Development of Spatial Probability Models to Estimate, Integrate, and Assess Ground-Water Vulnerability at Multiple Scales

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ReVA
Regional Vulnerability Assessment

USGS
science for a changing world

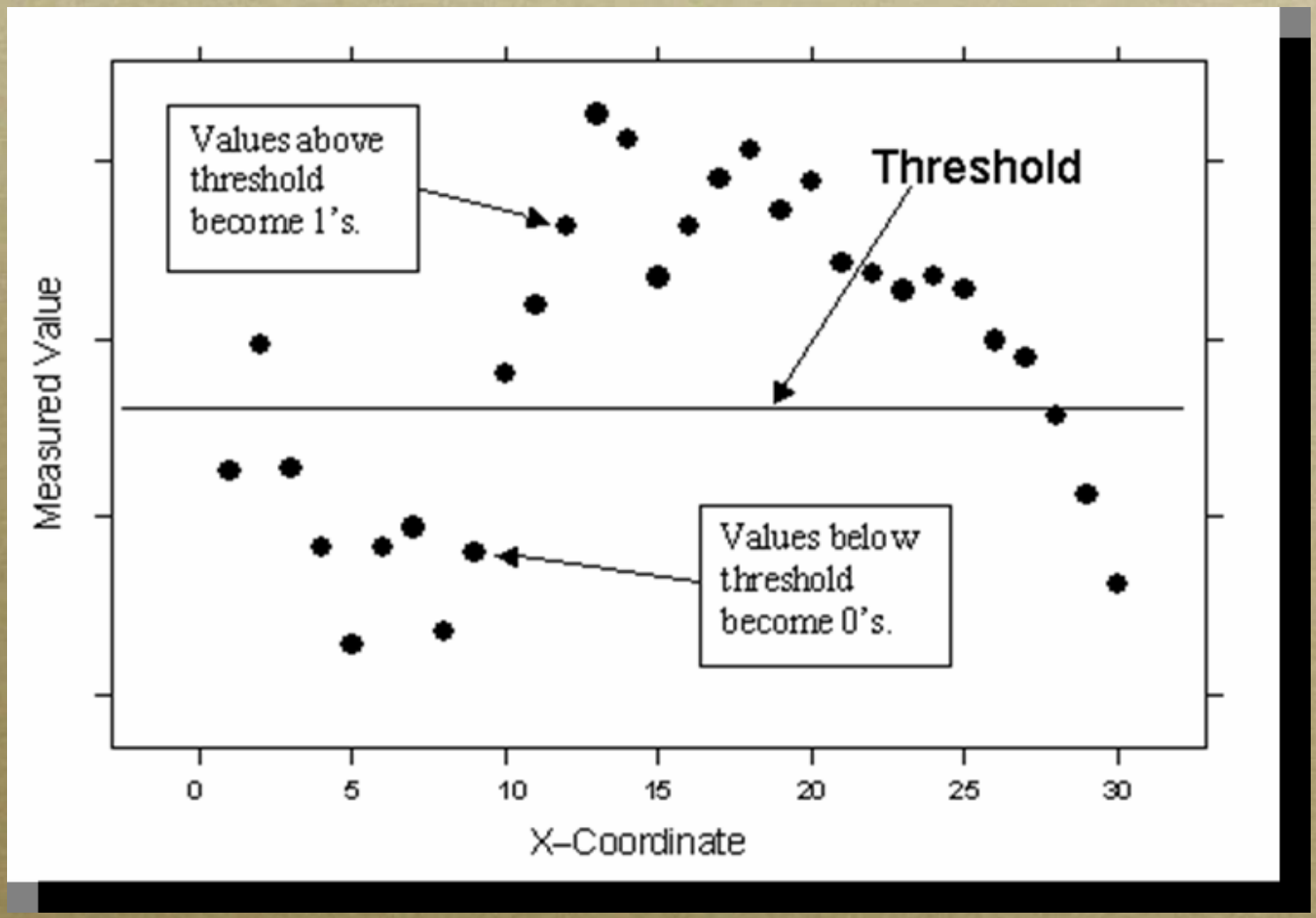
Research Overview

… to characterize the statistical relation between ground-water quality and geographic factors to generate shallow ground-water vulnerability maps at multiple-scales and at multiple management thresholds.

Ground-Water Vulnerability Strategies

- *Need to access ground-water vulnerability at multiple scales (national, regional, watershed, local)*
- *Integration with other "stressors" and "resource" variables*
  - *stressors (divers of change, nitrate, land use change, mining, pesticides)*
  - *resource (wetlands, water quality, human health, water availability)*
- *Integration methods and techniques*

Understand Thresholds



Jay Ver Hoef, 2002

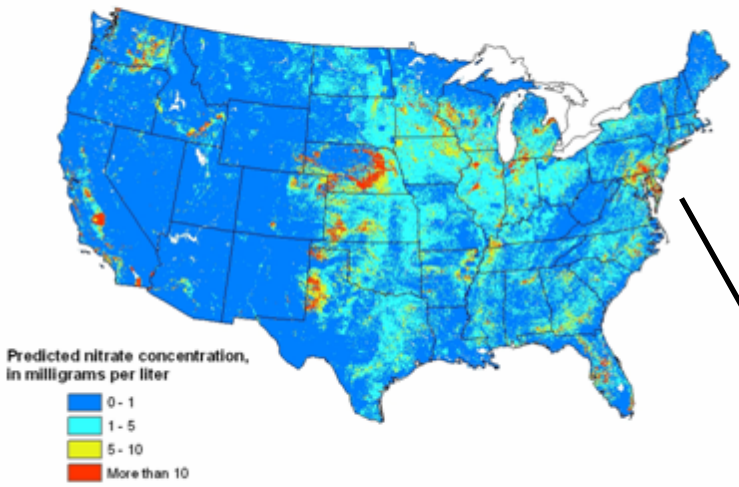
Statistical Model Development

- *Logistic-Regression method to predict the presence of nitrate concentrations above a specified management threshold value.*
- *Equations are developed using explanatory variables (land use, geology, soils, and other geographic datasets).*
- *Resulting equations are transformed to predict the probability of exceeding a specified management thresholds.*

Significant Variables in Ground-Water Vulnerability Model

- *Land Use/Cover*
- *Geology Type*
- *Nitrate Input Function: Manure, Fertilizer, Atmospheric Deposition*
- *Soil Data: Hydrologic group, Organic Matter, Depth to Bedrock, Depth to Water Table, and Percent Silt and Clay*
- *Population Density*

National, Regional, Local Scales of Ground-Water Vulnerability

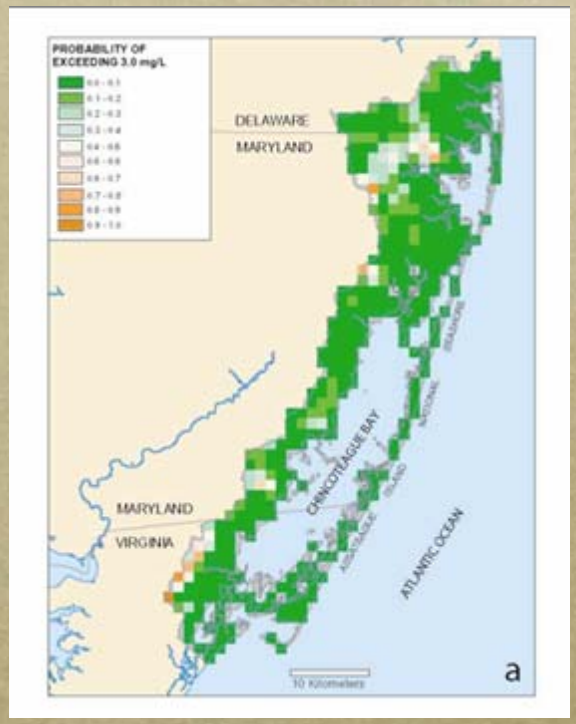


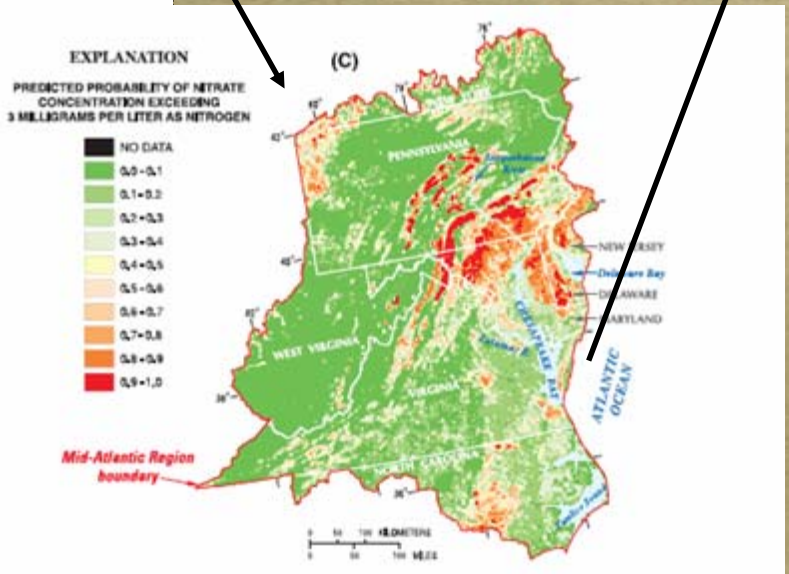
National

Nolan

Local

LaMotte and Greene, in press





Regional

Greene and others, 2004

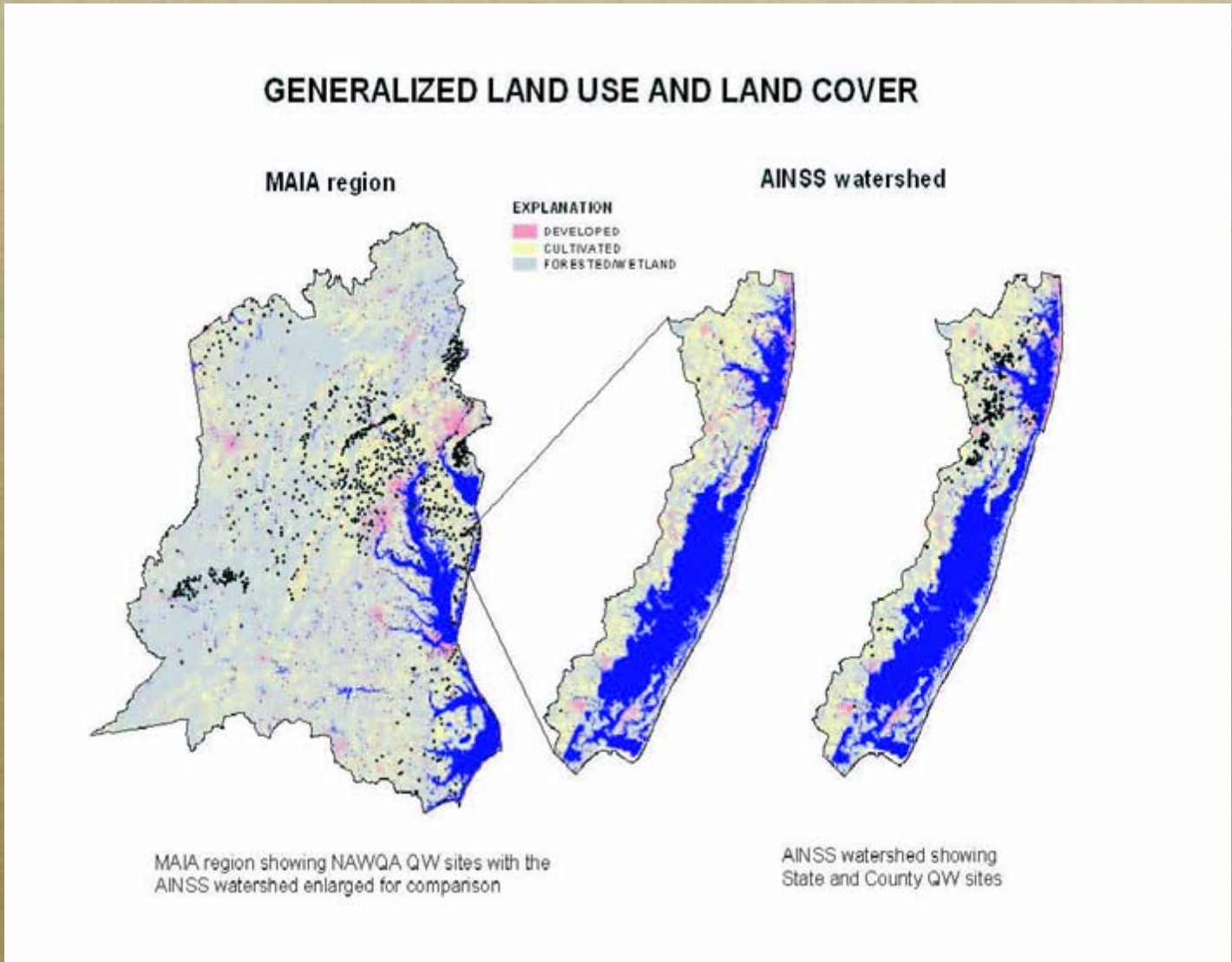
Regional Vulnerability Analysis (ReVA)

- 1. EPA's Regional Vulnerability Assessment (ReVA) program is an approach to regional scale assessments
- 2. The ReVA program is responsible for the collection, management, and analysis of multiple data sources to evaluate environmental conditions and known stressors within the Mid-Atlantic region.
- 3. Goal - evaluate environmental condition and known stressors within the Mid-Atlantic region, but predicting future environmental risk to prioritize efforts to protect and restore environmental quality.

Integration of Spatial Data: Methods for Evaluating Ground-Water Vulnerability

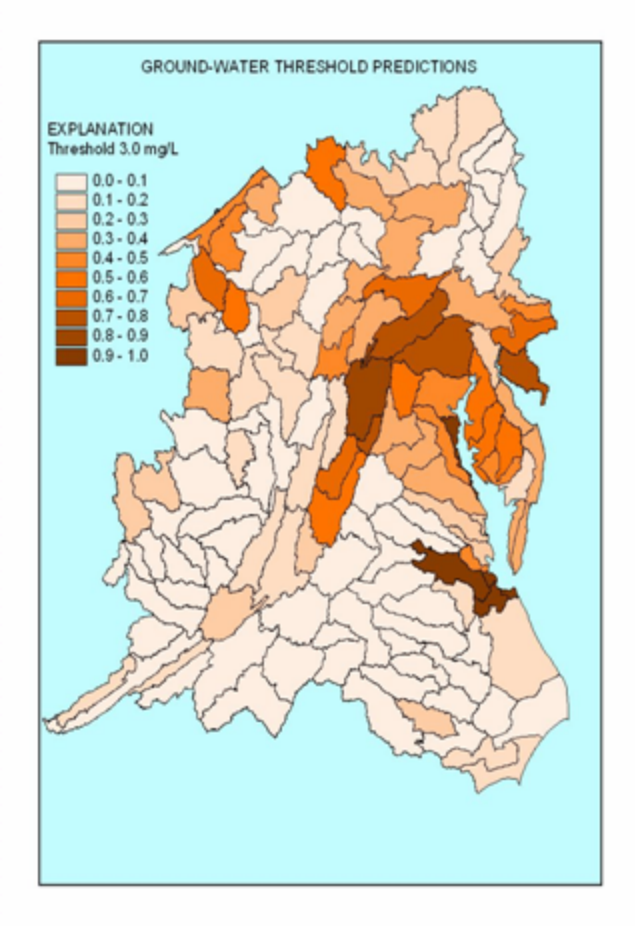
Spatial Data Information for Decision Makers

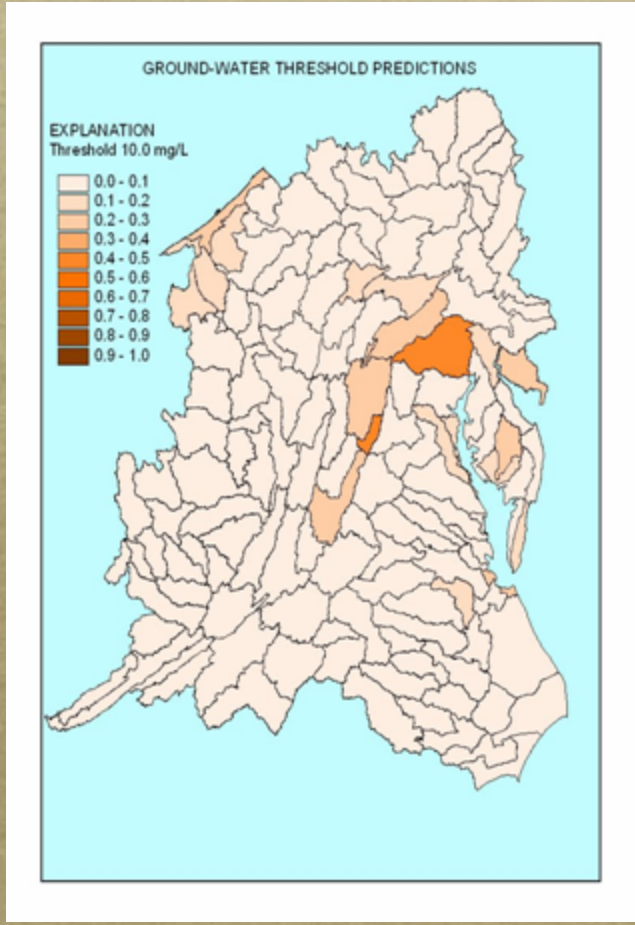
- **Data diagnostics and preparation**
- **Integration of data in selectable reporting units**
- **Statistical methods to support decision making**
- **Data access (summarized by reporting unit)**



Ground Water Vulnerability – Integration at a Watershed Scale

Overdispersion Statistical Method





Multiple Decision-Criteria Require Multiple Integration Methods

- **Ranking Methods *(Condition)***

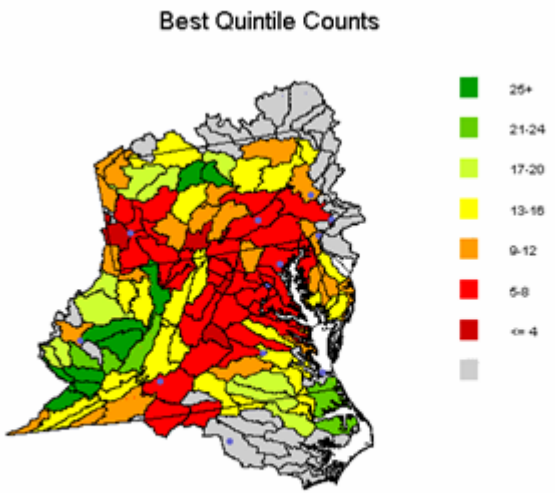
Quantiles, Sum of Ranks, AHP

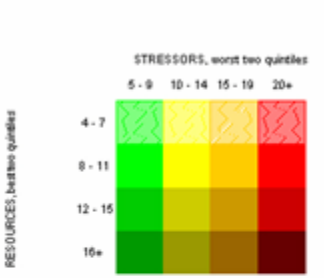
- **Distance from Reference Point *(Sustainability)***

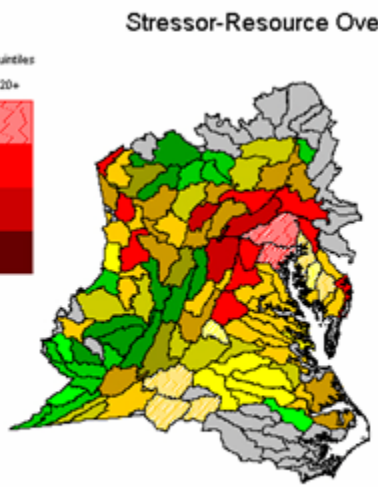
PCA, State Space, Criticality

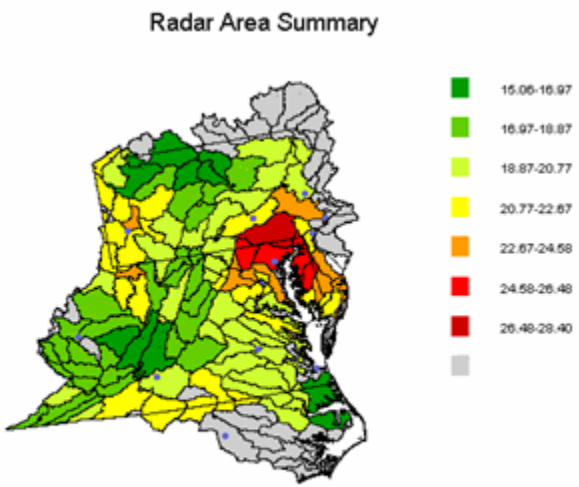
- **Overlay of stressors/resources *(Value)***
- **Grouping of Like Units *(Feasibility)***

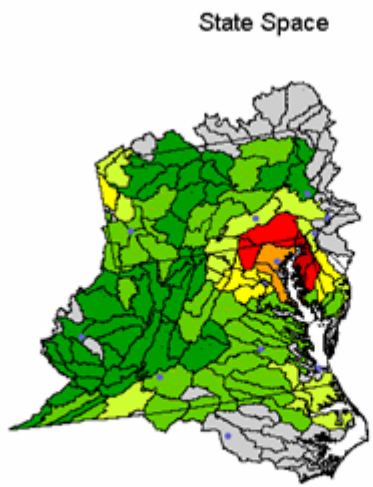
Cluster Analysis, Self-Organizing Maps











Integration Methods that Rank Condition

Quantiles – numeric range of variables divided into equal subdivisions

Sum of Ranks – regional ranks of individual variables are summed

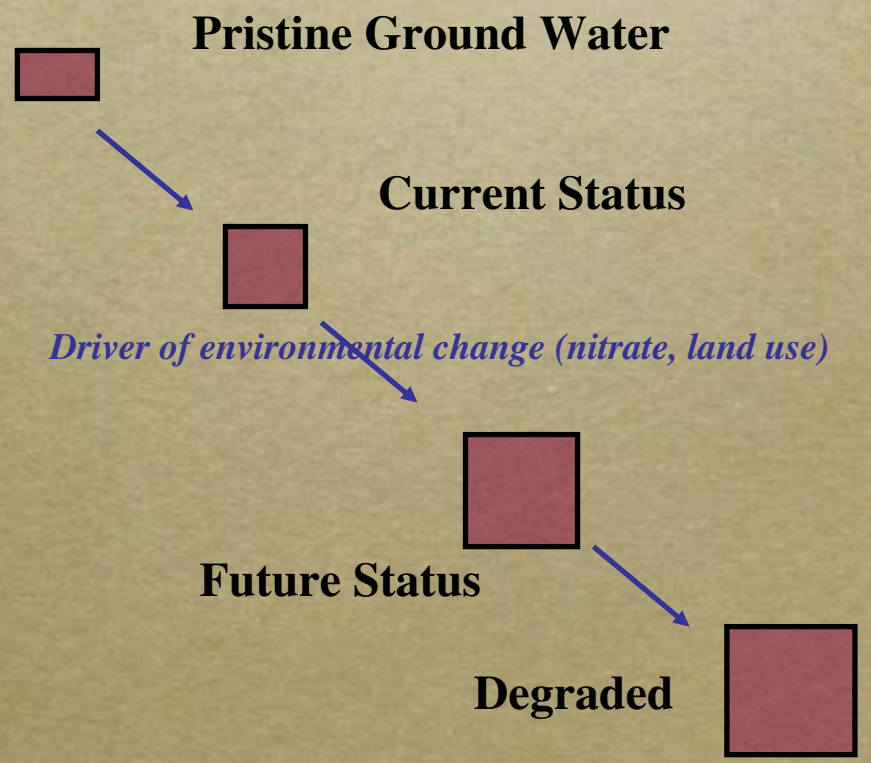
Analytical Hierarchy Process (AHP) – variables clustered by Principal Components Analysis and weighted by eigenvector scores

Integration Methods that Measure Distance From Reference

PCA – Euclidean distance from PCA-transformed watershed (ground water) scores

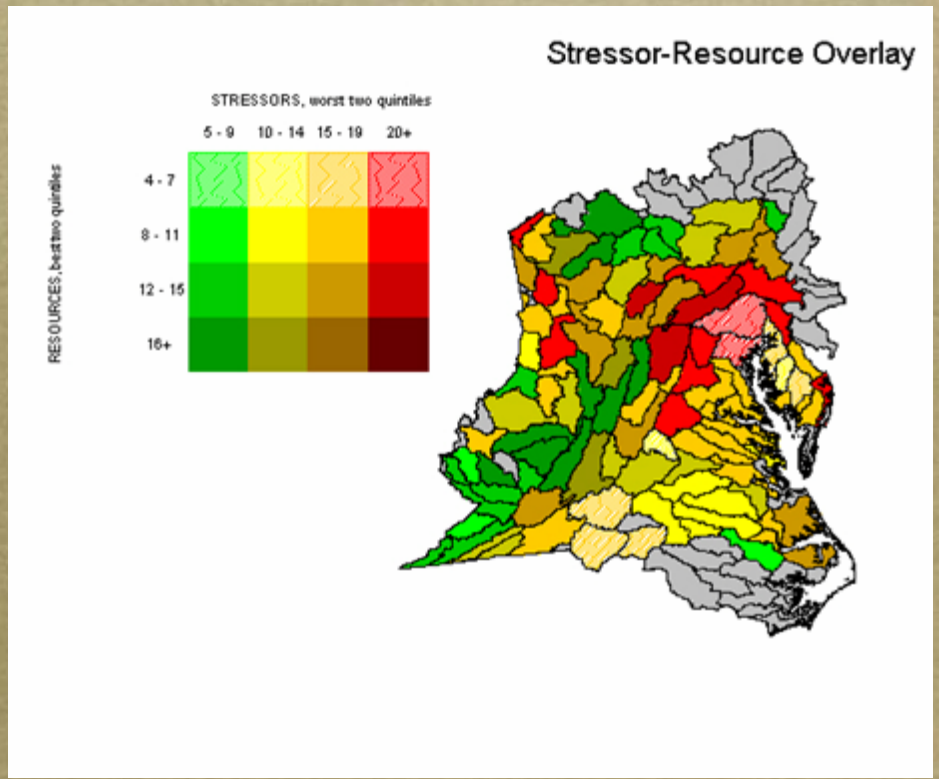
State Space – Mahalanobis distance from watershed (ground water) scores (good, bad, middle)

Criticality – Fuzzy distance between current and "natural" state



Integration Method that Ranks Vulnerability

Stressor / Resource Overlay – number of stressors overlayed with number of resources. Highest vulnerability is where there are high numbers of resources *and* high numbers of stressors.



Integration Methods that Group Like-Units

Cluster Analysis – robust partitioning method

Self-Organizing Maps – neural networks

Allows risk management of groups of units

Data Issues Associated with Integration

Discontinuity – sensitivity to variables that only have integer values – may need to leave out

Skewness – some variables have highly skewed distributions – log transform or drop outliers

Imbalance – variables not equally distributed across families (e.g. terrestrial biodiversity, human population variables) – only report scores within families, or average within families and sum averages

Interdependency – variables correlated – some integration methods account for interdependency, otherwise must be resolved individually

Which Integration Method is Appropriate for Specific Assessment Questions?

- **What is the over ground-water condition of the region?**

Quintiles (worst, best)

- **What is the relative condition of units (e.g. watersheds, ground-water quality) across a region?**

Sum, weighted sum, state space

- **What / where are the most vulnerable ground-water resources given future stressor distributions?**

Overlay

- **Where is there a risk of major change?**

Criticality method

- **Where are the priorities for regional risk reduction activities?**

Cluster analysis, self-organizing maps

Summary and Benefits to Resource Managers

- **Improve our Knowledge of Ground-Water Quality and Vulnerability**
- **Develop Grid Scale (Detail Scale) Models and Up-scaled Watershed Models for Integration**
- **Develop Watershed or County Based Specific Models**
- **Many Applications**
  - **Future Scenarios**
  - **Human Health**
  - **Monitoring Locations**
  - **Management**