- 1991 – USGS begins National Water Quality Assessment Program
- 1999 – USGS publishes “The Quality of Our Nation’s Waters” with specific reference to nutrients and pesticides

Main Findings

- Highest levels of N occur in streams and groundwater in agricultural areas
- Concentrations varied considerably from season to season and among watersheds
- Graphical plot of N input to agriculture and NO_3 concentrations in groundwater produced complete scatter of points

Conclusion

- Differences in natural features and land management practices make some areas more vulnerable to contamination than other areas.

Significance

- Recognition of differences in vulnerability to contamination can help target resources for protection of groundwater at greatest risk. The most extensive control strategies should be on the more vulnerable settings.

Groundwater vulnerability separated into intrinsic and specific vulnerability.

- Intrinsic are factors over which farmer has no control, such as soil hydrological properties and hydrogeological factors. Each type of irrigation system and crop has an intrinsic vulnerability.
- Specific vulnerability is a function of management factors such as quantity, rate, timing, and methods of nitrogen and water application.

National Academy of Science Water Science and Technology Board Committee on "Technologies for Assessing Groundwater Vulnerability"

- Definition: "The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer."
- First Law of Groundwater Vulnerability: All groundwater is vulnerable.
- Second Law of Groundwater Vulnerability: Uncertainty is inherent in all vulnerability assessments.

“It is the mark of an instructed mind to rest satisfied with the degree of precision which the nature of the subject permits, and not to seek an exactness where only an approximation of the truth is possible.”

Aristotle

WSTB Committee recommended a vulnerability assessment process

1. Identify purpose of the assessment
2. Select a suitable approach for assessment
    a. Overlay and index methods
    b. Methods using process-based simulation models
    c. Statistical methods

PURPOSE

To provide information for farmers to voluntarily target resources for management practices that will yield the greatest level of reduced nitrogen contamination potential for ground water by identifying the fields of highest intrinsic vulnerability.

This is not a new concept in California. I served on two committees that proposed using a hazard index based on the soil, crop, and irrigation systems. The most recent was the Nutrient Technical Advisory Committee (TAC) appointed by the State Water Resources Control Board (1994). The recommendations of TAC have never been implemented because a hazard rating for each crop and soil had to be established. We generally followed the guidelines proposed by TAC but did make some modification in detail.

Soil Rating

The hazard rating for soils is 1 through 5.

- Soils rated as 1 are those that have textural or profile characteristics that inhibit the flow of water and create an environment conducive to denitrification.
- Soils rated as 5 are those that have high water infiltration rates, high water transmission rates through the profile, and low denitrification potential.
- Soils rated 2, 3, or 4 are those with intermediate properties.

Crop Rating

The hazard rating for crops is from 1 through 4. Factors considered in establishing the crop hazard rating include:

1. **Rooting depth**
2. **Ratio of N in crop tops to recommended N application**
3. **Fraction of the crop top N that is removed from the field with the marketable product**
4. **Magnitude of the peak N uptake rate**
5. **Whether the crop is harvested at a time when the N uptake rate is high**

A slightly different set of criteria was used for tree and vine crops.

Irrigation System Rating

We accepted the rating system proposed by TAC for irrigation systems

1. Micro-irrigation accompanied by fertigation
2. Micro-irrigation without fertigation
3. Sprinklers used for pre-irrigation or throughout the irrigation system
4. Surface irrigation systems throughout the season

Integrated Hazard Index (HI)

- Multiply the soil, crop, and irrigation system hazard ratings
- Result is a number from 1 through 80
- We propose a HI of 1 through 20 is of minor concern
- A HI greater than 20 should receive careful management attention
- Equally, if not more, important than the numerical value of the HI are the factors that lead to the higher HI values. These provide management guidelines for reducing NO_3 transport to groundwater

What is Important in Protecting Groundwater

- Less NO_3 concentration or less total mass of NO_3 percolating beyond the root zone?
- Obvious answer is to have both.
- However, low concentration may not necessarily equate to low mass flow.

Consider Conservative Salt

$$C_d = C_i / LF$$

C_d is concentration of water leaving the root zone
C_i is concentration in irrigation water
LF is leaching fraction

$$LF = (AW-ET) / AW = DP / AW$$

AW is applied water that infiltrates the soil
DP is amount of deep percolation

$$C_d = C_i AW / DP$$

Increasing DP causes decreasing concentration

Relationship Between Fertilizer Application: Irrigation and N Concentration Below Root Zone

N Application kg/ha	Irrigation cm	N Conc. mg N/L	Calc. N Leached kg/ha
0	100	8.6	13.2
90	100	12.4	20.2
179	100	16.9	26.8
358	100	32.1	66.7
0	60	9.4	0.52
90	60	12.1	0.78
179	60	15.4	1.03
358	60	35.9	2.95
0	20	16.2	0.0
90	20	27.2	0.0
179	20	34.0	0.0
358	20	47.0	0.0

- NO_3 differs from conservative salt
- NO_3 can be denitrified
- Clay layer could restrict LF and contribute to high NO_3 concentration
- Clay layer could also cause denitrification and have low NO_3 concentration
  - NO_3 concentration could be increased or decreased depending on which mechanism predominated
- Both mechanisms reduce mass transfer of NO_3

Extensive Investigation on NO_3 in Ag. Tile Drain in 1970s

- No correlation between NO_3 concentration and fertilizer application
- Correlation between mass of NO_3 and fertilizer application
- No correlation between NO_3 concentration and amount of drainage water
- Correlation between mass of NO_3 and amount of drainage water

Whether, from a groundwater quality perspective, it is better to have a high volume of leachate water with a low concentration of NO_3 or to have a smaller volume of leachate with a higher concentration can be debated.

A conclusion that is well supported by research findings and scientific principles is that the concentration is not a valid indicator of good versus bad agricultural management.

Supporting Evidence for Hazard Index Concept

USGS measured NO_3 in groundwater beneath three agricultural land-use settings in eastern San Joaquin Valley 1993-1995

Land use settings were:

- Vineyards
- Almond Trees
- Crop Grouping of Corn, Alfalfa, Vegetables

Soils

Vineyards and almonds on similar coarse-grained soils with rather rapid water transmission properties and low potential for denitrification

The three-crop setting on relatively fine-grained sediments with lower transmission properties and higher denitrification potential

Our Hazard Index

Soil hazard rating higher for vineyards and almonds than the three-crop lands.

Crop hazard higher for almonds than vineyards because of lower N application to vineyards.

The three-crop system consists of alfalfa (lowest) and vegetables (highest hazard) – cumulative effect unknown but expected to be intermediate

Results

- NO_3 concentration in wells highest in almonds, intermediate in three-crop area, and lowest in vineyard area.
- Concentrations of Cl and NO_3 were correlated in almond and vineyard settings indicating little denitrification.
- The EC and Cl concentration higher in three-crop area than other settings indicating a lower leaching fraction.
- NO_3 and Cl not correlated in three-crop system indicating denitrification. Dissolved oxygen lower in three-crop systems.

Results of USGS measured NO_3 concentrations in domestic wells:

- NO_3 concentration not correlated with N-fertilizer application within a 0.25- and a 0.50-mile radius.
- No relationship between NO_3 concentration and soil permeability, hardpan percent, and clay percent.
- The lack of a relationship to soil properties in the counter balancing effect of reduced leaching fraction and increased denitrification. No measurement of mass flow.
- NO_3 positively correlated with dissolved oxygen concentration.
- NO3 positively correlated to EC, an indicator of LF effect.

- NO_3 mass in tile drainage was inversely correlated with highest percent of clay in the soil above the tile.

- Other studies in California have shown that textural changes in profiles have significant effects on NO_3 loss below the root zone.