Abstract

Understanding and minimizing the impact of agriculture chemicals upon groundwater quality is a current concern. An examination of this issue requires an understanding of most areas of soil physics. We used groundwater vulnerability assessment as a framework for teaching introductory soil physics. The properties and processes presented in traditional courses were presented as needed to assess the impact of surface applied chemicals upon groundwater quality. Thus the students had a use for each concept before it was introduced. Because of the focus on understanding and predicting the fate of surface applied chemicals, mathematical models and their use were major components of the course. The students learned how simple concepts such as conservation of mass and energy can be used to derive useful models. Simple experiments were used to demonstrate the ability of the models to describe observations. Interactive software was used to enable students to gain insight into each process and to see how soil properties affect that process. Students appreciated this approach in that it not only introduced them to important soil physical properties and processes, but it also demonstrated how principles of soil physics can be applied to real problems and it illustrated challenges involved in assessing the impact of our actions upon the environment.

Aquifer Vulnerability Assessment: A Framework for Teaching Soil Physics and More!

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Conceptualization:

- Development of Aquifer Vulnerability Assessment Decision-Support System for Central Canterbury at Lincoln University, Lincoln, New Zealand

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While at Lincoln University near Christchurch New Zealand, I developed a web-based decision-support system for assessing the impact of surface applied chemicals upon groundwater quality. When I returned, some friends suggested that this could be a framework for teaching a soil physics class. Several of us collaborated in a USDA Educational Challenge Grant that was funded. This talk deals with the results of that work and its use in class.

Overview

- Describe the approach
- Outline sequence of topics covered
- Identify advantages and disadvantages of this approach
- Describe resources developed
- Illustrate use of software
- Share selected reactions of students

I have divided the talk into these sections.

Approach

- Focus on the problem of assessing impact of surface applied pesticides on groundwater quality
- Making assessment requires understanding of processes that influence chemical transport and fate
- As each process is considered, soil properties that influence it are introduced

The entire course is focused on the evaluation of the impact of surface applied pesticides on groundwater quality. Regulatory agencies want assistance in making these assessments. Both farmers non-farmers want to protect the water resources in their area. An understanding of these processes will help all students to be responsible citizens as they move on in life. So the problem is relevant to all students.

Many processes interact to control the ultimate fate of surface applied chemicals. Many of these processes are the major components of traditional soil physics courses.

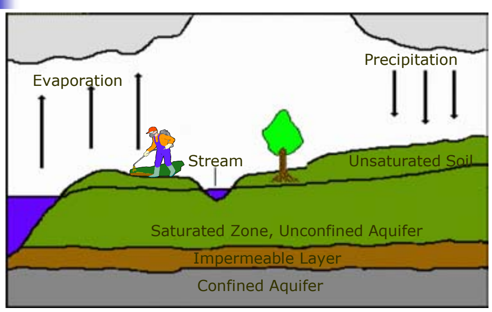
So this framework provides a manner in which we can introduce concepts as they are needed, not just as abstract facts that must be learned for some future use.

Goals

To enable students to

- Understand specific physical processes taking place in soils
- Understand the manner in which soil properties influence these processes
- Understand how these processes and others impact chemical transport
- Experience the application of scientific principles to address a real problem

Flow of Course and Topics Covered



Groundwater Quality

Concentration in Aquifer | Critical Concentration or Toxicity

Groundwater Hazard Index :

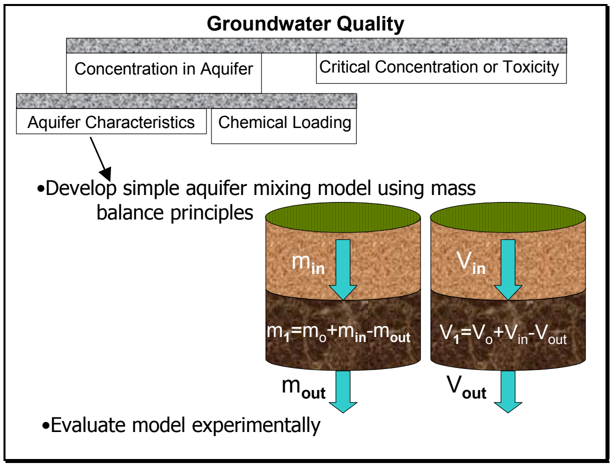
$$GWH = \frac{C_{aquifer}}{C_{critical}}$$

$GWH < 1$ implies low vulnerability

We begin with a discussion of groundwater quality, what determines it, and how it is measured.

We want to incorporate both the concentration of the pesticide in the groundwater and the toxicity or critical concentration of the pesticide. The groundwater hazard as defined here is a convenient index for doing this.

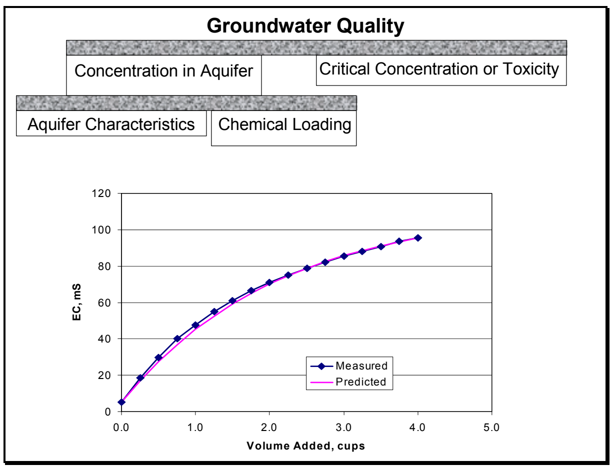
To calculate the groundwater hazard we must estimate the concentration of the pollutant in the groundwater



Simplistically that means we must determine the amount of chemical entering and leaving the aquifer and the way it is mixed in the aquifer.

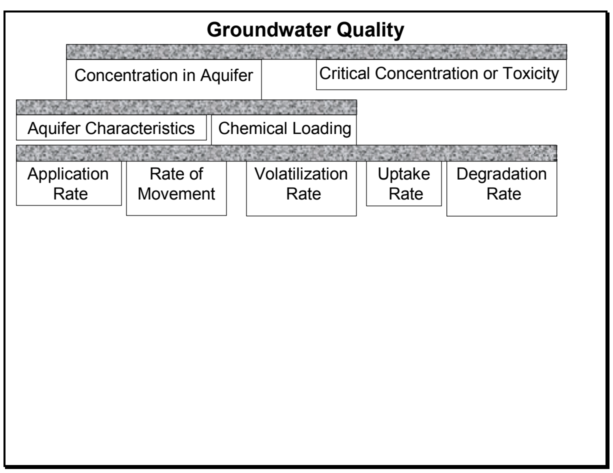
Discussing aquifer characteristics here allows us to review basic relationships such as bulk density, water content, porosity, as well as how they are determined.

We introduce the concept of mass balance and use it to derive a simple mixing model. We the proceed to experimentally determine if the simple aquifer model can describe data the students obtain experimentally in the classroom.



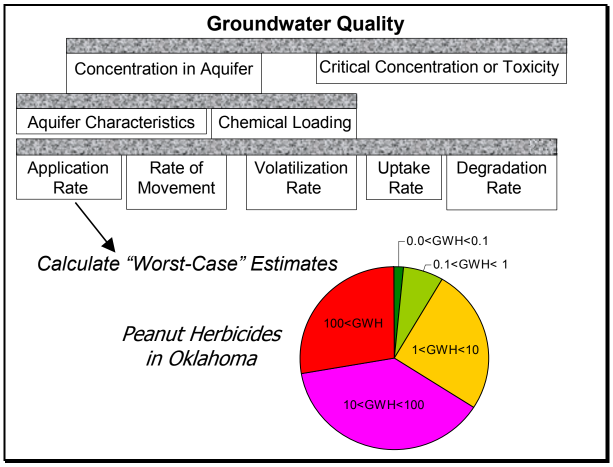
The simple experiment utilizes portable electrical conductivity meters as an indirect measure of salt concentration in the inflowing water and in the “aquifer”. This demonstrates that the simple model can describe concentration changes in the idealized aquifer.

This exercise is useful in demonstrating that simple concepts they understand can be used to create useful mathematical models that work.

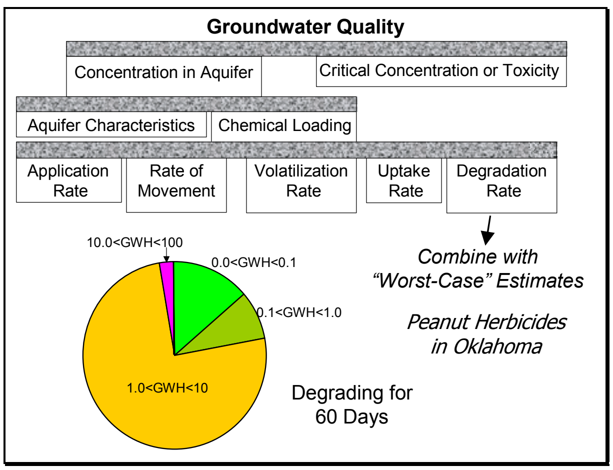


Having finished aquifer characteristics and mixing, we move on to focus on chemical loading. Some factors that influence loading are shown here.

It is useful to begin by considering application rates for different pesticides and to calculate worst case scenarios for labeled treatments. This is useful to illustrate the potential danger of different pesticides and the importance of the soil processes in the overlying soil.

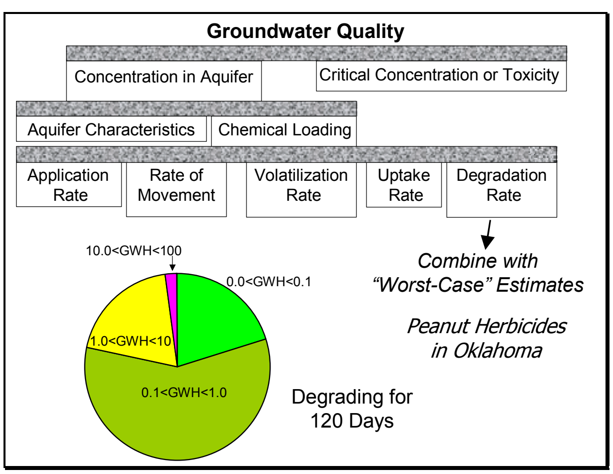


We see here that for peanut herbicides in Oklahoma, 9 % of labeled treatments will not exceed a groundwater hazard of 1 even if all of herbicide applied enters the aquifer and is mixed in the top 1 m of an aquifer with porosity of 0.3. On the other hand, approximately 30% of the treatments must have less than 1% of the applied amount enter the aquifer to prevent the concentration from exceeding the critical value for that chemical.

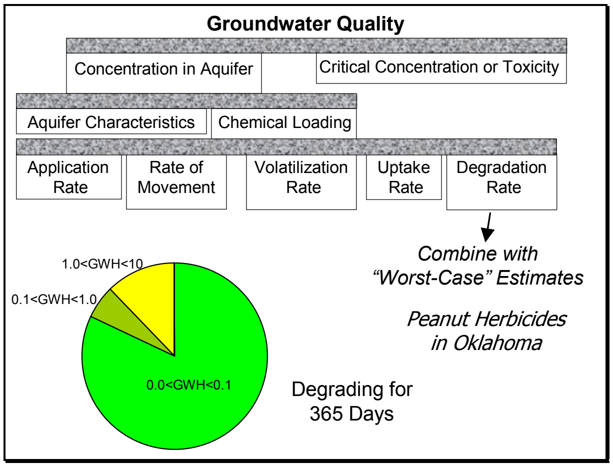


Given this starting point, we then examine processes that can decrease the amount of pesticide entering the groundwater. Volatilization, uptake, and degradation tend to decrease the quantity available for leaching. The extent to which each of these occurs is dependent upon the rate of movement of the chemical.

By combining information on the degradation rates for the different pesticides with the worst-case results, we can calculate the groundwater hazard for different degradation times. This one illustrates the maximum GWH if the product is in the biologically active soil for 60 days. Note that now nearly all herbicides have a hazard less than 10

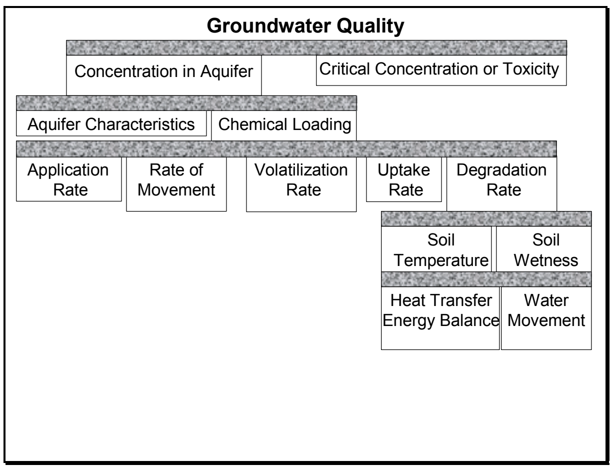


After 120 days, we now have approximately 80% of the treatments with groundwater hazards less than 1. That is the estimated concentration is less than the critical concentration for that pesticide in 80% of the treatments.



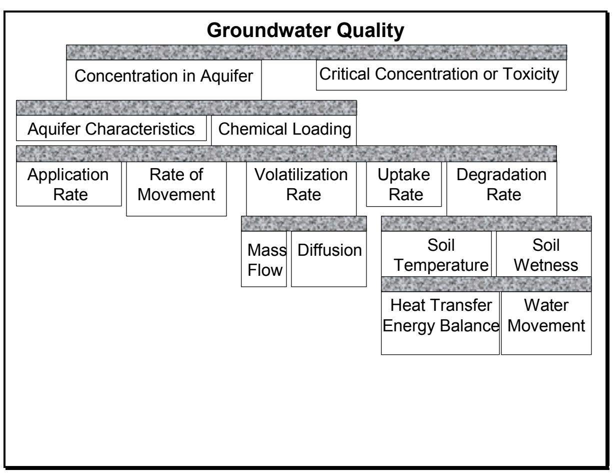
At the end of 1 year we see that we still have some treatments that can pose problems.

This simple exercise indicates that degradation can have a major effect on the quantity of pesticide reaching the aquifer. It also provides a basis for examining the speed at which chemicals move through the soil.

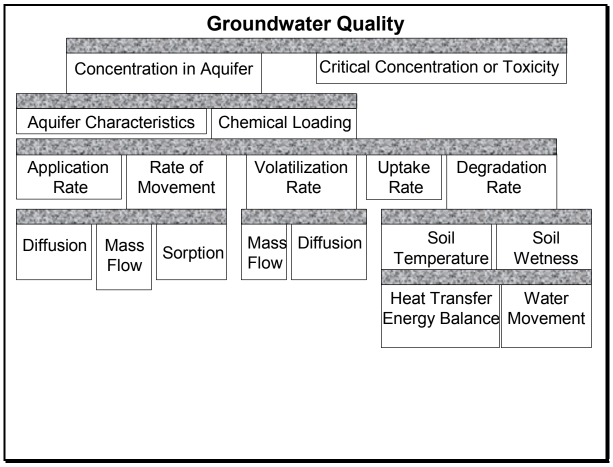


Before leaving our discussion of degradation, we examine published degradation rates and their dependence upon soil temperature and water content.

This leads to a detailed exploration of soil temperature, heat transfer, and energy balance.

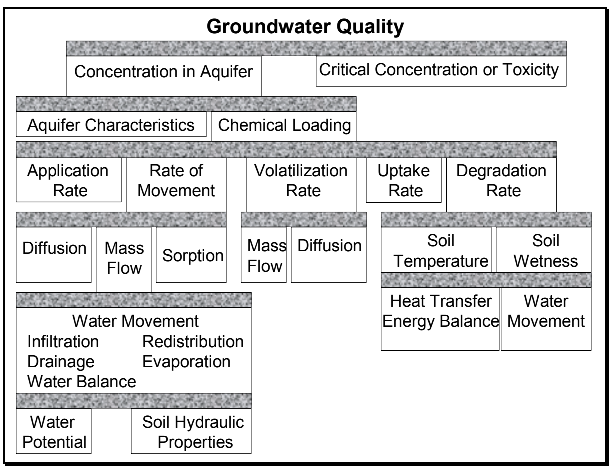


Volatilization losses provide a natural opening to examine movement of air and other gases in soils. Since volatilization of ammonia from swine effluent is a concern in Oklahoma, we took a look at that process and the factors that influence it.



The extent of pesticide loss by degradation, uptake, and volatilization depend upon the time available for these processes to occur and the position of the chemical in the soil profile. This leads naturally to a discussion of chemical movement and soil properties and processes that control it.

Here we explore sorption of pesticides to solid soil surfaces and its impact upon the rate of movement. We also examine diffusion to gain understanding of the magnitude of its contribution to movement.



Since pesticides move downward in the soil profile primarily with the soil solution, water movement is a major factor. At this point we examine the physics of water movement in both steady-state and transient flow conditions. Simple water balance calculations provide insight into the quantity and temporal distribution of water movement below the root zone and the variability of that movement from one year to another. More sophisticated models are used to describe the infiltration, redistribution, and evaporation processes.

This understanding then enables us to examine pesticide movement as influenced by soil properties, weather, irrigation practices, pesticide selection, and application practices. Combining these practices leads to more realistic estimates of the impact of these products upon groundwater quality.

Critique of our Vulnerability Assessment

- Compare model predictions to published experimental findings
- Uncertainty in predictions
- Simplifications made & processes ignored
- How can predictions be improved?
- What additional information is needed to make these improvements?

Published research in our journals provides examples we can use to examine our ability to model flow and transport processes. We quickly realize that weather has a large impact upon the rate of movement and leaching losses. Because future weather is not known, we must find a way to deal with this uncertainty. At this time we introduce Monte Carlo techniques and demonstrate how we can use them to obtain probability distributions of groundwater hazard values for a specific chemical, soil, location, and management system.

Throughout the course we attempt to note simplifications we have made and processes we have ignored. We then explore what information would be needed to make improvements in our estimates.

Advantages of This Approach

- Students have a known use for each new concept presented
- Students learn one method of addressing a real world problem
- Students learn about the many processes involved in understanding the fate of surface applied chemicals

We think this approach to teaching the class has some distinct advantages over the traditional approach. These are listed here.

We try desperately to introduce new terms and concepts only after the student can see the need or use of such a concept. This provides a good learning environment and helps to maintain interest. This is one advantage of using this framework.

A second advantage is that the student obtains a good grasp of a real world problem along with an understanding of soil physics.

Advantages (continued)

- Model development and use are a natural result of the need to predict vulnerability
- Students can see inside the "black boxes" of models
- Students can see the impact of spatial and temporal variability of soil properties and processes
- Students get experience in dealing with uncertainty

Some other advantages are shown here. I list the first two in particular because they do not get much exposure to model development and use in other courses. They often think of models as complex things way beyond their ability to comprehend and use, let alone develop.

The class provides a place to demonstrate the importance of variability in soil properties and weather upon estimated groundwater hazards. Hopefully this will enable them to be wiser users of all models in their careers.

Disadvantages

- Some time is needed to introduce important concepts not traditionally included in the course
- A continual effort is needed to point out other uses for the concepts and processes presented

There are two primary disadvantages to this approach. First of all, some class time must be devoted to topics not normally included in a traditional course. Secondly, instructors must remember to point out additional uses of the concepts presented.

Resources

- Interactive Software
- Power Point Presentations
- Exercises
- Spreadsheets

A collection of tools was developed to facilitate this approach. Interactive software allows students to gain an understanding of flow and transport processes and the extent to which soil properties influence them without concern about the mathematics involved. They are used with student exercises to enable students to discover how the soil systems respond in different conditions. Power Point presentations were developed as a resource for instructors. A few spreadsheets were constructed to demonstrate computational schemes in more advanced models and to remove some simplifications built into the interactive models. They also provide a tool for advanced students to examine numerical methods of solving the equations.

Resources: Interactive Software

- Aquifer Mixing
- First-order Degradation
- Temperature Dependent Degradation
- Soil Temperature
- Diffusion
- Convective-Diffusive Transport with Steady-State Water Flow

These slides list descriptive titles of the interactive software developed in this project. Each one includes a manual describing the mathematics of the model, simplifications inherent in it, and a glossary of terms that may not be understood. A set of exercises or numerical experiments is associated with each one.

Resources: Interactive Software (continued)

- Steady-State Water Flow
- Transient Water Flow
- Water Balance in the Root Zone
- Convective-Dispersive Transport with Transient Water Flow
- Chemical Movement in Soils Educational Model
- Chemical Movement in Layered Soils Management Model

Resources

- Interactive software, manuals, student exercises are available at http://soilphysics.okstate.edu/software/
- Additional Power Point lecture aids and spreadsheets can be obtained by contacting me at dln@okstate.edu

These resources are available at this web site or by contacting me. There is no cost associated with any of them. I will work with anyone wanting to add data for your area or to make other improvements. If you want to place the software on your local web server, just contact me.

Exciting Events

- Students identified simplifications in models and asked if they can be eliminated!
- Students questioned advisability of publicizing "Worst Case" results!

There were numerous times when the students pleased me with the depth of their thinking and questions. A few are listed here.

Early in the semester, a student asked if mass balance could be used for a more realistic aquifer mixing model. I was pleased to say "Yes" and asked what the student had in mind. We then discussed how that would change the model. Before the next class period I developed the new model in a spreadsheet and illustrated it to the class.

Exciting Events

- One student suggested that differences between theory (or model) and observation may be due to experimental error rather than due to a poor model!
- One student is pursuing graduate degree in soil physics due to the class!

Another student was concerned that the graphs we developed for "Worst-Case" leaching would be misused if published. That led to another good discussion.
Late in the semester, a student suggested that differences between model predictions and experimental data could be due to experimental and sampling errors. I was pleased again to see this demonstration of critical thinking.

Finally, one student decided to study soil physics in graduate school as a result of the class. That was truly exciting!

Opportunities

- Utilize an approach similar to this but focused on other questions or problems
  - Impact of nutrients on groundwater
  - Impact of manure applications on groundwater
  - Include impacts upon surface water quality
  - Examine large environmental systems, integrating other disciplines

In conclusion, I found this framework to be very useful in teaching the class. I think it could be used for many different classes and recommend it highly.