Probability of contamination of ground water in New Jersey by nitrate

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Purpose of presentation

To show:

- the results of statistical models from a USGS/NJWSC project conducted in conjunction with NJDEP Division of Science and Research
- how the statistical model was developed
- that stratification of data by hydro-geologic and land use factors is critical in development of robust statistical models
- where we need to go from here?

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Why do we need to understand N-inputs into environment?

Effects of Excess N Inputs
on Ecosystems and Human Health

- Primary production and ecosystem structure
- NO_3 concentrations in drinking water
- Increased disease
- Greenhouse gas N_2O emissions

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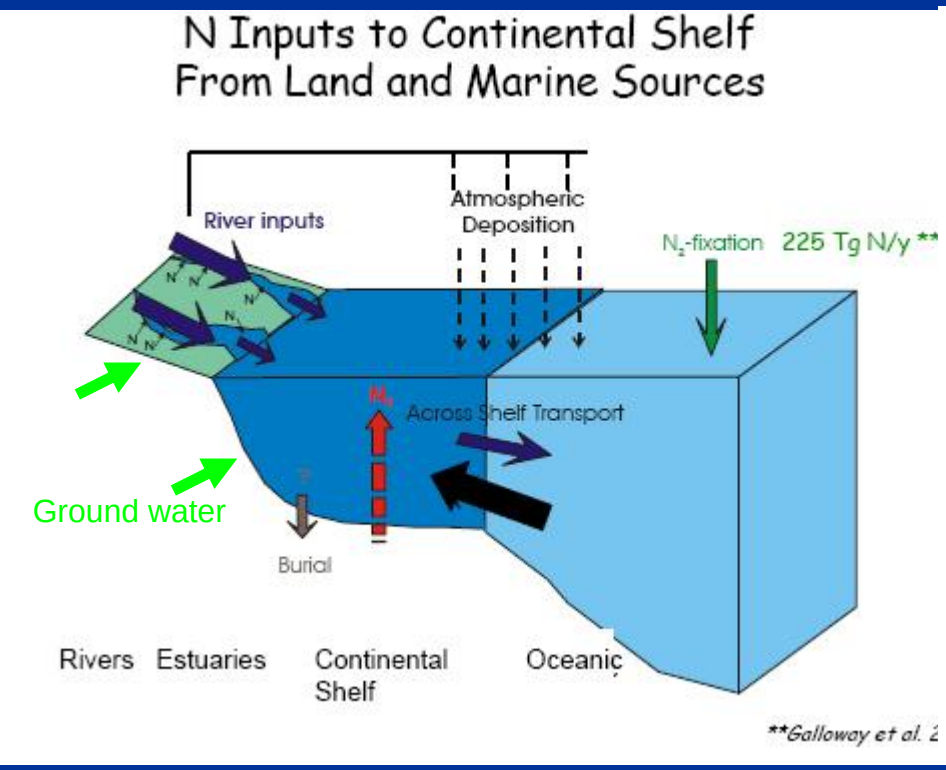
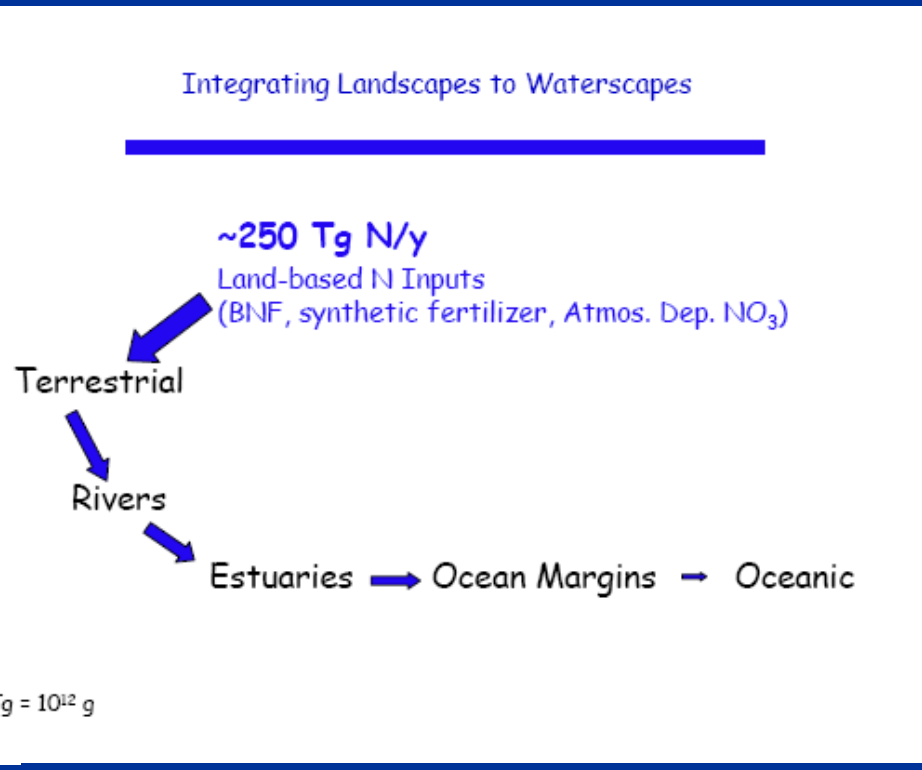
Flow of N from land to the oceans





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Statistical model development

GW Susceptibility = sensitivity + intensity

- Sensitivity hydrogeologic variables
  - Soil characteristics
  - Aquifer confinement and type
  - Well construction characteristics
- Intensity variables
  - Land-use percentages
  - Septic tank density

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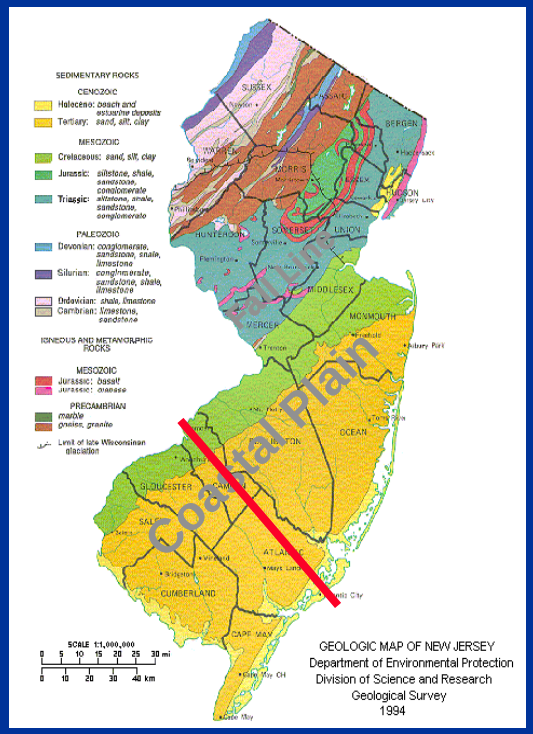
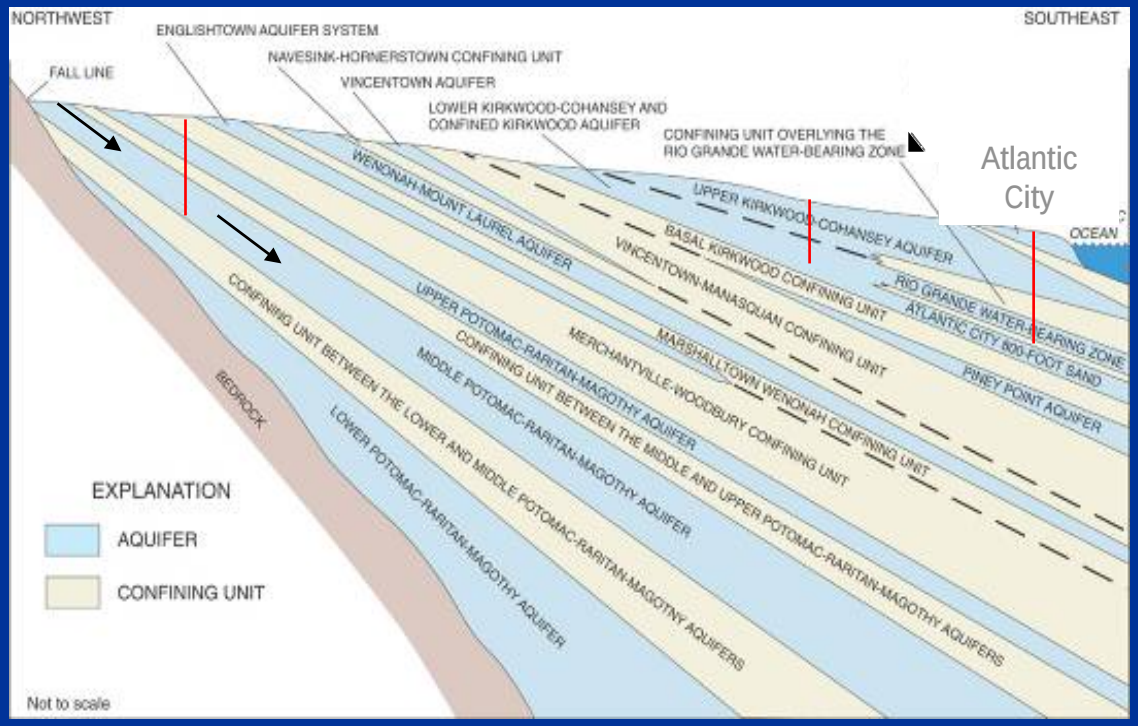
New Jersey Geology and Coastal Plain hydrogeology





- Alternating layers of aquifers and confining units
- Time of travel of water from outcrop area to down gradient parts of aquifers can be on the order of decades, centuries, millennia
- Contamination of water from Atlantic City 800-foot sand by human activities at the land surface is not common

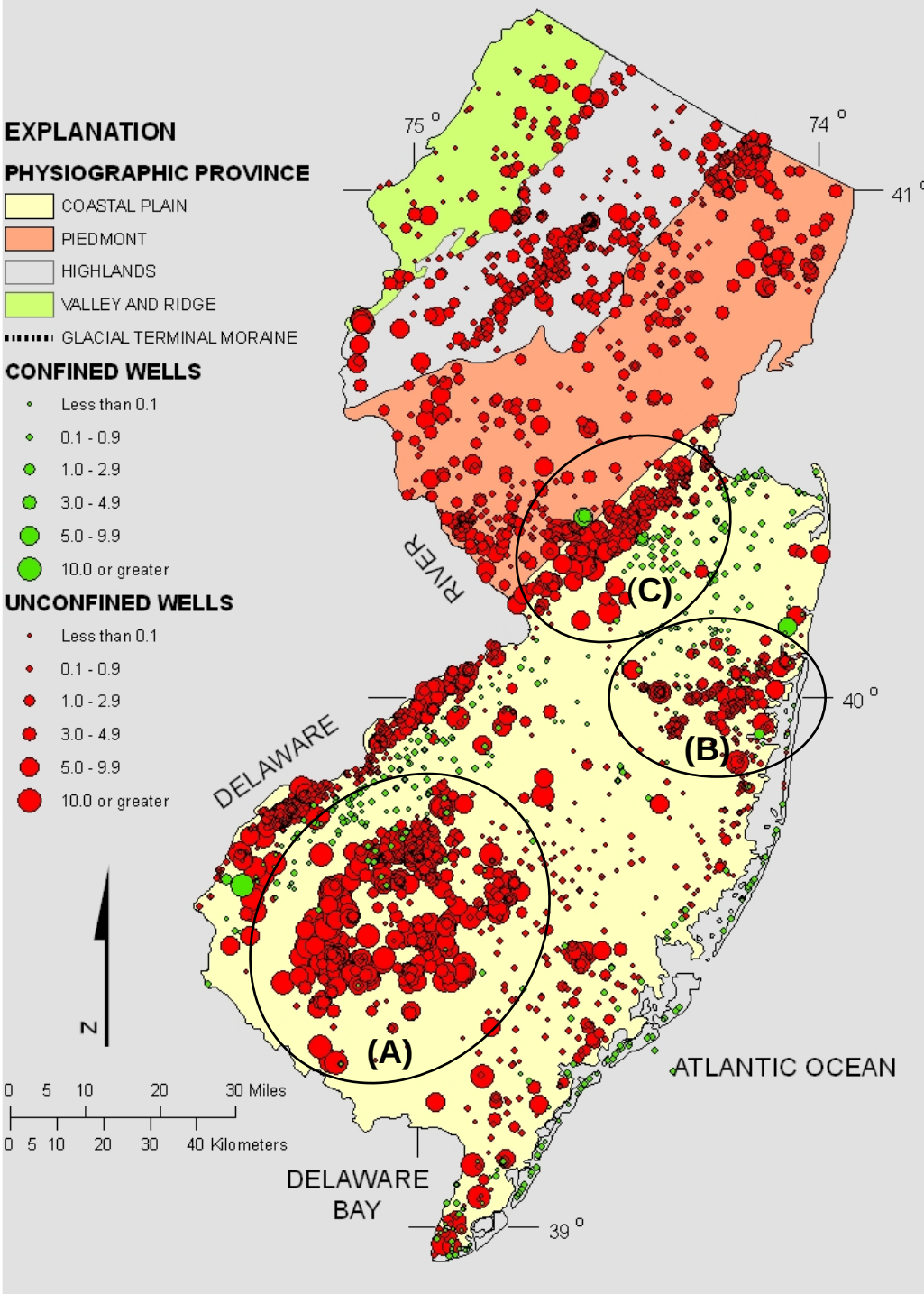
[NO_3^- as N] in mg/L in water from all wells in New Jersey sampled by the USGS NJWSC

- Difference in [NO_3^-] between unconfined (red) and confined (green) aquifers
- Spatial variability

(A) Agricultural area

(B) Change from chicken farming to urban land in 1980-90

(C) Change from potato farming to residential after 1940's



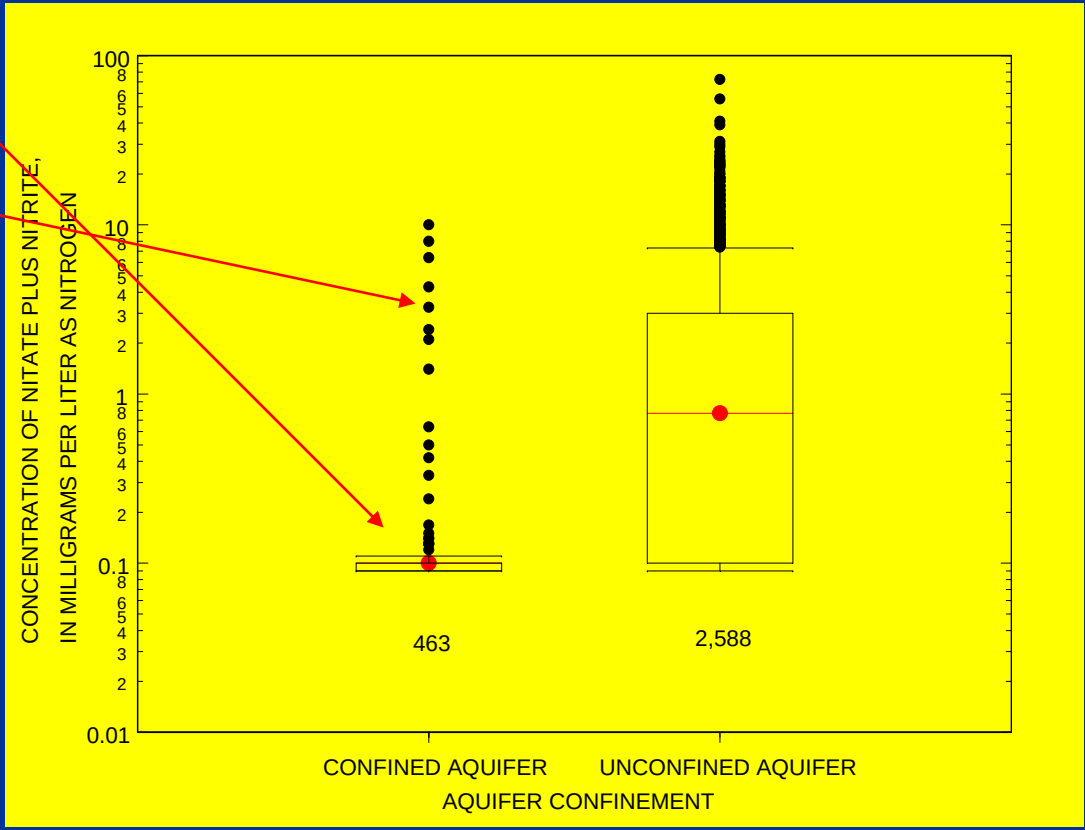
Relation of nitrate to aquifer confinement

Confined aquifers

- **Median [NO_3^-] less than 0.1 mg/L as N**
- **Outlier [NO_3^-] are in wells near outcrop area**

Unconfined aquifers

- **Median [NO_3^-] about 1 mg/L as N**



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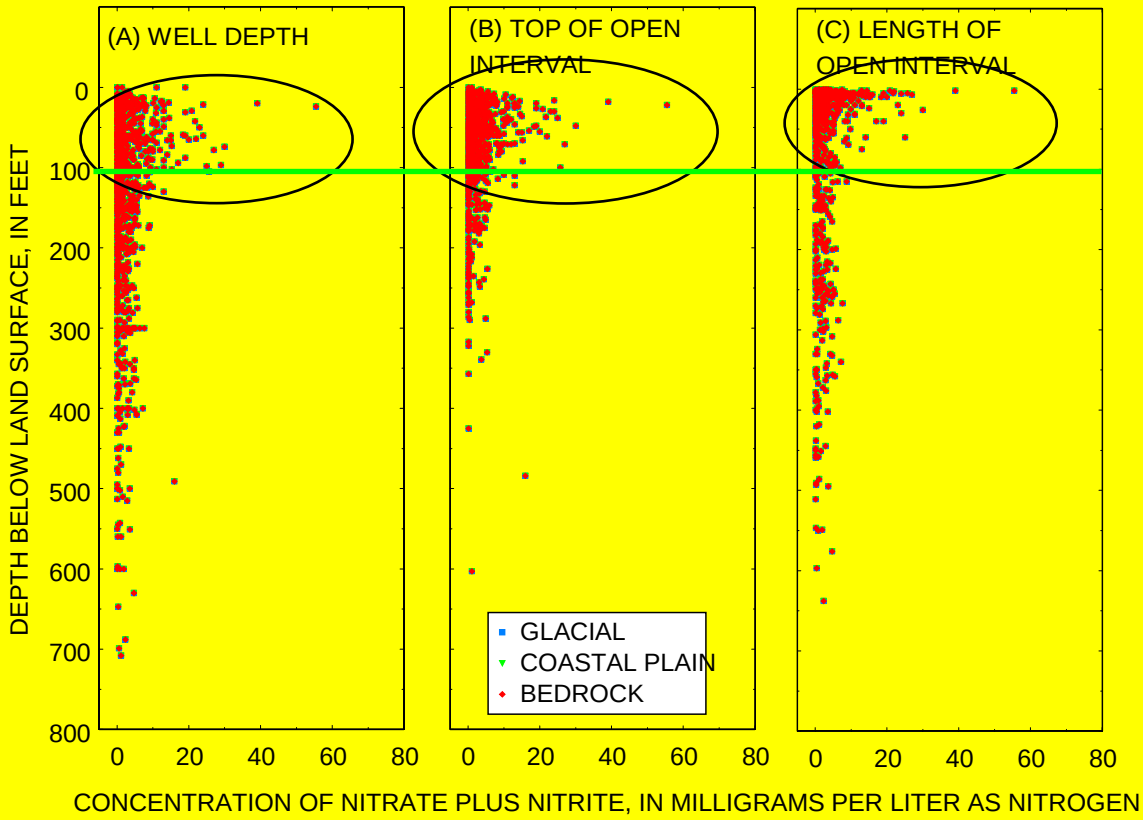
Relation of [NO_3^-] to well-construction characteristics

[NO_3^-] are largest in water from wells with:

- shallow depths (A)
- shallow depths to top of open interval (B)
- short length of open interval (C)



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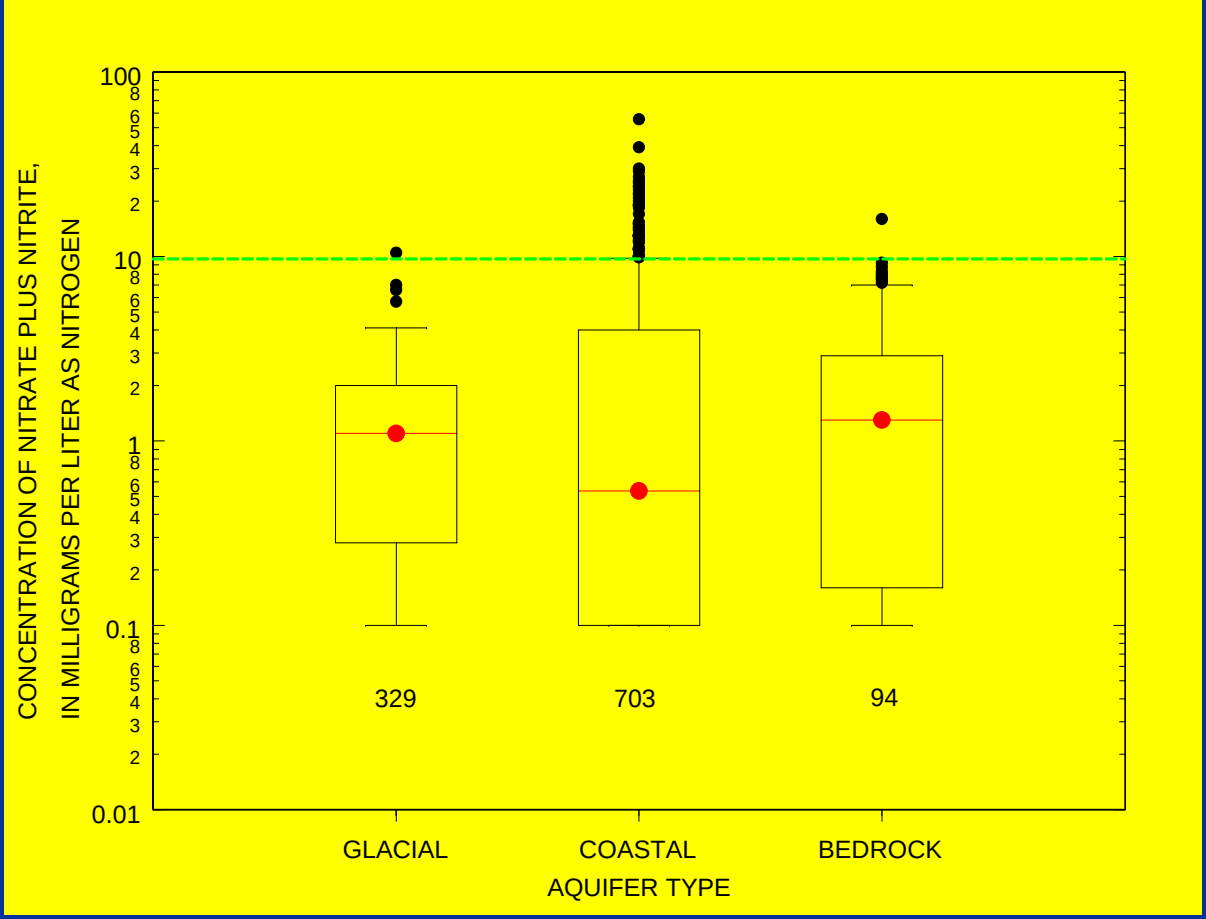
Aquifer type for unconfined wells

- $[NO_3^-]$ are similar by aquifer type
  - Glacial
  - Coastal Plain
  - Bedrock
- Large areas of the Coastal Plain are undeveloped or agricultural



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Land use in NJ 1995-97

source:
http://www.state.nj.us/dep/gis/lulc95shp.html

NJ is the "Garden State"

- **~18% agricultural**
- **~20% urban**
- **~62% undeveloped**
- **Highest population density in the USA**
- **Considerable land-use change in some areas**

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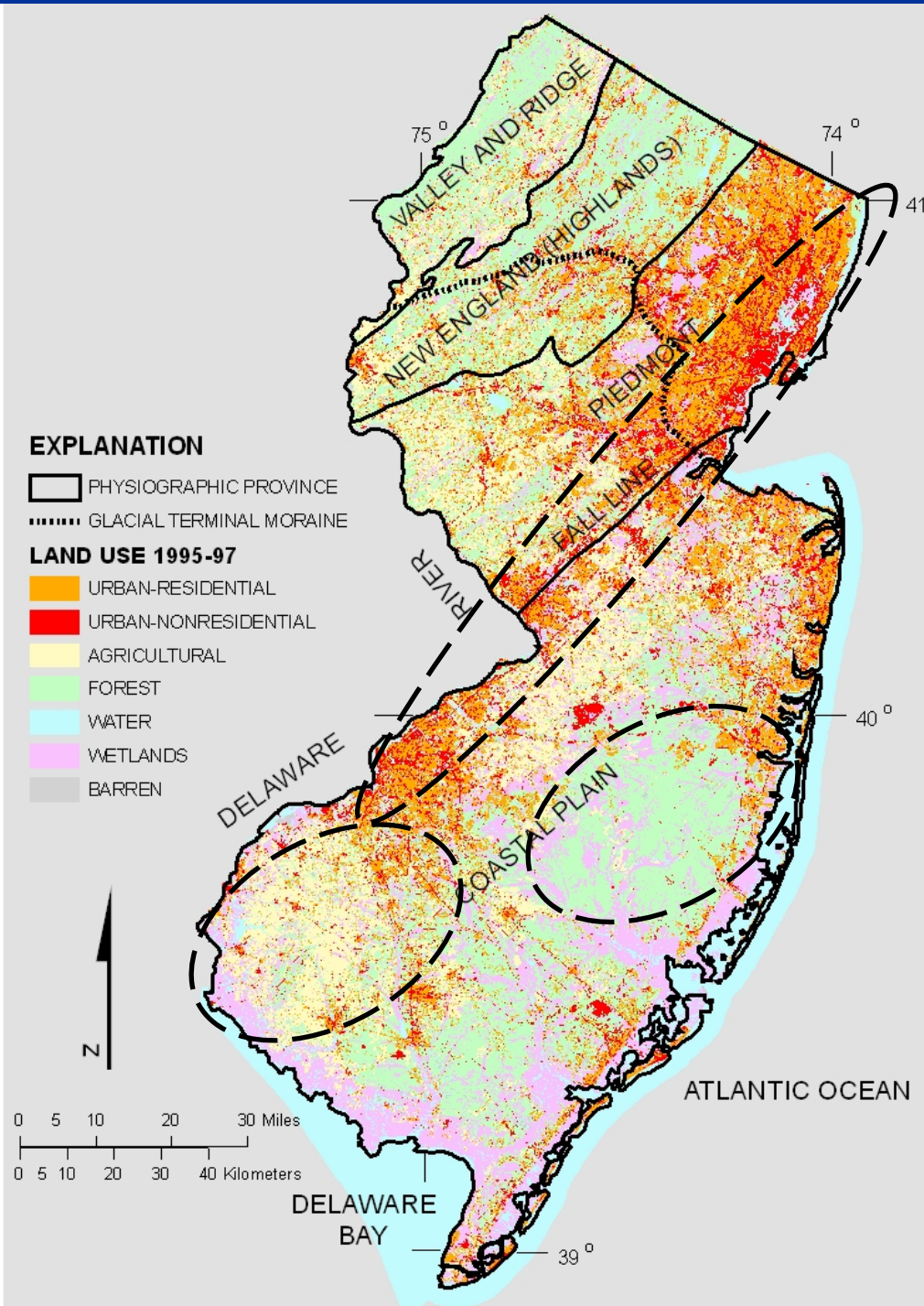
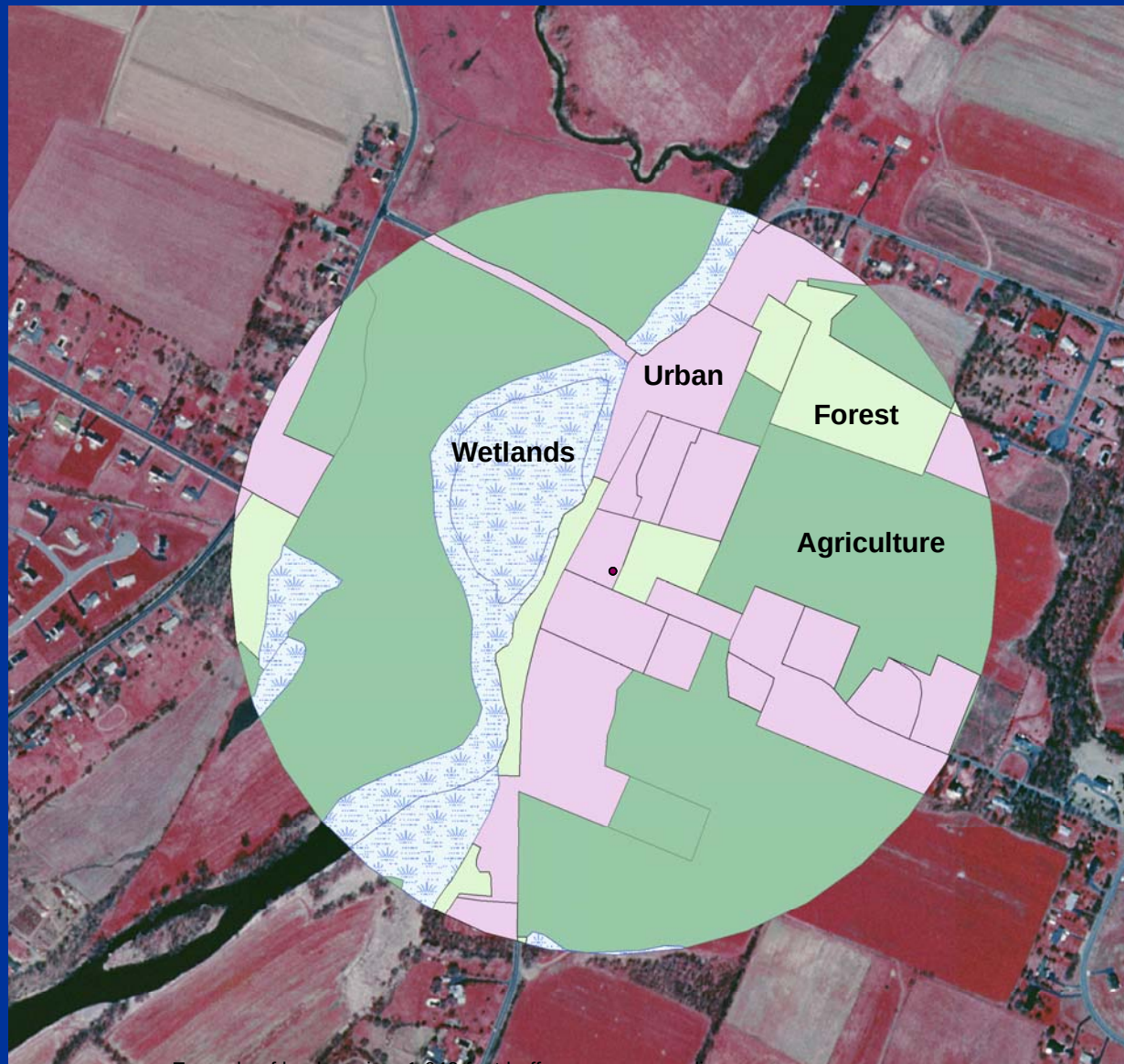


Land uses in 500-m-radius buffer zones

- 500-m-radius buffer areas used by USGS NAWQA studies to quantify land use effects to wells



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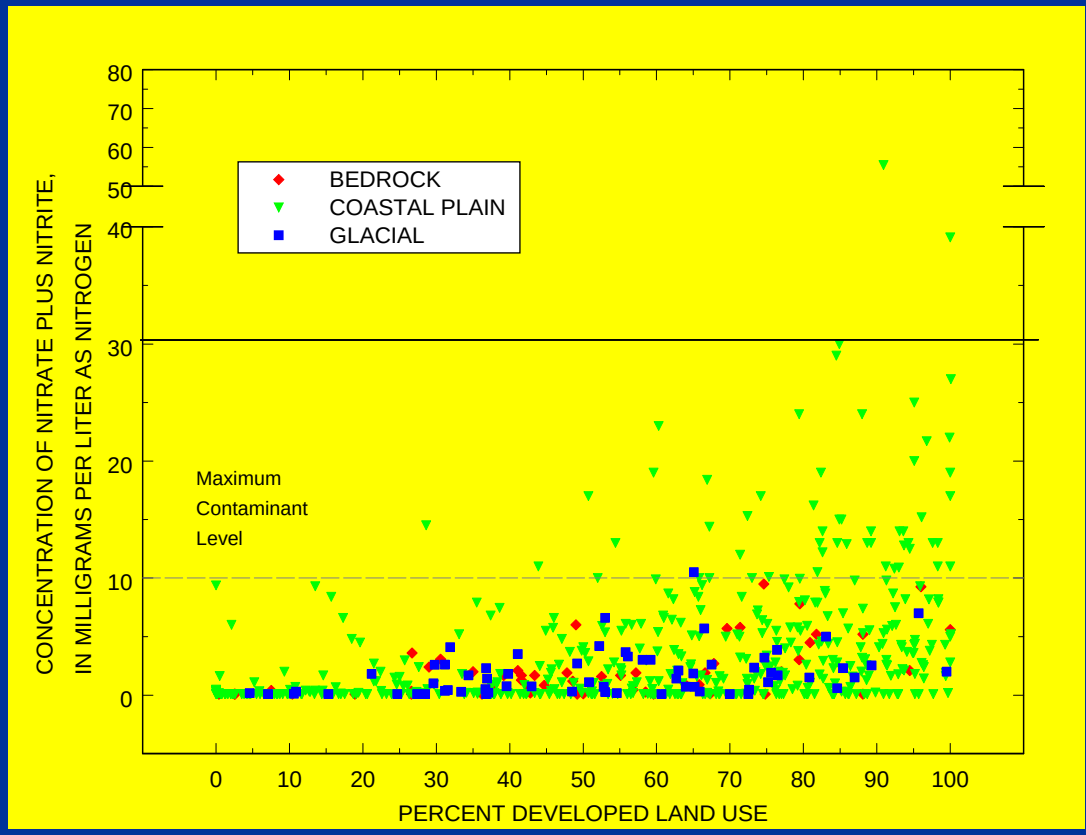
Relation of [NO_3^-] in water from wells <100 ft deep to percent developed land use

Developed land use = urban + agricultural

- Positive relation with percent developed land use
- Is the relation similar for urban and agricultural land uses?
- What about undeveloped land uses?



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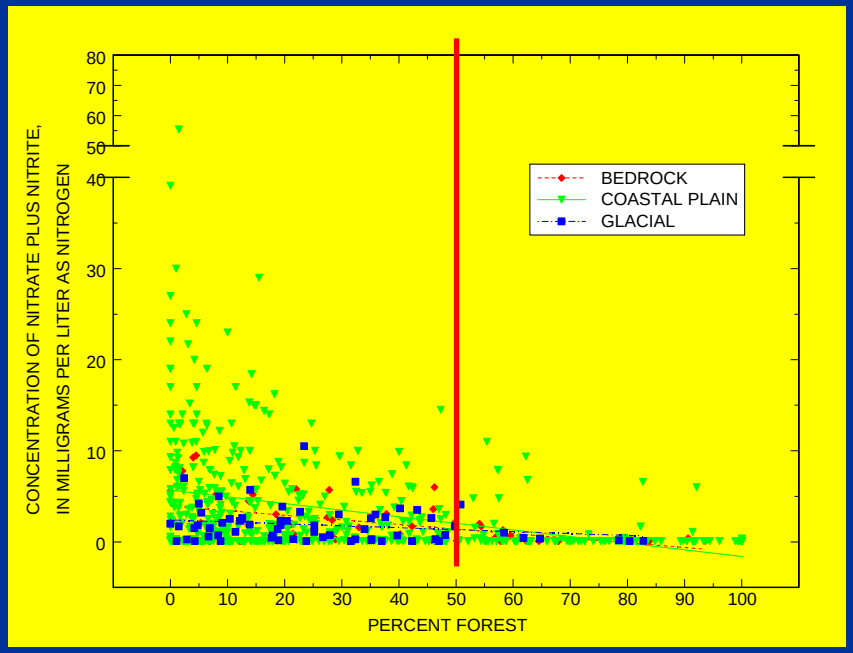
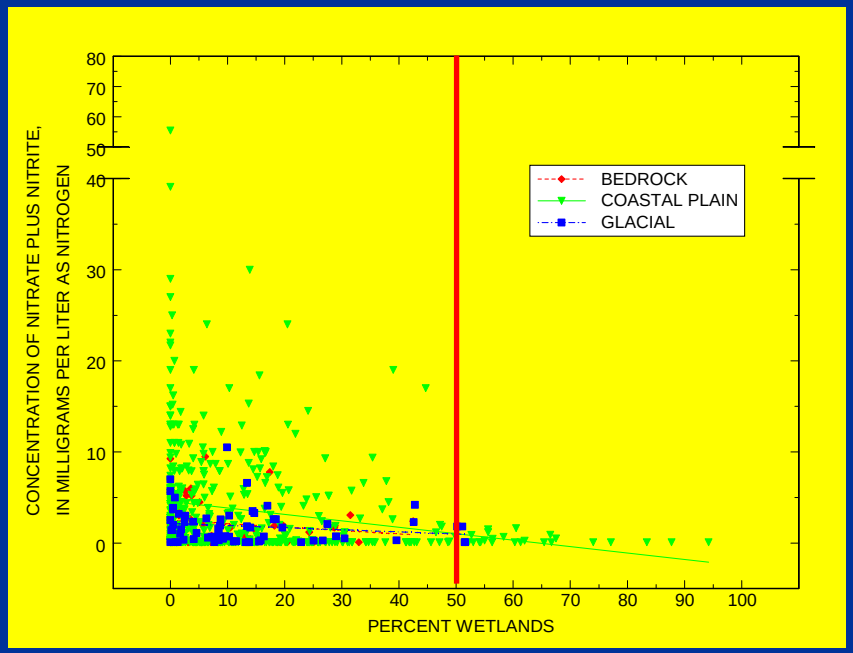
Relation of [NO_3^-] to % forest and % wetlands areas

- Negative correlation with percent forest and wetlands land cover
- Forested areas are not sources of nitrate
- Ground water in wetlands areas are sometimes anoxic: rarely above 0.1 mg/L-N when %wetlands >50%





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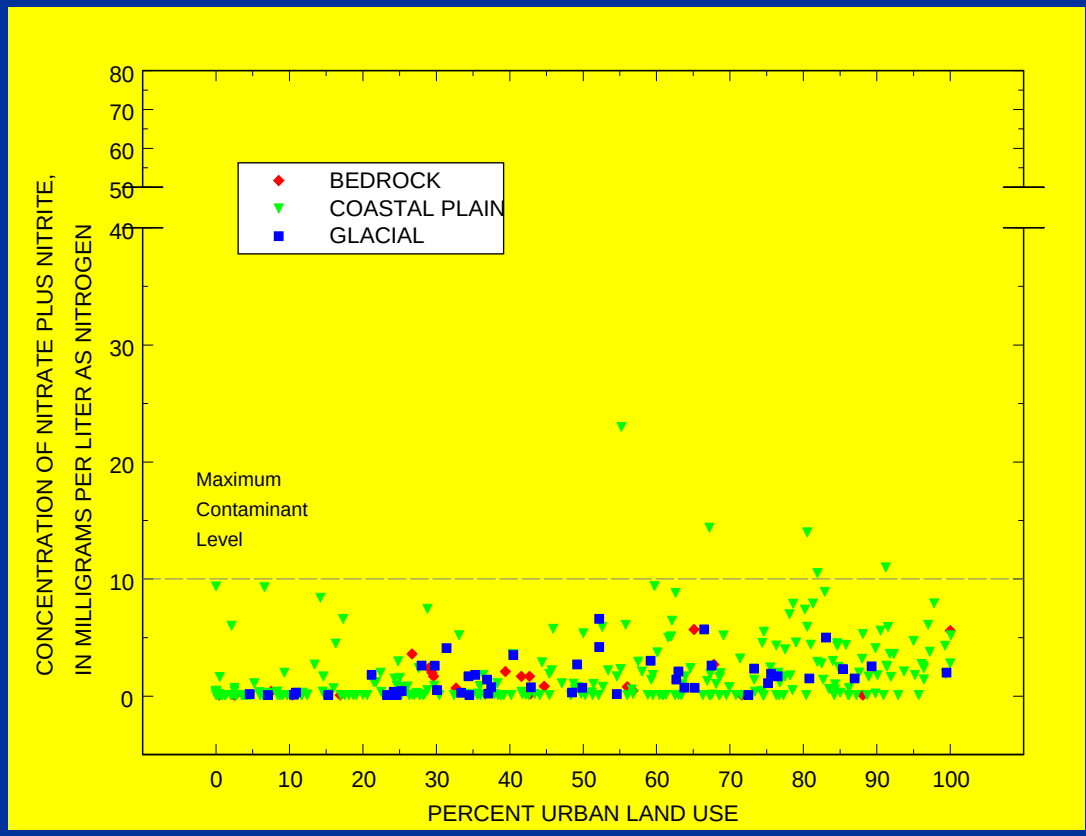
Relation of [NO_3^-] to percent urban land use in ground water with agricultural land less than 10%

Urban land use = residential + industrial + commercial

- Positive correlation with percent urban land use
- Rarely is [nitrate] greater than 10 mg/L-N
- As percent urban increases less septic systems used and more sewage treatment
- plants



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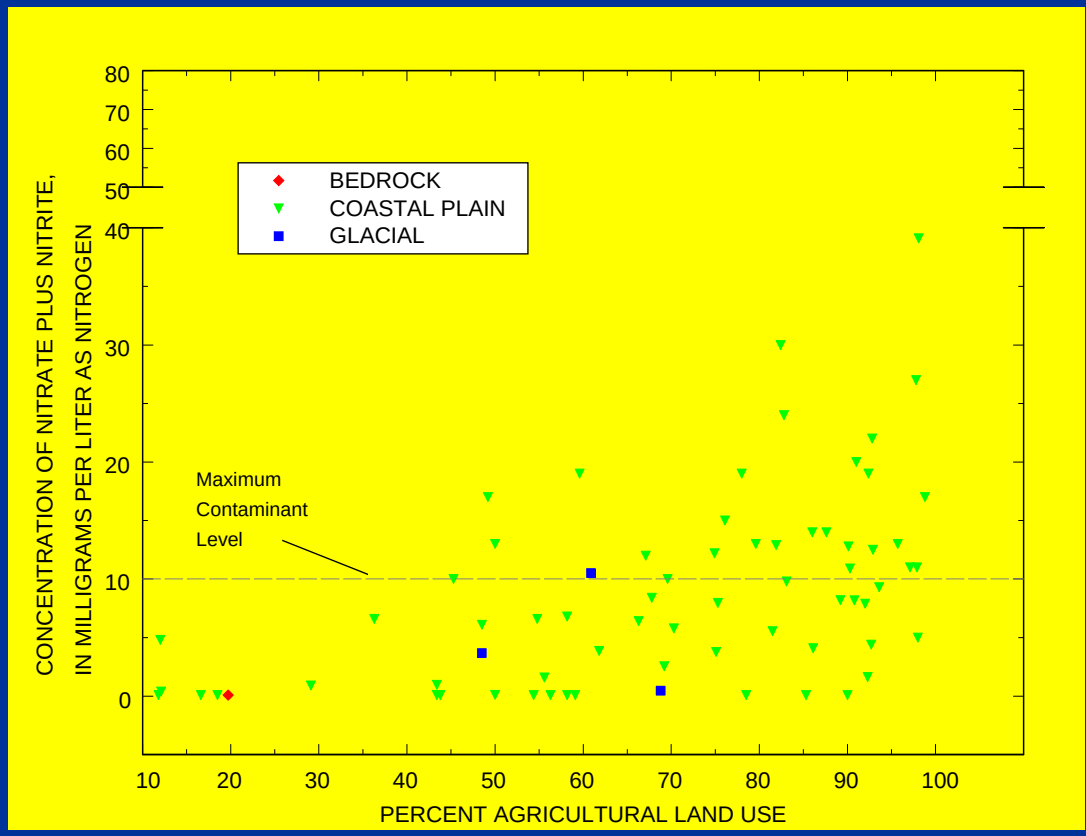
Relation of [nitrate] in ground water to percent agricultural land use with urban land less than 10%

- Positive correlation with percent agricultural land use
- [nitrate] often greater than 10 mg/L-N
- As percent agricultural land increases less septic system density



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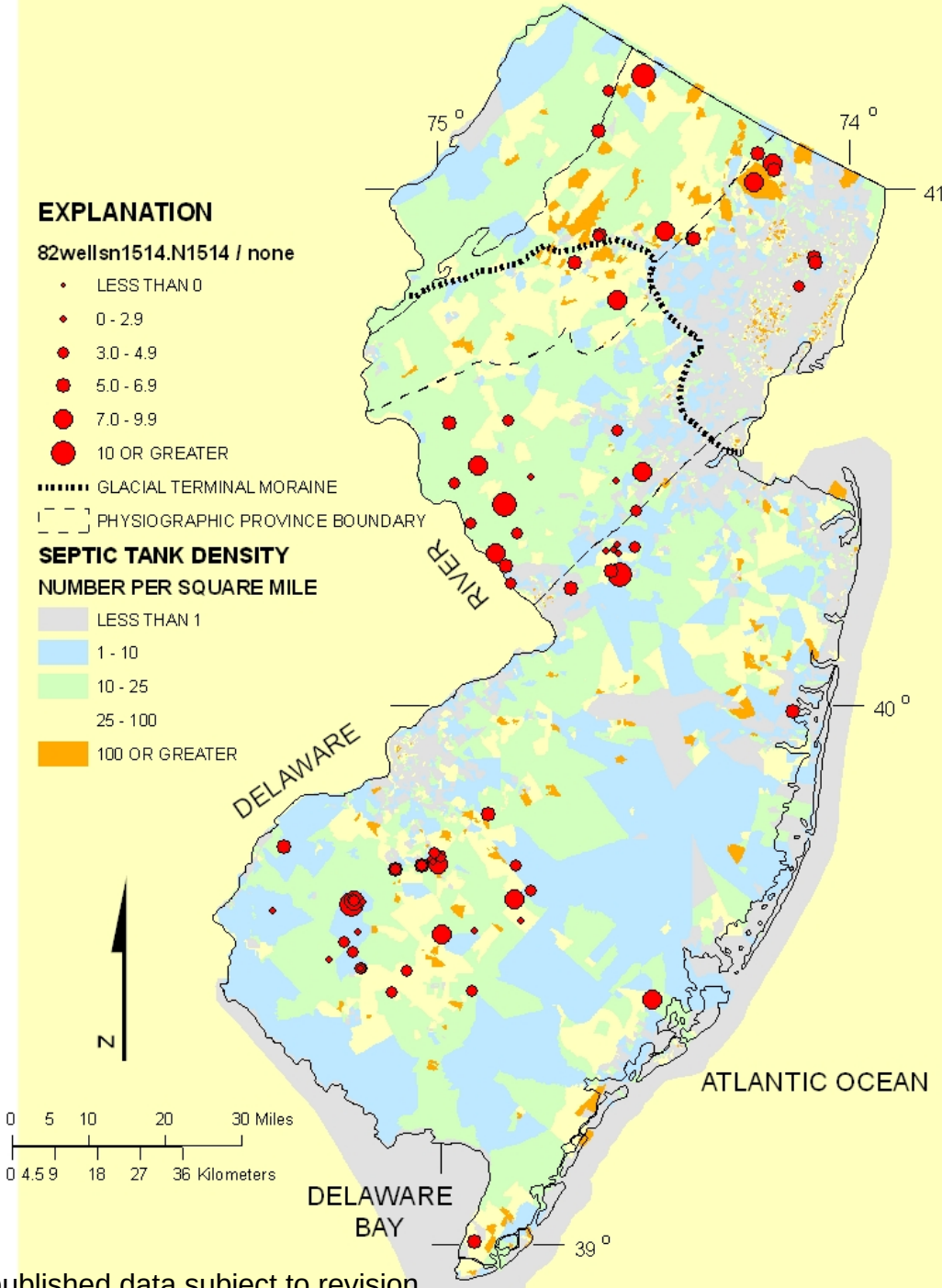
Methods to determine sources of N in ground water

Ratio of [$N^{15/14}$] in per mil

-2 to 7 = inorganic N

7-10 = transition zone

≥10 = organic N



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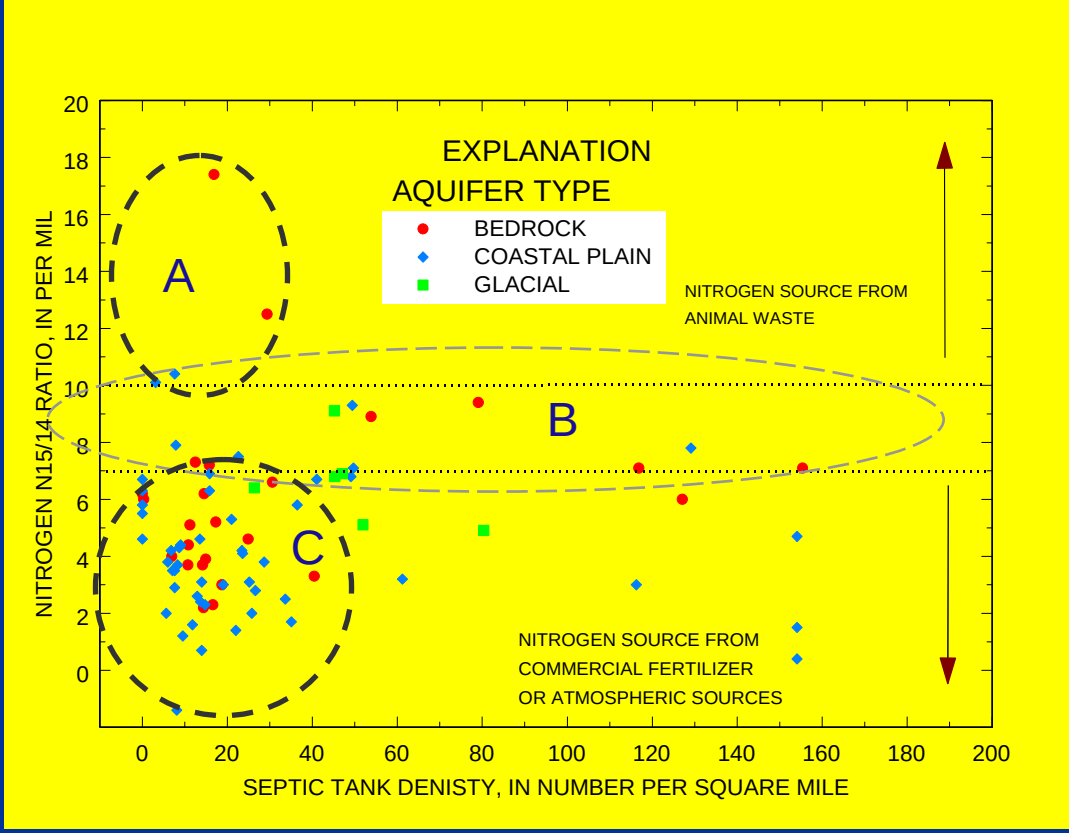
Nitrogen isotope ratios and septic tank density

A. At a few sites the source is clearly from animal waste

B. Some areas are in the transition zone where the septic-tank density is higher and septic effluent may be the source of the nitrate(

C. Most of nitrogen in ground water is from inorganic fertilizers



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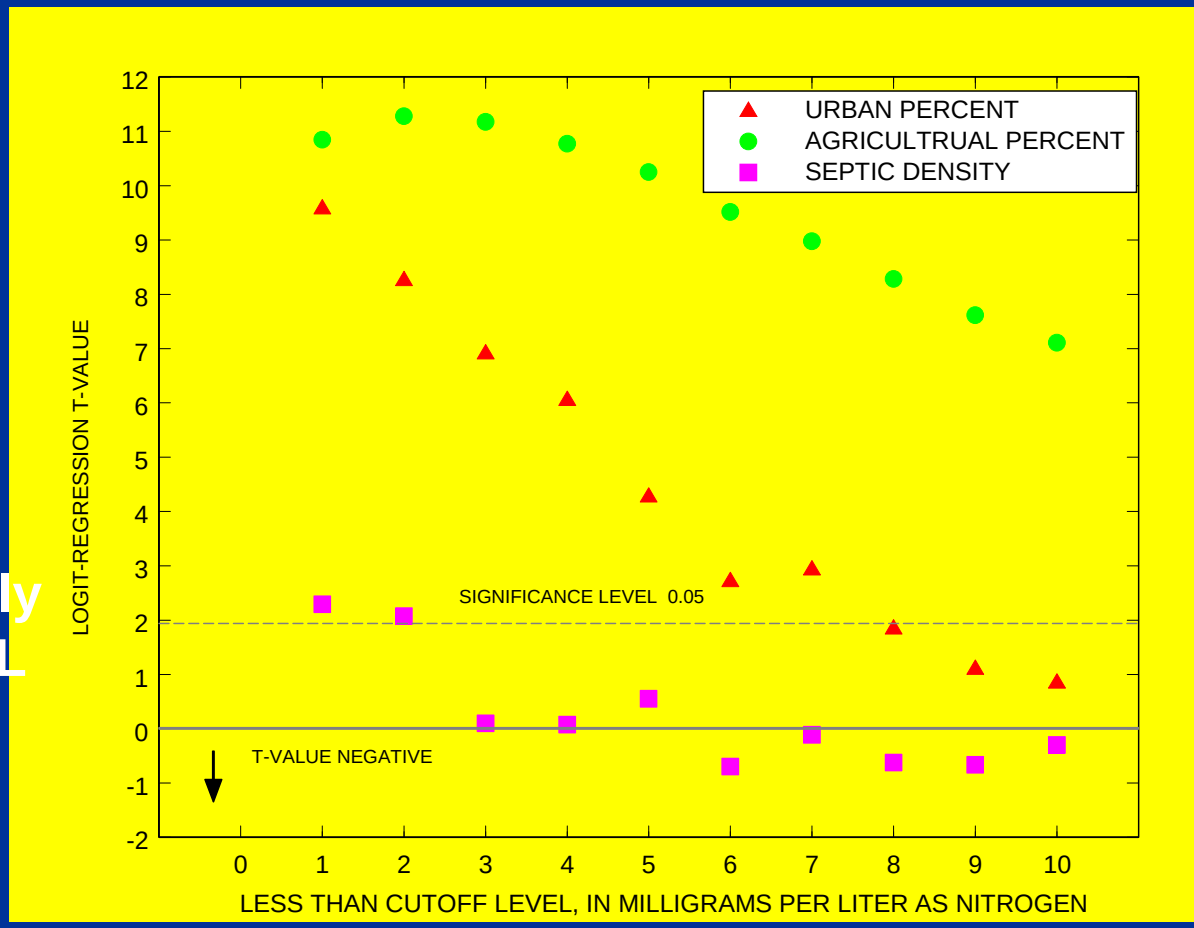
Logistic-regression t-value by [NO_3^-] cutoff level for each land-use predictor

- T-value is used as a relative guide for level of significance
- Agricultural land use significant at all cutoff levels
- Urban land use is significant up to about 7 mg/L
- Septic system density only significant at 1 and 2 mg/L as N



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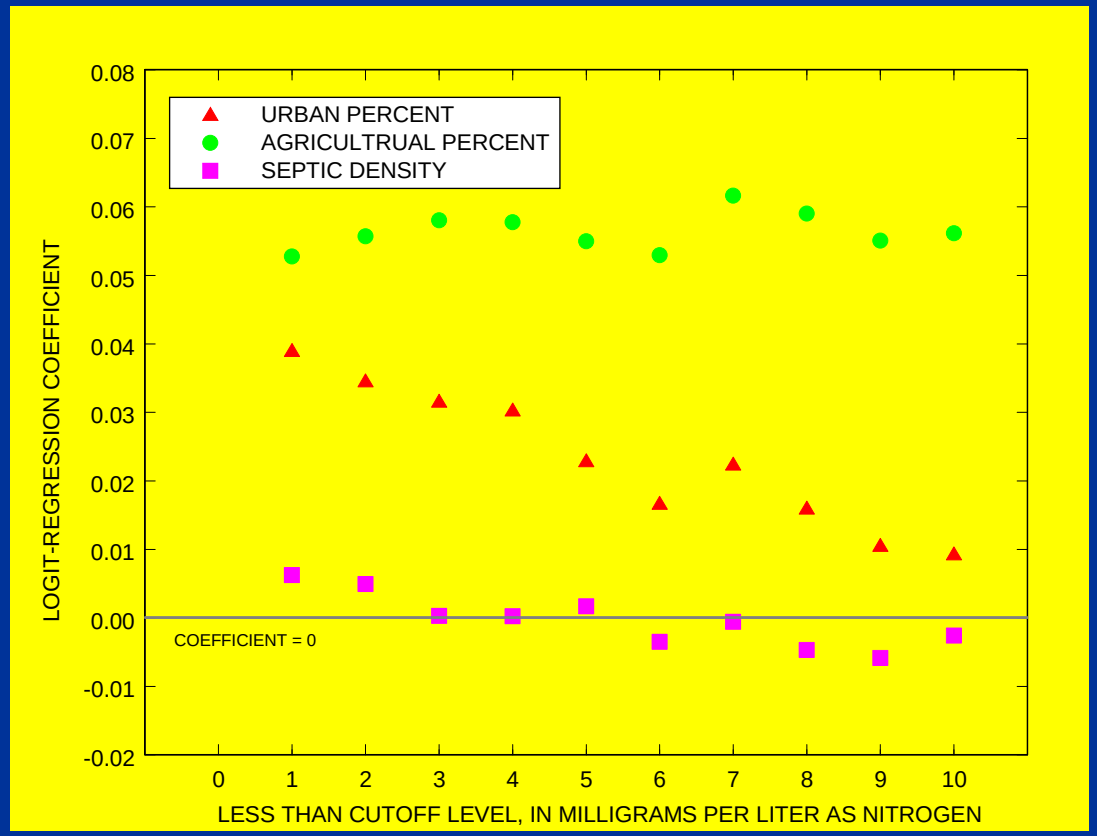
Logit-regression coefficient by [NO_3^-] cutoff level for each predictor

- Coefficient is used as a relative signal strength for each variable
- Agricultural land use is relatively similar for all cutoff evels
- Urban land use decreases as cutoff level increases
- Septic system coefficient is relatively low and goes negative above 7 mg/L as N



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The logistic regression model is expressed as:

$$\ln (p / (1-p) = a + bY + cZ\ldots \quad (1)$$

p = probability of the event occurring

a = y-intercept

b, c.. = empirically determined coefficients

Y, Z… = values of the independent variables

ln(p/(1-p) = the odds ratio

$$p = \exp (a + bY + cZ\ldots)/(1 + \exp (a + bY + cZ\ldots)) \quad (2)$$

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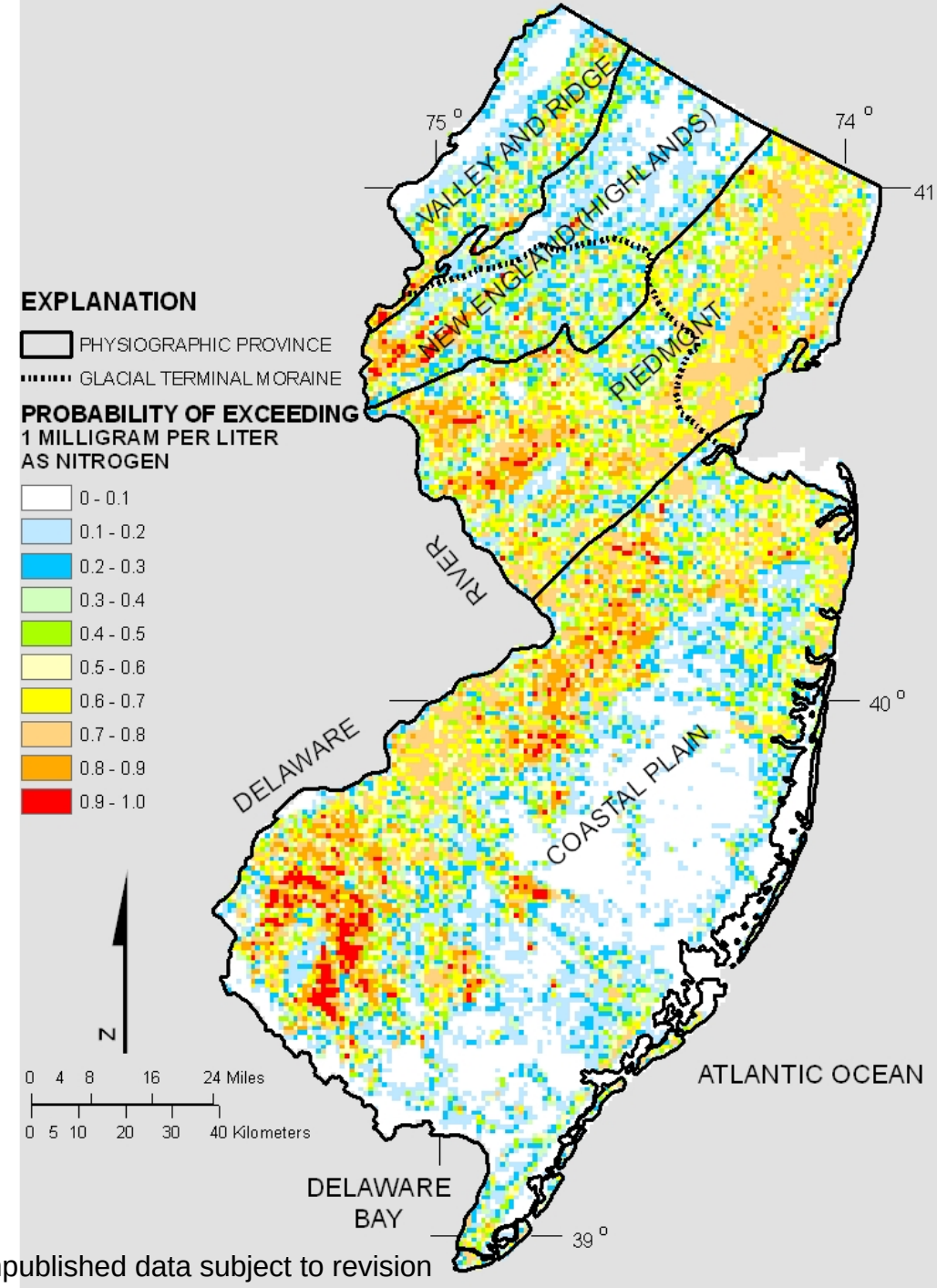
Probability of [NO_3^-] exceeding 1 mg/L as N in ground water ≤ 100 ft



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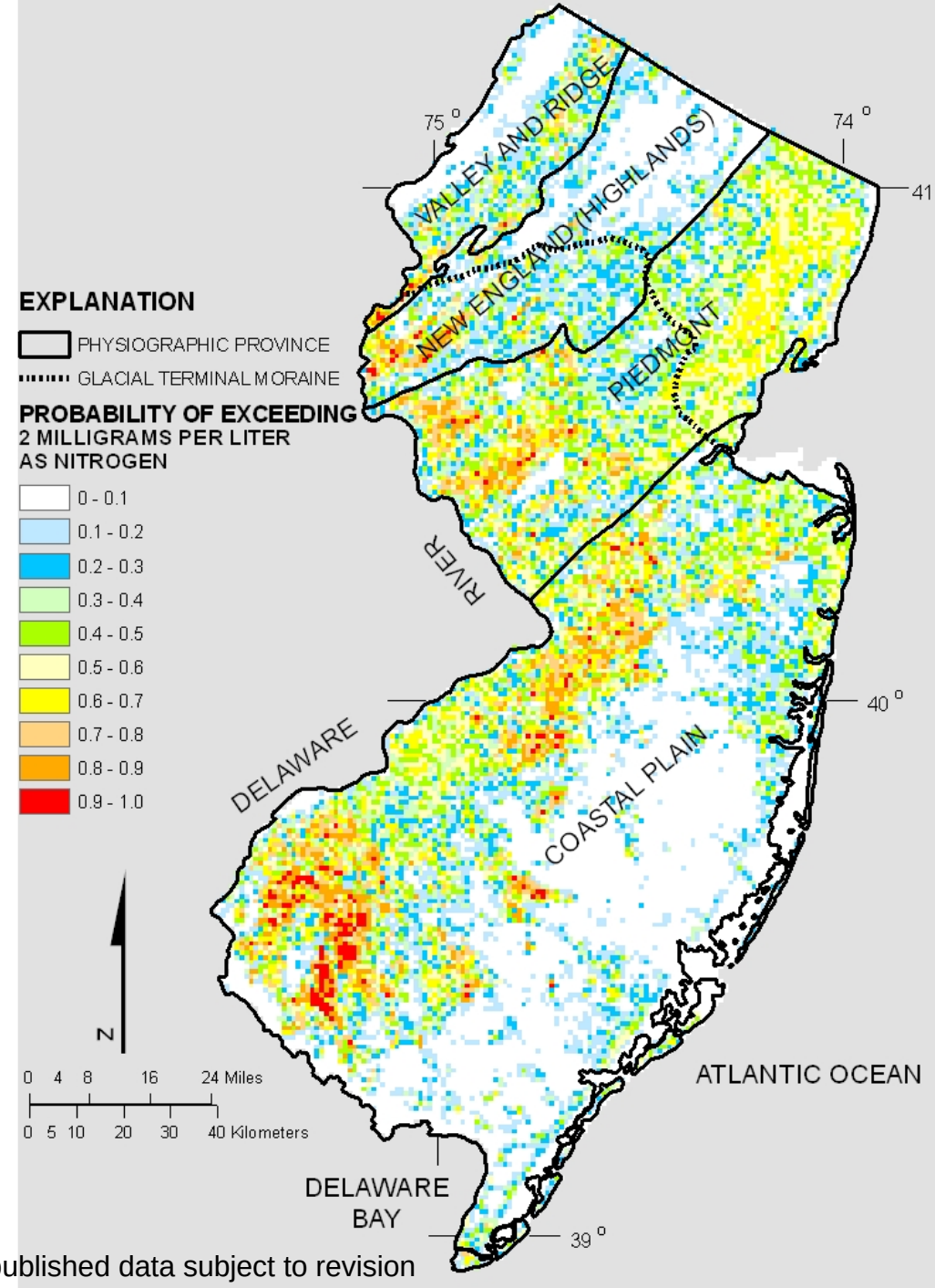
Probability of $[NO_3^-]$ exceeding 2 mg/L as N in ground water ≤ 100 ft



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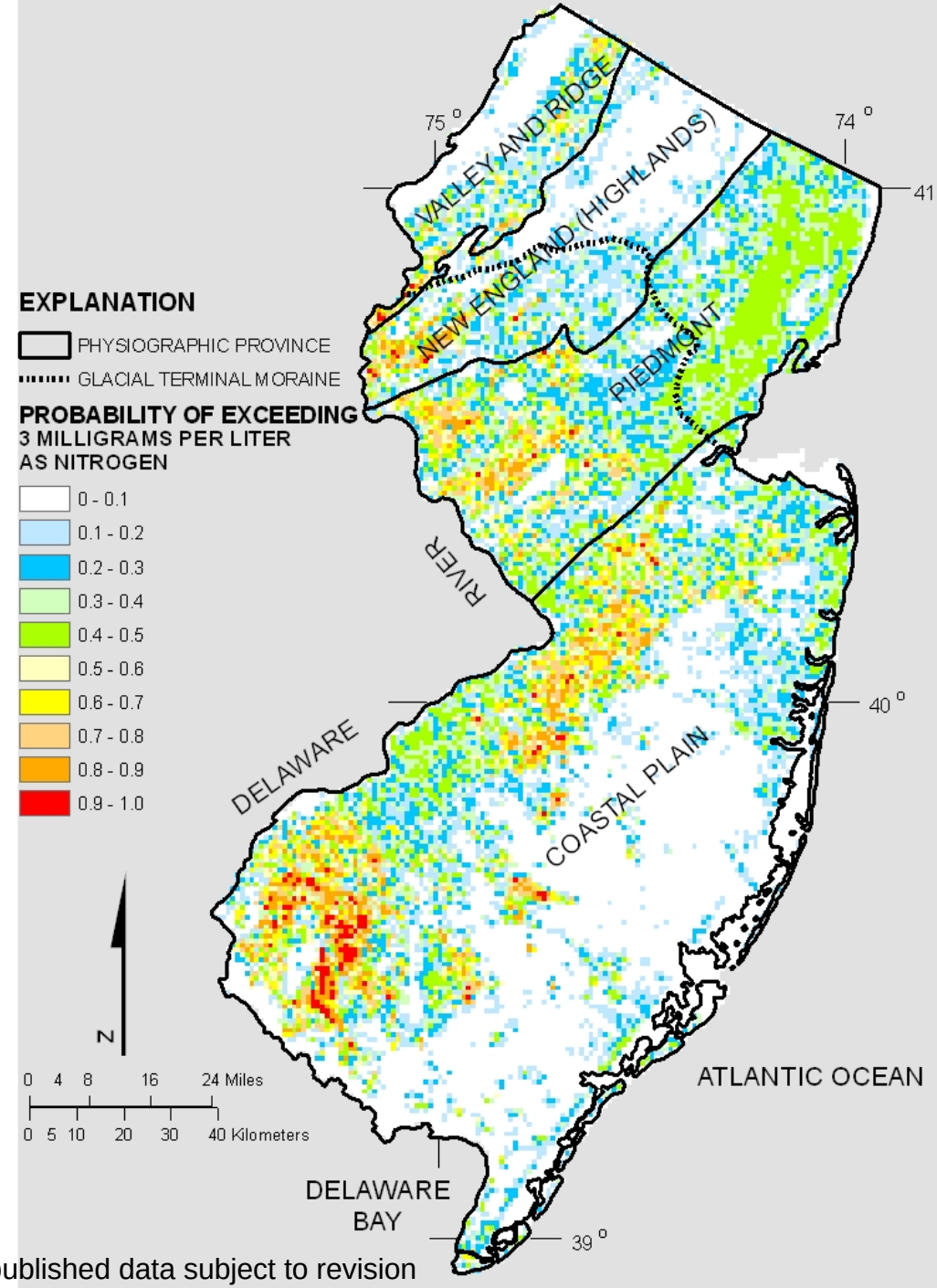
Probability of $[NO_3^-]$ exceeding 3 mg/L as N in ground water ≤ 100 ft



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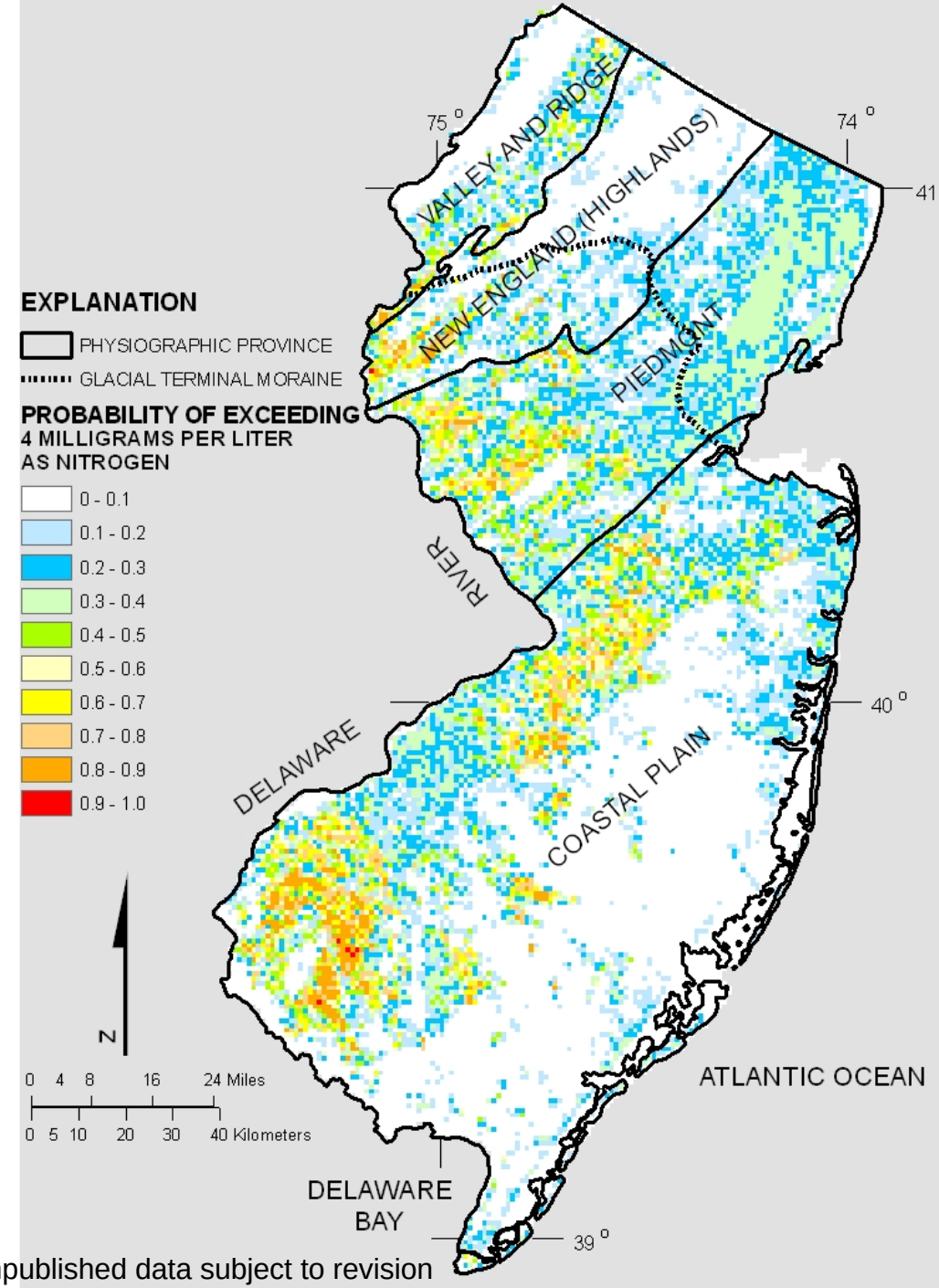
Probability of $[NO_3^-]$ exceeding 4 mg/L as N in ground water ≤ 100 ft



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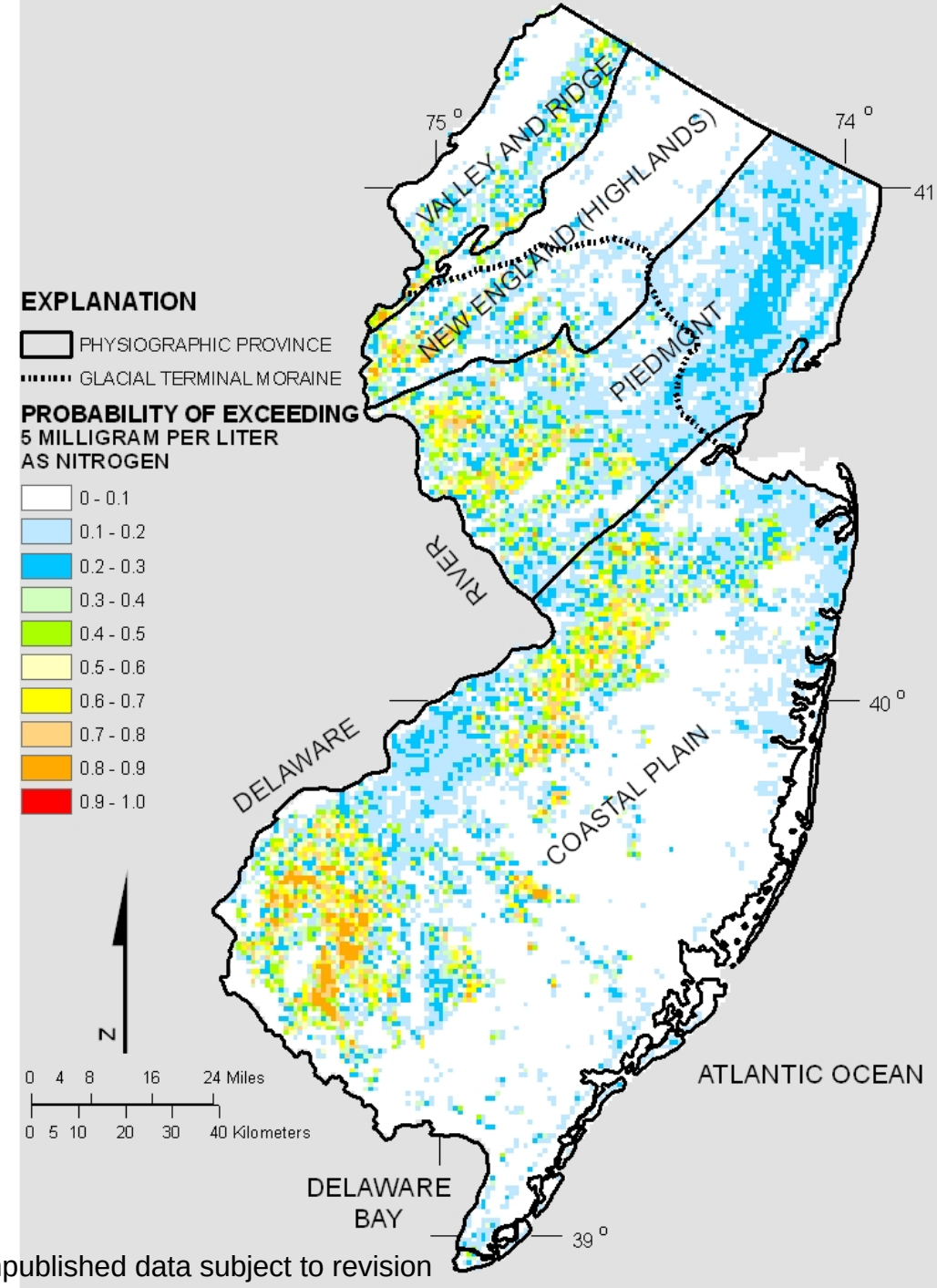
Probability of $[NO_3^-]$ exceeding 5 mg/L as N in ground water ≤ 100 ft



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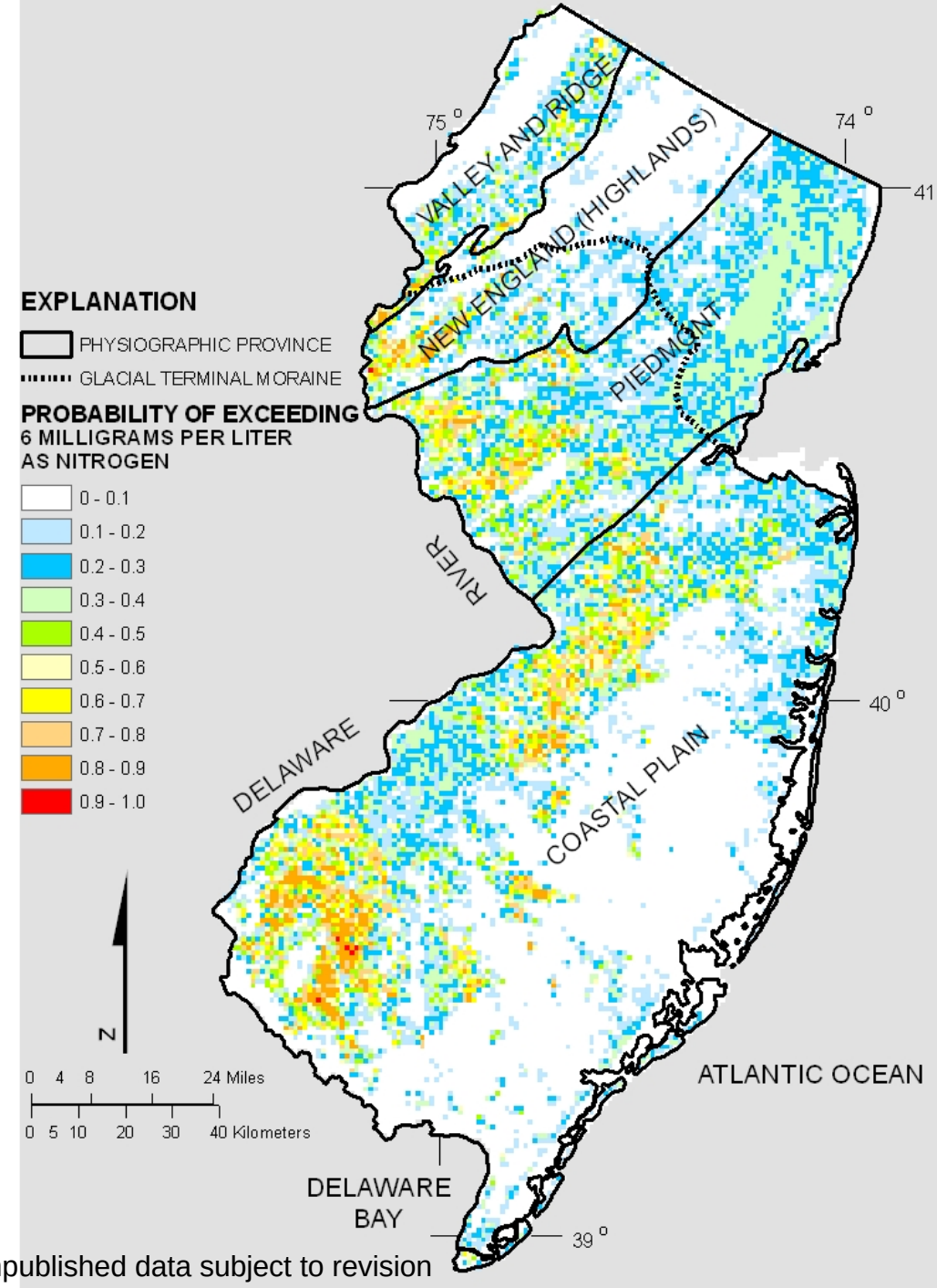
Probability of $[NO_3^-]$ exceeding 6 mg/L as N in ground water ≤ 100 ft



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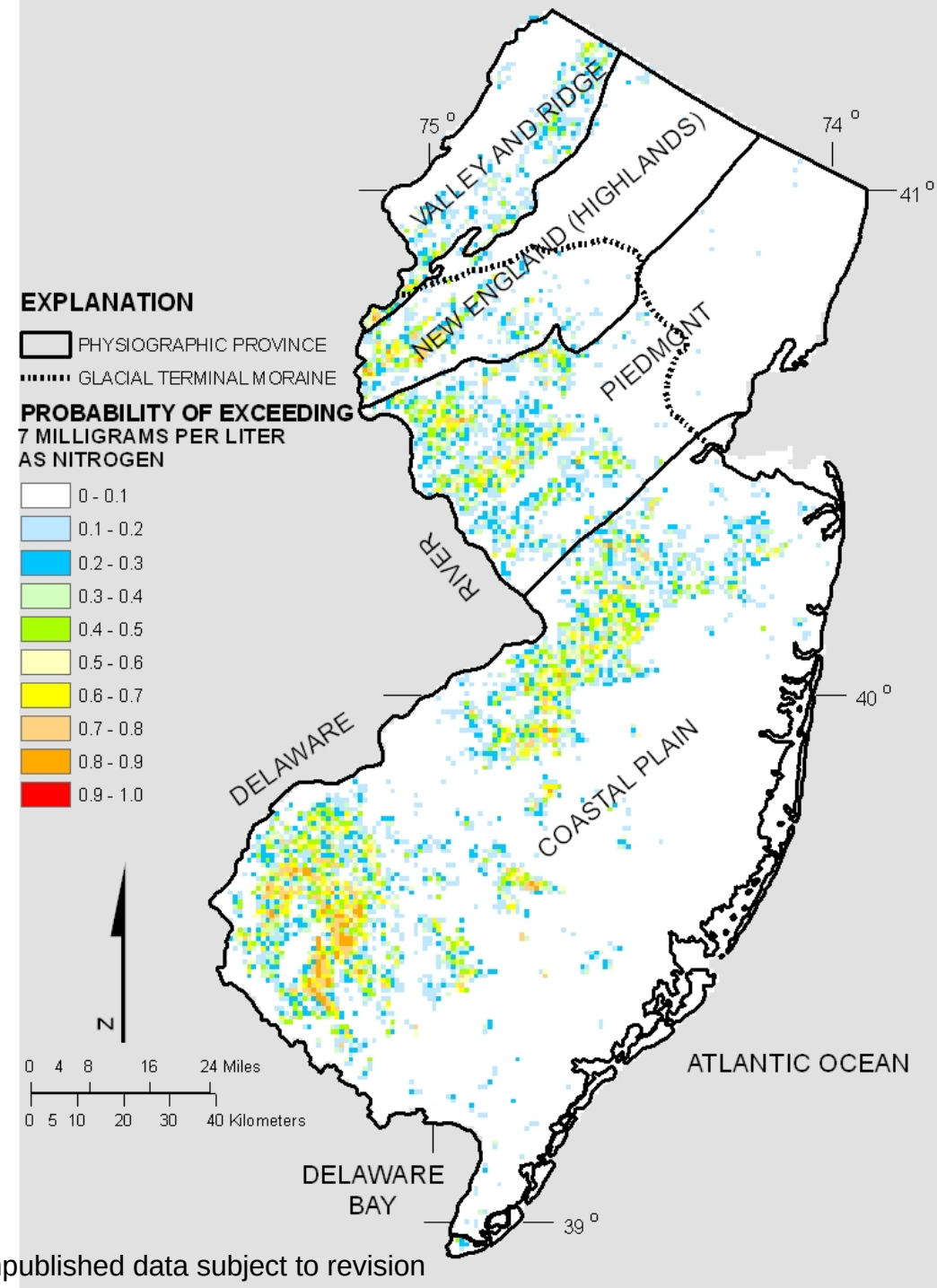
Probability of $[NO_3^-]$ exceeding 7 mg/L as N in ground water ≤ 100 ft



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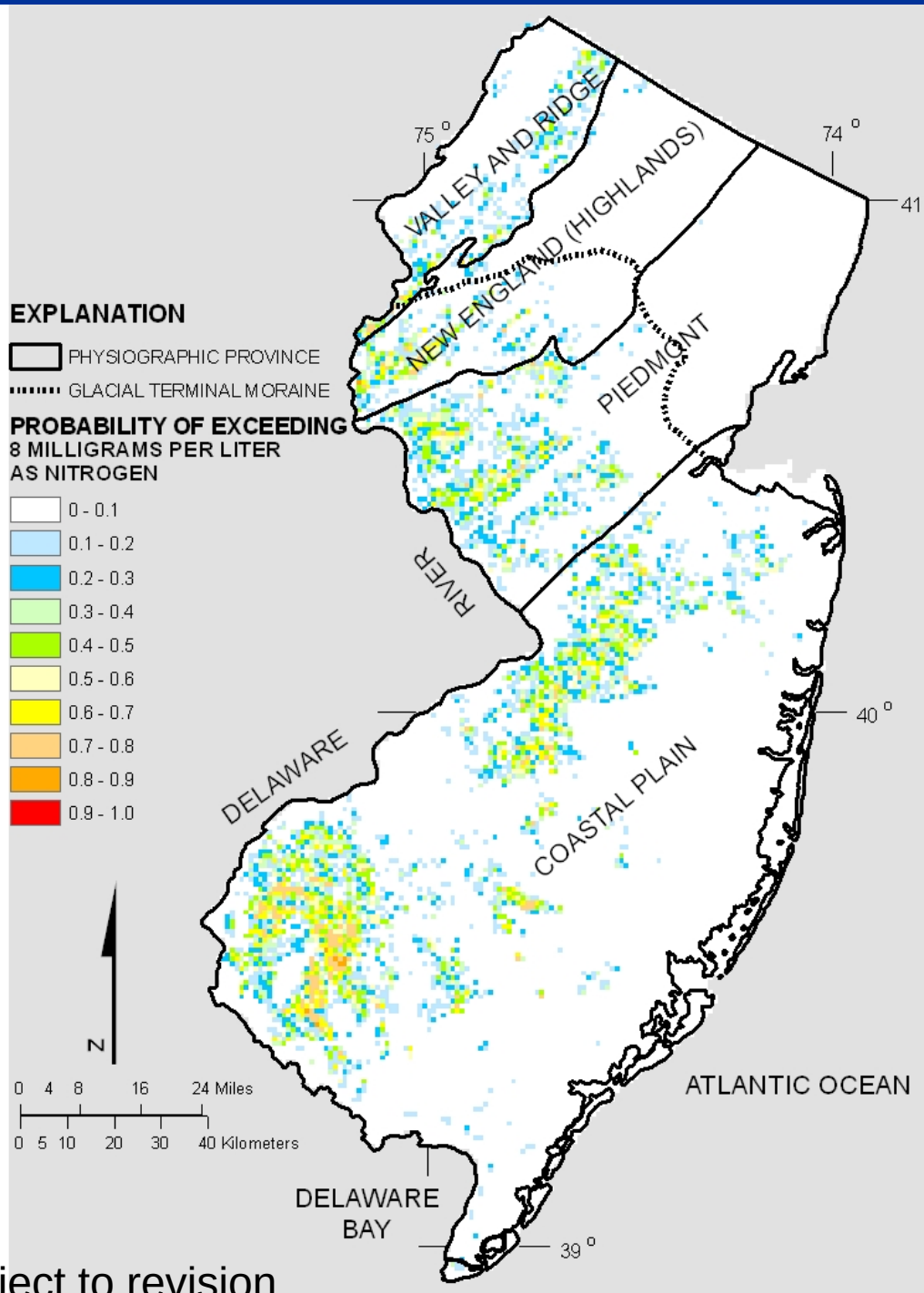
Probability of $[NO_3^-]$ exceeding 8 mg/L as N in ground water ≤ 100 ft



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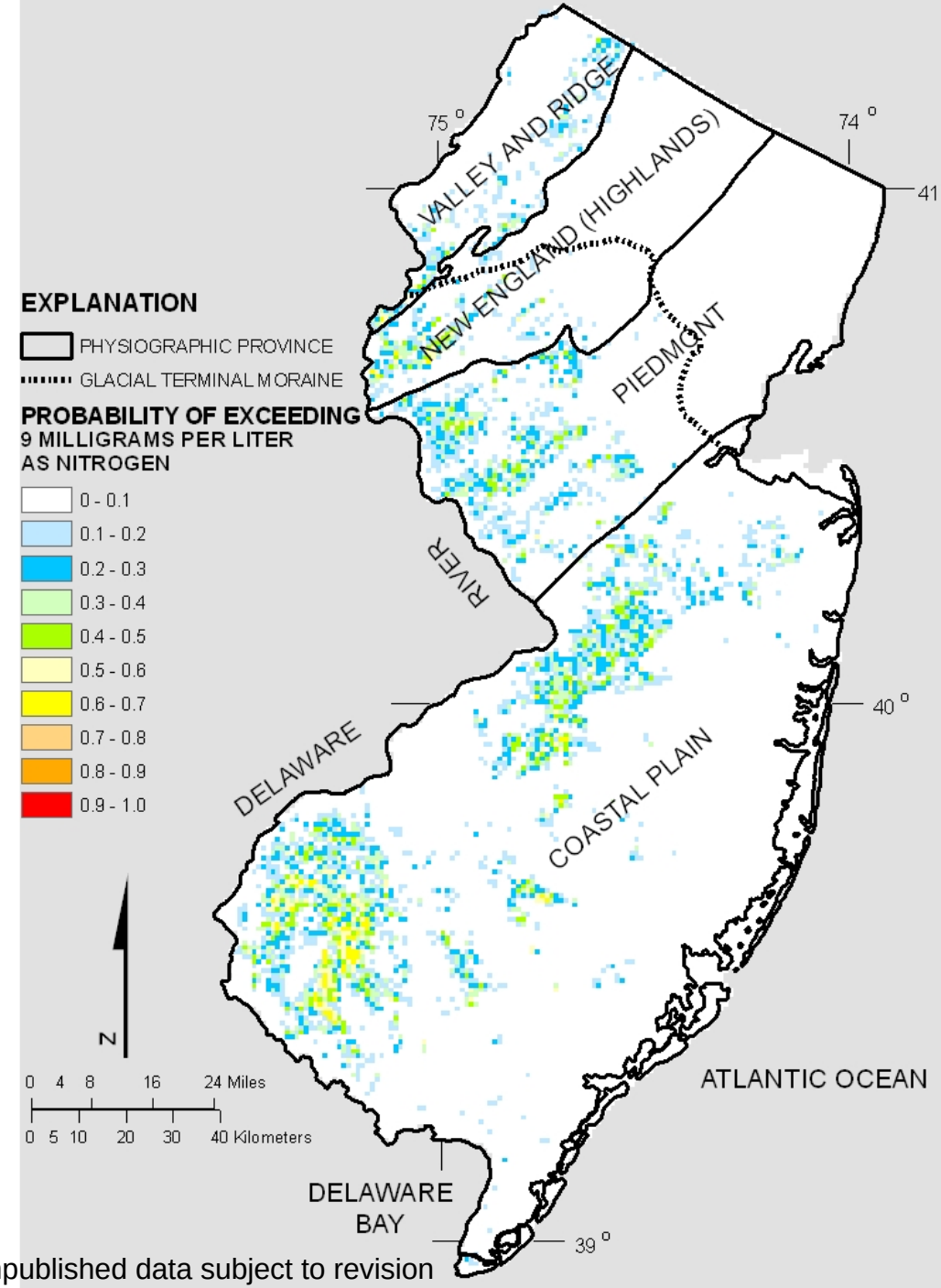
Probability of $[NO_3^-]$ exceeding 9 mg/L as N in ground water ≤ 100 ft



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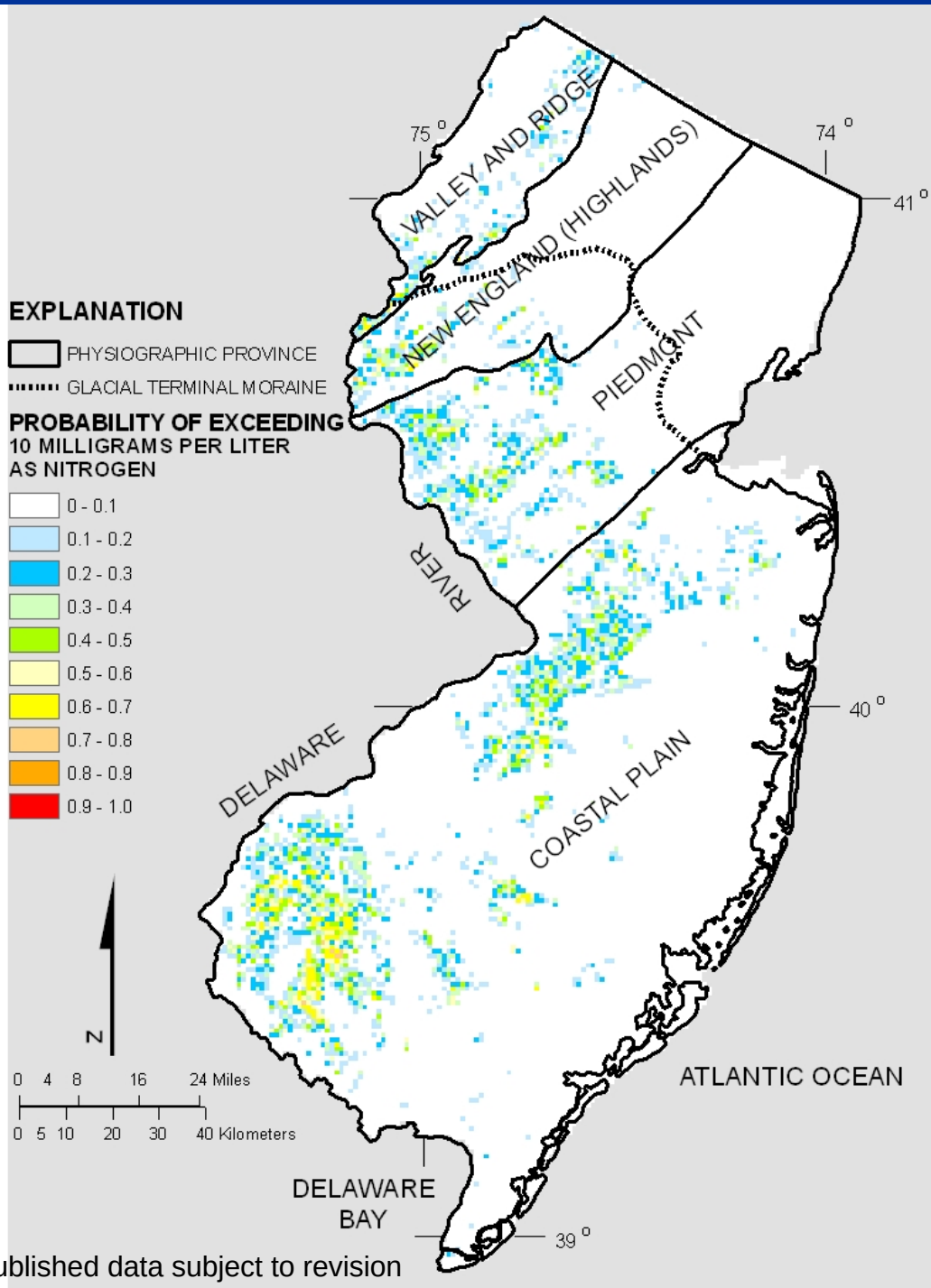
Probability of $[NO_3^-]$ exceeding 10 mg/L as N in ground water ≤ 100 ft



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Statistical model provides guidance on

- Where the problem areas are at each cut-off level
- The relative effects of agricultural and urban land uses and septic tank density

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Where do we go from here?

- Determine the relation of ground-water levels of nitrate to surface water concentrations
- More work on effect of septic-tank density with more refined coverages of septic density
- Try different data sets like the NJ private well testing act data set to verify these results

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