THE HAZARD INDEX CONCEPT

A supporting document for the
UC Center for Water Resources (http://www.waterresources.ucr.edu)
Nitrate Groundwater Pollution Hazard Index

The United States Congress appropriated funds to the US Geological Survey (USGS) to begin the National-Water Quality Assessment (NWQA) Program in 1991. As part of the NWQA Program the USGS works with other federal, state and local agencies to understand the spatial extent of water quality, how water quality changes with time and how human activities and natural factors affect water quality across the nation. The USGS published a report (USGS 1999) entitled, "The Quality of Our Nation's Waters" with specific reference to nutrients and pesticides. For the purposes of our report, we will only address nitrogen issues.

Some of the highest levels of nitrogen were reported to occur in streams and groundwater in agricultural areas. However, concentrations were found to vary considerably from season to season as well as among watersheds. A graphical plot of nitrogen inputs to agricultural land versus median nitrate concentrations in underlying shallow groundwater produced a complete scatter of points (USGS 1999, p 47). The range of nitrate concentrations was the same for all levels of nitrogen input. Differences in natural features and land management practices make some areas more vulnerable to contamination than other areas. Recognition of differences in vulnerability to contamination can help target the appropriate level of protection and monitoring to major aquifers at greatest risk. The most extensive control strategies should be considered in the more vulnerable settings.

Nolan (2001) used multi variant logistic regression models based on more than 900 sampled wells to predict the probability of exceeding 4 mg/L of nitrate in ground water in the United States. The model consisted of 6 variables: nitrogen fertilizer loading, percent crop land-pasture, natural log of population density, percent well-drained soils, depth to seasonally high water table, and presence or absence of a fracture zone within an aquifer. Although valuable at the large landscape scale, the results are not useful on a farm level scale where management decisions are made which could affect ground water degradation from nitrogen. Nevertheless, the concept of establishing vulnerability to groundwater contamination is valid and even more appropriate on a farm scale.

Estimates of groundwater vulnerability can be separated into intrinsic vulnerability and specific vulnerability (National Research Council, 1993). Intrinsic vulnerability is related to factors of which the farmer has no control such as the hydrologic properties of the soil and hydrogeologic factors such as proximity of an aquifer to land surface, etc. Although the farmer can choose the crop to grow, the choice is usually made on economic factors. Once a crop is chosen, each crop has an intrinsic vulnerability for groundwater contamination from nitrates. Likewise, irrigation systems may be selected, but each irrigation system has an intrinsic vulnerability. Specific vulnerability is a function of management factors such as quantity, rate, timing, and methods of nitrogen and water application and other agricultural management practices. Therefore, the farmer has some level of control over the specific vulnerability with little or no control over the intrinsic vulnerability.

The National Academy of Science Water Science and Technology Board appointed a committee on Techniques for Assessing Groundwater Vulnerability. The committee defined groundwater vulnerability as: "The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer." They pointed out that this definition of groundwater vulnerability is flawed, as is any other, by a fundamental principle that they stated as the First Law of Groundwater Vulnerability: "All groundwater is vulnerable." They also proposed a Second Law of Groundwater Vulnerability: "Uncertainty is inherent in all vulnerability assessments."

The committee suggested a vulnerability assessment process. The first step is to identify the purpose of the assessment. The next step is to select a suitable approach for conducting the assessment. They listed three methods of assessment: 1) overlay and index methods, 2) methods using process-based simulation models, and, 3) statistical methods. The report elaborated on each of these methods. We will follow the proposed steps by stating the purpose and then describing the assessment method.

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 groundwater by identifying the fields of highest intrinsic vulnerability.

ASSESSMENT METHOD: We used the overlay and index method. Although process-based simulation models were not specifically used, the basic physical and chemical factors that are incorporated into these models were used in deriving an index number. The overlay consists of soil maps, crop and irrigation system distributions. The soils, crops and irrigation systems were each indexed by an approach described below.

This approach is consistent with the recommendations of a Nutrient Technical Advisory Committee (TAC) appointed by the California State Water Resources Control Board. The TAC was assigned to propose a nutrient management approach in California that would meet the varied interests of those who have a stake in the quality of California's waters. The TAC proposed that farmers complete a hazard index for each field on their farm based on the soil, crop and irrigation systems. The TAC proposed that the soil be assigned a hazard value of 1, 2 or 3. Soils classified as 1 are those that have textural or profile characteristics that inhibit the flow of water and create an environment conducive to denitrification. Both denitrification and restrictive water flow decrease the migration of nitrate to groundwater. Conversely those soils classified as 3 are most sensitive to groundwater degradation by nitrate because of the high water infiltration rates, high transmission rates through their profile, and low denitrification potential. In our case, we expanded the hazard values to 1 through 5, but used the same criteria as proposed by TAC for assigning higher or lower hazard values.

The TAC proposed that crops be classified into three hazard indices based on their degree of potential for nitrate leaching. They suggested that those with the highest potential for nitrate leaching, which would have a hazard index of 3, are those with the following characteristics: (1) The nitrogen uptake in the crop is a small fraction of the total nitrogen applied to the crop; (2) the crop requires high nitrogen input and frequent irrigation to ensure rapid vegetative growth; (3) the value of the crop is such that there is a tendency to add excess nitrogen to ensure no nitrogen deficiencies; (4) the crop is not adversely affected when more than adequate amounts of nitrogen are applied; and (5) the crop has a shallow root system where a small amount of water movement could carry nitrate below the root system. Crops with the opposite characteristics of those listed would have a low potential for nitrate leaching and have a hazard index of 1. Crops with intermediate characteristics would be classified with a hazard index of 2.

The criteria that we used in assigning a hazard index for crops were consistent with those suggested by TAC, but differed in detail. We also expanded the crop hazard index to 1 through 4. The factors considered in establishing a hazard index for field crops and vegetables were as follows: 1) rooting depth, 2) ratio of N in the crop tops to the recommended N application, 3) fraction of the crop top N that is removed from the field in the marketed product, 4) the magnitude of the peak N uptake rate, and 5) whether the crop is harvested at a time when N uptake rate is high. A slightly modified set of criteria was used for tree and vine crops. The rooting depth is quite great in all cases and none is harvested at the time of peak N uptake rate. Therefore, these criteria were eliminated and replaced by the magnitude of leaf N deposit for trees and vines.

The crops with a shallower rooting depth have a higher potential for N leaching than deep-rooted crops. Crops that take up a high percentage of the recommended N application provide for a lower hazard for N leaching than those which take up a low percentage, thus leaving much N in the soil. Furthermore, removal of much of the N in the crop tops with the harvested product creates a lower hazard than when the crop residues containing much N are left on the field. Crops that have a very high peak N uptake rate over a short period are considered to be more hazardous than those with low peak N uptake rate because they require large quantities of mineral N to be available for that time period.

A matrix was constructed for each crop and the criteria used to establish the hazard index. The hazard index number that was chosen for each crop was based on an overall consideration of all the criteria. For example, lettuce has a hazard index of 4 because it is shallow rooted, is harvested at the time of peak uptake rate, and much of the N in the tops remains in the field. Conversely, alfalfa has a hazard index of 1 because it is deep rooted and nitrogen fertilizer application is not required. The matrix, as well as the hazard index number, will be reported for each crop.

The TAC recommended that the irrigation system be classified into a hazard index of 0 through 3. The "0" hazard index is a micro-irrigation system accompanied by fertigation. Small amounts of water and nutrients can be frequently applied in quantities to match the crop need. A micro irrigation system without fertigation is assigned a hazard index of 1. Sprinklers used throughout the irrigation season or for pre-irrigation for crop establishment is assigned a hazard index of 2. Entire surface irrigation systems such as furrow are assigned a hazard index of 3. We used the same criteria for indexing irrigation systems except that our range was 1 through 4 rather than 0 through 3.

In our case, the overlay and index method consists of having an overlay of the soil, crop and irrigation system maps and multiplying the hazard index numbers for each. The intrinsic hazard index number can range from 1 through 80. The TAC suggested adding the index numbers. Adding the numbers would provide a much smaller range between 3 and 13, which would consequently make it more difficult to distinguish the relative hazards among combinations of soils, crops, and irrigation systems.

Although the TAC proposed that farmers complete a hazard index for each field, the proposal has never been implemented. A major impediment to the implementation is that soils and crops have not been assigned hazard rating values. We have developed tables of hazard rating numbers for the major irrigated soils and crops in Arizona, California, and Nevada that can be used by farmers to assess the relative hazard for groundwater degradation by nitrate for each of their fields.

References:

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