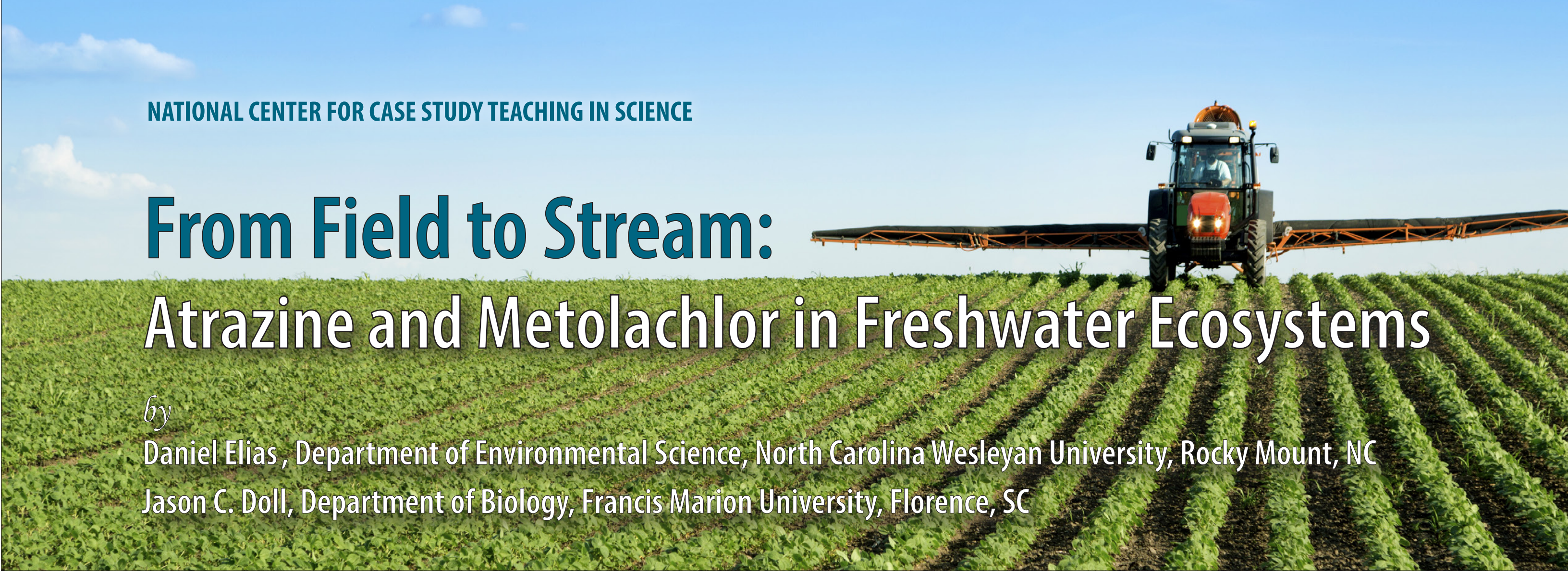

NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

From Field to Stream:

Atrazine and Metolachlor in Freshwater Ecosystems

by
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Introduction

During my first stream sampling trip in Indiana, I somehow picked one of the hottest days of the year and did not bring enough extra water for the group. We collected duplicate water samples from 12 locations, which left us dragging a cooler filled with 24 liters of stream water in amber glass bottles through a shallow stream with difficult access. It was miserable. Later in the year, we sampled the same stream again, but the conditions were completely different: the water level was higher, the cooler floated, the temperature was cooler, and we finished the day eating at a local buffet. That contrast helped me understand one of the main ideas in this case study: streams change across seasons, and those changes influence how chemicals move from agricultural fields into freshwater ecosystems.

In the Midwestern United States, corn and soybean production (Figure 1) relies heavily on herbicides to control weeds and maintain crop yields. Among the most applied herbicides are atrazine and metolachlor, typically sprayed before crop emergence in the spring. However, the timing of application and rainfall can create short periods of high chemical concentrations in streams, making it difficult to determine when and where these exposures present the greatest risk.

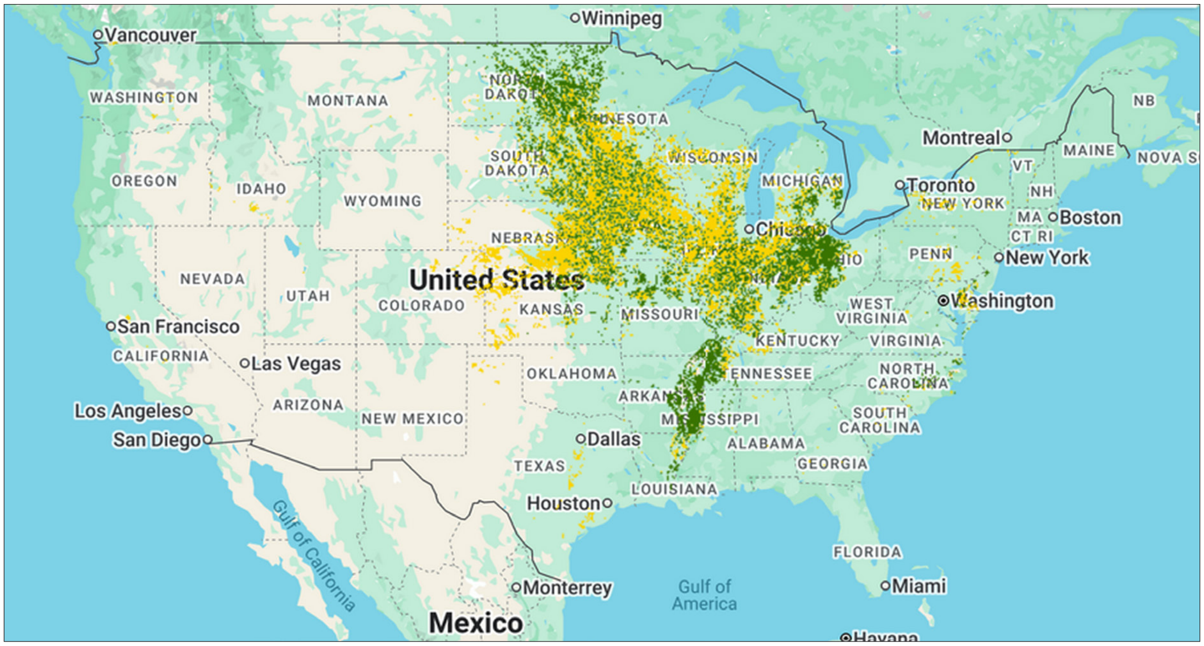

Figure 1. Distribution of corn (yellow) and soybean (green) production across the Midwest (U.S. Department of Agriculture National Agricultural Statistics Service, n.d.).). Midwest states: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. <https://www.nass.usda.gov/Research_and_Science/Cropland/Viewer/index.php>

Seasonal patterns in pesticide occurrence are associated with rainfall, fertilizer application, and land management practices, which influence their transport into surface waters, such as streams and rivers (Baker et al., 2006). Because of their widespread use, atrazine and metolachlor are frequently detected in streams (Gilliom et al., 2006), where they can adversely affect sensitive aquatic organisms, including amphibians. Further, when present in surface waters used for drinking supplies, atrazine and metolachlor have been associated with hormonal disruption, low birth weight, and increased cancer risk in humans, particularly non-Hodgkin lymphoma (Hayes et al., 2011). Understanding exposure duration, concentrations in streams, and species tolerance is critical for evaluating risks to both aquatic ecosystems and human health.

In this case study, you will interpret maps, diagrams, monitoring data, and simulated relationships to evaluate how herbicide use, rainfall, and agricultural runoff affect freshwater ecosystems. Refer to the glossary below for any unfamiliar terms as you work through the case.

Glossary

Acute effect: A rapid effect that occurs soon after exposure, often associated with high concentrations.

Agricultural runoff: Water from rainfall or irrigation that flows off fields and can carry soil, nutrients, pesticides, and other materials into streams.

Aquatic life benchmark: A concentration used by agencies to evaluate whether a chemical may pose risk to aquatic organisms.

Atrazine: A herbicide commonly used in corn production to control broadleaf weeds and some grasses.

Base flow sampling: Sampling during normal stream flow conditions, not immediately after a storm.

Chronic exposure: Repeated or long term exposure that may cause effects over time.

Concentration: The amount of a chemical present in a volume of water, often reported as mg/L or micrograms/L.

Endocrine disruption: Interference with hormone systems that regulate development, reproduction, growth, or metabolism.

Groundwater: Water below the land surface that fills spaces in soil, sediment, or rock.

Herbicide: A pesticide used to kill or suppress unwanted plants.

Metolachlor: A herbicide commonly used in row crop agriculture, including soybean and corn systems, to control grasses and some broadleaf weeds.

mg/L: Milligrams per liter. One mg/L equals 1,000 micrograms/L.

micrograms/L: Micrograms per liter, often written as μg/L. One microgram is one millionth of a gram.

Nitrate: A nutrient form of nitrogen commonly associated with fertilizer and agricultural runoff.

Pesticide: A chemical used to control pests, including weeds, insects, fungi, and other organisms.

Post-emergent herbicide: A herbicide applied after crops or weeds have already emerged.

Pre-emergent herbicide: A herbicide applied before crops or weeds emerge to prevent weeds from becoming established.

Regression line: A line that summarizes the overall relationship between two variables in a graph.

Riparian vegetation: Plants growing along stream banks that can slow runoff, stabilize soil, and provide habitat.

Runoff: Water that flows over the land surface after rainfall or irrigation.

Shallow groundwater flow: Movement of water through the upper soil or shallow subsurface layers toward streams.

Sublethal effect: A harmful effect that does not immediately cause death, such as reduced growth, reproduction, or behavior.

Temporal variability: Change over time. In this case, pesticide concentrations vary across months and seasons.

Tile drainage: Underground pipes that remove excess water from agricultural soils and can transport dissolved chemicals to streams.

Trophic level: A feeding position in a food web, such as producer, herbivore, predator, or top consumer.

Vegetated buffer strip: A planted area between fields and streams that slows runoff and helps trap sediment and chemicals.

Part I – Agricultural Practices and Chemical Transport

Herbicides can be applied before crops and weeds emerge (pre-emergent) or after they have already begun to grow (post-emergent). Atrazine and metolachlor are pre-emergent herbicides commonly used in corn and soybean production to control broadleaf weeds and certain grasses that compete with crops for light, water, nutrients, and space.

After application, rainfall plays a key role in moving these chemicals through the environment (Taghavi et al., 2010). Water can flow over the surface as runoff or move through the soil as shallow groundwater, carrying herbicides into nearby streams and rivers (Figure 2). In some regions, tile drainage systems (underground pipes that remove excess water from soil) can also rapidly transport water and dissolved chemicals into streams. This movement depends on factors such as soil type, land slope, vegetation cover, and rainfall intensity (Neumann et al., 2002; De Wilde et al., 2007).

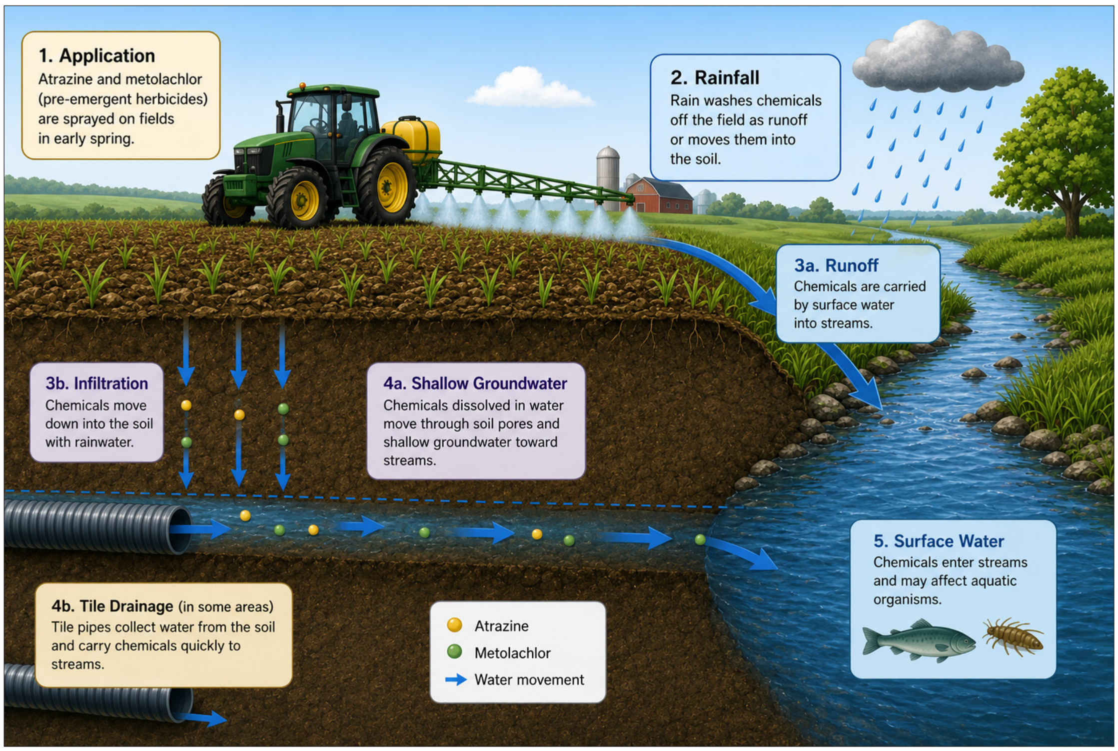

Figure 2. Conceptual diagram showing how atrazine and metolachlor move from agricultural fields to nearby streams.

Questions

1. If herbicides were applied after weeds were already established, how might that affect crop growth and herbicide effectiveness?

2. Using Figure 2, describe two pathways by which rainfall can move herbicides from fields into streams.

3. Which landscape features or farming practices would most likely reduce chemical movement into streams, and why?

4. Fertilizers and herbicides are different chemicals. Why might they still enter streams during the same period of the year?

Part II – Observing Seasonal Trends in Data

Monitoring programs (e.g., the USGS National Water Quality Assessment Program, NAWQA) measure pesticide concentrations in streams over time. These data show temporal variability, meaning concentrations change throughout the year rather than remaining constant. Monthly and long-term sampling indicate that atrazine and metolachlor concentrations increase during late spring and early summer (Figure 3). This pattern aligns with planting periods, when herbicides are applied to corn and soybean fields (Baker et al., 2006). Monitoring programs include both routine (base flow) sampling and post-storm sampling to capture short-term peaks in concentration caused by rainfall and runoff events.

Pesticide detections often occur at the same time as elevated nitrate and phosphate concentrations. This is because fertilizers and herbicides are typically applied during the same season and are transported by the same hydrological processes. In this case, nitrate and phosphate are included as indicators of agricultural runoff, helping identify when runoff is moving multiple chemicals into streams. The co-occurrence of these chemicals can indicate periods of increased agricultural runoff, when streams may receive multiple agricultural chemicals at the same time.

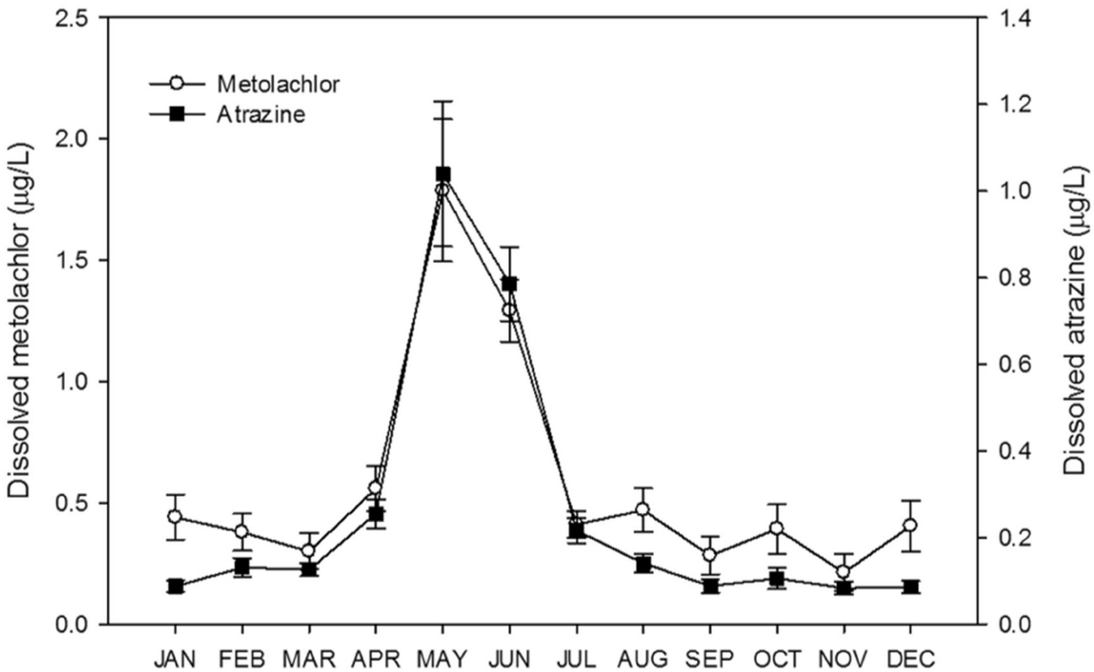

Figure 3. National monthly mean and standard deviation of peak concentrations of dissolved atrazine and metolachlor collected from the National Water Quality Assessment (NAWQA), and selected peer reviewed studies (Anderson et al., 1997; Kalkhoff et al., 1998; Starner et al., 2003; Raffel et al., 2011).

Questions

1. During which months are atrazine and metolachlor concentrations highest in Figure 3?

2. Choose one herbicide from Figure 3 and calculate the percent increase from its lowest concentration to its highest concentration. Estimates from the graph are acceptable. Show your work.

3. If nitrate and phosphate increase at the same time as herbicides, what does that suggest about the source and timing of runoff entering the stream?

Part III – Ecosystem and Human Health Considerations

Even low concentrations of agrochemicals can affect freshwater ecosystems because these chemicals are widely used and can persist in the environment, resulting in a background level of exposure. In addition to this baseline, higher concentrations often occur as seasonal pulses associated with pesticide application and rainfall events.

These pesticides may not cause immediate death (acute effects), but they can produce long-term sub-lethal effects (not causing death, but typically chronic) such as reduced growth, altered reproduction, and changes in species abundance in sensitive aquatic invertebrates, amphibians, and plants (Relyea, 2005).

Aquatic invertebrates and amphibians are often more sensitive because they have small body sizes, direct contact with water, and, in the case of amphibians, permeable skin that allows chemicals to be absorbed more easily. Over time, these effects can reduce reproduction and survival, leading to population declines and shifts in community structure (what organisms are present) and ecosystem function (what organisms do, their roles). Figure 4 illustrates this concept by showing how chemicals can influence multiple trophic levels simultaneously, from plants and aquatic insects to frogs and fish, rather than affecting a single species.

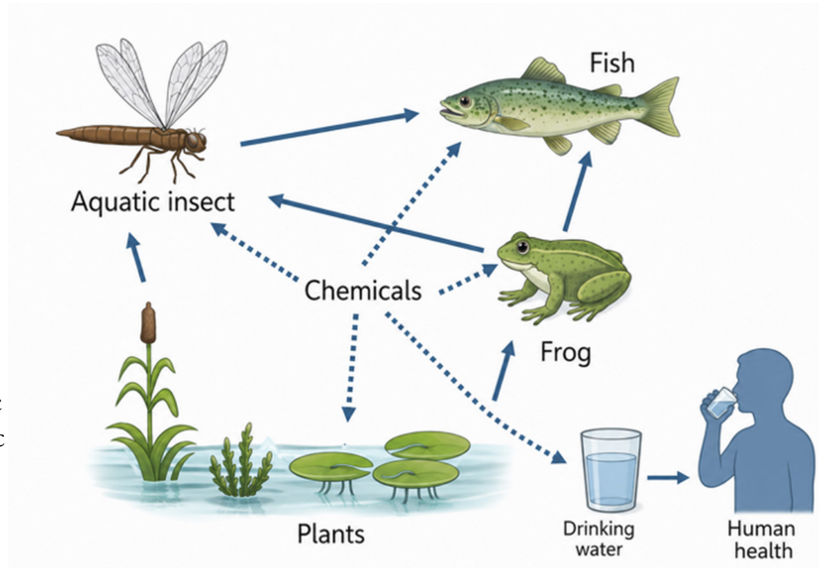

Figure 4. Simplified trophic relationships and exposure pathways in a freshwater ecosystem. Chemicals can affect aquatic plants, insects, frogs, and fish through direct exposure and food web interactions. Chemicals may also enter drinking water sources, creating potential long term human health concerns.

For humans, the main concern is long-term exposure through drinking water rather than acute toxicity. Monitoring studies show that atrazine and metolachlor are frequently detected at low concentrations, so regulatory agencies set maximum contaminant levels and aquatic life benchmarks to protect both ecosystem and public health. These thresholds are designed to provide a safety margin, reducing the risk of harmful effects rather than representing a strict boundary between safe and unsafe conditions. In the United States, the Environmental Protection Agency (EPA) maximum contaminant level for atrazine in drinking water is 3 µg/L, and chronic aquatic life benchmarks for metolachlor are ~1 µg/L for invertebrates and 30 µg/L for fish (EPA, 2016). In humans, long term exposure concerns include endocrine disruption, developmental effects, and potential cancer risk, which is why drinking water monitoring is important.

Questions

1. Why are sub-lethal effects, such as reduced growth or reproduction, important even when organisms do not die immediately?

2. Why are regulatory thresholds useful, and why should they not be interpreted as a simple line between “safe” and “unsafe”?

Part IV – Monitoring, Modeling, and Environmental Decisions

Building on the seasonal patterns and ecological impacts described earlier, scientists use long-term monitoring programs and statistical models to understand and predict how pesticide concentrations change across seasons and regions (Stone et al., 2014). Monitoring provides repeated measurements of pesticides, nutrients, and stream conditions, which helps identify seasonal peaks and runoff events. These data are then used to build models, which are tools that use environmental data (such as rainfall, land use, and soil characteristics) to estimate and predict pesticide concentrations in streams.

Agencies such as the Environmental Protection Agency (EPA) and the United States Geological Survey (USGS) use monitoring and modeling to evaluate risk, decide where and when to sample more frequently, and develop prevention strategies. For example, models can help identify areas where pesticide concentrations are likely to be highest following rainfall. These strategies can include vegetated buffer strips (which slow runoff and trap contaminants), soil conservation practices (which reduce erosion and chemical movement), or adjusting the timing and amount of chemical applications to reduce runoff. Together, these tools help shift environmental management from reacting to contamination toward preventing it.

Questions

1. Why is long-term monitoring more useful than collecting a single water sample when studying pesticide contamination?

2. How could a heavy rainfall event cause nitrate and pesticide concentrations to increase in a stream at the same time?

3. Using Figure 5, describe the relationship between nitrate and atrazine. Estimate the atrazine concentration when nitrate is about 5 mg/L.

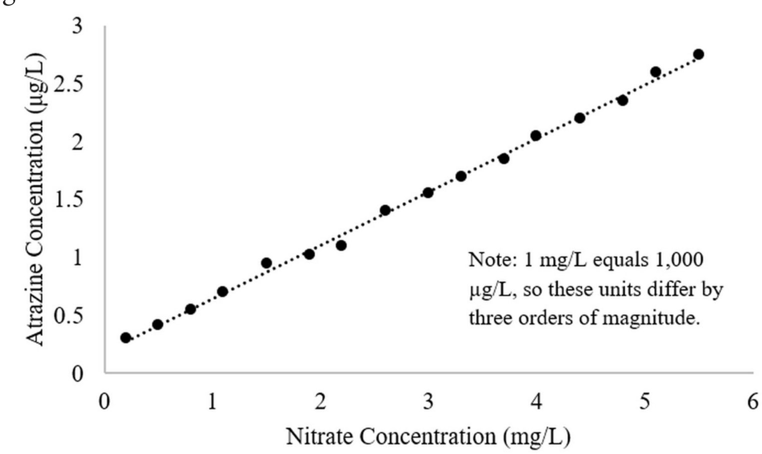

Figure 5. Simulated relationship between nitrate (mg/L) and atrazine (µg/L) in water. Data are hypothetical and illustrate a conceptual linear trend. Nitrate is included as an indicator of agricultural runoff because it can help identify periods when nutrients and pesticides are transported together.

4. What farming or land-management practices could reduce nitrate and atrazine movement into streams? How could predictive models help agencies decide where to apply these strategies?

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