and other natural resources of the New Jersey Highlands; that this comprehensive approach should consist of the identification of a preservation area of the New Jersey Highlands that would be subjected to stringent water and natural resource protection standards, policies, planning, and regulation… (P.L. 2004, Chapter 120, approved August 2004).

The Act provides a detailed spatial description of the Preservation Area (fig. 2). All land in the Highlands Region outside of the Preservation Area is defined as the Planning Area. The areas are about equal in size: the Planning Area totals 444,276 acres, and the Preservation Area 414,992 acres.

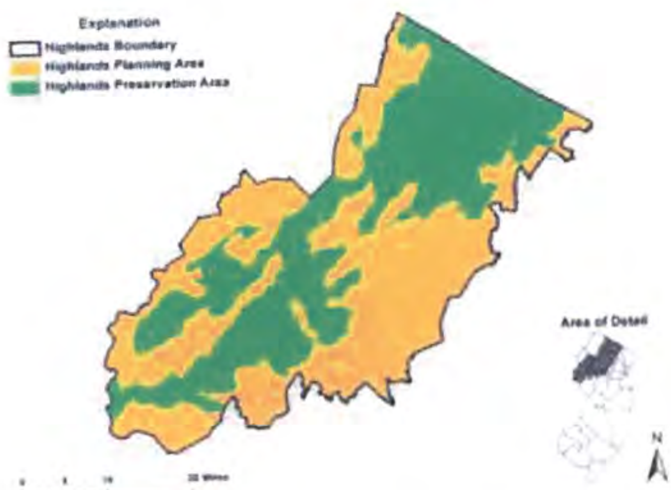

Figure 2. Planning and Preservation Areas in the Highlands Region of New Jersey.

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IV.B. Pristine and Mixed-Use Land-Use Groups

NJDEP provides analysis of land use in New Jersey based on aerial photography (NJDEP, 2010). This analysis is available for 1995/97, 2002, and 2007. The 2007 coverage is based on aerial photographs with a pixel size of 1 foot (NJDEP, 2012).

Each mapped unit is assigned a land use utilizing a modified Anderson approach (Anderson and others, 1976). Land uses are grouped into six general categories - agricultural, barren land, urban, forest, water and wetlands. Figure 3 shows mapped land use in the Highlands Region based on the 2007 aerial photographs.

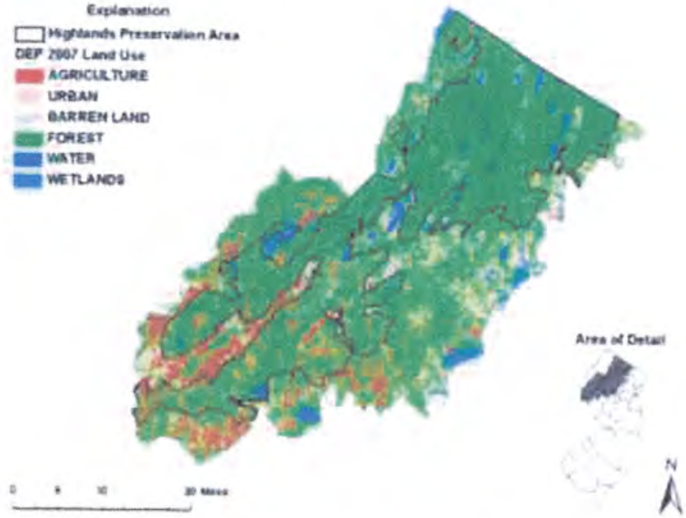

Figure 3. Land use in the Highlands Region of New Jersey, 2007.

Figure 4. Mixed-use and pristine land use groups in the Highlands Region.

For analysis purposes, NJDEP defined two land-use groups. The mixed-use group consists of the agricultural, barren-land, and urban-land uses and is 357,591 acres in size. The pristine group consists of the forest, water and wetlands land uses and covers 525,471 acres. Figure 4 shows these two land-use groups. Table 1 lists the area of each land use and group in the Highlands Region.

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Table 1. Acreage of land uses and groups in the Highlands Region of New Jersey

Group	Land Use	Acres
Mixed-Use	agriculture	112,107
	barren land	6,679
	urban	238,805
	subtotal	357,591
Pristine	forest	400,338
	water	35,232
	wetlands	89,901
	subtotal	525,471
Total Acreage		883,062

IV.C. Land Use Capability Zones

Another way of classifying land use in the Highlands Region is by Land Use Capability Zones (Highlands Council, 2008b). This approach is based on the Land use Analysis Decision Support (LANDS) model:

> The LANDS model provides for a comprehensive evaluation of both resource constraints and development opportunity at a regional scale. It addresses the potential for conflict between natural resource protection and economic growth by identifying environmental constraints and capacity limitations of land and infrastructure, and identifying those areas within the Highlands Region that can best support appropriate and varying levels of economic and development activity. (Highlands Council, 2008b).

The Land Use Capability Zones consist of three zones and four sub-zones. They are: the Protection Zone (which includes the wildlife management sub-zone), the Conservation Zone (which includes the conservation environmentally constrained sub-zone), and the Existing-Community Zone (which contains the existing-community environmentally-constrained sub-zone and the lake-community subzone). The summary tables and figures in this report consider only the three zones (fig. 5). Table 2 lists the areas of the three zones in the Highlands Region.

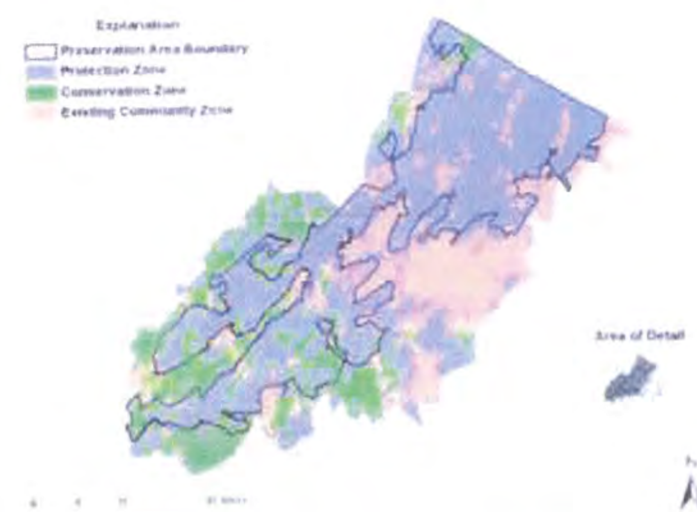

Figure 5. Land Use Capability Zones in the Highlands Region

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IV.D. Overlay Analysis

The three methodologies for subdividing the Highlands Region may be overlain to ascertain their areas of intersection. Table 3 lists the area of intersection of Highlands Areas with land-use types and groups. Table 4 lists the area of intersection of Highlands Areas with Land Use Capability Zones. Table 5 lists the area of intersection of Land Use Capability Zones with land-use types and groups.

Table 2. Acreage of Land Use Capability Zones in the Highlands Region of New Jersey.

Land Use Capability Zone	Acres
Protection	476,661
Conservation	184,280
Existing Community	198,417
Total Acreage	859,358

Table 5 is further subdivided to determine the intersection of Land Use Capability Zones and land-use types and groups: first the Planning Area (table 6) and then the Preservation Area (table 7).

Table 3. Acreage of intersection of Highlands Areas with land-use types and groups

Highlands Area	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-Total	Land Use			Sub-Total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Planning	72,387	4,200	162,083	238,671	141,895	15,137	48,491	205,523	444,194
Preservation	33,592	2,424	70,043	106,058	249,860	19,014	39,965	308,838	414,897
Total Acreage	105,979	6,624	232,126	344,729	391,755	34,151	88,456	514,361	859,091

Table 4. Acreage of intersection of Highlands Areas and Land Use Capability Zones

Highlands Area	Land Use Capability Zone			Total Acreage
	Protection	Conservation	Existing community	
Planning	148,868	129,673	165,488	444,028
Preservation	327,449	54,555	32,896	414,900
Total Acreage	476,317	184,228	198,384	858,928

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Table 5. Acreage of intersection of Land Use Capability Zones and land-use types and groups in the Highlands Region.

Land Use Capability Zone	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-total	Land Use			Sub-total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Protection	15,375	3,392	59,768	78,534	313,781	23,840	60,027	397,648	476,182
Conservation	91,281	1,175	21,550	114,006	49,379	1,701	19,140	70,220	184,227
Existing Community	3,100	3,569	137,879	144,549	35,992	7,923	9,921	53,836	198,384
Total Acreage	109,756	8,136	219,197	337,089	399,152	33,464	89,088	521,704	858,793

Table 6. Acreage of intersection of Land Use Capability Zones and land-use types and groups in the Planning Area.

Land Use Capability Zone	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-total	Land Use			Sub-total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Protection	6,886	1,293	27,364	35,543	79,885	7,024	26,363	113,272	148,815
Conservation	63,147	1,003	17,413	81,563	33,189	1,291	13,630	48,110	129,673
Existing Community	2,341	1,904	117,278	121,523	28,763	6,723	8,479	43,965	165,488
Total Acreage	72,374	4,200	162,055	238,629	141,837	15,038	48,472	205,347	443,976

Table 7. Acreage of intersection of Land Use Capability Zones and land-use types and groups in the Preservation Area.

Land Use Capability Zone	Mixed-Use Group				Pristine Group				Total Acreage
	Land Use			Sub-total	Land Use			Sub-total	
	Agriculture	Barren land	Urban		Forest	Water	Wetlands		
Protection	8,259	1,974	38,013	48,246	228,583	17,189	33,348	279,121	327,367
Conservation	24,911	177	7,533	32,621	16,037	510	5,386	21,933	54,554
Existing Community	417	273	24,491	25,181	5,188	1,308	1,219	7,715	32,896
Total Acreage	33,587	2,424	70,037	106,048	249,808	19,007	39,953	308,769	414,817

V. NITRATE CONCENTRATIONS IN GROUNDWATER

Estimates of background nitrate concentrations are based on the type of data used and the geographic area from which the data were gathered. To date there have been three slightly different approaches, the first two based on water quality in observation wells and the third adding data from domestic wells. Each approach, and the estimated background nitrate values, are summarized below.

V.A. Observation Well Data, NJDEP 2008

NJDEP (2008a) estimated background nitrate data based on water-quality data from observation wells. Serfes (2004) provided an estimate of 0.76 mg/l of median ambient nitrate concentration in noncarbonate bedrock of northern New Jersey. This value is based on data from 45 observation wells from the National Water Inventory System (NWIS) data base maintained by the U.S. Geological Survey. NJDEP assumed this value applied to land used in the mixed-use group.

In order to estimate background nitrate concentration in the groundwater of pristine land-use group NJDEP analyzed land use near observation wells in the Highlands Region. The land-use classification was based on 2002 aerial photos interpreted using the modified Anderson classification scheme (NJDEP, 2012). If the land use within 500 meters of an observation well was 90 percent or more forest, wetlands and water then NJDEP assumed groundwater in that well represented a pristine situation (NJDEP, 2008a). Of 388 NWIS wells in and near the Highlands Region only 7 were both in the Highlands Region and in a pristine area. The median nitrate value of these 7 wells was 0.21 mg/l nitrate. NJDEP assumed this value was appropriate for use as a background groundwater nitrate value in areas not impacted by human activities (NJDEP, 2008a).

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V.B. Modeling of Observation Well Data, Highlands Council 2008

The Highlands Council in 2008 reported on a logistic-regression water-quality model of median groundwater nitrate concentrations based on land-use characteristics (Highlands Council, 2008c). Nitrate values are from 352 observation wells in the U.S. Geological Survey's National Water Information System (NWIS) database that cover the Highlands but minimize overlap between wells. Data from the NWIS database are considered to be of "exceptional quality" (Baker and others, 2015). The logistic-regression water-quality model correlates observed nitrate in the NWIS wells to five land use characteristics (percent of urban land use, percent of agricultural land use, number of contaminated sites, stream length, and average size of properties using septic tanks) within 500 meters of each well head to estimate median nitrate in areas with no observation wells.

The Highlands is drained by 4 major watersheds (Passaic, Raritan, Delaware, and Wallkill). These are divided into 183 subwatersheds following a classification scheme described in Ellis and Price (1995). The subwatersheds (shown in figure 6) are the basis of the Highland Council's water resource management approach.

Figure 6. Major drainage basins and subwatersheds in the Highlands Region of New Jersey.

The Highlands Council predicted median groundwater nitrate values in each subwatershed using the logistic-regression water-quality model. Based on the median value of each subwatershed, the Highlands Region-wide median concentration was estimated to be 0.83 mg/l. Each sub-watershed was also assigned to either the Planning or Preservation Area and to a Land Use Capability Zone (Highlands Council, 2008b). The Highlands Council estimated median concentration in the Planning Area to be 0.72 mg/l in the Protection Land Use Capability Zone and1.87 mg/l in the Conservation Zone. The model was not used to predict a median nitrate value in the Existing-Community Zone but rather the Highlands Council selected a value of 2.0 mg/l as this is consistent with the statewide groundwater quality standard (Highlands Council, 2008c).

Table 8. Estimated median background groundwater nitrate in the Planning Area, Highlands Council 2008 estimates

Land Use Capability Zone	Nitrate Concentration (mg/l)
Protection	0.72
Conservation	1.87
Existing Community	2.0

169x

V.C. Modeling of Observation Well and PWTA Data, Baker and others, 2015

The Highlands Council's 2008 approach was based on groundwater-quality data from NWIS observation wells. An additional data set has become available because of the requirements of New Jersey's Private Well Testing Act (PWTA). Baker and others (2015) of the U.S. Geological Survey present a logistic-regression approach to incorporating these PWTA data with the NWIS data in order to estimate median nitrate concentration based on land-use characteristics.

Private Well Testing Act

New Jersey's Private Well Testing Act became effective in 2002. It requires sellers of homes with domestic wells to test untreated groundwater prior to selling the property (Atherholt and others, 2009). The results must be shared with potential buyers. The Act requires water from domestic wells to be tested for pH, presence of total coliform bacteria, concentration of nitrates, lead, 26 volatile organic chemicals, iron and manganese. These results are submitted to NJDEP and are used to conduct regional analyses (such as NJDEP, 2008b). The Act also requires that the submitted water-quality data be kept confidential.

Analysis of groundwater quality data generated by the Private Well Testing Act must be done with several caveats in mind:

- Most of the wells are located in rural and low-density suburban areas. Information is not available for all areas of the state.
- Coastal communities, parks, preserved forests, and wildlife preserves have very few or no wells.
- NJDEP does not enforce the data submission requirement. It is unknown if any data are missing from the NJDEP data base.
- NJDEP has observed errors in laboratory reporting. Although laboratories must be certified to perform PWTA analysis there is no post-submission quality control of the data to ensure that collection, testing and analysis are done properly and consistently except to validate locations.

There are several different ways to summarize these nitrate data. By definition, the PWTA database represents areas with some level of development. Thus the PWTA data over-represent developed areas and under-represent undeveloped areas. Taking a simple average of the PWTA nitrate data will skew the estimated nitrate value. In order to avoid this limitation the USGS developed a model to predict median nitrate based on land use characteristics. This model was then applied to areas with no observed nitrate values.

NJDEP queried the PWTA data base and found 19,369 data points in the Highlands Region. The PWTA law requires, however, that the nitrate data be kept confidential. To respect this requirement, NJDEP subdivided the Highlands Region into a grid of 9,744 cells, each measuring 2,000 feet by 2,000 feet. NJDEP assigned each PWTA nitrate reading to an individual grid cell. Baker and others (2015) added NWIS data to individual grid cells resulting in a total of 19,670 nitrate values in the Highlands. Of the model cells, 4,516 contained one or more nitrate values. The number of observed nitrate values ranged from 1 to 114 per cell, with an average of 4.3 samples per cell. There were 5,228 grid cells with no nitrate values. The observed median nitrate concentration in each cell ranged from 0.027 mg/l to 26.2 mg/l. Each of the cells was assigned to either the Planning or Preservation Area and to a Land Use Capability Zone based on location of the cell centroid. Table 9 breaks out the number of cells by Highlands Area and Land Use Capability Zone. Cells whose centroid fell outside the GIS coverage of the Highlands Area and Land Use Capability Zones are excluded from this analysis.

Table 9. Number of grid cells by Highlands Area and Land Use Capability Zone.

Land Use Capability Zone	Number of Cells		
	Highlands Wide	Preservation Area	Planning Area
Protection	5,191	3,578	1,613
Conservation	2,003	595	1,408
Existing Community	2,158	358	1,800

Logistic Regression Model

In order to compile nitrate levels for the remaining 5,228 cells lacking observed nitrate data, USGS developed a logistic-regression model. Baker and others (2015) investigated 320 geographic and environmental characteristics to determine which characteristics were significantly correlated with median nitrate values. They determined that five land use characteristics in each cell were significant:

- percentage of urban land use
- percentage of agricultural land use
- number of contaminated sites
- stream length
- average size of properties using septic tanks

Baker and others (2015) then used the correlation to estimate median nitrate values in all cells based on these five cell-specific land use characteristics.

Results below detection limits

An additional concern developed with analyses for which nitrate was not detected in a sample, that is, nitrate was below the detection limit (DL) of the analysis technique. A non-detect (ND) report does provide valuable information but complicates a simple parametric analysis. The PWTA data were reported from multiple labs with differing nitrate detection limits. For the reported nitrate values the DL ranged from 0.02 to 10.0 mg/l. Of all samples that fell within the Preservation Area 25.8% had nitrate values lower than the detection limit of the sample-specific analysis technique. In the Planning Area the non-detect percentage was 19.9%. Table 10 shows the number of samples with no detected nitrate sorted by detection limit of the analysis technique used for each sample.

Table 10. Number of samples with no detectable nitrate (ND) by nitrate detection limit (DL)

detection limit (mg/l)	number of samples	detection limit (mg/l)	number of samples
0.02	312	0.25	23
0.029	1,795	0.3	181
0.05	2	0.345	15
0.1	4	0.35	97
0.11	2	0.5	97
0.2	1,223	1	1
0.245	23	10	696

In order to use ND samples in the analysis each had to be replaced by a value. Baker and others (2015) looked at four different approaches to substituting a ND reading with a numerical value:

- 0.0 mg/l
- ½ of the detection limit of the sample analysis technique
- The detection limit of the sample analysis technique
- A value based on a Kaplan-Meier analysis of other nitrate values in the cell

Baker and others (2015) created four different data sets, each generated by replacing all ND values with one of the above approaches. Each data set then became the basis for a logistic regression model that correlated nitrate data with land use in each grid cell. Each model was then used to estimate median nitrate data in all grid cells. Figure 7 shows the estimated cell values in all grid cells in the Highlands Region when all ND values are placed by a Kaplan-Meier estimate of the actual value.

Baker and other (2015) also estimated median nitrate value of the cell medians Highlands wide, in the Preservation and Planning Areas, and in each of the Land Use Capability Zones in each Area. These results are reproduced in table 11.

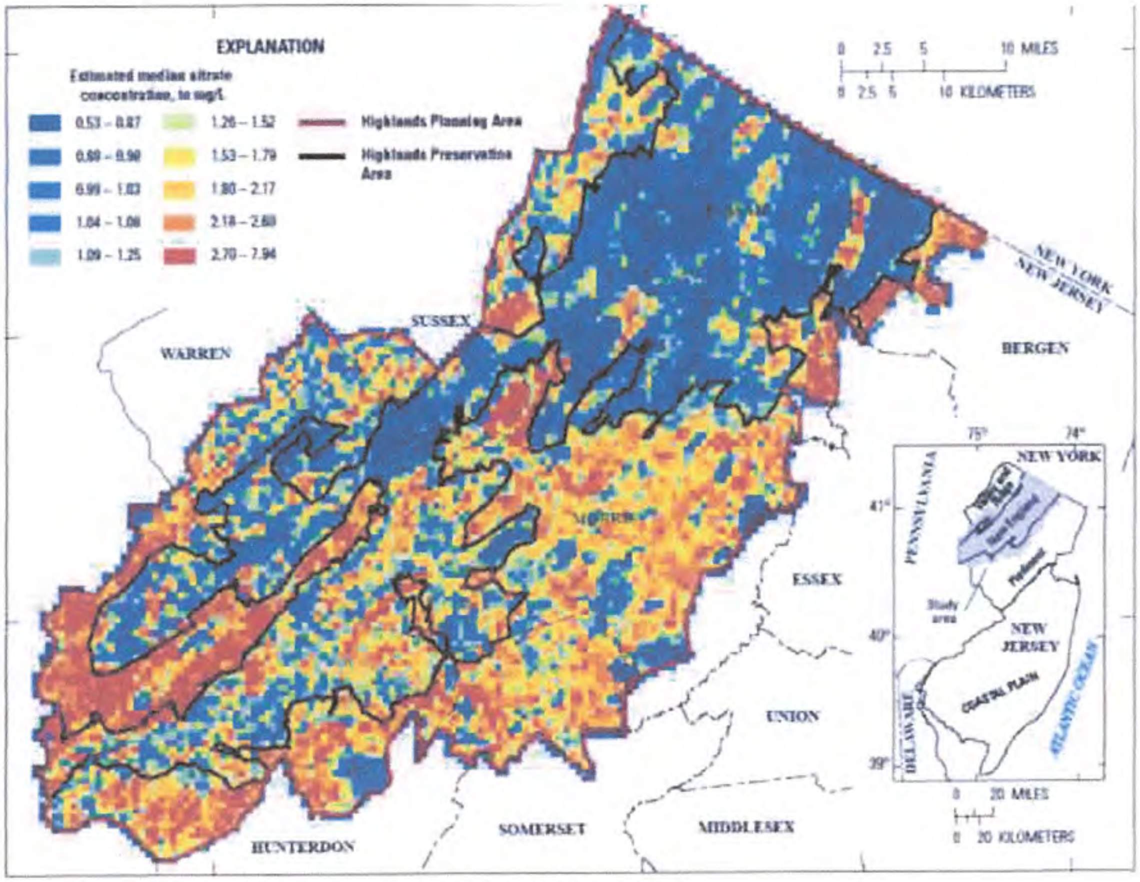

Figure 7. Estimated median nitrate values in Highlands Region grid cells.
(from Baker and others, 2015)

Table 11. Estimated Median Nitrate (mg/l) by Subdivision of the NJ Highlands

Subdivision of the NJ Highlands	Replacing all NonDetect (ND) values by			
	Zero	½ of Detection Limit	Detection Limit	Kaplan-Meier estimate
Entire Highlands	*1.21*	*1.23*	*1.25*	*1.25*
Preservation Area				
Entire	*0.95*	*0.98*	*1.09*	*1.08*
Protection Zone	0.80	0.83	1.06	1.05
Conservation Zone	1.60	1.61	1.63	1.64
Existing Community Zone	1.77	1.77	1.79	1.79
Planning Area				
Entire	*1.52*	*1.53*	*1.55*	*1.55*
Protection Zone	1.14	1.17	1.20	1.19
Conservation Zone	1.76	1.77	1.78	1.78
Existing Community Zone	1.74	1.76	1.78	1.78

173x

Conclusion

It is clear that the various methods of handling non-detect values do not make a significant impact on the results except in one case. In the Preservation Area, Protection Zone the estimated median nitrate is very similar when ND values are replaced by either 0 mg/l or ½ of the detection limit. These estimated medians are, respectively, 0.80 and 0.83 mg/l. When all ND values are replaced either by a value based on a Kaplan-Meier analysis or by the DL, the estimated medians are, respectively, 1.05 and 1.06 mg/l. This is because this is the area with the least impacted groundwater and thus expected to have more nitrate readings below the detection limit than other zones.

NJDEP generally uses a value of half of the detection limit in other cases of analysis of water data (NJDEP, 2014). Replacing ND values with ½ of the DL for samples in from the Preservation Area, Protection Zone is more conservative (results in a lower estimate of the background median nitrate value) than using either the Kaplan-Meier approach or substituting all ND values with the DL of each sample.

VI. REFERENCES

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer. R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 41 p., available at http://landcover.usgs.gov/pdf/anderson.pdf.

Atherholt, T.B., Louis, J.B., Shevlin, J., Fell, K., and Krietzman, S., 2009, The New Jersey private well testing act, an overview: N.J. Dept. of Environmental Protection, Division of Science, Research and Technology, technical report, 8 p., available at http://www.state.nj.us/dep/dsr/research/pwta-overview.pdf.

Baker, R.J., Chepiga, M.M., and Cauller, S.J., 2015, Median nitrate concentrations in groundwater in the New Jersey Highlands region estimated using regression models and land-surface characteristics: U.S. Geological Survey Scientific Investigations Report 2015-5075, 27 p., available at http://dx.doi.org/10.3133/sir20155075.

Ellis, W.H. and Price, C.V., 1995, Development of a 14-digit hydrologic coding scheme and boundary data set for New Jersey: U.S. Geological Survey Water-Resources Investigation Report 95-4134, 1 plate, scale 1:250,000.

Highlands Council, 2008a, Highlands regional master plan: New Jersey Highlands Water Protection and Planning Council, Chester, NJ, 490 p., available at http://www.highlands.state.nj.us/njhighlands/master/index.html.

Highlands Council, 2008b, Land Use Capability Zone map: New Jersey Highlands Water Protection and Planning Council, Chester, NJ, technical report, 27 p., available at http://www.highlands.state.nj.us/njhighlands/master/index.html.

Highlands Council, 2008c, Water resources volume I, watersheds and water quality: New Jersey Highlands Water Protection and Planning Council, Chester, NJ, technical report, 324 p., available at http://www.highlands.state.nj.us/njhighlands/master/index.html.

Hoffman, J.L. and Canace, R.J., 2004, A recharge-based nitrate-dilution model for New Jersey: N.J. Geological Survey Open-File Report 04-1, 27 p., available at http://www.njgeology.org/pricelst/ofreport/ofr04-1.pdf.

Hoffman, J.L., and Domber, S.E., 2004, Potable water supplied in 1999 by New Jersey's Highlands: N.J. Geological Survey technical report, 8 p., available at www.state.nj.us/dep/njgs/enviroed/freedwn/highpotwater.pdf.

Hoffman, J.L. and French, M.A., 2008, Ground-water recharge in the New Jersey Highlands Region: N.J. Geological Survey Open-File Report 08-1, 18 p., available at http://www.njgeology.org/pricelst/ofreport/ofr08-1.pdf.

Johnson, L. B., 1968, Letter to the President of the Senate and to the Speaker of the House transmitting an assessment of the nation's water resources: *in* Lyndon B. Johnson: 1968-1969 (in two books): containing the public messages, speeches, and statements of the president. [Book 2] , Office of the Federal Register, National Archives and Records Service, General Services Administration, available at http://quod.lib.umich.edu/p/ppotpus/4731573.1968.002.

Lewis, J.V. and Kummel, H.B., 1940, The geology of New Jersey: New Jersey Geological Survey Bulletin 50, Trenton, N.J., 203 p., available at http://www.njgeology.org/enviroed/oldpubs/bulletin50.pdf.

New Jersey Department of Environmental Protection, 2008a, Basis and background of the septic density standard of the Highlands Water Protection and Planning Act Rule at N.J.A.C 7:38-3.4: technical report, 39 p., available at www.nj.gov/dep/highlands/docs/septicdensity.pdf.

New Jersey Department of Environmental Protection, 2008b, Private well testing act program well test results for September 2002 – April 2007: Division of Water Supply, Bureau of Safe Drinking Water and Division of Science, Research and Technology, technical report, 75 p., available at http://www.state.nj.us/dep/pwta/pwta_report_final.pdf.

New Jersey Department of Environmental Protection, 2010, Frequently asked questions about digital imagery: web page available at http://www.state.nj.us/dep/gis/faqdigimg.htm.

New Jersey Department of Environmental Protection, 2012, Land Use/Land Cover 2007 Update: Office of Information Resources Management, Bureau of Geographic Information Systems, metadata for New Jersey's 2007 land use/land cover, edition 20100712, available at http://www.nj.gov/dep/gis/listall.html.

New Jersey Department of Environmental Protection, 2014, 2014 Integrated Water Quality Monitoring and Assessment Methods: Division of Water Monitoring and Standards, Bureau of Environmental Analysis, Restoration and Standards, technical report, 52 p.

New Jersey Potable Water Commission, 1907, To investigate the practicability and probable cost of the acquisition by the State of the title to the potable waters of the state: Trenton, NJ, 101 p., available at http://hdl.handle.net/10929/28751.

Serfes, M.E., 2004, Ground-water quality in the bedrock aquifers of the Highlands and Valley and Ridge Physiographic Provinces of New Jersey, New Jersey Geological Survey Report GSR 39, 28 p., available at http://www.state.nj.us/dep/njgs/pricelst/gsreport/gsr39.pdf.

Vermule, C.C., 1894, Report on water supply, water-power, the flow of streams, and attendant phenomena: New Jersey Geological Survey, vol. III of the Final Report of the State Geologist, John L. Murphy Publishing Co., Trenton, NJ, 448 p., available at http://www.njgeology.org/enviroed/oldpubs/SG-FINAL-REPORT-VOL-III.PDF.

Appendix A. Relevant Internet Links

Programs	
New Jersey Dept. of Environmental Protection	http://www.state.nj.us/dep/
NJDEP Highlands Act and Rule	http://www.state.nj.us/dep/highlands/
New Jersey Geological and Water Survey	http://www.njgeology.org
New Jersey Highlands Council	http://www.state.nj.us/njhighlands/
General Data Repositories	
NJDEP GIS coverages	http://www.nj.gov/dep/gis/lists.html
N.J. Highlands Council GIS coverages	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data.html
N.J. Geographical Information Network	https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp
Specific GIS Data Sets	
Highlands Boundary	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data/HL_Boundary.zip
Preservation and Planning areas	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data/HL_Preservation_and_Planning_Area.zip
Land Use Capability Zones	http://www.highlands.state.nj.us/njhighlands/actmaps/maps/gis_data/LUCZ.zip

Note: All Internet links active August, 2015.

(77x

1 November 2016

Senator Robert Simth, 17th District
216 Stelton Road
Suite E-5
Piscataway, NJ 08854

Scientists, Engineers & Environmental Planners Designing Innovative Solutions for Water, Wetland and Soil Resource Management

Re: NJDEP Proposes Modification of the Highlands Septic Density Rule
Sent by Email

Dear Senator Smith:

In my capacity as the president of Princeton Hydro, a company dedicated to the management of water resources, I prepared the following evaluation regarding the proposed modification of the Highlands Septic Density Rule. As per the NJDEP, the proposed modification reflects a "common sense, science-based approach to protecting the region's precious water supplies, while creating reasonable additional opportunities for economic growth and jobs". In my opinion this modification is not a truly science based approach.

I personally have spent much of the past 30+ years managing, restoring and protecting the surface and groundwater resources of the Highlands Region. As you are aware, the majority of the surface waters in the Highlands Region are protected by the State's anti-degradation rules (N.J.A.C. 7:9B-1.5(d)). These rules clearly state that Category 1 waters are protected from "any measurable changes (including calculable or predicted changes) to the existing water quality". Furthermore such waters "shall not be subject to any manmade wastewater discharges", which would include septic leachate. Furthermore, the rule state that "the Department shall not approve any activity which, alone or in combination with any other activities, might cause changes, other than toward natural water quality, in the existing surface water quality characteristics". As such, the rules are very specific regarding the need to protect Category 1 waters from perturbation and degradation that would result in any measurable changes to their existing water quality.

This protection applies not only to a stream's water quality but to its ability to meet its ecological services and functions and its ability to provide an exceptional level of recreational use. Specifically, as per N.J.A.C. 7:9B Category 1 waters are defined as waters protected "from measurable changes in water quality based on exceptional ecological significance, exceptional recreational significance, exceptional water supply significance or exceptional fisheries resource(s) to protect their aesthetic value (color, clarity, scenic setting) and ecological integrity (habitat, water quality and biological functions)".

The proposed Highlands Density Septic Rule Proposal is inconsistent with the anti-derogation rules and the intent of the highland regulations to protect the region's surface and groundwater quality. The analysis is flawed in that the NJDEP is making use of well data compiled by the USGS from wells recognized as being "clustered in urban areas". The database is lacking in terms of groundwater data collected from wells located within largely undeveloped, forested areas. As such, the NJDEP is using data from developed areas to support an increase in septic density throughout the Highlands that could

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result in the degradation of surface and groundwater resources in undeveloped or far less developed areas.

This is especially troubling if the use of this data resulted in an increase in the development in the headwaters of Category 1 watersheds. Headwater areas, even if located on the periphery of developed areas, are especially sensitive to the hydrologic, hydraulic and water quality impairments associated with land development. Because headwater streams rely on groundwater discharge for baseflow, an alteration in groundwater quality could trigger ecological impacts to the streams and the pollution sensitive biota that these streams support. The water quality standard for nitrate-N in drinking water is 10 mg/l. Our studies of numerous lakes and streams throughout New Jersey (not just the Highlands) have shown that nitrate-N concentrations as low as 0.2-0.4 mg/l are associated with eutrophic surface water systems. While the target nitrate-N concentration projected by the NJDEP under the modified density rules is between 0.8 and 1.77 mg/l, these projected concentrations are far greater than what we have repeatedly measured in ecologically compromised streams.

The proposal also fails to assess the secondary impacts to water quality related to the proposed increase in development density in the Highlands. Again, the implications of increased development can be significant with respect to the inevitable increase in nutrient loading, impacted aquatic habitat and reduced ecological services and functions. Although, one may argue that the stormwater rules (N.J.A.C. 7:8) will protect streams and lakes from development related increases in pollutant loading the existing rules have no mandatory provisions regarding the post-development management of nitrogen and phosphorus loading.

In summary, the data being used by the NJDEP to support the proposed increased septic density is flawed and the results do not recognize the eutrophication impacts this added nutrient loading will have on receiving systems, especially ecologically sensitive headwater streams. More importantly, promoting this increase in septic density will lead to a decline in the water quality of Category 1 streams, which is inconsistent with the Department's own antidegradation standards. In closing, it is my opinion that the NJDEP's approach to the proposed changes in septic densities in the Highlands does not constitute an objective approach based on sound science and fails to consider compliance with New Jersey's antidegradation standards; standards that were crafted to protection the quality of the region's groundwater and surface water resources.

Sincerely,

Stephen J. Souza, Ph.D.
President
Princeton Hydro, LLC

Cc: Mark Gallagher, Princeton Hydro

LEGISLATIVE VIEWPOINT

NJLM New Jersey State League of Municipalities

222 West State Street, Trenton, New Jersey 08608
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Michael J. Darcy, CAE EXECUTIVE DIRECTOR | Michael F. Cerra ASSISTANT EXECUTIVE DIRECTOR | Jon R. Moran SENIOR LEGISLATIVE ANALYST | Loretta Buckelew SENIOR LEGISLATIVE ANALYST | Edward W. Purcell LEAGUE STAFF ATTORNEY

November 3, 2016

Re: A-1649/S-853

Dear Member of the Senate Environment and Energy Committee:

The League of Municipalities had initially opposed A-1649/S-853, which would require local governments and authorities to obtain financing cost estimate required to be provided by New Jersey Environmental Infrastructure Trust for certain projects, due to mandates it placed on municipalities that would have added expense and time to projects. However, the Assembly committee amendments made to the bill address our concerns. Based on those amendments, we withdraw our opposition.

We thank the sponsors for amending the bill by removing the hurdles that would have made environmental infrastructure projects challenging and costly for municipalities. Municipalities will continue to pursue funding from the New Jersey Environmental Infrastructure Trust when it best meets the needs of their community.

Very truly yours,

Michael F. Cerra

Michael F. Cerra
Assistant Executive Director

MFC/sc

NewJersey
Builders Association

www.njba.org
www.abconvention.com
www.njmxd.com
www.foundationforhousing.com

July 14, 2016

G. Colin Emerle, Esq.
ATTN: (DEP Docket No. 02-16-04)
NJ Department of Environmental Protection
Office of Legal Affairs
Mail Code 401-04L; PO Box 402
401 East State Street, 7th Floor
Trenton, NJ 08625-0402

RE: Proposed Highlands Septic System Density Standards

Dear Mr. Emerle:

On behalf of the State association and our local affiliates, the Metropolitan Builders and Remodelers (Metro), Builders and Remodelers Association of Northern New Jersey (BRANNJ), the New Jersey Builders Association (NJBA) submits the following comments regarding the Department of Environmental Protection's (Department) proposed amendments to the Highlands Septic System Density Standards. BRANNJ members represent the Highlands counties of Bergen, Passaic and Sussex, while Metro represents the Highlands counties of Hunterdon, Morris, Somerset and Warren. NJBA strongly supports the comments as presented by the New Jersey Farm Bureau at the June 1, 2016 public hearing.

NJBA applauds the Department for reviewing and subsequently proposing to *revise* the Septic Density Standards based upon larger dataset (specifically, 19,371 nitrate samples from private potable water supply wells) that was obtained through the implementation of the New Jersey Private Well Testing Act (N.J.S.A. 58:12A-26 et seq.)). NJBA and other affected entities had questioned the development of the existing Standards, which were based upon a significantly smaller well water dataset. NJBA believes that the Department's regulatory programs should always be grounded in up-to-date science and in keeping with the latest information and technological advancements. However, while the Department's rulemaking is supported and should move forward to rule adoption, NJBA recommends that the underlying methodology and formula should still be re-examined, since we believe even this proposed Rule amendment is overly conservative and not fully supported by the data.

NJBA further notes that the proposed revisions and data collected are limited to the Preservation Area of the Highlands Region, which is under the purview of the Department. The rule proposal indicates that data has also been obtained for the Planning Area i.e. where the Highlands Council has jurisdiction. NJBA strongly urges and recommends that the Highlands Council also review the data to determine if any improvements may be made to allow for appropriate development in the Planning

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Area. Similar to the Department, the Highlands Council should also utilize the best available data in its decision making and regulatory programs. Without the Council also taking such a proactive step for the *Planning Area*, the NJBA views that this rule proposal is *only* an incremental step towards addressing global issues of how to facilitate appropriate economic development opportunities in the Highlands Region.

NJBA has also questioned the scientific basis underlying the current septic density standards and in particular the reliance on deep aquifer recharge for septic dilution. The current rules require very large lots (up to 88 acres) in order to develop on septic systems, whereas the proposed septic standards would be respectively 23, 12 and 11 in the Protection, Conservation and Existing Community Zones, which would yield 1145 new septic systems. NJBA recognizes the opportunities that such developments would yield, but reiterates that this re-evaluation should be extended to the Highlands Planning Area.

Given the need for such large lots with standard septic systems, the NJBA had previously supported and again encourages the Department to allow development on smaller lots utilizing alternate septic system designs. Following the successful model of the Pinelands Commission, the Council should allow alternative design septic systems that have proven effective at removing nitrates. These systems support clustering and low impact development on reasonably sized lots. Alternative septic systems are equivalent to mini-sewer treatment systems and provide much better environmental protection than would low density development.

The current Septic Density Standards not only inhibit economic growth, which in turn frustrated the "balance" that the Highlands Act was to strike with environmental protection, but also contributed significantly to sprawl patterns of land development. Therefore, NJBA strongly supports the Department's proposed amendments and encourages that they be adopted without delay. NJBA further encourages the Department and the Highlands Council to review their respective regulations that negatively impact the economic prosperity of the Highlands Region without any environmental benefit.

Please contact NJBA if you have any questions regarding these comments.

Sincerely,

Carol Ann Short, Esq.
Chief Executive Officer

C: Stephen Shaw, Shaw Built Homes
Margaret Nordstrom, Executive Director, Highlands Council

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May 31, 2016

Senator Bob Smith – 17th District
216 Stelton Road
Suite E-5
Piscataway, NJ 08854
732-752-0770

Re: NJDEP Highlands Septic Density Rule Proposal

Dear Senator Smith:

As you requested, I reviewed the proposed Highland Septic Density Rule Proposal and supporting documents including "Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics" U.S. Geological Survey Scientific Investigations Report 2015–5075, by Baker, R.J., Chepiga, M.M., and Cauller, S.J., 2015.

To begin this analysis, I first reviewed "Basis and Background of the Septic Density Standard of the Highlands Water Protection and Planning Act Rule at N.J.A.C. 7:38-3.4." This document explains the origin of the existing two ambient nitrate standards of 0.21 mg/L for forest and 0.76 mg/L for mixed land use. According to this document, data from 1,315 wells in the Highlands were retrieved from the NWIS database during the spring of 2005. An effort was made to use only the data that represented background conditions in the region. Results from 45 wells were used to determine the ambient nitrate concentration for mixed land use, and seven wells were used to determine the ambient background concentration for forested land use.

For the new septic density proposal, the USGS used NWIS data from 782 wells in the Highlands Region. In their report, USGS stated that "generally, NWIS wells are clustered in urban areas," which makes sense since only seven of the original 1,315 NWIS wells in the 2005 analysis were considered representative of forest conditions and used in the forested ambient nitrate concentration calculation. A logistic-regression model was created using the NWIS data. It is important to note that although data were available from the Private Well Testing Act (PWTA), it is clearly stated in the USGS Report that only NWIS data were used develop the logistic-regression model.

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A logistic-regression model is fairly simply. The concept is that nitrate concentrations can be dependent on different physical variables such as percent agricultural land use, population, septic system density, etc. The logistic-regression model considered 320 of these types of "explanatory" variables and determined that ambient nitrate concentrations can be based on five variables: percentage of urban land use, percentage of agricultural land use, septic system density, total length of streams, and number of known contaminated sites in the well buffer area. The Highlands Region was then divided into 610-meter square cells (9,745 cells in total). For each cell, median nitrate concentrations were calculated based upon the five variables described above. These calculated values were then compared to the median measured nitrate concentration among all the water samples in the combined NWIS-PWTA database. It is important to note that about one-half of the grid cells did not have any nitrate data and these grid cells tended to have a larger percentage of forested land uses.

Here are the problems with the analysis. Since the NWIS and PWTA wells are primarily located in urban areas, the final results of the USGS analysis is biased to these areas and are most likely predicting higher ambient nitrate concentrations than actually occur. For example, PWTA well data is collected from a residential home that has an existing septic system. It is expected that nitrate concentrations would represent a degraded condition since development has already occurred in this area (i.e., a home with a septic system exists on the lot). This is clearly stated on Page 14 of the USGS Report: "Over-representation of urban and possibly agricultural areas and under-representation of forest areas in the combined NWIS-PWTA database must, therefore, result in higher median nitrate concentrations for all water samples than the actual median concentration for groundwater underlying the entire Highlands Region or any Area, Zone, or Area:Zone combination."

Another issue is that since very few of the wells are representative of forested land use, the logistic-regression model does not consider forested land use in its analysis. This simply was not identified as an important "explanatory" variable since there were very little well data collected in forested areas.

If the goal is to prevent degradation of groundwater, only wells located in undeveloped areas should be considered when determining ambient background nitrate concentrations, which was not done in this analysis. While the logistic-regression model is a good model, it does not provide information that can be used to determine ambient nitrate background concentrations in the Highlands Region and can be used only to determine existing nitrate concentrations in urban and agricultural land use areas.

Two important points should be made. The target nitrate concentration being proposed in the new septic density rules, which ranges from 0.80 to 1.77 mg/L, is well below the state criteria of 10 mg/L, even though it will most like result in some degradation of groundwater quality. Secondly, there are alternative advanced on-site wastewater treatment systems that can be used to reduce the nitrate concentration entering the groundwater from septic systems. The existing

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regulations and the proposed regulations are only considering conventional septic systems and do not consider innovative technologies that have proven to be effective in other portions of the country.

I hope these comments were helpful. Please contact me if you have any additional questions.

Sincerely,

Christopher C. Obropta, Ph.D., P.E.
Director, NJWRRI

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November 15, 2016

Senator Robert Smith, 17th District
216 Stelton Road, Suite E-5
Piscataway, NJ 08854

(By US Mail and email: SenBSmith@njleg.org)

Re: NJDEP Proposes Modification of the Highlands Septic Density Rule

Dear Senator Smith:

This letter serves to follow up on Thonet Associates Inc.'s testimony regarding the above-referenced issue, discussed at the Senate Environment and Energy Committee Hearing on November 3, 2016.

At that hearing I advised the Committee that between July 30, 2015 and January 16, 2016, I had met with the NJDEP regarding its proposed modification of the Highlands Septic Density Rule and had reviewed three (3) separate study documents, all prepared by the USGS and/or the NJDEP, and all presenting the scientific basis for the proposed modification of the septic density rule. In addition, I testified that during this same time period and at the NJDEP's invitation, Thonet Associates participated in an exchange of written communications with the Department regarding those proposed modifications and the scientific basis for those proposed septic density modifications.

The three (3) documents that Thonet Associates reviewed, which purported to provide the scientific justification for the proposed septic density modifications were:

1. New Jersey Geological & Water Survey Technical Memorandum (TM) 14-1, entitled, *Nitrate Concentrations in Groundwater of New Jersey's Highlands Region,* prepared by Jeffrey L. Hoffman and Alexandra Petriman, New Jersey Department of Environmental Protection, Water Resources Management, New Jersey Geological and Water Survey, dated 2014, unrevised, Source: NJDEP's website.

   This 2014 report presented results of a USGS' 2012 regression analysis that estimated median nitrate concentrations in the Highlands Region, utilizing as its well sampling database, (i) 352 observation wells, that were originally utilized in the USGS' 2008 analysis that became the basis for the current Highlands Septic Density Rules; and (ii) 19,369 domestic wells tested under New Jersey's Private Well Testing Act, which became effective in 2002.

2. New Jersey Geological & Water Survey Technical Memorandum (TM) 14-1, entitled, *Nitrate Concentrations in Groundwater of New Jersey's Highlands Region*, also prepared by Jeffrey L. Hoffman and Alexandra Petriman, New Jersey Department of Environmental Protection, Water Resources Management, New Jersey Geological and Water Survey, dated 2014, revised 2015, and marked "Preliminary Subject to Revision," Source: provided to Thonet Associates by Jeffrey L. Hoffman.

   This revised (2015) version of the NJDEP's originally published Technical Memorandum 14-1, referenced immediately above, similarly presents results of a USGS' 2012 regression analysis that estimates of median nitrate concentrations in the Highlands Region utilizing the identical well database referenced in the original (2014) TM-14 report, except that in this revised (2015) report, the regression estimates of median nitrate concentrations were completely and significantly different.

   This revised (2015) report contains the same estimates of median nitrate concentrations as found in the USGS' Scientific Investigations Report (SIR) 2015-5075, referenced immediately below, that both the NJDEP and the USGS indicate represents the "official" and "final" report of the USGS' 2012 analyses.

   Mr. Hoffman explained to Thonet Associates that the difference in the results between 2014 and 2015 was due to a mistake made by the USGS in its original (2012) regression analyses made two (2) years earlier. In support this explanation, Mr. Hoffman provided a copy of an undated letter from Richard Kropp of the USGS, purporting to explain that mistake.

3. USGS Scientific Investigations Report (SIR) 2015-5075, entitled, *Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics*, prepared by the US Geological Survey in cooperation with the New Jersey Department of Environmental Protection, published in 2015.

   According to both the NJDEP and the USGS, this SIR represents the "official" and "final" report of the USGS' 2012 analyses and thus the scientific basis for the proposed modifications to the Highlands septic density rules.

Following my testimony, I provided the Committee with copies of the above-referenced documents.

Thonet Associates also provided the Committee with copies of the following additional documents in support of my testimony:

1. A copy of my professional curriculum vitae, summarizing my 44 years of experience in the fields of professional engineering, professional planning and environmental consulting;

2. A copy of a letter, undated, from Richard H. Kropp, Center Director, USGS NJ Water Science Center, to Jeffrey L. Hoffman, P.G., Acting State Geologist, NJ Geological & Water Survey, NJDEP Division of Water Supply & Geosciences.

   In this letter, the USGS explains the following to Mr. Hoffman:

   a. Regarding the original (2008) USGS nitrate analyses:

      1) The USGS provided a "draft report" the NJ Highlands Council in 2008, presenting estimates of median nitrate concentrations, developed utilizing nitrate data available from 352 observation wells from the USGS National Water Information System (NWIS).

      2) The NJ Highlands Council submitted the USGS' draft report to the NJDEP for technical peer review and the NJDEP reviewer comments were sent to the USGS and the USGS in turn addressed each comment to the satisfaction of the Highlands Council.

      3) The NJ Highlands Council adopted and edited specific sections of the USGS' 2008 draft report and included them in one section of their Highlands Master Plan Technical Report published in 2008.

      4) The 2008 "draft report," however, was not a formal USGS Scientific Investigation Report (SIR).

   By this letter, the USGS is apparently disavowing that in 2008, it provided any "formal" or "final" analysis or report to the NJDEP and the NJ Highlands Council for purposes of estimating nitrate concentrations in the NJ Highlands Region.

   This claim by the USGS would appear to be inconsistent with the information provided to the public, during public hearings and in the final NJ Highlands Regional Master Plan and its supporting Technical Reports.

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Thonet Associates actively participated in and commented extensively on the RMP and its supporting Technical Reports, including the reports on the nitrate dilution model, and no such claim was ever made by the NJDEP of the NJ Highlands Council that the septic density provisions in the RMP were based on a "draft report" from the USGS.

Simply put, this is new information that is being provided to the public, and presumably to the NJ Legislature as well, eight years after the USGS' 2008 study was submitted.

b. Regarding the new (2012) USGS nitrate analyses:

1) The USGS' undated letter states that,

   "By 2012, a large number of domestic supply wells had been sampled as a result of the Private Well Testing Act..." and that,

   "The USGS, NJDEP, and Highlands Council recognized that using the additional nitrate values from the PWTA data set could be used to improve nitrate estimates for the Highlands that were developed in 2008."

   Please note that this statement by the USGS is historically unsupportable. The PWTA became effective in the fall of 2002 and by 2008, when the USGS' original nitrate concentration estimates were provided, there already would have been thousands of PWTA wells available to utilize within the NJ Highlands Region, that could have been used had the USGS and NJDEP chosen to do so.

   Thus, while it is true that by 2012, 10 years after the PWTA became effective, there were over 19,000 wells in the PWTA, by 2008, six (6) years after the PWTA became effective, clearly there would have been data available from thousands of PWTA wells that the USGS, in cooperation with the NJDEP and the NJ Highlands Council, obviously chose not to use.

2) In preparing its 2012 study, the USGS made an error, which it did not discover until 2014. The error that the USGS reported was that,

   "...a statistical correction was incorrectly applied in calculating the 2012 estimated quantile median nitrate values..."

   and, the undated letter goes on to state that,

   "...The correction was determined to be unnecessary and is not part of the quantile model estimates of the median nitrate concentrations documented in the USGS 2015 report."

The USGS' letter fails to explain exactly what the unnecessary "statistical correction" really was and why eliminating that correction resulted in such a large change in the estimated median nitrate concentrations.

Indeed, when specifically asked at the Committee's hearing to explain the unnecessary "correction," the USGS simply replied that it was a "coefficient." In Thonet Associates' opinion, the USGS' explanation was unresponsive to the question asked and Thonet Associates indicated as much at the hearing.

3) The USGS letter also acknowledges that there are some problems associated with the use of the PWTA well data set, including:
   a) Lack of information on well location, construction and use in the PWTA data set;
   b) Aquifers sample;
   c) Quality of the PWTA data; and
   d) Uncertainty about land use around each well due to lack of locational information.

   This is nothing less that a written "admission" by the USGS that there is uncertainty regarding the quality and accuracy of the PWTA data set.

   It should be noted that the NJDEP made the same acknowledgement of the uncertainties associated in the use of the PWTA well data set in both its original (2014) and revised (2015) Technical Memorandum 14-1, discussed above, both of which were authored by Jeffrey Hoffman of NJDEP.

3. The following correspondence between Thonet Associates and Mr. Jeffrey Hoffman, NJ State Geologist between September 1, 2015 and January 16, 2016, regarding the NJDEP's proposed modification of the Highlands Septic Density Rule: based on:
   a. Memorandum dated September 1, 2015, from John A. Thonet, PE, PP, of Thonet Associates, Inc. to Jeffrey L. Hoffman, NJ State Geologist, NJDEP, providing Thonet Associates' preliminary comments regarding the USGS Scientific Investigations Report (SIR) 2015-5075, entitled, *Median Nitrate Concentrations in Groundwater in the New Jersey Highlands Region Estimated Using Regression Models and Land-Surface Characteristics*, published in 2015, which is the report that forms the basis for the NJDEP's proposed modification to the Highlands Septic Density Rule;

b. Letter dated December 18, 2015, from Jeffrey L. Hoffman, NJ State Geologist, NJDEP and Thonet Associates, responding to Thonet Associates' above-referenced September 1, 2015 memorandum;

c. Memorandum dated January 16, 2016, from John A. Thonet, PE, PP, of Thonet Associates, Inc. to Jeffrey L. Hoffman, NJ State Geologist, NJDEP, responding to Mr. Hoffman's above-referenced letter to Thonet Associates of December 16, 2015 and providing continuing comments regarding the USGS SIR 2015-5075.

The above correspondence documents that Thonet Associates and the NJDEP were professionally engaged in a serious discussion of the USGS study results that purported to provide a scientific basis for modifying estimated existing nitrate concentrations in the Highlands Region.

During this professional exchange, Thonet Associates advised the NJDEP of the following:

a. Any PWTA well data after 2004, when the NJ Highlands Act became law, would not represent existing conditions "at the time of the Act" and hence it would be inappropriate to utilize that data to estimate "existing conditions" median nitrate concentrations in the NJ Highlands.

   Obviously, "existing conditions" cannot be a "moving target."

b. Mr. Kropp of USGS, in his undated letter to Jeffrey Hoffman, acknowledged the uncertainty (potential inaccuracy) involved in utilizing the PWTA well data set that is the primary basis for the new regression model.

c. Mr. Kropp's explanation of the significant differences between its original (2012) results utilizing the combined NWIS well data set and the PWTA well data set, and its "corrected" (2015) results, is simply inadequate, given the significant differences between the two analyses that utilize exactly the same well data.

d. The PWTA well data set has a bias in that private wells tested under the Act are generally only located in areas where some form of development has occurred. Thus, using such a "biased" well data set as the basis for a regression analysis aimed at predicting median nitrate levels throughout the Highlands "Protection Area," which is nearly 75 percent undeveloped forests,

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wetlands and waters, is not scientifically valid, and will provide "biased," and thus wrong, results.

e. The Highlands "Preservation Area" should be studied and modeled separately from the Highlands "Planning Area" because:
   1) These two areas are significantly different with regard to land use and regression analyses are most accurate when applied to areas that are reasonably similar; and
   2) The "Preservation Area," unlike the "Planning Area," is in a water quality "non-degradation" area, subject to the most stringent NJDEP water quality standards.

f. The Highlands "Preservation Area" simply lacks sufficient well sampling data within its undeveloped forests, wetlands and water areas, which constitute about 75 percent of the "Preservation Area," and thus, the NJDEP should establish some observation wells within these predominantly undeveloped areas in order to obtain the data necessary to develop an accurate regression analysis, that would be truly capable estimating median nitrate concentrations in the Preservation Area.

Thonet Associates has not changed its opinion regarding the problems, uncertainties and inaccuracies associated with the USGS' 2015 estimates of median nitrate concentrations in the NJ Highlands' Preservation Area.

In Thonet Associates' opinion, the USGS' SIR 2015-5075, which is the basis for the NJDEP's proposed modifications to the Highlands Septic Density Rules, is scientifically invalid and under no circumstances can be depended on to provide accurate estimates of existing median nitrate concentrations within the NJ Highlands "Preservation Area."

I thank the Senate Committee on Environment and Energy for the opportunity to provide these follow-up comments to my November 3rd testimony.

Very truly yours,

THONET ASSOCIATES, INC.

John A. Thonet, PE, PP