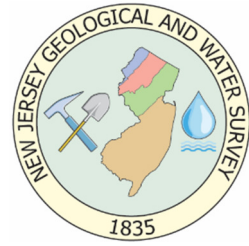


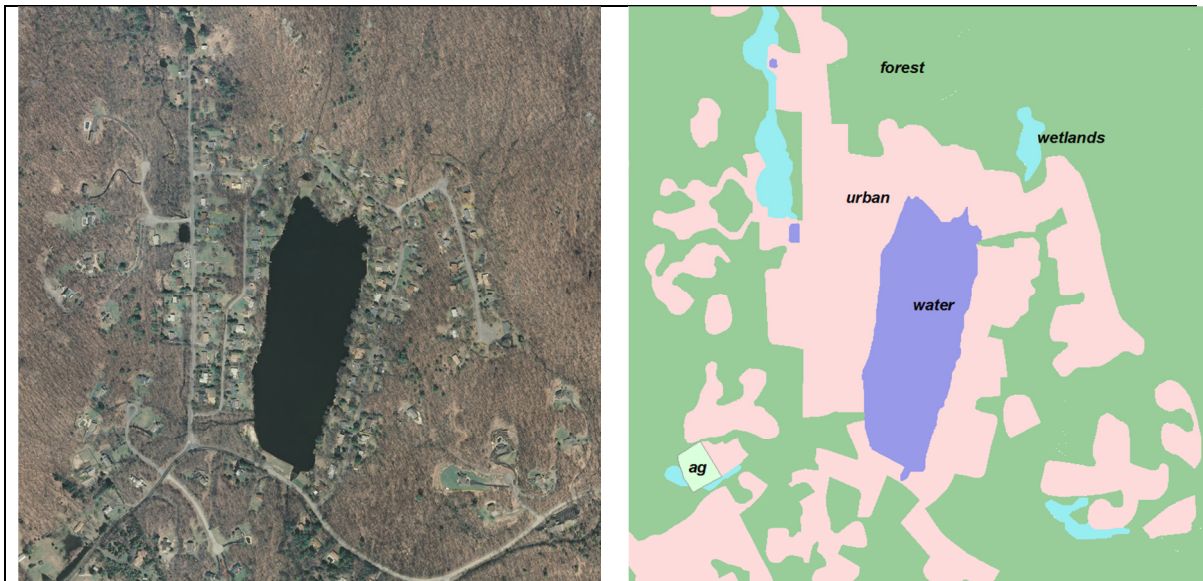


**NEW JERSEY GEOLOGICAL &
WATER SURVEY**

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

STATE OF NEW JERSEY

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Water Resources Management

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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.

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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.

Nitrate Concentrations in Groundwater of New Jersey’s Highlands Region

by
Jeffrey L. Hoffman and Alexandra Petriman
2014
(revised 2015)

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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)

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2014

(revised 2015)

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 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 land use.' This grouping of land uses has also been termed 'impacted.' Forest, water, and wetlands are grouped as 'forested land use.' This grouping of land uses has also been called 'pristine' (NJDEP, 2008a).
- (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 sampled wells in northern New Jersey to calculate median nitrate concentrations (NJDEP, 2008a). The median nitrate value in mixed-use lands, based on 45 sampled wells, was estimated to be 0.76 mg/l. The median nitrate value in pristine lands, based on data from seven 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 Information System (NWIS) sampled 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. Median nitrate values in the Protection, Conservation, and Existing-Community Land Use Capability Zones were 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. 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 groundwater 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, on a regional basis, 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 groundwater-quality data only;
- a logistic-regression model relating available groundwater-quality data to appropriate land-use characteristics to predict median nitrate; and
- an update of the model adding groundwater-quality data from the Private Well Testing Act.

II.A. Data Sources

The spatial 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).

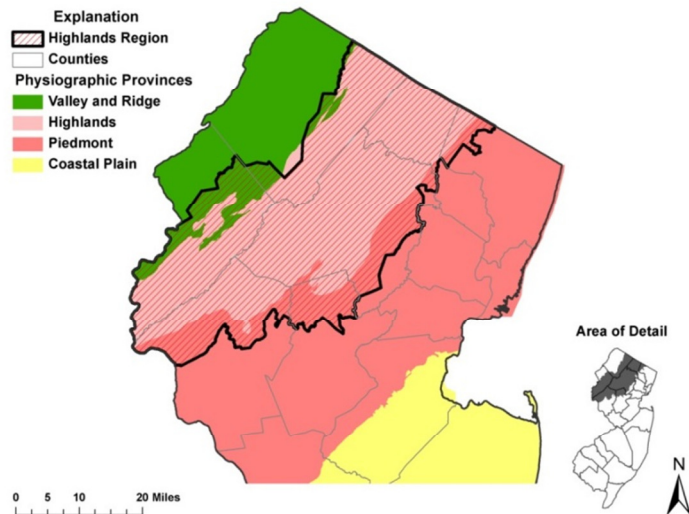


Figure 1. New Jersey's Highlands Region and Physiographic Provinces.

The ridges are about 400 to 600 feet higher than the neighboring valley floors (Hoffman and French, 2008).

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 about 444,276 acres, and the Preservation Area about 414,992 acres.

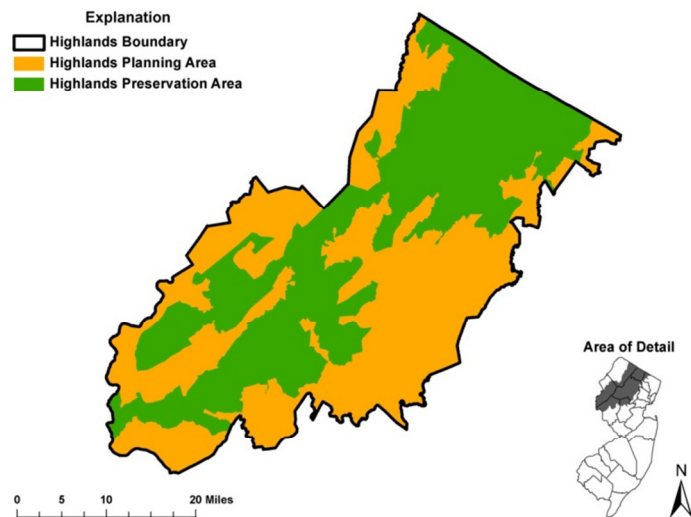


Figure 2. Planning and Preservation Areas in the Highlands Region of New Jersey.

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.

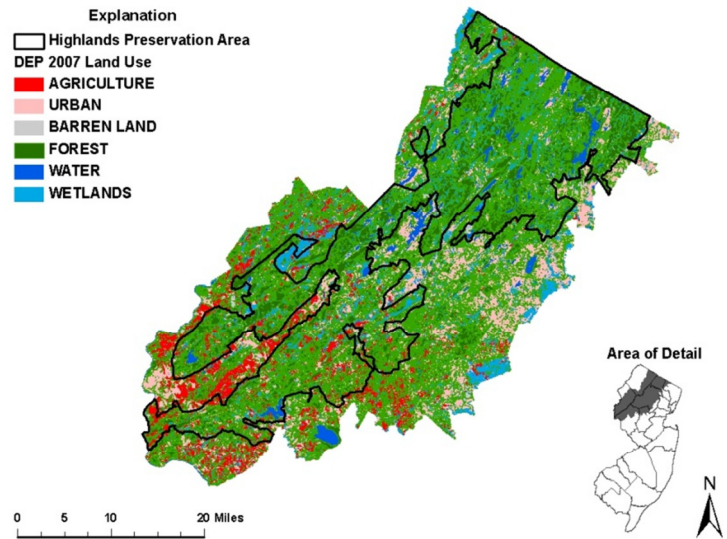


Figure 3. Land use in the Highlands Region of New Jersey, 2007.

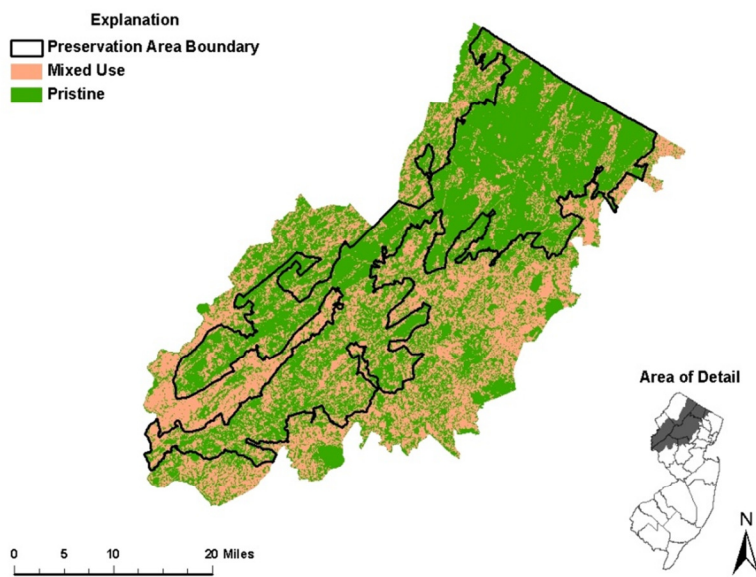


Figure 4. Mixed-use and pristine land use groups in the Highlands Region.

For analysis purposes, NJDEP (2008a) defined two land-use groups. The mixed-use group consists of the agricultural, barren-land, and urban-land uses and is about 357,591 acres in size. The pristine group consists of the forest, water and wetlands land uses and covers 525,471 acres. (NJDEP (2008a) terms this grouping of land uses ‘forested’ but uses ‘pristine’ as a synonym. Pristine is used in this report in recognition that the Anderson land use categories of water and wetlands are included in this grouping.) 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.

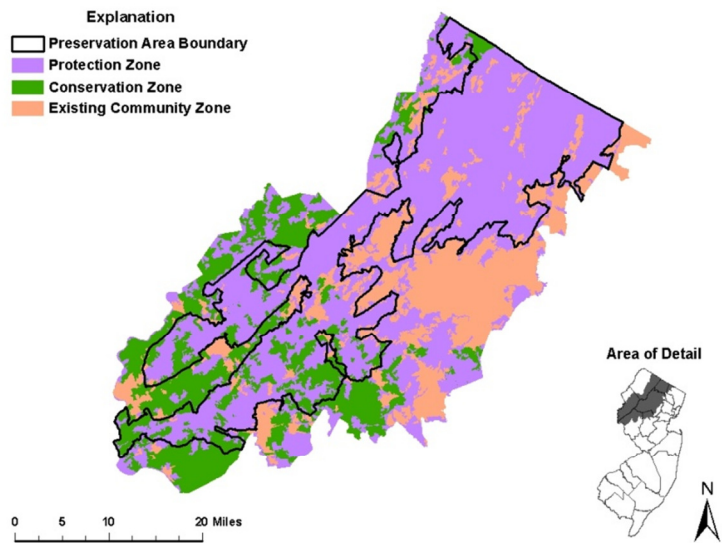


Figure 5. Land Use Capability Zones in the Highlands Region.

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 a limited number of wells and the third adding a much larger data set from domestic wells. Each approach, and the estimated background nitrate values, are summarized below.

V.A. Groundwater Data, NJDEP 2008

NJDEP (2008a) estimated background nitrate data based on water-quality data from wells. Serfes (2004) provided an estimate of 0.76 mg/l for median ambient nitrate concentration in noncarbonate bedrock of northern New Jersey. This value is based on data from 45 wells from the National Water Information 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 sampled 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 a sampled 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).

V.B. Modeling of Sampled 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 sampled 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 septic systems per unit area) within 500 meters of each well head to estimate median nitrate in areas with no sampled wells.

The Highlands is drained by 4 major watersheds (Passaic, Raritan, Delaware, and Walkkill). 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.

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 and 1.87 mg/l in the Conservation Zone. The

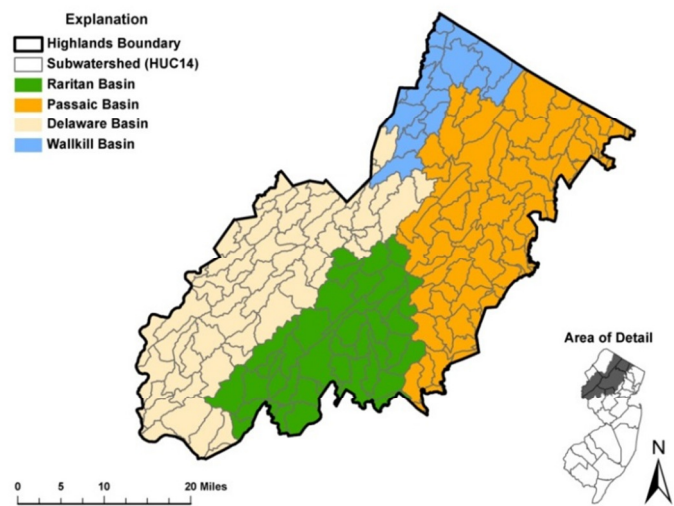


Figure 6. Major drainage basins and subwatersheds in the Highlands Region of New Jersey.

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.*

Land Use Capability Zone	Nitrate Concentration (mg/l)
Protection	0.72
Conservation	1.87
Existing Community	2.0

* Highlands Council (2008a)

V.C. Modeling of Sampled Well and PWTA Data, Baker and others, 2015

The Highlands Council's 2008 approach was based on groundwater-quality data from NWIS sampled 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 domestic 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 9,745 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.

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

Baker and others (2015) developed a logistic-regression model to estimate the median nitrate value in all cells. They 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
- septic systems per unit area

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.

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

Table 10 shows the number of samples with no detected nitrate sorted by detection limit of the analysis technique used for each sample.

The combined NWS and PWTA database contained 19,670 samples for nitrate. Of these, 4,523 (23.0%) were below the DL of the sample-specific analysis technique (table 11). Of the 10,437 nitrate samples in the Preservation Area, 25.7% showed levels below the sample-specific detection limit. In the Planning Area the non-detect percentage was 19.8%.

Table 11. Number of nitrate readings relative to detection limits by area and zone in the combined NWIS and PWTA data base

Area	Zone	# readings relative to Detection Limit			Sum	% of Total
		<DL	>DL	% ND		
Planning	Existing Community	690	3,331	17.2%	4,021	20.4%
	Conservation	341	1,575	17.8%	1,916	9.7%
	Protection	<u>747</u>	<u>2,293</u>	24.6%	<u>3,040</u>	<u>15.5%</u>
	sum	1,778	7,199	19.8%	8,977	45.6%
Preservation	Existing Community	657	2,226	22.8%	2,883	14.7%
	Conservation	188	791	19.2%	979	5.0%
	Protection	<u>1,838</u>	<u>4,737</u>	28.0%	<u>6,575</u>	<u>33.4%</u>
	sum	2,683	7,754	25.7%	10,437	53.1%
Grid centroid	outside Highlands*	62	194	25.8%	240	1.2%
Grand Total		4,523	15,147	23.0%	19,670	100.0%

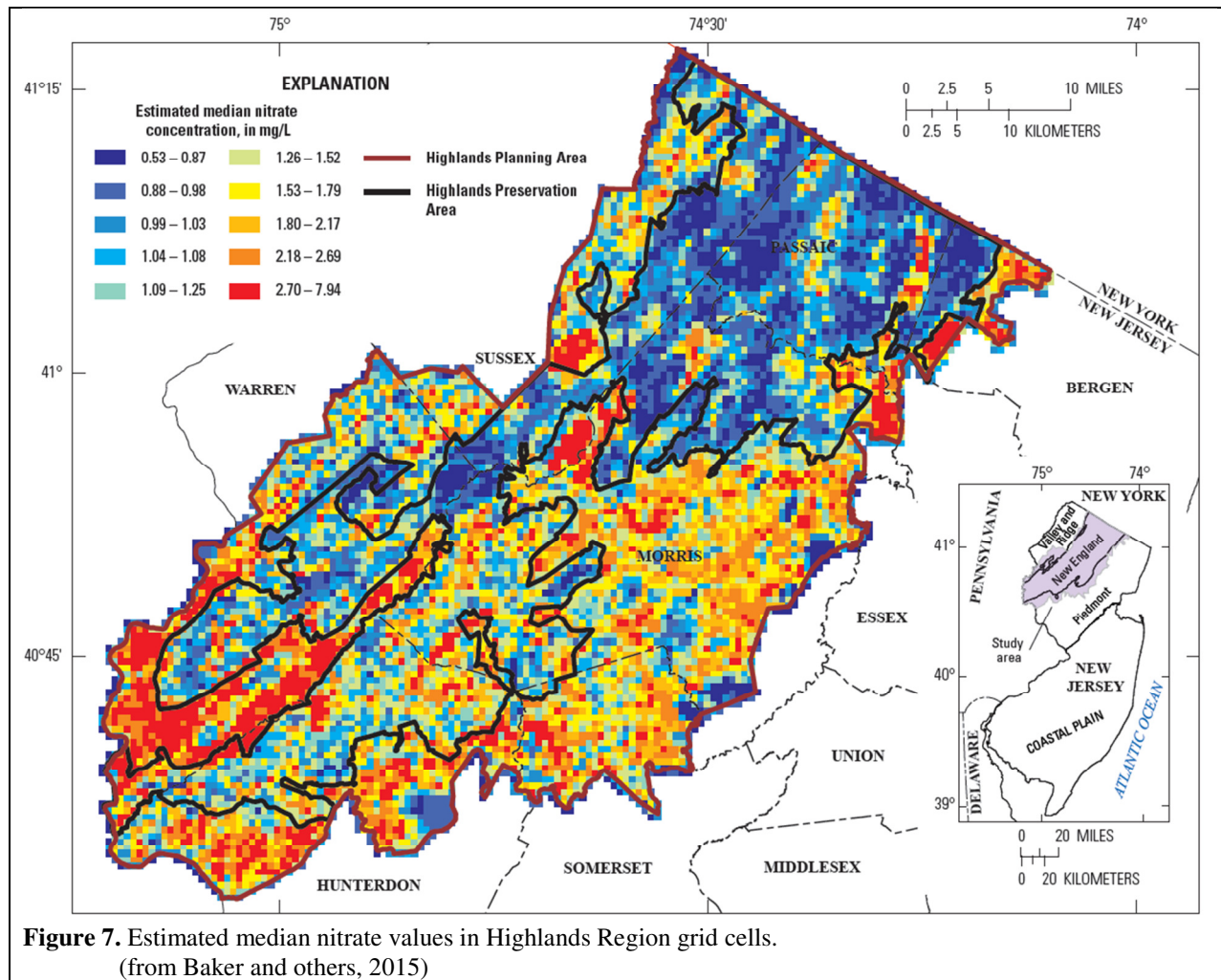
Abbreviations: DL – Detection Limit; ND – NonDetect; NWIS – National Water Information System; PWTA – Private Well Testing Act

*The area and zone of a grid cell are based on its centroid location. Some cells with nitrate values are partially within the Highlands but the centroid falls outside. Land use characteristics and nitrate values for these cells were used in the analysis. (Ron Baker, USGS, personal communication, 2015.)

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 Highlands-wide median nitrate value in the Preservation and Planning Areas and in each of the Land Use Capability Zones in each Area. These results are reproduced in table 12. The method of handling ND values results in no major significant difference in the estimate of the median nitrate in any area/zone combination except for the Preservation Area, Protection Zone. For this area/zone combination, replacing ND values by either 0 mg/l or ½ of the detection limit give similar results, 0.80 and 0.83 mg/l, respective. In contrast, replacing ND values by the sample-specific detection limit or by an estimate based on a Kaplan-Meier analysis of other samples in the grid yields median estimates of 1.06 and 1.05 mg/l, respectively.

Table 12. 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
<i>Entire Highlands</i>	<i>1.21</i>	<i>1.23</i>	<i>1.25</i>	<i>1.25</i>
Preservation Area				
<i>Entire</i>	<i>0.95</i>	<i>0.98</i>	<i>1.09</i>	<i>1.08</i>
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				
<i>Entire</i>	<i>1.52</i>	<i>1.53</i>	<i>1.55</i>	<i>1.55</i>
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

*from Baker and others, 2015

Conclusion

It is clear that the various methods of handling non-detect values do not make a significant impact on estimates of median nitrate except in the Preservation Area, Protection Zone. In this specific area/zone combination there is a difference of about 20% between estimates of median nitrate resulting from replacing ND values by either 0 mg/l or ½ of the detection limit (0.80 and 0.83 mg/l, respectively) and the estimates resulting from using either the DL or an estimate based on a Kaplan-Meier approach (1.06 and 1.05 mg/l respectively). The Preservation Area, Protection Zone is that area expected to have the least anthropogenic impacts. It is reasonable to expect that this area will have the lowest nitrate values and thus likely have the most readings below nitrate detection limits.

NJDEP generally uses a value of half of the detection limit in the analysis of water data with nondetect values (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. Thus using estimates of median nitrate of 0.83, 1.61 and 1.77 mg/l in the Protection, Conservation, and Existing Community Zones in the Preservation Area of the Highlands would be consistent with the current NJDEP approach to handling ND values.

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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.
