Update

Stone Environmental News on FIFRA and Environmental Fate Issues

FALL 2003

Inside:

40 Plots Under One Rainfall Simulator

To our knowledge there had never been a field study that used simulated rainfall to generate runoff from 40 test plots simultaneously until Stone Environmental accomplished this feat in June 2003. For a project funded by the Lake Champlain Basin Program, Dave Braun of Stone Environmental and Don Meals of Ice.Nine Consulting established 40 test plots in a Vermont hayfield to monitor runoff from hay land receiving liquid dairy manure. The purpose was to evaluate the effectiveness of a series of simple, low-cost management practices in reducing microorganism levels in runoff from agricultural land—a major source of the microbial pollution of surface waters.

In addition to meeting our client's needs, the study also gave us an opportunity to pursue research and development work with our rainfall simulator close to home. This work will undoubtedly benefit our agrochemical industry clients in the coming years.

Stone received the test substance from this lot.

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The Future of Aquatic Herbicide Registration

In July 2003, a discussion group on the registration of aquatic herbicides was held during the annual conference of the Aquatic Plant Management Society in Portland, ME. Led by Donald Stubbs (herbicide registration branch chief, US EPA Office of Pesticide Programs) and Dr. Kurt Getsinger (US Army Engineer Research and Development Center), the meeting was attended by representatives of many of the major chemical companies, state agencies, universities, consulting firms, and others involved in the registration of aquatic herbicides. During the discussion, Stubbs and Getsinger made a number of helpful recommendations regarding strategies companies should consider using to register aquatic herbicides in the future.

How EPA Sets Priorities

One of the major topics covered was how EPA prioritizes the products it considers in any given year. Too many applications and too few resources prevent it from completing all its work in a reasonable time frame. Hence EPA has devised a complicated prioritization scheme, a simplified version of which follows (highest priority first):

1. Methyl bromide alternatives
2. Organophosphate (OP) alternatives that pass the reduced-risk screen
3. Other reduced-risk chemicals
4. OP alternatives submitted to the Reduced-Risk Committee that are denied reduced-risk status, but recommended by the committee for expediting
5. USDA/EPA-identified potentially vulnerable crops
6. Minor use priorities
7. Trade irritants

Fee-for-Service Coming

To address resource constraints and long response times, EPA and industry have been working on a "fee-for-service" system that gives registrants an opportunity to pay a significant portion of the cost of the registration process. This would allow EPA to bring in the resources it needs to accomplish the registration in a more timely fashion. This fee-for-service system is likely to be adopted in the near future.

EUPs Relaxed to 100 Acres Soon

The discussion also covered experimental use permits (EUPs). Current regulations allow registrants to test surface water bodies of less than 1 acre without an EUP. The disincentive to testing larger areas (and going for the required EUP) is that it requires companies to use one of their priority points. A new guidance allowing the application of a test substance to up to 100 acres without an EUP may be issued by EPA as soon as 2004. It would apply only to the chemicals that have been through the FQPA assessment since 1998, and there might be other restrictions.

Aquatic Herbicides Board a Good Idea

Another topic was minor use (IR-4) registration. To preserve precious priority points, industry can consider the Minor Use Program for getting applications reviewed by EPA. Members of the audience raised the concern that the aquatic herbicides group has no board to represent it, and it is difficult to compete for IR-4 applications against large groups like the Strawberry Board and the Onion Board. It was suggested that such an alliance to champion aquatic use registrations be investigated.

24(c) Limits

Companies must have federal registrations in order to apply for 24(c) applications. EPA would look favorably upon a company applying for a limited number of 24(c)s for one product, but for 24(c)s in more than five states, Donald Stubbs highly recommended modifying the federal registration.

Dave Braun of Stone Environmental, Inc., Dr. William T. Haller of the University of Florida, and David Stephens of Ag Research Associates treat a Florida pond with an aquatic herbicide.

Stewardship Plans

Stubbs mentioned that companies may need to combine a stewardship plan with their registration. He felt strongly that such a plan needed to include more specific restrictions on who could apply the chemical and how. It was agreed by the group that there is much work to be done in addressing spray-drift issues. Stubbs stressed that a stewardship plan

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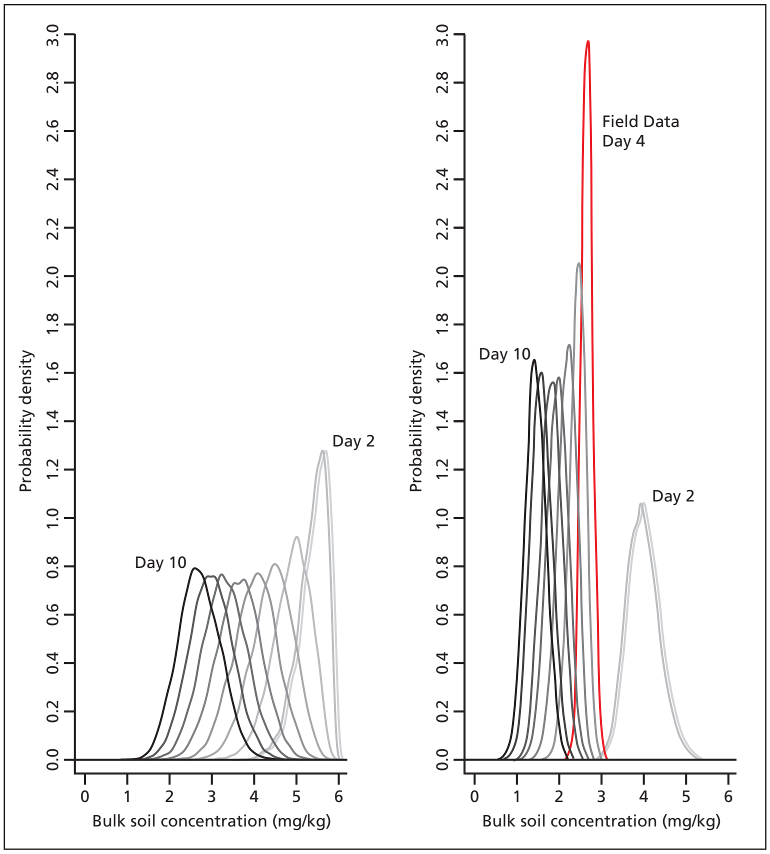
“Moditoring”—What Would It Look Like?

By Lawrence A. Burns, Ph.D., US EPA

In the Fall 2002 edition of this *Update*, Paul Hendley suggested that “modelers should use a ‘moditoring’ approach—using monitoring and modeling together in the field.” Although he did not develop the idea further in his editorial, the problem he was responding to is one of long standing: Pesticide registration relies very heavily on data from laboratory chemical and biological studies, incorporated into tiered computer modeling that extends the laboratory results into field conditions, to establish an initial set of use conditions. Once a pesticide is registered and field data begin to become available, a natural curiosity arises as to the degree to which the predictive power of the lab work and the computer models has been borne out by experience. Although one effect of a “moditoring” approach could be to provide a testing ground for the process completeness and predictive accuracy of risk models, it is, in addition, rather easy to imagine an “adaptive regulation” scheme (analogous to “adaptive management” of wildlife and fisheries) in which field experience could be continually used to sharpen knowledge of the offsite or nontarget impacts of pesticides, leading to relaxed supervision in some cases or, at the other extreme, to cancellation of a product showing unexpected adverse environmental impacts.

At the recent (August 2003) Ecological Society of America meeting in Savannah, GA, ISEM (the International Society for Ecological Modeling) sponsored a symposium on the “Death of Determinism.” Far from advocating abandonment of the application of physical and ecological knowledge as a basis for formulating models, however, the presentations and discussions were focused on the uses of statistical mechanisms and procedures as powerful adjuncts to structural equation modeling and as superstructures for an underlying “deterministic skeleton” in ecological modeling. Structural equation modeling provides statistical “confirmatory” testing of a hypothesized theoretical model confronted with data (Pugesek et al., 2003); the concept of a “deterministic skeleton” of orderly processes underlying, for example, dauntingly variable population dynamics continues to attract research attention and theoretical development (Henson et al., 2003). These approaches indeed use “monitoring and modeling together in the field” and provide tools for testing and “validating” pesticide exposure models, but the larger problem is one of using monitoring data as a means for constantly checking and rechecking the validity of regulatory decisions based on the risk assessment modeling.



(Left) Predicted soil concentrations from Day 2 through Day 10 of the simulation in the absence of field monitoring data. (Right) The effect of a field sampling program (conducted on Day 4) in narrowing the predicted range of field pesticide residues. Uncertainty increases again after Day 4, but the field program results in an overall improvement in the precision of the model predictions.

Introduction to Bayesian Statistics

Fortunately, a body of knowledge and formal procedures for allowing models to continually learn from experience is already available, through what is called *Bayesian statistics*, after the Reverend Thomas Bayes, an 18th-century English cleric.

The Bayesian approach to statistical inference can be contrasted with the “Frequentist” approach developed by R.A. Fisher and now the usual approach to university training. Bayesian methods differ primarily in their allowance for an initial subjective estimate of probabilities (the *prior* distribution—based on lab studies, for example) and incorporation of formal methods for updating based on further experience (field data, say), leading to the *posterior* distribution.

Bayes’s (1763) theorem about probabilities states that “The *probability of an event* is the ratio between a value at which an expectation depending on the happening of the event ought to be computed, and the value of the thing expected upon its happening.” Hively (1996) began his summary of the appendix to Bayes’s paper thus:

> Fortunately, Bayes had an editor. To illustrate how the method worked—how he *thought* it worked—the editor added an appendix containing a charming example: “Let us imagine to ourselves the case of a person just brought forth in this world” and left alone to observe it. “The Sun would, probably, be the first object that would engage his attention; but after losing it the first night he would be entirely ignorant whether he should ever see it again.” Our new person, dreading the uncertainty, decides to compute the probability of sunrise.

How should he go about this?

An Illustration

First, he must form a conjecture as to the likelihood of the event—say, 50%. Then he must develop a mechanism for computing probabilities. In the example, he lays in a supply of yellow and black balls (to represent sunrise and continued darkness, respectively), places one of each in a large jar, and awaits developments. Each day as the sun rises, he adds a yellow ball to the jar. At intervals, he counts the balls in the jar, and computes the probability of sunrise as the ratio of yellow balls to the total, ultimately concluding, we must suppose, that the probability of sunrise is sufficiently high that the matter deserves no further attention.

There are three points of interest in this illustration. First, note that the exact value of the initial estimate (the *prior* probability) is of no importance to the final outcome, because continued experience will soon enough “wash out” the initial condition no matter its value. In other words, had the initial estimate been composed of 99 black balls and one yellow, at the end of one year of additional observations the estimate would still be 366/465 = 79% chance of the sun rising on the morrow.

The second point to notice is that Bayesian and Frequentist methods are largely convergent, that is, they compute probabilities in much the same way. Bayesian methods have an advantage in that they can be initiated by any reasonable guess as to the actual state of nature, so preliminary decision-making is not crippled by a lack of definitive prior experience. Many Bayesians hold that the guess (the *prior*) need not even be particularly accurate, as in the foregoing illustration.

When Does the Experiment End?

Finally, observe that there is no obvious place to stop the experiment. In the example, had we started with a prior of 1% chance of sunrise, would the finding of a 79% chance of sunrise at the end of the first year of observation justify abandoning the study? Rules for ending the experiment can certainly be formulated for particular instances. For example, the P=95% rule often alleged to indicate "statistical significance" could be invoked, or a rule could be based on how much the estimate (the *posterior* probability) changes with each additional observation. Although an arbitrary choice of <1% or <0.1% change per observation would appear reasonable, a logical choice of a stopping rule could be based on the reduction in risk achieved by the incremental decrease in uncertainty associated with each observation (i.e., a "value of information" analysis). The most general statement of the Bayesian position, however, is that the study ends when a sufficient comfort is achieved in the decisions to be derived from the outcome—however this may be accomplished.

Bayesian methods are particularly well suited to problems in which a single study is unlikely to provide a definitive answer, even when the results are statistically significant. They have been applied to water quality modeling (for updating the values of model parameters based on monitoring experience [Steinberg et al., 1997]), to fisheries problems (e.g., for estimating the impact of Inuit take on whale populations [Raftery and Zeh, 1993; Raftery et al., 1995]), to health care (for evaluating the conclusions to be drawn from multiple clinical trials of treatment regimens and medications [Brophy and Joseph, 1995; Brophy et al., 2003]), and to the analysis of model uncertainty (Patwardhan and Small, 1992). They appear to be especially appropriate for situations in which initial conclusions based on laboratory data must be revisited as monitoring and incident data accumulate—which is emphatically the case for the pesticide regulatory situation faced by EPA's Office of Pesticide Programs (OPP).

The Reverend Thomas Bayes

Applying the Theory

The ready availability of computer software (e.g., WinBUGS, available gratis at *www.mrc-bsu.cam. ac.uk/ bugs/welcome.shtml*) for creating models in a Bayesian context is bringing the ability to combine process-based models and field observation within the reach of every practitioner. At a February 2002 SETAC "Pellston Conference," for example, it proved embarrassingly simple to derive a field scale cropland and farm pond scenario from standard regulatory models, establish reasonably sensible prior distributions for such things as the field dissipation and aquatic metabolism rates, and allow the resulting model to learn from (hypothesized) experimental field studies.

In the usual regulatory analyses, aquatic exposure models link the erosion of pesticides from agricultural fields to exposure in adjacent aquatic ecosystems. For demonstrating the usefulness of Bayesian approaches, we linked a simple field dissipation model to the MUSS equation (the small-watershed version of the Modified Universal Soil Loss Equation [MUSLE] discussed at *www.brc.tamus.edu/ epic/documentation/erosion.html# rainfall*) estimates of soil loss in a single event. This event was presumed to contaminate the water column of an adjacent pond, in which the pesticide dissipated at the aquatic metabolism rate. The demonstration illustrated Bayesian methods for incorporating uncertainty into model parameters, prediction uncertainty of constituent models, and the ability of Bayesian methods to improve exposure estimates by incorporating appropriate additional field or monitoring data.

Bayesian methods are beginning to make their way into chemical risk assessment modeling. For example, the RIVM (National Institute of Public Health and the Environment, the Netherlands) has developed a software system (BUSY) for implementing probabilistic risk assessment techniques, including Bayesian methods, as presented in a short course (November 8–9) at the 2003 Society of Environmental Toxicology and Chemistry (SETAC) meeting in Austin, TX.

Aiding Adaptive Regulation

The technical feasibility for "adaptive regulation" is thus already here; the institutional mechanisms to make it a reality may prove to be the more difficult problem. Proposals for monitoring the success of mitigation methods required for some pesticides, and for systematic analysis of the health of ecological resources in agricultural landscapes, have been advanced (Aquatic Dialogue Group, 1994). Agreement among the interested parties—involving, as it must, chemical manufacturers, agricultural producers, state and federal regulators, natural resource managers, and conservation organizations—has yet to be achieved. Bayesian methods, however, provide an objective framework for organizing linked modeling and monitoring ("moditoring") pilot studies that may eventually lead to agreed-upon formal methods for long-term monitoring and maintenance of ecologically responsible uses of pesticides in agricultural landscapes. ⚟

References are available online at www.stone-env.com/doclib.html.

For discussion, please contact Lawrence Burns at US EPA via burns.lawrence@epamail.epa. gov.

Registration

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could not be used as a tool to further protect product patents.

The Risk Cup and Water Tolerance

Stubbs explained how EPA views the risk cup. There is no tolerance set for water (the Drinking Water Level of Concern or DWLOC). Whatever is left in the risk cup after considering all other exposures is the tolerance for water. If one fills the cup with exposures from other routes, then there is no room for a contribution from water sources, which isn't realistic for most chemicals. Limiting non-water exposures leaves more room in the risk cup for water tolerance.

Suggestions

A discussion about how to expedite EPA registration yielded these suggestions:

1. Manage room in the risk cup for water exposure.
2. Provide the basic registration application data.
3. Consider making application rates as low as possible—if only 85% efficacy is needed, don't ask for 100% efficacy.
4. Know the endangered species before beginning a registration process (understand where they are, know what impacts are likely, and be prepared to "label around" them). There was some discussion of the fact that Endangered Species Task Force members have good data, but it is available only to them, or possibly to those willing to share in the cost of data compilation.

Looking ahead, Stubbs said he would be interested in having industry members contribute to the conversation on the consumption of freshwater fish and shellfish, which has yet to be addressed in the risk cup. Apparently, some dialogue has begun with the Environmental Justice branch of EPA.

In addition, discussions to define the term *treated area* are at a standstill pending availability of better modeling or monitoring data on hydrodynamics in a waterbody.

All in all, this was an interesting and helpful discussion, actively engaged in and appreciated by the participants. ⚟

NEWS BRIEFS


Mike Winchell


Scott Johnstone


Chris Stone


Susan Alexander


Dave Braun


Kim Watson

Mike Winchell was promoted to group leader of the Applied Information Management (AIM) group this summer. Former Group Leader **David Healy** will remain as group officer and will still be involved with the team as he launches a new venture called ISD (Information for Sustainable Development). The FIFRA group frequently takes advantage of Winchell's GIS and SWAT modeling expertise.

Scott Johnstone joined the Wastewater group as senior project director. Johnstone was formerly the secretary of the Vermont Agency of Natural Resources. During his career in government he developed a reputation for bringing regulators, environmentalists, industry, and political leaders together to agree on effective strategies for such issues as storm water, transportation, invasive species, and public land management. He holds a B.S. in Civil Engineering from the University of Maine at Orono.

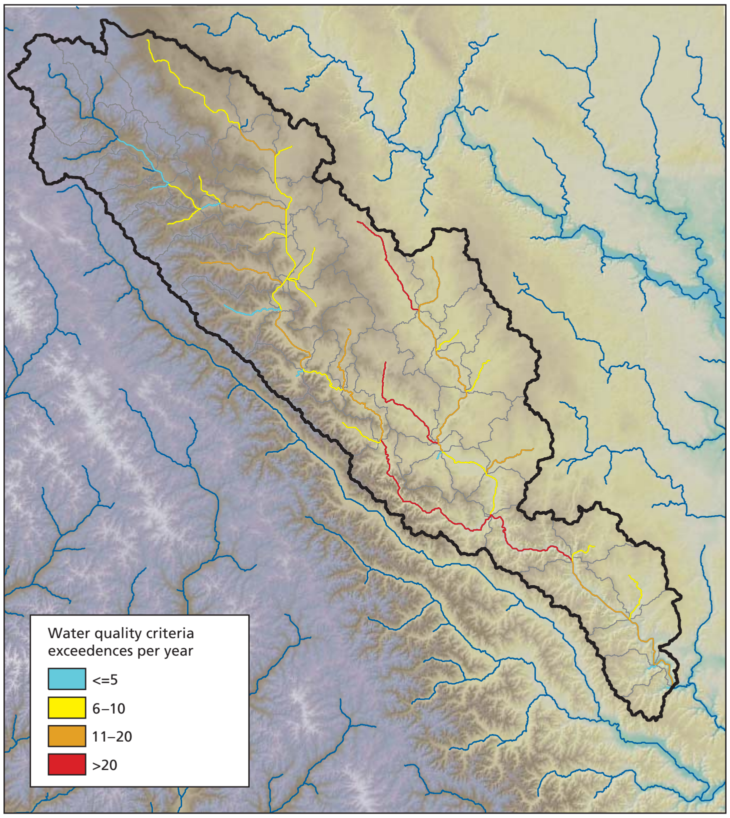
Chris Stone presented a paper titled *Methodology for Assessing Human Exposure to Pharmaceuticals in Drinking Water* at the National Ground Water Association's 3rd International Conference on Pharmaceuticals and Endocrine Disrupting Chemicals in Water, held in March in Minneapolis, MN.

Chris Stone and **Susan Alexander** attended the July meeting of the Aquatic Plant Management Society in Portland, ME.

In May, the 2003 American Water Resources Association (AWRA) Spring Specialty Conference in Kansas City, MO, was attended by **Dave Braun.**

Kim Watson conducted a presentation on *Techniques in Manual Integration* at the Annual NY & PA Environmental Laboratory Convention & Exposition on August 12, and attended the 19th Annual Meeting of the Society of Quality Assurance in October in Arlington, VA.

Stone Uses SWAT Modeling for Pesticide Risk Assessment



Stone recently finished an evaluation of the fate and transport of a pesticide in a complex California watershed using SWAT (Soil and Water Assessment Tool).

SWAT is a watershed-scale pollutant transport model that integrates directly with GIS, enabling us to incorporate detailed land cover, soil, and topographic spatial data sets directly into the parameterization of the model. With this powerful tool, our clients can examine the spatial variability of pesticide concentrations across rivers and streams throughout a watershed.

The example shows river reaches color-coded according to how often a water quality criterion is exceeded. This kind of SWAT output helps to identify areas of a watershed most vulnerable to pesticides, as well as to prioritize the implementation of best management practices. It is also effective for the design and implementation of TMDLs.

Successful Facility Audits

Two inspections took place at Stone Environmental's offices this summer with favorable results. With the exception of a minor revision to a curriculum vitae and an update to a Standard Operating Procedure, the Bayer CropScience inspection in June was complimentary. The Syngenta Crop Protection inspection, conducted in August, yielded "no findings," which is the best possible result for this type of audit.

Both inspection teams reviewed our compliance status with the EPA FIFRA GLP regulations at 40 Code of Federal Regulations (CFR) Part 160, as well as several studies that were or are being performed by Stone.

New Home on Stone Cutters Way

Stone moved to its new office in January. Only a few blocks from the former location, the new space is more than twice as large, with floor-to-ceiling windows, airy conference rooms, and a mahogany sun deck.

40 Plots

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Background

There is growing interest nationally and in the Lake Champlain Basin (Vermont, New York, Quebec) in describing processes that lessen the runoff of microorganisms (bacteria, protozoa, and viruses) from agricultural fields. Scientists have learned much about the fate and transport of sediments, nutrients, and pesticides. However, the impact of management practices on microorganism loss is less well understood.

Study Design

The hypothesis Stone tested is that levels of *E. coli* in runoff from agricultural land could be significantly reduced through the use of alternative manure management practices. By extension, adoption of alternative management practices could lead to improved water quality in the Lake Champlain Basin and elsewhere.

We considered the practicality of different options with Vermont's predominantly small dairy farms in mind, and chose the following treatments:

- Duration of manure storage (90-, 30-, or ~1-day storage)
- Height of hay receiving manure (<6 or >12 cm)
- Timing of rainfall/runoff after application of manure (3-day or 1-day delay)

Of course, the use of the simulator to deliver rainfall when desired was key to testing the last treatment. We evaluated these treatments using a factorial design that tested each combination.

Manure Application and Simulated Rainfall

The study plots were 1.5 x 3 meters. We inserted metal flashing at the downslope end of each plot to direct water to a funnel, which discharged it to a sealed 20 L carboy. We applied the manure manually (yes, with buckets and saucepans) at the typical agronomic rate of 5,000 gallons per acre. Then we applied simulated rain on June 24, 2003, for approximately 4 hours. We tested all treatment combinations, plus a control without manure, in triple-replicated plots.

Analysis of rainfall catch in cups located in each plot indicates that the simulated rainfall intensity

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Aquatic Herbicide Review in Massachusetts

The rapid spread of invasive aquatic plants in the US is increasing the demand for tools to manage ponds, lakes, and rivers. Unchecked growth of aquatic nuisance species can degrade water quality, fisheries, and waterbird habitat; it can also adversely affect recreation, aesthetics, and property values. In the Northeast, Eurasian watermilfoil and water chestnut are gaining ground in lakes and ponds, while southern states are battling hydrilla, giant salvinia, and water hyacinth, among others.

Aquatic herbicides are available to manage these invasive species, as are non-chemical options, including mechanical harvesting of weeds, biological control (usually through the introduction of grass carp or release of an insect that is a tested biocontrol agent), installation of physical barriers on the lake or pond bottom, and water drawdown. There is a place in the lake manager's toolbox for each of these measures, but the option that is most effective in managing nuisance aquatic plant problems while minimizing impacts on native plant and animal species is often an aquatic herbicide.

Concord, Massachusetts.

States Looking at Potential Impacts on Wells

In a growing number of states, lake managers wishing to apply an aquatic herbicide face an increasingly complicated permit process. State governments are putting in place regulations that are often more stringent than the requirements of federal pesticide labels, addressing the potential impacts of aquatic herbicides on endangered species, surface drinking water supplies, and, recently, private wells near treated bodies of water. The issue of potential impacts on private wells via groundwater recharge from treated lakes and ponds appears to be gaining momentum, with states such as Michigan, New Jersey, and Massachusetts considering the location of private wells in aquatic herbicide use permitting.

2,4-D Review

The herbicide 2,4-D has been used successfully to manage many invasive species for more than 30 years. Stone Environmental was asked by the 2,4-D Task Force and two lake managers in Massachusetts to evaluate the potential for 2,4-D to affect private drinking-water wells near treated lakes and ponds via groundwater recharge. To date, the limited monitoring of private wells near treated lakes and ponds that has been conducted in Michigan and other states has not revealed any detectable residues of 2,4-D.

Stone drafted a white paper that reviewed aspects of 2,4-D product chemistry, the results of well monitoring studies for 2,4-D, and the implications of the hydrogeologic setting of lakes and ponds in Massachusetts. We presented our findings to the Massachusetts Department of Environmental Protection, and worked with the Department to incorporate elements of our evaluation into a guidance document on lake management.

Hydrogeologic Setting Protects Groundwater

We found that the potential for 2,4-D in private wells adjacent to treated lakes and ponds in Massachusetts is low. Most waterbodies in Massachusetts *receive* groundwater rather than *recharge* groundwater, because groundwater flows along a gradient from uplands to low-lying areas where lakes and ponds are typically located. Since groundwater is flowing toward the waterbody, and not away from it, groundwater degradation from aquatic herbicides is improbable. (Exceptions are shoreline areas near some dams, as well as lakes and ponds without surface outflows.)

Slowly permeable surficial geology is the second reason that wells near most of the lakes and ponds in the state are not vulnerable. Approximately 65% of the lake and pond area overlies fine-grained deposits or bedrock, indicating that rates of exchange between surface water and groundwater are low.

However, some lakes and ponds in the state are located in vulnerable hydrogeologic settings, such as glacial outwash and dune terrain in southeastern Massachusetts. These lakes and ponds are typically underlain by highly permeable deposits of sand and gravel, and commonly have groundwater seepage entering one side and groundwater recharge exiting on the opposite side. Current practices regarding 2,4-D use in Massachusetts's lakes and ponds are unlikely to pose a realistic risk to private wells, but targeted monitoring of wells in these vulnerable hydrogeologic settings may be warranted.

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averaged 0.98 inches per hour, very close to our target of 1.0 inches per hour. Despite windy conditions, we achieved good uniformity across the test field, with a coefficient of variation among the 40 plots of just 11%.

Results

Runoff generation across the test field was surprisingly variable. We believe that the differences among the plots resulted from spatial variation in plot slope and soils. Note that on the larger plots more often used in pesticide runoff studies, these small-scale differences in runoff potential across the field would be less apparent.

Preliminary analysis of the effects of individual treatments suggests that duration of manure storage had a dramatic effect on runoff levels of *E. coli* bacteria. The plots treated with fresh manure had exceedingly high *E. coli* levels in runoff, averaging in excess of 1 million *E. coli* per 100 ml (geometric mean = 1.1 x 10^6/100 ml). *E. coli* levels in runoff from the plots treated with 30-day manure (geometric mean = 3.2 x 10^4/100 ml) were approximately 97% lower on average than levels in runoff from the comparable plots (same rain delay and hay height) treated with fresh manure. *E. coli* levels in runoff from the plots receiving 90-day manure (geometric mean = 4.6 x 10^3/100 ml) were approximately 99.5% lower on average than levels in runoff from the comparable plots treated with fresh manure.

Delaying rainfall for 3 days after application appeared to have an effect on runoff concentrations of *E. coli*. For equivalent plots (same manure age and hay height), runoff from the 3-day rain delay plots had *E. coli* levels that were 42% lower on average than levels in runoff from the 1-day rain delay plots. However, this difference was not statistically significant. Grass height did not appear to have a consistent effect on *E. coli* concentrations in runoff.

The Best Alternative Practices

The combination of treatments that led to the highest average *E. coli* levels in runoff was the fresh manure applied 1 day prior to rainfall on the high grass plots. This represents the typical practice for manure applications on hay land in Vermont. All three replicates of this treatment combination exceeded 2.4 x 10^6 *E. coli* per 100 ml. The combination of treatments with the lowest *E. coli* levels in runoff was the 90-day manure applied 3 days prior to rainfall on the high grass plots. This reduced *E. coli* in runoff by approximately 99.9% from the typical practice.

Our results suggest that storing liquid dairy manure (allowing it to age) and not spreading it when rain is forecast will reduce runoff of bacteria and pathogens. These practices may ultimately become part of a recommended suite of best management practices to reduce microorganisms in the Lake Champlain Basin. Unfortunately, the *E. coli* levels in runoff from this combination of practices still exceeded the Vermont water quality standard of 77 per 100 ml by an order of magnitude, suggesting that consistent attainment of water quality standards may be difficult even when improved manure management is practiced.

Reconsidering Experimental Design Basics

In every runoff study Stone has conducted in cooperation with clients in the agrochemical industry, there has been extensive debate about plot size and the replication of treatments. Questions arise because of the lack of EPA guidelines for conducting simulated rainfall runoff studies and the differences in study objectives and crop types.

The benefits of replication are not disputed: replication provides greater sensitivity, power, and confidence in quantifying a treatment effect than does the use of unreplicated plots. The main argument for using three or more plots is that one can perform powerful statistical analyses (analyses of variance) not possible with one or two plots.

The use of a rainfall simulator avoids the risk of dependence on natural rainfall, but it also places an upper limit on plot size. Because the key processes affecting bacteria export—die-off in storage, soil interaction, vegetation interaction, and time between application and rainfall—are not strongly scale-dependent, the smaller plot size was acceptable in this study. In most scenarios, smaller plots will provide results comparable to those of larger plots, except for processes that are a function of slope length, runoff time, or distance of travel (such as erosion or transport through a vegetated filter strip).

EPA is currently considering ways to standardize runoff study design to ensure comparability among studies, and USDA-ARS anticipates playing a role. The approach USDA-ARS has used for pesticide runoff studies in recent years includes triple-replicated plots of 2 x 3 meters. On the basis of our good experience with a nearly identical design in this project, we think that a study design with triple-replicated small plots might be appropriate in many simulated rainfall pesticide runoff studies in the future. It is scientifically rigorous, it is cost-effective, and with all the plots under one simulator, it is also easy to administer without relying on fickle weather.