Title: Nitrate leaching hazard index developed for irrigated agriculture
Author(s): David Birkle , Christine French , John Letey , Yvonne Wood and Laosheng Wu
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In 1991, the National Water Quality Assessment Program was initiated. The U.S. Geological Survey (USGS) as the lead agency worked with other federal, state, and local agencies to understand the spatial and temporal occurrence of water quality degradation, including the effects of both human activities and natural environmental factors. The results of this initiative were published as, "The Quality of Our Nation's Waters" (USGS, 1999), with specific reference to the influence of agricultural nutrients and pesticides on water quality.

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Some of the highest levels of nitrate were reported to occur in streams and groundwater in agricultural areas. However, the USGS study found that nitrate concentrations vary considerably from season to season as well as between watersheds across the United States. A graphical plot of fertilizer nitrogen inputs to agricultural land versus median nitrate concentrations in underlying shallow groundwater aquifers produced a complete scatter of points (p 47. USGS, 1999) and the range of groundwater nitrate concentrations was the same for all levels of nitrogen input. This phenomenon underscores the strong influence of differing natural features and land management practices upon the movement of contaminants through the soil to reach underlying aquifers. Recognition of these differences can help target the appropriate level of protection and monitoring to protect those major aquifers at greatest risk.

The Water Science and Technology Board (WSTB) of the National Academy of Sciences appointed a committee to evaluate techniques for assessing groundwater vulnerability. The committee (National Research Council, 1993) 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 also recognized that "all groundwater is vulnerable," and "uncertainty is inherent in all groundwater assessments."

Further, the committee proposed separating groundwater vulnerability into intrinsic vulnerability and specific vulnerability. Intrinsic vulnerability was defined as factors over which a grower has no control, such as the hydrologic properties of the soil and hydrogeologic factors such as the proximity of an aquifer to the land surface. Although the farmer can choose the crop to grow, the choice is usually based upon economic factors. Once a crop is chosen, it has an intrinsic vulnerability for groundwater contamination by nitrates. Likewise, irrigation systems may be selected, but after an irrigation system is in place, it has an intrinsic vulnerability. Specific vulnerability was defined as management factors such as quantity, timing, rate, and methods of water and nitrogen application. Therefore, the farmer has control over the specific vulnerability but minimal control over the intrinsic vulnerability.

The WSTB committee suggested a two-step vulnerability assessment process. The first step is to identify the purpose of the assessment; step two 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 purpose we identified for our study was to provide information to farmers to voluntarily target resources for management practices that will yield the greatest level of reduced nitrate contamination potential for groundwater by identifying the fields of highest intrinsic vulnerability. We chose the index and overlay method as will be described below.

Our approach is consistent with Shaffer and Delgado (2002) who stated, "Field staffs, consultants, and farmers need a simplified nitrate leaching index as a screening or assessment tool to quickly estimate the vulnerability of agricultural fields to nitrate leaching that could contaminate underlying aquifers and enter adjacent streams and lakes." They proposed a three-tiered nitrate leaching index assessment tool. For tier 1, they proposed the use of an expert system to separate medium, high, and very high from low and very low leaching potential levels by qualitatively screening non-numeric inputs from users. Recognition of differences in vulnerability to contamination can help target the appropriate level of protection and monitoring to aquifers at great risk. The most extensive control strategies should be considered in more vulnerable settings.

Objectives

The objectives of our study were to (1) develop a nitrate leaching hazard index applicable to irrigated agriculture at the field scale; and (2) provide easily obtainable information to growers so that they can voluntarily select those management practices that will yield the greatest level of reduced nitrate contamination potential for groundwater.

Procedures

We choose an overlay and index method to assess the intrinsic vulnerability of those aquifers underlying agricultural fields. The overlay consists of soil, crop, and irrigation system distributions, which were indexed as described below. We have chosen to use the word 'hazard' rather than 'vulnerability' because while the groundwater is vulnerable, the crops and irrigation systems represent different levels of hazards to groundwater degradation.

Indexing soil hazards. A numerical index of one through five was used for the soil hazard. Soils classified as one are those 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 five are most likely to contribute to groundwater degradation by nitrate because of high water infiltration rates, high transmission rates through the profile, and low denitrification potential. Values of two, three, and four were assigned to soil series with intermediate characteristics.

The methodology used included three persons individually reviewing 590 soil series descriptions for the irrigated soils in California, Arizona, and Nevada, as found on the U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) website. Reviewers paid particular attention to the Typical Pedon, Range in Characteristics, and Drainage and Permeability sections of the descriptions and rated the soils one through five. Where there was disagreement, the three persons met as a committee and agreed on a single value. When this process was complete, the results were sent to USDA soil scientists and cooperative extension soils experts for evaluation and comment on the ratings based on their knowledge of the soil in the field. These comments were collected and summarized. Where differences of opinion existed, the final rating was based upon the majority outside expert opinion. A typical soil for each of the five ratings, shown in Table 1, had complete agreement by as many as seven independent reviewers.

Indexing irrigation system hazards. For irrigation systems a numerical scale of one through four was used. Micro irrigation with fertigation was designated as one; microirrigation without fertigation, or sprinkler irrigation with fertigation as two; sprinkler irrigation used for pre-irrigation or throughout the irrigation season without fertigation as three; and surface irrigation as four. The following website contains the details of irrigation principles considered for the development of the irrigation index:
http://www.waterresources.ucr.edu/wqp/hazard/HI%20IrrigationPrinciples.pdf

Indexing crop hazards. A scale of one through four was used for crops. The factors used for assigning hazard ratings to field and vegetable crops were: 1) rooting depth, 2) ratio of nitrogen (N) in the crop tops to the recommended N application, 3) fraction of the crop top N that is removed from the field with the marketed product, 4) 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. For these latter crops the rooting depth is quite deep in all cases and none of these crops are harvested during the peak N uptake rate, which is predominantly in the spring. Therefore, these criteria were eliminated or reduced in significance and replaced by the magnitude of the leaf N deposits for trees and vines.

Crops with a shallow rooting depth have a higher probability for nitrate leaching than deep-rooted crops. Crops that take up a high percentage of the recommended N application provide for a lower hazard of N leaching than those that 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 portion creates a lower hazard than leaving substantial N in the crop residues on the field. Crops with a high narrow peak for the N uptake rate are potentially hazardous because they require a large concentration of mineral N in the soil at the time of peak uptake. Crops harvested near the time of peak N uptake rate leave substantial quantities of mineral N in the soil available for leaching. Examples of hazard index for crops are presented in Table 2.

Assigning an overall hazard index for the field. The ratings for soil, crop and irrigation systems are multiplied together to obtain the hazard index rating for an individual irrigated field. With this procedure, the hazard index ranges from one through 80 (Figure 1). We propose that a hazard index of one through 20 is of minor concern. The grower must still implement sound management practices but extraordinary procedures are not required. Fields of index numbers greater than 20 should receive careful attention by the grower. Under such circumstance, the first step is to determine whether it is the soil, crop, or irrigation system, or a combination thereof that contributed to the higher hazard index. This evaluation will allow the grower to focus on that segment of the management system that can produce the largest reduction in potential nitrate transport to groundwater.

The main message is that the hazard index, per se, is of little value unless it is less than 20, which is an indicator that no special management is necessary. It is not meaningful to numerically compare the hazard index ratings when they are greater than 20. Rather, the approach is designed to allow the identification of those factors that led to the high hazard index number in order to select appropriate management practices for a specific field.

For instance, if the overall hazard index greater than 20 is due to a crop with a high rating, management should be focused on those factors contributing to the high hazard index number. For example, if a shallow root system was a factor in the higher rating, careful attention should be given to irrigation techniques to minimize the water percolating below the root zone. If a crop hazard index were high because of high residual mineral and/or organic N after crop harvest, the use of a cover crop to capture the N and prevent leaching would be advisable.

If the high hazard index were caused by both high soil and high irrigation system values, attention should be focused on irrigation management. If irrigation were by furrows, decreasing the length of the furrow, increasing the flow rate as high as possible without stimulating erosion, and decreasing the duration of irrigation would decrease the total amount of infiltration.

Supporting evidence for the hazard index

The USGS measured the occurrence of nitrate in groundwater beneath three agricultural land-use settings in the Eastern San Joaquin Valley of California during the period 1993 to 1995 (Burow et al., 1998). Water samples were collected from 60 domestic wells in land-use settings of (1) vineyards, (2) almond trees, and (3) a crop grouping of corn, alfalfa, and vegetables. Information from this study can be used to compare relative hazard index for the different settings and compare this to the nitrate measured in groundwater.

The vineyards and almonds were located on similar coarse-grained, upper and middle parts of alluvial fans with rather rapid water transmission properties and low potential for denitrification. The three-crop setting was on the lower part of the fan consisting of relatively fine-grained sediments that would have lower water transmission properties and a higher denitrification potential. We rated the soil hazard index higher on the vineyard and almond lands than on the three-crop lands. We gave the vineyards a lower crop hazard index than the almond orchards as explained above (Table 2). The three-crop system includes alfalfa with the lowest hazard index and vegetables with the highest hazard index so the cumulative effect is unknown and is expected to be intermediate.

The nitrate concentrations in the wells were higher in the almond area than in the vineyard area. Since the soils and irrigation systems were similar in these two areas, we would expect the results to be related to the crop hazard ratings. The higher concentration under almonds than vineyards is consistent with the higher hazard index for almonds (2) than for vineyards (1). The nitrate concentration in the wells in the three-crop system was intermediate, but because of the mixture of crops, it is not possible to relate the findings to crop type.

The soils under almonds and vineyards would have a higher hazard rating than the soils for the three-crop system. Although no conclusions can be drawn from the nitrate concentrations in the groundwater because of the variable crop systems, additional analysis of the results can be made. Both chloride and nitrate are mobile. The concentrations of chloride and nitrate were correlated in the almond and vineyard settings, indicating very little denitrification as would be expected for these soils. In contrast, the chloride and nitrate were not correlated in the three-crop system, suggesting that some denitrification occurred which would be consistent with the finer textured soils in the three-crop system. Also, the dissolved oxygen concentration was lower in the three-crop area than in the others. Finally, the electrical conductivity and chloride concentration were higher in the water under the three-crop area than in the other two areas, indicating a lower leaching fraction on the finer textured soils.

The findings on nitrate concentration in groundwater in the three settings are in general agreement with expectations based on the hazard index concept.

Application of the hazard index system

The hazard index system is available to anyone with Internet access. It can be found on the University of California Center for Water Resources website: http://www.waterresources.ucr.edu. A click on "Nitrate Groundwater Pollution Hazard Index" will access the hazard index homepage. Another click on "Find Your Index Number" will provide the opportunity to select the crop, soil, and irrigation system using drop down selection lists, and then determine a hazard index. The chart depicted in Figure 1 will appear with the hazard index identified for the specific case. A user can access additional information that provides suggestions and guidelines specific to the crop, soil, and irrigation system selected.

Presently hazard index ratings are only available for irrigated soils in Arizona, California, and Nevada, but the concept can be extended to other states by assigning hazard ratings to the appropriate soils. The hazard index for crops and irrigation systems should be applicable to any irrigated areas.

References Cited

Burow, K.R., S.V. Stork, and N.M. Dubrovsky. 1998. Nitrate and pesticides in groundwater in the eastern San Joaquin Valley, California: Occurrence and trends. U.S. Geological Survey Water Resource Investigations Report 98-4040, Sacramento, California. 33 pp.

National Research Council. 1993. Groundwater vulnerability assessment-Predicting relative contamination potential under conditions of uncertainty. National Academy Press, Washington, D.C.

Shaffer, M.J. and J.A. Delgado. 2002. Essentials of a national nitrate leaching index assessment tool. Journal of Soil and Water Conservation 57(6):327-335.

U.S. Geological Survey (USGS). 1999. The quality of our nations waters. U.S. Geological Survey Circular No. 1225.

Author credit:

Laosheng Wu, John Letey, Christine French, Yvonne Wood and David Birkle are with the University of California Center for Water Resources in Riverside, California.

TABLE 1: FIVE TYPICAL SOILS WITH HAZARD INDEX (HI) RANGED FROM ONE TO FIVE.

SOIL SERIES	A HORIZON	B HORIZON	C HORIZON
CASTRO	CLAY	NONE	CLAY
BOLFAR	CLAY LOAM	CLAY LOAM	LOAM
YOLO	SILT LOAM	NONE	SILT LOAM
BRYMAN	LOAMY FINE SAND	SANDY CLAY LOAM	SAND
HANFORD	FINE SANDY LOAM	FINE SANDY LOAM	SANDY LOAM

SOIL SERIES	MOTTLES/HARD PAN	PERMEABILITY	HI
CASTRO	PROMINENT MOTTLES	SLOW TO VERY SLOW	1
BOLFAR	PERCHED WATER-TABLE	MODERATELY SLOW	2
YOLO	NONE	MODERATE	3
BRYMAN	NONE	MODERATE	4
HANFORD	NONE	MODERATELY RAPID	5

FOR A LISTING OF THE SOIL HAZARD INDEX FOR ALL IRRIGATED SOILS IN THE THREE STATES CHECK THE FOLLOWING WEBSITE: HTTP://64.167.89.169/HAZARDINDEX/SEARCH2.PHP

TABLE 2. EXAMPLES FOR CROP HAZARD INDEX (HI).

CROP	HI RATING	RATING FACTORS
ALFALFA	1	ROOTING DEPTH: DEEP RECOMMENDED ADDITION OF N: NONE REMOVAL OF PLANT N AT HARVEST: MOST MISCELLANEOUS: REMOVES MOST SOIL AVAILABLE N
VINEYARD	1	ROOTING DEPTH: DEEP RECOMMENDED ADDITION OF N: LOW REMOVAL OF PLANT N AT HARVEST: MEDIUM MISCELLANEOUS: (1) REMOVES MOST SOIL AVAILABLE N (2) LIMITED LEAF DROP RETURNS LOW AMOUNTS OF N TO THE FIELD'S SURFACE IN THE FALL, WITH MOST PLANT N RETAINED IN THE WOODY STEMS
ALMONDS	2	ROOTING DEPTH: DEEP RECOMMENDED ADDITION OF N: MODERATE REMOVAL OF PLANT N AT HARVEST: LITTLE MISCELLANEOUS: LEAF DROP RETURNS MODERATE AMOUNTS OF N TO THE FIELD'S SURFACE IN THE FALL
TOMATO	3	ROOTING DEPTH: MODERATE RECOMMENDED ADDITION OF N: MODERATE REMOVAL OF PLANT N AT HARVEST: MODERATE N UPTAKE RATE BY THE PLANT: HIGH
LETTUCE	4	ROOTING DEPTH: SHALLOW RECOMMENDED ADDITION OF N: HIGH REMOVAL OF PLANT N AT HARVEST: MODERATE N UPTAKE RATE BY THE PLANT: HIGH MISCELLANEOUS: AFTER HARVEST, PLANT RESIDUE RETURNS HIGH AMOUNTS OF N TO THE FIELD'S SURFACE

	SOIL					
CROP	1	2	3	4	5	IRRIGATION

1	1	2	3	4	5	1
1	2	4	6	8	10	2
1	3	6	9	12	15	3
1	4	8	12	16	20	4
2	2	4	6	8	10	1
2	4	8	12	16	20	2
2	6	12	18	24	30	3
2	8	16	24	32	40	4
3	3	6	9	12	15	1
3	6	12	18	24	30	2
3	9	18	27	36	45	3
3	12	24	36	48	60	4
4	4	8	12	16	20	1
4	8	16	24	32	40	2
4	12	24	36	48	60	3
4	16	32	48	64	80	4

FIGURE 1: MATRIX FOR THE OVERALL HAZARD INDEX'S THAT OVERLAY SOIL, CROP AND IRRIGATION.

Wu, Laosheng^Letey, John^French, Christine^Wood, Yvonne^Birkle, David

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