# SESSION 8
# RISK MANAGEMENT


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# Predicted impact of transgenic crops on water quality and related ecosystems in vulnerable watersheds of the United States

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## ABSTRACT

The agricultural industry of the United States faces a challenge to reduce the loadings of pesticides into ground and surface waters. While most water resources are not impacted significantly, monitoring data show that the water quality of vulnerable watersheds can be affected when certain pesticides of high mobility and/or environmental persistence are widely used. Even in these relatively rare cases, the presence of these products in water supplies is thought to have minimal ecological impacts, but little work has focused on the potential sub-acute cumulative impacts of mixtures of these products on either individual species or entire ecosystems. Transgenic cropping systems are intended to reduce the types and quantities of pesticide necessary for production of food, feed, and fiber. Because of this decreased reliance on chemical pesticide use, such cropping systems may be anticipated to result in reduced impacts on water quality and possibly related ecosystems. In this paper, we examine the potential water quality and related ecosystem impacts of three new transgenic cropping systems: corn (maize) modified to withstand nonselective herbicides, cotton modified to combat certain lepidopteran pests through the insertion of genetic material from *Bacillus thuringiensis (Bt)*, and corn similarly modified to prevent damage from European Corn Borer and other pests. Simple screening modeling is used to examine the displacement of insecticides by two *Bt*-cropping systems. Higher tier computer modeling is used to compare impacts on drinking water quality among various herbicide treatment scenarios commonly used in conventional and transgenic, herbicide-tolerant corn. All three transgenic cropping systems are predicted to result in significantly lower pesticide concentrations in ground and surface waters, thereby reducing whatever impacts these products have on drinking water quality and related ecosystems.

## INTRODUCTION

The agricultural industry of the Midwestern United States faces a challenge to reduce the loadings of pesticides into ground and surface waters (Wauchope, 1978; Leonard, 1990; Thurman *et al.*, 1991; Goolsby *et al.*, 1991; Richards *et al.*, 1993; CAST, 1994; Clark *et al.*, 1999). While observed concentrations are generally below human health and other standards intended to prevent impacts on related ecosystems, monitoring data show that vulnerable watersheds can be affected when mobile and persistent pesticides are heavily used. Detectable levels can occur in drinking water and - in the most vulnerable systems - occasionally attain concentrations above chronic human health standards and ecotoxicological standards established by the United States Environmental Protection Agency (US EPA). While these standards are highly conservative and risk assessments suggest there is a reasonable certainty of no harm to the public or related ecological systems (Richards, *et al.*, 1995), the presence of these residues has been a significant public concern. Under the Food Quality Protection Act of 1996 (US Public Law, 1996), these residues are added to the aggregate risk calculated for uses of these products. For these reasons there is an impetus to adopt practices and technologies for agriculture that offer the promise of continued production with decreased water resource impacts.

The options now available include crops that have been genetically engineered to produce their own insecticide (eg. *Bt*-corn and *Bt*-cotton) or to withstand applications of non-selective herbicides such as glufosinate and glyphosate. Growers planting the *Bt*-crops are able to avoid spraying certain chemical insecticides. Growers planting the herbicide-tolerant varieties are similarly able to avoid use of the pre-emergent herbicides known to occur in ground and surface water supplies. The glufosinate- and glyphosate-based herbicides which replace them may be expected to have a lower human risk, both because they are less toxic and because they have a lower potential to reach water resources (Shipitello *et al.*, 2000; Wauchope *et al.*, 2001). According to a recent report (Carpenter, 2001), the introduction of *Bt*-cotton varieties has reduced the amount of insecticides used by approximately 2.7 million pounds per year in the US. Corn farmers have achieved more modest reductions through the planting of current varieties of *Bt*-corn, but the introduction of new *Bt*-corn varieties engineered to resist Corn Root Worm is expected to result in more significant reductions in insecticide use in corn in the US.

In this paper, the potential water quality and related ecosystem impacts of three transgenic cropping systems are considered: *Bt*-corn, *Bt*-cotton, and herbicide-tolerant corn. The first two systems represent the complete elimination of certain insecticide applications, and the reduced edge-of-field loadings to water supplies can be modeled using simple EPA Tier 1 modeling tools. Herbicide-tolerant corn involves the replacement of certain herbicides by glufosinate and glyphosate, and determining the net impact on drinking water quality requires the use of more sophisticated computer modeling techniques. We use Tier 2 PRZM/EXAMS modeling to quantitatively compare the net impact on both ground and surface water quality in representative case study watersheds, if growers were to switch from conventional corn to transgenic, herbicide-tolerant corn. This choice of end-points (aquatic ecological impacts for the Bt cropping systems and drinking water impacts for herbicide tolerant corn) is motivated by the general sentiment that these tend to be the key regulatory drivers for these classes of materials. The insecticides used in corn and cotton are generally not regarded to have the same frequency of detection in drinking water as do the herbicides used in corn. Similarly, herbicides are not thought to have the same potential as insecticides to have short-term acute ecological impacts on aquatic organisms.

## MATERIALS AND METHODS

The two *Bt*-transgenic cropping systems and the insecticides subjected to modeling are listed in Table 1. The six corn- and four cotton-insecticides were chosen based on a recent study (Carpenter and Gianessi, 2001) listing the insecticides that have had their use reduced by the greatest amount during the introduction of *Bt*-corn and *Bt*-cotton, respectively. They are all insecticides that target the same pests controlled by the transgenic crop varieties. The data source for all toxicity data used is the USEPA Pesticide Toxicity Database (Montague, 1996). The lowest EC50 or LC50 for a standard regulatory test (48-hr *Daphnia magna* or 96-hr fish) with the active ingredient was selected for each compound.

Table 1. Properties of insecticides included in ecological effects modeling

| | | Physical properties | | Aquatic toxicity (µg/L) | | |
|---|---|---|---|---|---|---|
| **Transgenic cropping system** | **Insecticides displaced** | **Koc (L/kg)** | **$DT_{50}$ (days)** | **48-hr *Daphnia* $EC_{50}$** | **96-hr Bluegill $LC_{50}$** | **96-hr Rainbow trout $LC_{50}$** |
| *Bt*-Corn | carbofuran | 22 | 50 | 29 | 88 | 362 |
| | chlorpyrifos | 6070 | 30 | 0.1 | 1.7 | 7.1 |
| | λ-cyhalothrin | 180000 | 30 | 0.23 | 0.21 | 0.24 |
| | permethrin | 100000 | 30 | 0.039 | 0.79 | 2.1 |
| | tefluthrin | 74000 | 30 | 0.07 | 0.13 | 0.06 |
| | terbufos | 500 | 5 | 0.31 | 0.77 | 7.6 |
| *Bt*-Cotton | cypermethrin | 100000 | 30 | 1 | 1.78 | 0.82 |
| | methomyl | 72 | 30 | 8.8 | 480 | 860 |
| | profenofos | 2000 | 8 | 0.93 | 19 | 21 |
| | thiodicarb[1] | 350 | 7 | 27 | 1470 | 2650 |

[1] *Thiodicarb is a dimer of methomyl. The properties listed here are for parent thiodicarb.*

The herbicides subjected to modeling are listed in Table 2. The first two of these herbicides (alachlor and atrazine) are representative of the many chloroacetanilide and triazine pre-emergent soil-applied herbicides that are used in the production of corn in the US and elsewhere. The other two products (glufosinate and glyphosate) are the two non-selective herbicides for which transgenic, herbicide-tolerant varieties of corn and several other crops have been developed and introduced. As discussed elsewhere (Wauchope *et al.*, 2001), these transgenic varieties can be grown using either none or significantly reduced application rates of the pre-emergent soil-applied products, such as alachlor and atrazine.

Table 2. Properties of corn-herbicides included in drinking water modeling

| Herbicide | Corn Use Rate (kg/ha) | Koc (L/kg) | $DT_{50}$ (days) | MCL (µg/L) |
|---|---|---|---|---|
| alachlor | 4.48 | 170 | 15 | 2 |
| atrazine | 2.8 | 156 | 60 | 3 |
| glufosinate | 0.91 | 600 | 16 | 170[1] |
| glyphosate | 1.66 | 22,300 | 17 | 700 |

[1] *No MCL established for glufosinate; this is the chronic DWLOC (see text).*

The physical properties and use rates shown in Tables 1 and 2 are taken directly from the literature (Hornsby *et al.*, 1995; Tomlin, 1997) and the US EPA "One-Liner" Database. The Maximum Contaminant Levels (MCL's) shown in Table 2 are those established by the US EPA Office of Water and are to be interpreted as an annual average concentration. In the US, Community Water Systems are required to monitor for those products with MCL's, and demonstrate that the specified concentrations are not exceeded. Glufosinate does not have an MCL, but EPA has recently determined a chronic Drinking Water Level of Comparison (DWLOC) for the US population to be 170 µg /L. Though not shown in Table 2, the aquatic toxicity of these herbicides to *Daphnia* and fish is significantly less than that of the insecticides. The corresponding $EC_{50}$ and $LC_{50}$ values range from 1-780 mg/L with a median of 140 mg/L, i.e. generally at least 3 orders of magnitude higher than those of the insecticides.

**Tier 1 Surface water exposure modeling (for Bt-corn and Bt-cotton)**

The US EPA computer model GENEEC (v 1.2, Parker, 1995) was used to estimate pond concentrations of the 10 insecticides. The estimated concentrations correspond to a standard, worst-case scenario of a hypothetical farm pond, 1 hectare in size, 2 m deep, receiving spray drift and runoff from an adjacent 10 hectare agricultural field. The field is intended to be in a highly vulnerable area; the model assumes a rain even occurs 2 days after each application, and that rainfall washed 10% of the insecticide remaining in the top 1 inch of soil into the pond. Besides the Koc and DT50 physical properties already presented for each insecticide, the GENEEC model utilizes water solubility and hydrolysis rates, which were both available for these products (Hornsby *et al.* 1995). An important limitation of GENEEC comes with the fact that a single site is used to represent all possible use patterns. This site represents an extreme scenario that is unlikely to occur for most applications. With this approach only the highly vulnerable farm pounds are pertained in the assessment. These farm ponds represent only a small minority of the run off scenarios in the US. Based on this extreme scenario GENEEC computes an upper bound exposure estimate taking into consideration run off and drift. Being a screening model, the algorithms within GENEEC lack many fundamental processes that are necessary to simulate the actual run off events in an accurate way. Also the processes incorporated in the model to account for the fate in the aquatic environment are rather limited.

**Tier 2 Drinking water exposure modeling (for herbicide-tolerant corn)**

The US EPA computer model PRZM v3.12 (Carsel *et al.*, 1998) was used to determine leachate concentrations on a vulnerable Wisconsin site and potential loadings to surface water in edge-of-field runoff in each of three vulnerable watersheds in corn growing geographical areas (see Table 3). The surface water loadings are used as input to the EXAMS v2.98.01 (Burns, 2000) model to generate distributions of estimated reservoir exposure concentrations for several application scenarios. We estimate pesticide concentrations in a reservoir using the standard Index Reservoir approach developed by US EPA (Jones *et al.*, 1998). The selected drinking water reservoir is that used at Salem, Illinois: 962 hectares in size, draining directly into a 30 hectare drinking water reservoir of 2 meter depth, with a measured corn crop area factor of 0.26 (meaning that 26% of the watershed was assumed to be treated by herbicide). Modeling was performed under the principles of Good Modeling Practices described by Estes and Coody (Estes *et al.*, 1993).

Table 3. Geographic scenarios included in PRZM modeling

| Scenario class | Site name | Soil type | Weather station[1] | Mean annual precip. (cm) |
|---|---|---|---|---|
| Surface Water | Coshocton, OH | Cardington SiL[2] | Dayton, OH (1948-1983) | 84.81 |
| | Four-Mile Creek, IA | Tama SiL | Waterloo, IA (1961-1995) | 79.48 |
| | Salem, IL | Bluford SiL | Evansville, IN (1948-1983) | 104.98 |
| Ground Water | Central Sands, WI | Friendship LS[3] | Wausau, WI (1963-1987) | 74.10 |

[1] *Daily meteorlogical values.* [2] *SiL = Silt loam* [3] *LS = Loamy Sand*

For all four field settings, seven pairs of agronomic scenarios were included in the modeling plan (see Table 4). The paired scenarios (eg. 1A and 1B) differ only by whether a "burn-down" application of glyphosate was included as a pre-plant application, such as would often accompany no-till or some other conservation tillage practice. The baseline agronomic scenario (1) is one in which a conventional corn variety is planted and weed control is accomplished using an early post-emergent application of the full label rates of a pre-mix of alachlor and atrazine. Scenarios 2 and 3 represent two potential conventional methods of mitigation: banding and incorporation (Baker & Laflen, 1979). The other four pairs of scenarios represent the two transgenic corn systems, Liberty Link and Roundup Ready corn. In both Liberty Link scenarios (4 and 5), the transgenic corn receives two herbicide treatments. In Scenario 4, the first application is a pre-mix of a half-rate of alachlor and atrazine, plus an application of glufosinate. In Scenario 5, both in-crop herbicide applications are glufosinate alone, at the maximum labeled rates. Scenarios 6 or 7 are identical to Scenarios 4 and 5, except that Roundup Ready corn is substituted for the Liberty Link corn, and the glufosinate applications are replaced by glyphosate treatments.

Table 4. Agronomic scenarios included in PRZM modeling

| Scenario number* | Corn variety | Early post-emergent application | Late post-emergent application |
|---|---|---|---|
| 1A, 1B | Conventional | Alachlor 4.48 kg $ha^{-1}$<br>Atrazine 2.8 kg $ha^{-1}$ | none |
| 2A, 2B | Conventional | Alachlor 2.24 kg $ha^{-1}$†<br>Atrazine 1.4 kg $ha^{-1}$† | none |
| 3A, 3B | Conventional | Alachlor 4.48 kg $ha^{-1}$‡<br>Atrazine 2.8 kg $ha^{-1}$‡ | none |
| 4A, 4B | Liberty Link | Alachlor 2.24 kg $ha^{-1}$<br>Atrazine 1.4 kg $ha^{-1}$<br>Glufosinate 0.50 kg $ha^{-1}$ | Glufosinate 0.41 kg $ha^{-1}$ |
| 5A, 5B | Liberty Link | Glufosinate 0.50 kg $ha^{-1}$ | Glufosinate 0.41 kg $ha^{-1}$ |
| 6A, 6B | Roundup Ready | Alachlor 2.24 kg $ha^{-1}$<br>Atrazine 1.4 kg $ha^{-1}$<br>Glyphosate 0.83 kg $ha^{-1}$ | Glyphosate 0.83 kg $ha^{-1}$ |
| 7A, 7B | Roundup Ready | Glyphosate 0.83 kg $ha^{-1}$ | Glyphosate 0.83 kg $ha^{-1}$ |

* *For each numbered scenario, "A" includes a pre-plant application of 4.1 kg $ha^{-1}$ glyphosate as a "burn-down" chemical tillage application. Scenario "B" has no such application.*

† *Banded applications of the full label rate to stripped areas along the corn rows covering only 50% of the field*

‡ *Soil incorporated such that the soil residues have a linearly decreasing concentration from 0 to 7.5 cm soil depth*

## MODELING RESULTS AND DISCUSSION

### Acute aquatic toxicity assessment for insecticides displaced by *Bt*-Corn and *Bt*-Cotton

The GENEEC modeling results for the 10 insecticides are summarized in Table 5.

Table 5. GENEEC modeling summary

| Transgenic cropping system | Insecticide | Rate (kg/ha) | No. of applications | Interval between apps (d) | Aqueous solubility (mg/L) | Hydrolysis $DT_{50}$ (d) | GENEEC 96-hrEEC (ppb) |
|---|---|---|---|---|---|---|---|
| *Bt*-Corn | carbofuran | 1.12 | 3 | 14 | 351 | 288 | 129.7 |
| | chlorpyrifos | 2.80 | 3 | 10 | 0.4 | 29.4 | 19.6 |
| | λ-cyhalothrin | 0.034 | 4 | 3 | 0.005 | none | 0.031 |
| | permethrin | 0.22 | 3 | 6 | 0.006 | none | 0.24 |
| | tefluthrin[1] | 0.18 | 1 | -- | 0.2 | none | 0.036 |
| | terbufos[1] | 1.47 | 1 | -- | 5 | 3.3 | 7.35 |
| *Bt*-Cotton | cypermethrin | 0.11 | 6 | 3 | 0.004 | none | 0.233 |
| | methomyl | 0.56 | 12 | 6 | 58000 | none | 188 |
| | profenofos | 1.12 | 6 | 5 | 28 | 24 | 19.99 |
| | thiodicarb | 1.01 | 6 | 7 | 19.1 | 8.6 | 39.3 |

*1. Granular, no drift; incorporated to 2 inches. All others were ground spray (1% drift) with no incorporation.*

The distribution of risk ratios based on Tier 1 GENEEC exposure values for cotton and corn are shown in Figures 1 and 2, respectively. Values greater than 1.0, provide a preliminary indication that there is a possibility of the expected environmental concentration exceeding the LC or EC50. For corn, the probability of a risk quotient exceeding 1.0 falls from 54, with normal insecticide use, to approximately 24 for the 50% reduction-in-use scenario. The probability drops further to about 9.3 for the 80% reduction scenario. For cotton, the probability of a risk quotient exceeding 1.0 is predicted to drop from 39 to about 18 for a 50% reduction in insecticide use and to about 6.9 for an 80% reduction. Results of surveys indicate that introduction of *Bt* cotton has resulted in actual reductions in insecticide use from 12% to 61% globally (Betz *et al.*, 2000). These reductions can decrease the probability of exposure and associated risk, as described above. The magnitude of the reduction will depend on the percent of *Bt* cotton planted relative to traditional cotton in a given watershed.

The data presented in Figure 1 and 2 are from Tier 1 GENEEC modeling which uses very conservative assumptions for screening purposes. Consequently, although some of the ratios for the corn and cotton scenarios are shown to exceed 1.0, this does not indicate that a field incident will occur. More sophisticated modeling and biological effects testing would need to be considered in order to predict such an outcome. It is also important to recognize that the pond EECs in this edge-of field analysis do not change under the various reduction-in-use scenarios, since the application rate is assumed to remain the same in fields not growing *Bt* crops. Rather, the probability reflects the reduced likelihood of discrete occurrences of EECs exceeding the LC or EC50 at the watershed level, because fewer fields will be treated.

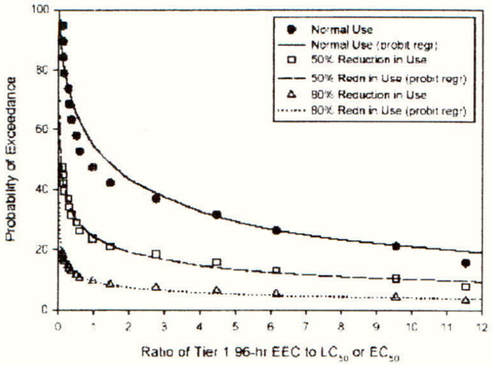


Figure 1. Tier 1 Surface water modeling of corn insecticides

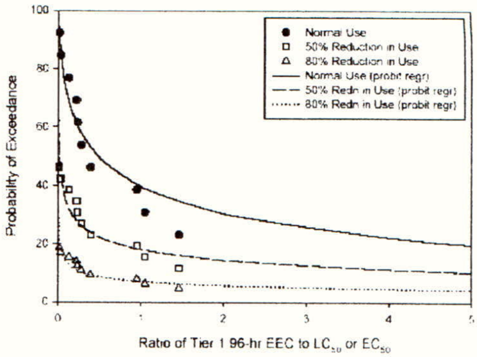


Figure 2. Tier 1 surface water modeling of cotton insecticides

The distance along the vertical line segment between the curves in Figures 1 and 2 at a ratio of 1 indicates the relative area in which vulnerable sites would no longer have a potential exposure to an insecticide in excess of its $LC_{50}$ or $EC_{50}$. For instance, in Figure 1 it can be seen that the area having potential exceedances from nearly 60% to less than 10% when there is an 80% reduction in corn insecticide use brought about by the introduction of *Bt*-corn to the landscape.

**Chronic drinking water assessment for the herbicide-tolerant corn scenarios**

Leaching Results

The results of the leaching simulations are shown in Figure 3. These results show in these vulnerable leaching scenarios atrazine applications result in average concentrations in recharge water moving 2 m would be about 1 to 2 ppb, alachlor concentrations would be negligible (0.002 to 0.004 ppb), and essentially no gyphosate or glufosinate would move below 2 m. Therefore, this simulations show that a move to transgenic, herbicide-tolerant corn would not result in increased residues of herbicides in ground water.

The simplistic nature of these simulations needs to be recognized. First, this scenario is quite extreme and in many use areas no significant leaching of any of these herbicides occur. The important transport mechanism in this scenario is chromatograph leaching. In finer-textured soils, preferential flow may result in greater movement than predicted by chromatograph leaching (however, $K_{oc}$ is still usually an important factor affecting the amount leached). Point sources due to improper transport, storage, handling, and disposal can result in any chemical moving to ground water. Another limitation is that these simulations considered the movement of parent only (although similar results would be expected including metabolites, the additional complexity for assessing both exposure and toxicological significance is beyond the scope of this paper). Finally concentrations in recharge moving below 2 m below the soil surface is an upper bound on the concentration of ground water entering a drinking water well due to processes such as mixing, dilution, dispersion, and degradation. In spite of all of these simplistic assumptions, the conclusion that a move to transgenic, herbicide-tolerant corn would not result in increased residues of herbicides in drinking water from ground water is still valid.

Surface Water Results

The PRZM modeling predicts that the compounds will behave differently in the field. Alachlor and atrazine have higher edge-of-field losses, ranging as high as 8-9% of the amount applied. Glufosinate and glyphosate have lower annual losses, up to 4.8% and 2.2%, respectively. Most of the losses of alachlor, atrazine, and glufosinate are dissolved in runoff water rather than sorbed to eroded sediment. The reverse is true for glyphosate, which is bound mainly to sediment, because of its much higher soil-sorption coefficient. For the four compounds included in the simulations, the most appropriate toxicologically-relevant endpoint is the annual average concentration. The 90$^{th}$ percentiles of these annual average concentrations for the Illinois soil/weather scenario and all of the different agronomic scenarios are presented in Figure 4. As illustrated therein, the banding and incorporation mitigation measures reduce atrazine and alachlor concentrations by a factor of about two with little difference between the two mitigation measures. The pre-plant application of glyphosate (used to avoid the need for tillage) is not necessarily associated with Roundup Ready corn, as this application can be used with any corn variety. However, the post-emergence applications of both glufosinate and glyphosate are made exclusively to transgenic, herbicide-tolerant corn. Annual concentrations from each application of glyphosate can be added to obtain an average annual concentration, but peak concentrations are less than the sum of peak concentrations resulting from each application.

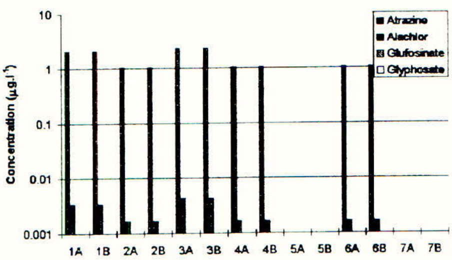


Figure 3. Tier 2 Modeling predictions of mean concentrations in soil pore water at 2m soil depth

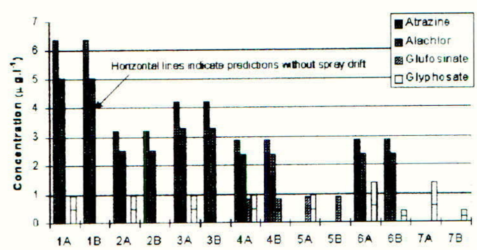


Figure 4. Tier 2 Modeling predictions of 90$^{th}$ percentile annualized mean concentrations in an index reservoir (Illinois soil/weather scenario)

Interpretation of the simulation results should consider the predicted concentrations relative to their respective MCL's (which are different for each of the four compounds). The results show that the annual average concentrations expressed as a fraction of the guideline level are significantly lower for glyphosate and glufosinate than for atrazine and alachlor. This is due to three factors. First, the amount applied per unit area is somewhat less than with the conventional herbicides, making less compound available for runoff (the pre-plant application of glyphosate is not included in this statement). Second, the soil sorption of both compounds is higher, making the percent loss in runoff generally lower, for this range of $K_{oc}$ values. Finally the permissible water quality standards are numerically larger for both glyphosate and glufosinate.

## CONCLUSIONS

The simple screening modeling predicts that the displacement of insecticides by two *Bt*-cropping systems is likely to significantly reduce the potential for exceedances of aquatic toxicology threshold concentrations in vulnerable watersheds. The higher tier computer modeling predicts that herbicide treatment scenarios associated with transgenic, herbicide-tolerant corn result in lower drinking water concentrations. All three transgenic cropping systems are predicted to result in significantly lower pesticide concentrations in ground and surface waters, thereby reducing whatever impacts these products have on drinking water quality and related ecosystems.

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# Evaluation of best management practices in a midwestern watershed

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## ABSTRACT

The impact of agricultural production on water quality continues to be a major issue. Every public water supply in the United States is required to sample quarterly for regulated contaminants, including several herbicides. Best management practices (BMPs) have been shown to effectively reduce herbicide and sediment movement into surface water. The goals of this five-year project are to evaluate a range of BMPs for protecting surface water, and to assess changes on a watershed scale. The study area is a 66,000 hectare watershed in central Illinois. Surface water quality is being monitored using a network of 12 in-stream sampling stations. Automatic samplers record stream flow data and collect water samples from five to six runoff events annually. The sampling network will help identify vulnerable areas in the watershed and track changes over the course of the project. Water samples are analyzed for six herbicides, nitrate, phosphorus, and total suspended solids. On-farm demonstration plots have been established to study specific BMPs and evaluate their effectiveness on reducing runoff. In addition, a geographical information system (GIS) framework is being developed for the entire watershed to assist in project evaluation.

## INTRODUCTION

National and state monitoring studies of surface water quality have helped identify the most common contaminants, and when they are most likely to occur. The extent of pesticide loss from treated fields due to surface runoff can range from less than one percent to over ten percent of the applied product (Wauchope, 1978). Several have shown that chemical losses are often greatest when heavy rainstorms closely follow pesticide applications (Thurman *et al.*, 1991).

In April 1994, a 15 cm rainstorm in a 24-hour period produced considerable runoff and resulted in high levels of atrazine in Lake Springfield. Although atrazine concentration in finished water was temporarily elevated, the public water supply never exceeded the maximum contaminant level (MCL) of 3 μg $L^{-1}$. The water utility was able to treat with powdered activated carbon (PAC) to successfully reduce atrazine concentrations in the finished drinking water, but it was an expensive process (Brown *et al.*, 1996).

The practice of treating with PAC has been successfully used to manage atrazine fluctuations in the lake. Figure 1 and figure 2 demonstrate the variation of atrazine concentration in Lake Springfield between 1998 and 1999, while finished water levels are kept relatively consistent.

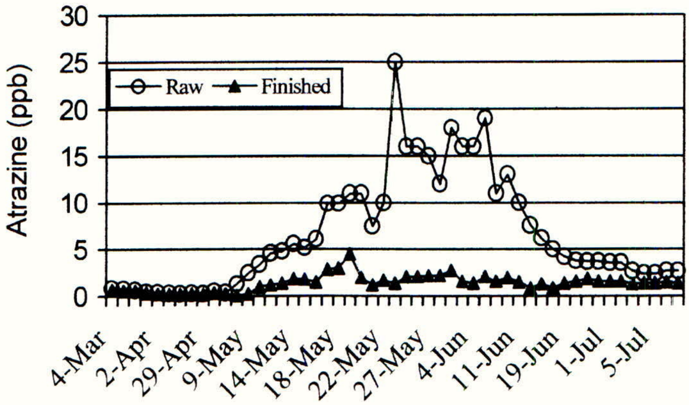


Figure 1. Atrazine concentration in Lake Springfield raw and finished water in 1998.

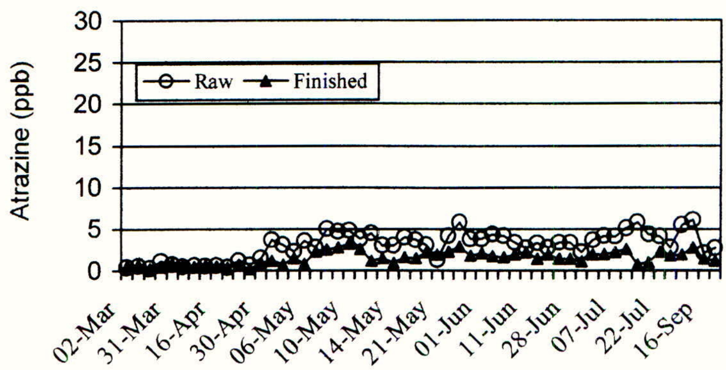


Figure 2. Atrazine concentrations in Lake Springfield raw and finished water in 1999.

Although treatment may reduce seasonally high concentrations of pesticides in water, most would agree that prevention and reducing the risk of pesticide runoff is a preferred approach. Best management practices are designed to minimize adverse impacts on surface water and groundwater quality. In addition to protecting the environment, these practices must be economically sound. Baker and Mickelson (1994) reviewed management factors such as herbicide application and timing, conservation tillage, and filter strips for minimizing herbicide runoff. Hirshi *et al.*, (1997) provided a comprehensive summary of management practices for protecting surface water.

BMPs that are specific to a watershed are likely to be more effective than treating every acre the same way. In most cases, a combination of practices will be required to achieve water quality goals, and the suggested BMPs may vary depending on soils, topography and individual farm operation.

## MATERIALS AND METHODS

Lake Springfield is a 1,700 hectare reservoir with a storage capacity of approximately 66 billion liters of water. It is the public drinking water supply for over 150,000 people. The Lake Springfield watershed includes 66,000 hectares of area southwest of the actual lake. Approximately 88% of the watershed's highly productive soils are intensively cropped, with about 61,000 hectares planted each year. Historically, sedimentation has been a concern in the area, and was a major reason that a watershed resource planning committee was formed in 1990.

### BMP demonstration project

The Lake Springfield Watershed project is a collaborative effort involving many different individuals and groups. It includes farmers and landowners, City Water, Light and Power, the Illinois State Water Survey, the Natural Resource Conservation Service, Syngenta Crop Protection, Inc., Sangamon County Soil and Water Conservation District, the Soil Tilth Laboratory/USDA/ARS and University of Illinois Extension.

Specific goals of the project are to; 1) evaluate the effectiveness of BMPs for protecting surface water 2) identify combinations of BMPs that can reduce off-site movement of sediments, pesticides, and nutrients and 3) provide farmers and landowners a range of alternatives that are both environmentally and economically viable.

Practices such as grass filter strips, riparian buffers, waterways, sediment control basins, conservation tillage, and integrated pest management are some of the possible solutions. Some of these BMPs will be monitored at the field and sub-watershed level.

Currently, 12 in-stream automatic samplers are installed. This sampling network will help to identify vulnerable areas in the watershed and track changes over the course of the five-year project. Automatic samplers record stream flow data during five or six major runoff events, while grab samples are periodically collected all year. Water samples are being analyzed for atrazine, simazine, cyanazine, alachlor, metolachlor, acetochlor, nitrate nitrogen, ortho-phosphorus, and total suspended solids

## DISCUSSION

Over the course of this five-year project, data from over 300 runoff events will be collected. An example of one runoff event from a single station is presented. Atrazine and acetochlor concentrations from stream sample station #2 on May 4, 1998 are shown in Figure 3. During 1998, automatic samples were taken at two-hour intervals during runoff events.

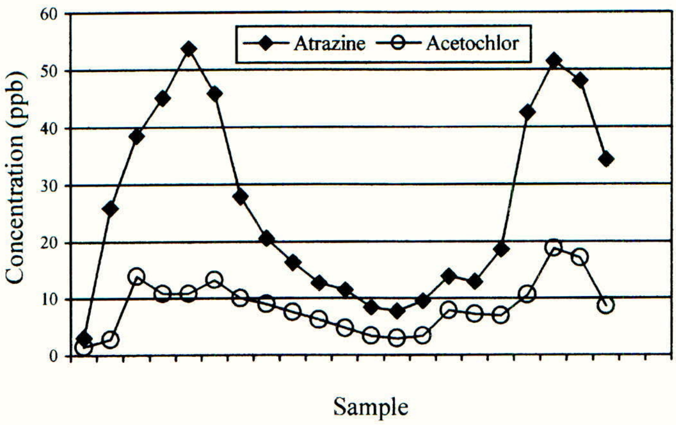


Figure 3. Herbicide concentration at stream station #2 on May 4, 1998.

Although soil erosion and herbicide runoff are the primary water quality concerns in this project, nutrient levels in streams are also being measured. Figure 4. shows the nitrate nitrogen concentration at station #2 during the May 1998 runoff event. During rainfall events, stream stations recorded nitrate levels above the drinking water standard of 10 mg $L^{-1.}$ However, nitrate concentration in the lake rarely exceeds 5 mg $L^{-1}$

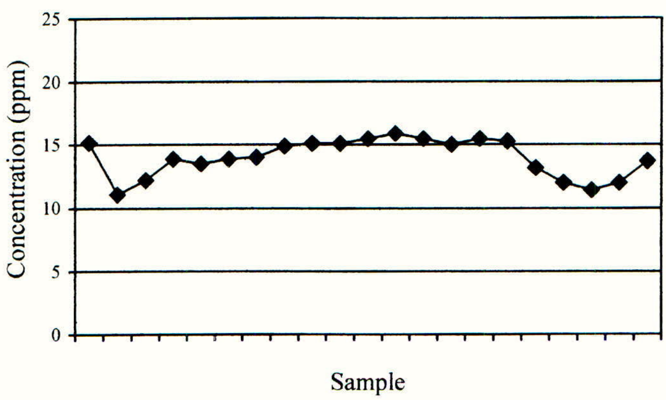


Figure 4. $NO_3$ –N concentration at stream station #2 on May 4, 1998.

### On-farm demonstrations

Working with local farmers, edge-of-field research sites were established to study specific BMPs and evaluate their effectiveness in reducing soil erosion and surface water runoff.

Practices include a disk-chisel system with and without a grass filter strip, a first year term no-till system, and a long-term no-till system. Treatments were replicated three times. Plots were 22 m long and 11 m wide and were surrounded by metal borders. Runoff was directed into a 208-liter collection reservoir that was emptied and analyzed after each rainstorm.

As shown in Figure 5, filter strips significantly reduced atrazine concentrations in runoff from small plots following a rainstorm.

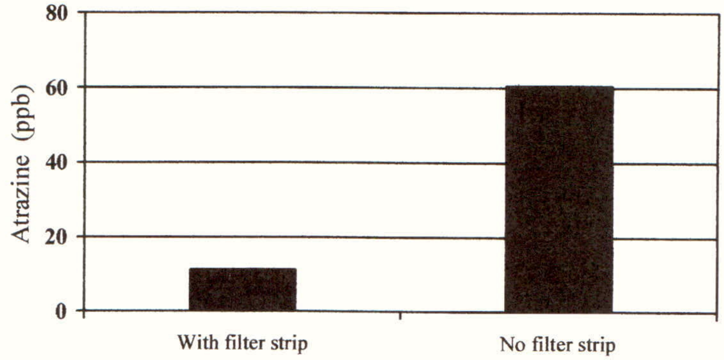


Figure 5. Atrazine concentration in runoff on April 28, 1999.

Figure 6 shows a comparison of first year no-till plots with long term (12 year) no-till plots on April 5, 1999. Atrazine concentration in runoff was reduced by approximately 90% in the long-term no-till system compared to a field in its first year of no-till.

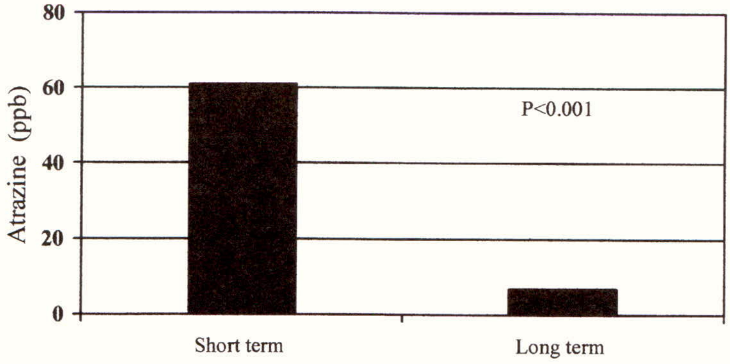


Figure 6. Atrazine concentration in runoff on April 5, 1999.

Geographical information system (GIS) and information databases are being created for the entire watershed to assist in data evaluation. Since education is a major component of the project, regular updates and progress reports are provided to farmers, landowners, and the general public. Additional publications, field meetings, and demonstrations will continue over the course of the project.

The Lake Springfield BMP project brings together many different groups and organizations that may have individual interests, but that all share the common goal of protecting water resources. Since it is being directed at the local level, it relies heavily on the input and involvement of people living in the watershed. Finally, the experience and knowledge gained from this project can be shared with other communities in Illinois and across the country.

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