Proceedings of the Integrated Crop Management Conference

Proceedings of the 22nd Annual Integrated Crop Management Conference

Dec 1st, 12:00 AM

Fifty years of atrazine in Iowa: Benefits, impacts, and current status

Richard S. Fawcett
Fawcett Consulting

Fifty years of atrazine in Iowa: Benefits, impacts, and current status

Richard S. Fawcett, Fawcett Consulting

Atrazine was first registered for use in the U.S. in 1958. It quickly became the preferred herbicide of corn growers, controlling both grasses and broadleaf weeds and being used either as a postemergence or preemergence application, unlike the primary alternative herbicide of the time, 2,4-D (Muller 2008). Over 50 years later, atrazine is still an important weed management tool for corn growers, and was the most widely used herbicide until recently when only glyphosate was used on more acres.

Atrazine was used on 42% of corn as reported in the first Iowa State University pesticide use survey done in 1977 (Table 1) (Jennings and Stockdale 1978). At that time atrazine was used little in North Central Iowa, where high pH soils increased risk of carryover at common atrazine use rates of the time which were higher than those used today. By 1990, atrazine was used on 61% of Iowa corn, being by far the most commonly used corn herbicide (Hartzler and Wintersteen 1991). Atrazine use remained at 60% or above through 2005 (the latest USDA National Agricultural Statistics Service data available), despite the introduction of many new herbicide active ingredients.

Table 1. Percent of Iowa corn treated with atrazine.

Year	% Corn Acres Treated
1977	42
1985	49
1990	61
1996	68
2000	64
2005	61

1977, 1985, and 1990 data from Iowa State University Pesticide Use Surveys; 1996, 2000, and 2005 data from USDA National Agricultural Statistics Service Surveys.

Atrazine use rates have been lowered especially as it has been used in more combination and sequential treatments. Atrazine is now used routinely in the high pH soil region of North Central Iowa, where rates of 1 lb/A and less present a relatively low risk of potential carryover and thus do not impact soybeans which are commonly grown in rotation with corn. While rates of 2 lb/A were common outside North Central Iowa 20 years ago, today average rates of application in Iowa are a pound per acre or less.

Atrazine's benefits in improved weed control and yields have been evident to corn growers, accounting for its widespread usage. Atrazine has become even more important in the last two decades due to its facilitation of conservation tillage which significantly reduces soil erosion and siltation. The soil residual activity of atrazine helps to control weeds which can germinate sporadically through a season when the one time germination stimulus of tillage is lacking in no-till systems. Atrazine also performs well in heavy crop residue conditions, as it is washed with rainfall off surface crop residue to reach the soil. Atrazine is used preferentially by conservation tillage farmers, and was applied on 65% of no-till corn, 57% of reduced tillage corn, and 32% of conventional tillage corn in the US in 2009 (GfK Kynetec). Conservation tillage in turn produces many environmental benefits including reduced soil erosion, less siltation of waterways, less nutrient and pesticide runoff, fuel savings, carbon sequestration, and improved wildlife habitat (Fawcett 2008). More recently, atrazine has become an important tool in management of herbicide resistant weed biotypes and represents an alternative mode of action to glyphosate which is now the most widely used herbicide in both corn and soybeans, and as such, has caused increasing selection pressure for glyphosate-resistant weed biotypes.

Groundwater

Due to its widespread use and its physical properties, atrazine has been detected in Iowa's ground and surface water, although nearly always at concentrations below its drinking water standard of 3 parts per billion (ppb). Monitoring in the 1980's led the Iowa Department of Natural Resources (IDNR) to estimate that over 40 percent of all wells in Iowa had pesticide detections (Fawcett 1989a). The consequent publicity and public concern eventually helped to spur subsequent passage of groundwater legislation in Iowa. The first action of the Iowa legislature directed the IDNR to develop the Iowa Groundwater Protection Strategy. This document, released in January, 1987, served as a basis for the Iowa Groundwater Protection Act, passed by the legislature a few months later.

The Groundwater Protection Strategy drew several conclusions as to the source of pesticides detected in groundwater, based largely on Iowa Geological Survey Bureau (IGSB) studies such as the Big Spring Study and public and rural well monitoring. These conclusions were challenged by some water quality researchers. Conclusions included: "It is clear that the most commonly used pesticides are leaching to shallow groundwater across the state," and "that the major source of these pollutants is their widespread application to farm fields and subsequent movement through soils to groundwater." The Groundwater Protection Strategy ruled out point sources as causes of detected contamination in Iowa, assuming that concentrations from point sources should be much higher than what was being detected.

The Big Spring Study, conducted by IGSB in northeast Iowa, raised questions about pesticides in groundwater, especially atrazine. Big Spring, fed by a 103-square-mile watershed in Clayton County, was sampled about 65 times a year starting in 1982, with water samples analyzed for the presence of pesticides and nitrate (Libra et al. 1991). While this study provided one of the first comprehensive long-term studies of pesticides in groundwater, the presence of many sinkholes in this karst topography, which allowed surface runoff direct entry into the shallow aquifer feeding the spring, complicated the interpretation of results. IGSB personnel at the time concluded that sinkholes were not important in delivering pesticides to the aquifer. It is now accepted that such sinkhole-fed aquifers actually behave more like rivers (surface water), greatly increasing in flow with muddy water with every runoff event. Figure 1 shows the annual flow weighted average atrazine concentrations in Big Spring water. Starting at about 0.2 ppb in 1982, concentrations rose each year to almost 0.7 ppb in 1985. This led to alarming predictions that these detections were the "tip of the iceberg", with much higher concentrations coming in the future. The data showing an increase in concentrations puzzled many researchers, because it was very different from studies in other regions where no upward trends had been found. Variations in weather, with more springtime runoff events delivering atrazine down sinkholes in later years, likely caused the uptrend. I waited anxiously for 1986 results. It was a long wait. IGSB personnel would not release data from 1986, 1987, and 1988. In the meantime the alarming graph showing atrazine concentrations going up and up was used to support regulatory actions such as the Iowa Groundwater Protection Act in 1987. It was only after the National Agricultural Chemicals Association filed a Freedom of Information Act request in 1989 that the IGSB released data from 1986 to 1988 to Iowa State University. The data that had been locked away showed that rather than continuing to increase, as portrayed by the IGSB, atrazine concentrations had actually been falling every year, ending up at the lowest concentration of the study, which represented an 80% decline. Atrazine concentrations fluctuated in later years with rainfall and runoff changes. The last data for the Big Spring study published are for 1999 (Liu et al. 2000). From 1992 through 1999 annual flow weighted mean atrazine concentrations were around 0.2 ppb or less.

Unlike the IGSB initial assumptions, sinkholes are very important in delivering atrazine and other pesticides to the aquifer. Runoff carries dissolved atrazine and sediment adsorbed atrazine to the aquifer. The sediment-bound atrazine is then slowly released over time. So in years with high spring runoff the atrazine concentrations increased. In years with less runoff the concentrations decreased. The important lesson from the Big Spring study was that to protect the karst aquifers, as represented by the Big Spring study, field runoff into sinkholes should be reduced. The same kinds of practices used today to protect surface water, such as conservation tillage and buffers, work to protect these vulnerable karst aquifers.

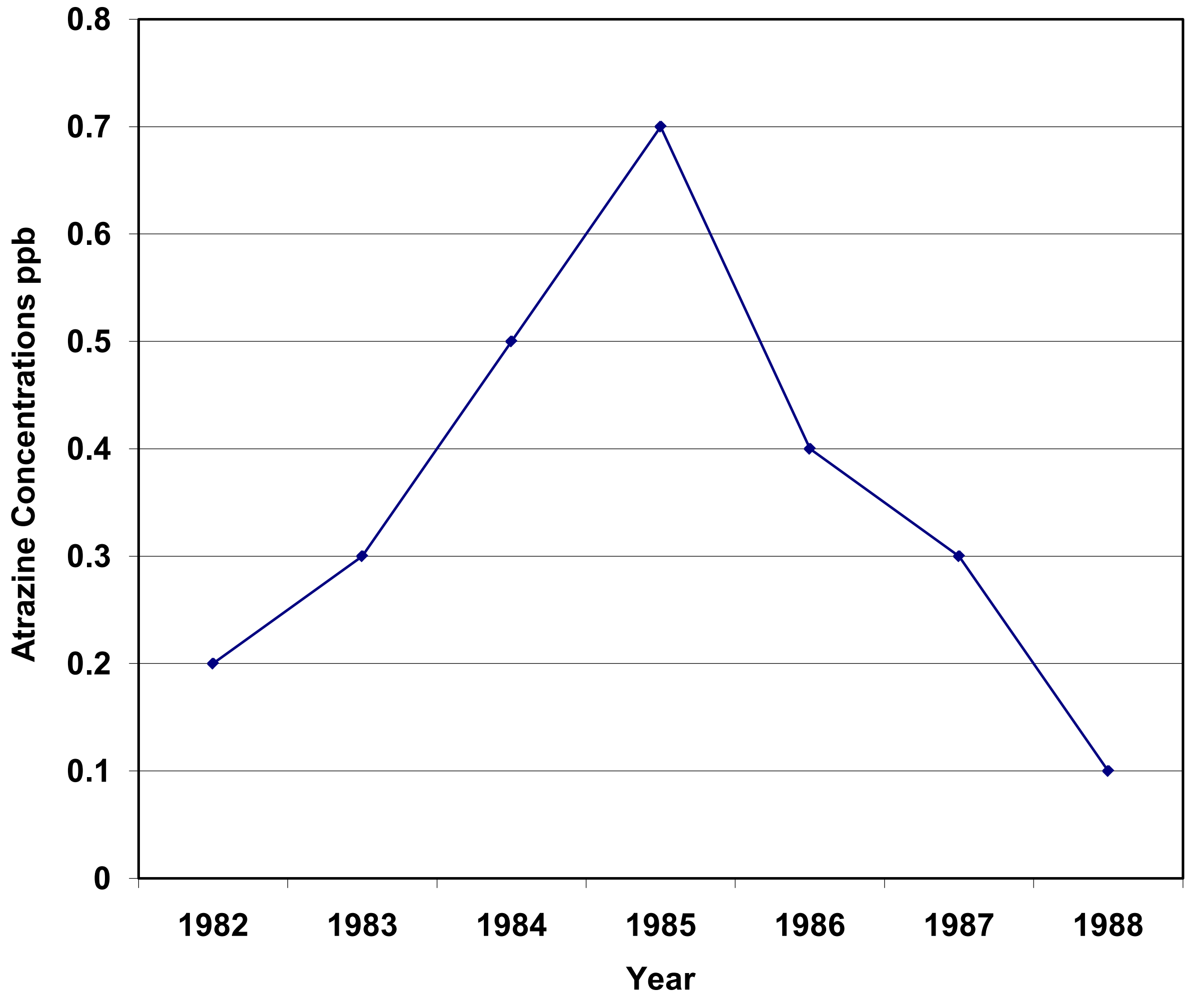

Figure 1. Annual mean atrazine concentrations in Big Spring, Clayton County, Iowa from 1982 to 1988. Source Libra et al. 1991.

Similar disagreements as to the causes of well contamination also occurred in the past, with the IGSB concluding nonpoint leaching from treated fields was the cause of detection of pesticides in wells (as per the Groundwater Protection Strategy), with point sources relatively unimportant. Many who knew how herbicides had been stored, mixed, handled, and especially where sprayers had been rinsed over the years, both at commercial facilities and on the farm, disagreed with this conclusion. Prior to diking and containment regulations which were enacted by the Iowa Department of Agriculture in 1985, it was common practice to rinse sprayers at the agricultural chemical dealership. Spills or leaks of pesticides were not contained to the extent they are today. Inevitably this built up concentrations of pesticides in the soil, exceeding the ability of the soil to adsorb the compounds. If the town well was a considerable distance away no problem would be encountered, but if the well was nearby and shallow, it might become contaminated.

In 1985, the IDNR tested all Iowa public water supplies for the presence of pesticides and other synthetic organic compounds. The Des Moines Register erroneously reported that two-thirds of Iowa public wells had pesticides detected. Contrary to this report, two-thirds had detects of other synthetic compounds, while just 8% had pesticide detects. Many of these wells were shallow wells in sand and gravel aquifers along rivers containing very low (less than 1 ppb) concentrations of atrazine. This type of well is directly influenced by surface water, and the atrazine source was likely nonpoint surface runoff to the river where it interacted with the underlying sand and gravel rather than it leaching from an agricultural field. Wells with any pesticide other than atrazine were less common, allowing me to personally inspect each well. Over 80% of all wells with pesticide detections other than atrazine (all herbicides except for one case of insecticide) had an obvious point source within a few hundred feet of the well, usually the local agricultural chemical dealer (Fawcett 1989c). Data from studies conducted in other states later showed similar results supporting these conclusions. In Illinois, 450 public wells were sampled for pesticides, and only 3 had pesticide detections. All wells with pesticide detections were near point sources. Because detected pesticide detections correlated so strongly with point sources, fifty-six wells definitely near agricultural chemical mixing-loading sites were analyzed. Forty-three of 56 wells, or 77%, contained pesticide residues (Fawcett 1989c).

The same kinds of pesticide mixing and disposal activities have taken place on the farm. Nearly always farmers mixed herbicides and rinsed sprayers at the well in the past, as that was the water source. Today, because of better awareness and use of mobile nurse tanks, farmers seldom fill and rinse sprayers at the farm well, but in the past the practice was nearly universal. Add the fact that rural wells often were not properly sealed in the upper 20 feet, as now required by the Iowa Well Code, and the risk to wells was increased even more. Not only did rinsing sprayers at the well risk contamination through leaching, but backsiphoning incidents were also common.

When we first used atrazine on my home farm when I was a kid, it didn't work very well. Back then we used a homemade sprayer made with 55 gallon drums for the only other herbicide we sprayed, 2,4-D. The sprayer simply didn't have any agitation and that coarse wettable powder formulation of atrazine had all sunk to the bottom of the barrel. It was there when we dumped the barrels out in the driveway in front of the well. Few worried about that kind of activity near wells even in the 1980s. A 1989 Wallaces Farmer survey showed that 58% of farmers reported that they filled their sprayers and mixed herbicides at the farm well (Fawcett 1989b). In confidential surveys I handed out at my Extension meetings in the late 1980s more like 80% of farmers reported mixing herbicides at the well.

Atrazine label changes and the Iowa Atrazine Management Plan

Concern about atrazine detections in wells led to changes in the federal label and in the adoption of the Iowa Atrazine Management Plan (one of the nation's first pesticide management plans) enacted by the Iowa Department of Agriculture. In addition to regulatory changes, intensive educational efforts were carried out by the Iowa State University Extension, herbicide manufacturers, and agricultural organizations.

In 1988, a groundwater advisory statement was added to the federal label, cautioning against use where surface soils are coarse and groundwater shallow. Wording of the advisory was: "This product is a chemical which can travel (seep or leach) through the soil and can contaminate groundwater which may be used as drinking water. This product has been found in groundwater as a result of agricultural use. Users are advised not to apply this product where the water table (groundwater) is close to the surface and where soils are very permeable, i.e. well-drained soils such as loamy sands. Your local agricultural agencies can provide further information on the type of soil in your area and the location of groundwater."

In 1989, the Iowa Secretary of Agriculture, Dale Cochran, signed administrative rules enacting the Iowa Atrazine Management Plan. Major components of the plan included:

1) Classification of atrazine as a Restricted Use Pesticide.
2) Reduction of maximum application rates statewide from 4 lb/A to 3 lb/A.
3) Mandate of annual reporting of atrazine sales by dealers.
4) Prohibition of application within 50 ft of sinkholes and wells.
5) Prohibition of mixing and loading within 100 ft of any well, cistern, sinkhole, streambed, lake, or impoundment.
6) Requirement that mixing, loading, and clean-out be conducted either with secondary containment or in the field.
7) Establishment of atrazine management areas where groundwater was highly vulnerable due to sinkholes, and/or agricultural drainage wells. In these areas, delineated at the township level in 23 counties, maximum atrazine rates were limited to 1.5 lb/A (one half the allowed rate in the rest of the state).

In 1990, the federal label was changed to include many provisions similar to those enacted in Iowa, such as Restricted Use Classification, requirement of untreated setbacks around wells and sinkholes, and a maximum rate reduction.

Although not specific to atrazine, diking and containment regulations enacted by the Iowa Department of Agriculture in 1985 were crucial in preventing contamination of public wells near agricultural chemical dealerships. Iowa was the first state in the nation to require impervious dikes and pads at pesticide storage, mixing and loading sites. Pesticide dealers had until November 1988 to install these systems (Fawcett 1989c).

Atrazine trends in Iowa groundwater

A number of monitoring studies are useful to track atrazine detection rates and concentrations over time. Each study is briefly summarized.

Iowa Groundwater Monitoring Program (IGWMP)

Since 1982, untreated, raw groundwater from Iowa municipal wells has been analyzed for the presence of selected pesticides. Using data from 89 wells which had been sampled repeatedly from 1982 to 1995, Kolpin, et al. (1997) analyzed for significant trends in pesticide concentrations using the Kruskal-Wallis test and a 95% confidence level. This analysis revealed a "substantive decrease in median atrazine concentration between the 1987 to 1991 and 1992 to 1995 time periods." There were decreases in median atrazine concentrations in 80% of the wells with atrazine detects, and alluvial wells showed the greatest decrease in those median concentrations. Precipitation changes were ruled out as a potential cause of atrazine trends, the authors concluding, "There is no apparent relation between precipitation and the temporal patterns in median concentrations found for atrazine." Rather, the authors concluded that changes in management of atrazine (lower use rates, increased postemergence application, and state management plan restrictions) were causes of declining atrazine concentrations in wells.

Iowa Pesticide Water Resources Database (IAPEST)

Initiated in 1991 by IGSB, the IAPEST database was begun to aid the Iowa Department of Agriculture in its development of a Generic State Pesticide Management Plan. A wide range of datasets from many sources is included in this database. Skopec and Hoyer (1998) analyzed this database for trends in pesticide detections from 1982-1995. The rate of detection (percent of samples with atrazine detected at any concentration) in groundwater declined from about 30% in 1982 to about 5% in 1995.

Floyd and Mitchell County well study

In 1986 and 1987 IGSB and the University of Iowa Department of Preventative Medicine conducted a study of farm wells in Floyd and Mitchell Counties, a region with shallow bedrock, sinkholes, and agricultural drainage wells. This study produced valuable background data, as this area was later designated an atrazine management area in 1989. Atrazine was detected far more frequently in these vulnerable wells than in other Iowa studies. Detection rates in Floyd and Mitchell counties were as high as 72%, compared to a 4% detection rate in the State-Wide Rural Water-Well Survey discussed later.

Quade et al. (1994) resampled these same wells in 1994, finding that both detection rates and concentrations of atrazine had declined. Atrazine was detected in 72% of wells in May 1986 and 64% of wells in May 1994. However, atrazine concentrations declined more dramatically from a mean concentration of 1.8 ppb in 1986 to 0.24 ppb in 1994 which represented an 87% decline. Maximum concentrations declined from 13.8 ppb to 1.1 ppb. In 1986, 6% of wells had a sample exceeding 3 ppb, which became the Maximum Contaminant Level (MCL) drinking water standard in 1991. In 1995, no wells exceeded the drinking water standard. Statistical analysis showed that these declines were highly significant. A comparison of water level and weather data between the two periods did not show any significant change in weather conditions, which could have led to the decline in atrazine. Rather, the authors concluded that the use of best management practices described in the Atrazine Management Plan led to the improved well water quality.

It is important to consider the fact that usage of atrazine in these counties did not decrease during this time period. In fact, herbicide use surveys conducted in 1984 and 1994 showed that atrazine use actually increased, although the average rate per acre remained nearly constant at 1.5 lb ac^{-1} (Quade et al. 1994). Use of atrazine in tank mixes and package mixes (often at reduced rates) has increased in Iowa, partially explaining the trend of use on more acres in

Iowa. By changing how atrazine was mixed and loaded (e. g. divorcing such activities from wells) and applied (e. g. use of runoff-filtering setbacks adjacent to sinkholes) farmers were able to still gain the weed control and economic benefits of atrazine while providing better protection to their wells, and improving groundwater quality.

Statewide rural well studies

The State-Wide Rural Well-Water Survey (SWRL) was a stratified, systematic sampling of water quality in randomly selected Iowa rural wells (Kross et al. 1990). Between April 1988 and June 1989, 686 private rural wells were sampled and analyzed for common pesticides. Wells were sampled once each throughout the 15-month period. Atrazine was detected in 4% of wells (8% of wells had either an atrazine detect or atrazine metabolite detect). The maximum atrazine concentration detected was 6.61 ppb. Five wells contained atrazine at concentrations exceeding 3 ppb.

In 2006-2008, 116 of the original SWRL wells were resampled (Center for Health Effects of Environmental Contamination 2009). A much lower detection limit in the new study complicates interpretation, as the new study had an atrazine detection limit of 0.05 ppb, compared to 0.13 ppb in the first SWRL study. However, the authors analyzed the data by using the same minimum detection limit (MDL) for both studies to allow for direct comparisons. They concluded "There were only 2 atrazine detections in the SWRL 2 sampling when using the SWRL MDL (0.13 ppb)." That would equal a detection rate of 1.7% in 2006-2008 compared to a 5.2% detection rate for the same wells in the 1988-1989 study. In the 1988-1989 study the maximum atrazine concentration detected was 6.61 ppb. In the 2006-2008 study, the maximum concentration detected was 0.5 ppb, six-fold below the 3 ppb drinking water standard.

Surface water

Pesticide runoff losses are influenced by how tightly chemicals are adsorbed to soil particles. Tightly adsorbed compounds are lost mainly adsorbed to eroded soil particles. Atrazine is moderately adsorbed (k_{oc} of 100) and is lost primarily dissolved in runoff water. Stopping soil erosion alone will not significantly reduce atrazine runoff. For this reason some early observers concluded that soil conservation practices like conservation tillage and filter strips would not reduce atrazine runoff. We now know that these practices change water behavior as well, slowing runoff and causing more infiltration, taking the chemical into the soil where it can do its job and degrade naturally. As farmers have adopted best management practices (BMPs) to reduce soil erosion, pesticide and nutrient runoff also have been reduced. The USDA Natural Resource Conservation Service (NRCS) recently concluded that current adoption of soil conservation practices alone has resulted in a 51% reduction in atrazine loads in the Mississippi River (USDA-NRCS 2010).

The atrazine federal label was changed in 1993 to address occurrence in surface water. The maximum rate (total per season) was reduced from 3 lb/A to 2.5 lb/A, with an additional rate restriction of 1.6 lb/A on highly erodible land (HEL) unless protective surface crop residue is present. A 66 foot untreated setback was required at points of entry of surface runoff into streams. A 200 foot untreated setback was required adjacent to lakes and reservoirs. The atrazine label was the first pesticide label to tie application rates to the presence of runoff -reducing surface crop residue and to require buffers next to streams. Few other pesticides require such surface water protecting setbacks. Therefore, more surface waters are protected from all pesticide runoff when atrazine is used in combination with other products.

In the paper "Efficacy of Best Management Practices to Reduce Runoff of Chlorotriazine Herbicides to Surface Water: A Review" research conducted on various BMPs and their effectiveness in reducing atrazine runoff is summarized. This full paper is available on the Iowa State University Weed Science Website (www.weeds.iastate.edu). Some highlights from the review paper: Over nine site-years of data in published natural rainfall runoff studies reductions in runoff of atrazine and simazine with no-till ranged from 23 to 100% and averaged 75%. In 18 filter strip studies, retention of atrazine ranged from 2 to 100% and averaged 68%. In eight studies of mechanical incorporation, reductions in runoff with incorporation ranged from 36 to 72% and averaged 51%. Postemergence application reduced atrazine runoff by 70%. Large ranges of effectiveness of BMPs are due mainly to differences in soil moisture content at the time of the study. When soil is saturated, practices like conservation tillage and filter strips do not increase infiltration as much as when soils are drier. Increases in infiltration account for much of the benefits of conservation tillage and filter strips in reducing atrazine runoff.

Atrazine trends in Iowa surface water

Many BMPs commonly used by Iowa farmers have been effective in reducing atrazine runoff in controlled studies. So how have they worked in the real world? Extensive surface water monitoring has documented dramatic declines in atrazine concentrations.

U.S. Geological Survey (USGS) monitoring

Midwestern rivers have been repeatedly monitored by the USGS during spring runoff events, timed when maximum herbicide concentrations were expected. Median atrazine concentrations declined from 10.9 ppb in 1989 to 5.54 ppb in 1995, and to 4.27 ppb in 1998, a 61% decline (Thurman and Scribner 2008). The authors concluded that "changes in herbicide usage and best management practices have significantly decreased the amount of atrazine and cyanazine concentrations found in surface water." A more recent analysis of National Water-Quality Assessment monitoring data (Sullivan et al. 2009) confirms the continued downward trend in atrazine concentrations in surface water across the Midwest through 2006.

Rathbun Lake

Monitoring results from Rathbun Lake provide strong evidence that BMPs used by farmers are working. Rathbun Lake, in southern Iowa, is typical of many reservoirs providing drinking water to rural and urban residents. The 11,000 acre lake provides drinking water for 70,000 people in Iowa and Missouri. The watershed contains more than 354,000 acres of farmland, much of which is HEL and vulnerable to herbicide field runoff. The Rathbun Regional Water Association (RRWA) has participated in voluntary atrazine monitoring programs since 1994, sampling raw and finished water every week from April through September, when atrazine concentrations are likely to be highest, and every other week for the remainder of the year. Atrazine annual mean concentrations in raw water which began at about 2.5 ppb in the mid-1990s have consistently dropped over the years so that in 2009, the mean concentration was 0.41 ppb, the lowest concentration of the entire period (Figure 2). Atrazine concentrations are now far below the 3 ppb MCL drinking water standard, even in the untreated water. While differences in rainfall patterns can cause up or down changes in runoff from year to year, atrazine concentrations have clearly declined dramatically in this reservoir, with current annual mean atrazine concentrations at only 15% of those which occurred in 1996. A sign of the improving surface water quality in Iowa is the fact that surface water samples from the IDNR's Ambient Water Quality Monitoring Program are no longer analyzed for atrazine. When the number of analytes in the program were reduced for budgetary reasons in 2008, atrazine was eliminated due to relatively low detection rates.

Educational efforts related to atrazine in the Rathbun Watershed began in 1992 with the Southern Iowa Herbicide Education Program (SIHEP), sponsored by Ciba-Geigy (now Syngenta), the Iowa Fertilizer and Chemical Association, the Iowa Natural Heritage Foundation, and Iowa Area XV Regional Planning Commission. Farmer and dealer meetings discussing BMPs were held and educational materials produced, including a videotape featuring John Glenn, a no-till farmer in the watershed who was then Water Distribution Superintendent for the RRWA (Fawcett 1993). Today, Glenn is the Chief Executive Officer of RRWA. Educational activities once performed by SIHEP are now carried out by the Rathbun Land & Water Alliance, which promotes a wide array of BMPs addressing nutrients, bacteria, sediment and pesticides.

It is important to note that the dramatic decline in atrazine concentrations in Rathbun Lake occurred during a time when atrazine continued to be widely used in the watershed. The Iowa Groundwater Protection Act of 1987 directed the Iowa Department of Agriculture and Land Stewardship (IDALS) to collect pesticide sales data from pesticide dealers. Pope et al. (2005) have used these sales data to calculate usage of selected pesticides by USDA Crop Reporting Districts (CRD). As pesticides may be bought in one CRD and applied in another, and pesticides purchased in one year may be applied in the next, these sales data do not exactly represent annual usage in a CRD, but are useful in examining trends over time. Rathbun Lake Watershed is entirely contained in the South Central Iowa CRD. Atrazine amounts sold in this CRD remained relatively constant from 1994 through 2005, the last year sales data are available (Figure 2). Annual mean concentrations of atrazine in untreated raw reservoir water declined from a high of 2.7 ppb in 1996 to a low of 0.4 ppb in 2009, an 85% decline. Despite the continued reliance on atrazine by southern Iowa farmers, atrazine concentrations in the Rathbun Lake have steadily declined since 1996. Thus, it is evident that the reason for the decline in atrazine concentrations in the Rathbun Lake is not due to a decline in atrazine use, but rather to the widespread adoption of BMPs which keep pesticides on the land and out of the water resource. Farmers have been able to continue receiving the benefit of atrazine while improving water quality.

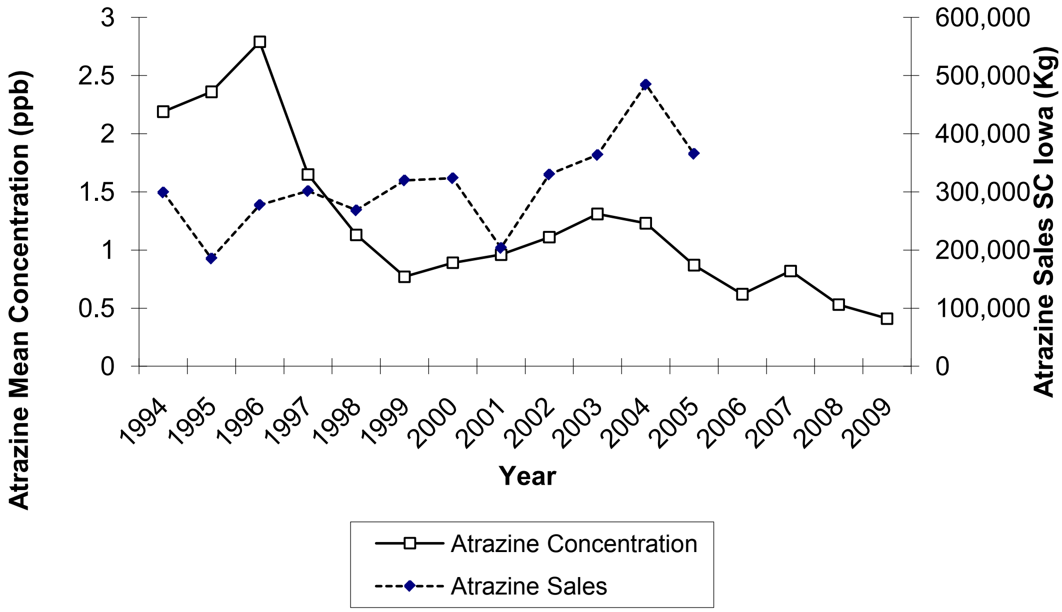

Figure 2. Annual mean concentrations of atrazine in raw water from Rathbun Lake, 1994-2009 and annual atrazine sales in the South Central Iowa Crop Reporting District containing the Rathbun Watershed, 1994-2005. Atrazine concentration data are from Syngenta Atrazine Monitoring Programs. Atrazine sales data are from Pope, et al. 2005 for 1994-2001 and from Richard Pope, Iowa State University for 2002-2005. Atrazine rate per planted corn acre reported by Pope, et al. 2005 has been converted to total sales in the CRD using USDA National Agricultural National Agricultural Statistics Service corn acreage values.

Other southern Iowa reservoirs

Atrazine concentrations have declined in the other reservoirs used as drinking water sources across Southern Iowa. For example, an Atrazine Mitigation Plan was developed for Lakes Morris and Ellis at the Chariton Community Water System (CWS) in 2003. As a requirement of the reregistration of atrazine in 2003, USEPA required the development of Atrazine Watershed Mitigation Plans for eight CWS in the U.S., including Chariton. As a part of the Mitigation Plan, twice a year watershed stakeholders were brought together to review monitoring results and to discuss appropriate BMPs to protect the lakes. Figure 3 shows monitoring results for raw (untreated) water from 1994-2008. Atrazine concentrations dropped significantly, and in 2008 USEPA waived any further requirements for monitoring at the Chariton CWS.

West Lake, at Osceola, was one of the first drinking water reservoirs targeted for educational efforts to reduce herbicide runoff, beginning over 20 years ago. The heavy, clay soils of this watershed increase herbicide runoff potential. In 1998, the lake was listed on Iowa's Impaired Waters (303d) list under the category of "pesticides". Later in 2002, a Total Maximum Daily Load (TMDL) for atrazine was adopted. Figure 4 shows that atrazine concentrations in the raw water have decreased significantly due to management efforts in the watershed. For the last six years atrazine concentrations in the finished water have been consistently 0.5 ppb or less. IDNR removed West Lake from the impaired waters list in 2008 due to the efforts of farmers in the watershed.

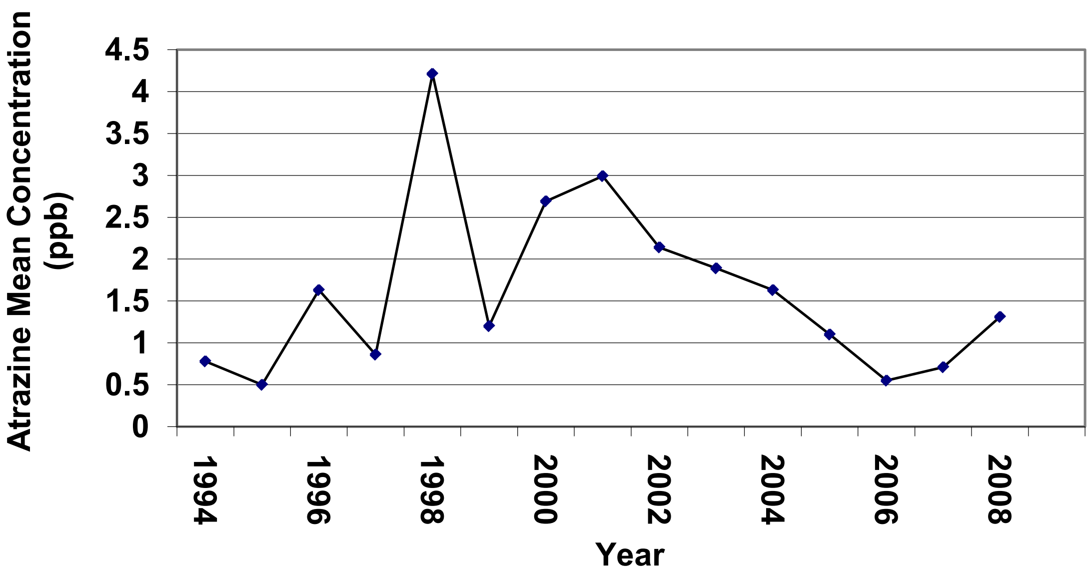

Figure 3. Annual mean atrazine concentrations in raw (untreated) reservoir water, Chariton, Iowa 1994-2008. Data are from Syngenta Atrazine Monitoring Programs.

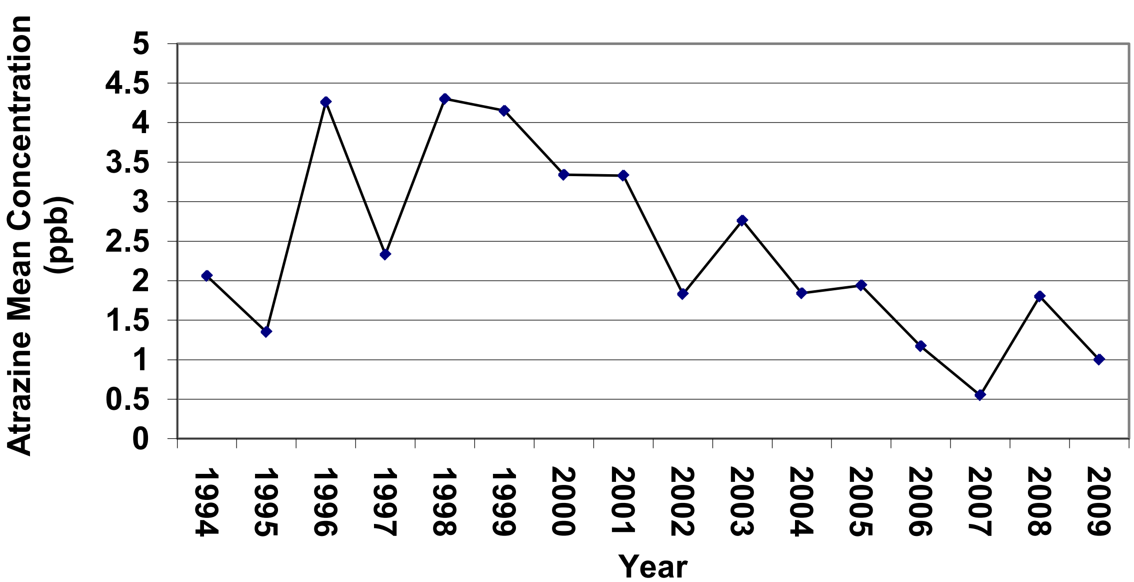

Figure 4. Annual mean atrazine concentrations in raw (untreated) reservoir water, West Lake, Osceola, Iowa 1994-2009. Data are from Syngenta Atrazine Monitoring Programs.

Atrazine benefits

Considering the long history of atrazine's wide use as the preferred herbicide in corn production, having to prove its benefits might seem unnecessary, since farmers presumably would not use it to the extent they have unless there were significant benefits. Never the less, there are activists who argue that there are no benefits to using atrazine. They say that the product could be banned, eliminating any concern about detections in water, and farmers would suffer no harm, simply switching to alternative herbicides. There have indeed been many new herbicides introduced as possible "atrazine replacements," but atrazine is now used with these new products to control weeds missed by these new chemistries. Atrazine improves the performance of nearly all corn herbicides. And while glyphosate could be used on glyphosate-tolerant corn to control most weeds without the addition of atrazine, glyphosate-resistant weeds have evolved, making atrazine even more important as a resistance management tool.

Several extensive analyses have been conducted for the Triazine Network using data from the North Central Weed Science Society Research Report to determine if there is a yield benefit to using atrazine in herbicide combinations when compared to other broad-spectrum herbicide combinations without atrazine (Fawcett 2008b). This journal was an outlet for annual university field research studies and was published for 62 years. Due to budgetary reasons, the journal was discontinued in 2006. No other source contained as much herbicide efficacy data as was in this journal. Studies reporting yields were identified and treatments containing atrazine were compared to treatments without use of atrazine. To make fair comparisons, any treatment included in the efficacy assessment had to control both broadleaf and grassy weeds, usually meaning at least two active ingredients were present. Treatments had to be registered for use and used at label rates. A number of other conservative treatment and study criteria had to be met to ensure consistent, fair comparisons. Data from 1986 through 1995 were analyzed and reported in 1996. Then the following 10 years of data, 1996 through 2005, were analyzed and also reported. Results of all 20 years of data are found in the paper "Twenty years of university corn yield data: with and without atrazine" (Fawcett 2008b). For the 20-year period, 236 qualifying studies were identified, with a total of 5,871 qualifying treatments. All data came from states in the Corn Belt, including results from Iowa State University. For the 1986-1995 period, corn yields averaged 6.3 bu/A or 5.9% higher with atrazine. For the next decade, 1996-2005, corn yielded an average 5.4 bu/A or 4.6% higher with atrazine. Thus, even with the introduction of all the new herbicide active ingredients and new technologies such as herbicide tolerant crops, the atrazine benefits remain.

One of the criteria for study selection was adequate numbers of atrazine and non-atrazine treatments in the study. However, many studies were excluded because they either had no non-atrazine or very few non-atrazine treatments. Further analysis showed that the number of treatments containing atrazine included by university researchers in their trials had increased over the years. Table 2 shows the percent of all treatments meeting selection criteria (broad-spectrum treatments) containing atrazine in university trials from 1986-2005. It shows a very interesting pattern. In early years about half of treatments contained atrazine. Then, beginning in the 1990s, at the time when many new active ingredients were being evaluated, treatments containing atrazine declined to a low of 17% in 1995. Then inclusion of atrazine steadily increased until 80% of treatments contained atrazine in 2004. It is clear that as researchers started to recognize the short-comings of new herbicides, they began to add atrazine to improve weed control. Similarly, herbicide manufacturers either included atrazine in package mix products (there are over 40 package mix corn herbicides containing atrazine) or recommending the use of atrazine in tank mixes.

Atrazine continues to provide consistent weed control and yield benefits to Iowa farmers at a very low cost. There would be economic consequences should its use be lost.

Current regulatory status

In 2003, USEPA issued its Interim Re-registration Eligibility Decision, confirming the safety of atrazine and allowing its continued use. This decision called for several ongoing research projects.

USEPA identified a list of CWS relying on surface water with a history of atrazine detects and targeted them for intensive atrazine monitoring. Many of these CWS already participated in Syngenta's Voluntary Atrazine Monitoring Program. Monitoring is being conducted for parent atrazine as well as its chlorometabolites, deethyl atrazine, deisopropyl atrazine, and diamino chorotriazine to determine total chlorotriazine (TCT). In addition, 8 CWS were identified that had reached a 90-day TCT rolling average of 12.5 ppb at least once between 1997 and 2002, requiring the implementation of a Watershed Atrazine Mitigation Plan for each (the Chariton mitigation plan results were described previously).

Table 2. NCWSS Research Report herbicide efficacy studies 1986-2005. Percent of treatments containing atrazine.

Year	% of treatments containing atrazine
1986	55
1987	60
1988	65
1889	46
1990	51
1991	46
1992	45
1993	29
1994	25
1995	17
1996	31
1997	46
1998	44
1999	45
2000	43
2001	47
2002	74
2003	76
2004	80
2005	79

Two of the eight CWS identified for mitigation plans no longer produce their own drinking water but purchase from other CWS. For the other six CWS, mitigation plans have been successful, with atrazine concentrations well below 3 ppb in both raw and finished water. Many of the CWS targeted for intensive monitoring have been waived out of the program by USEPA, as atrazine concentrations have been consistently below trigger levels.

Because one researcher had conducted studies indicating atrazine might harm gonadal development in frogs, USEPA convened a Science Advisory Panel (SAP) of experts in 2003 to review all existing data. The SAP ruled that the evidence was inconclusive on whether or not atrazine harmed amphibians. USEPA then required a further series of studies to be conducted. In 2007, following another SAP which examined the new studies showing no harmful effect on amphibians, USEA concluded that there is "no compelling reason to pursue more testing" on the question of the effect of atrazine on amphibian life.

USEPA asked for further studies on ecological monitoring. In 2007 an SAP met to review the new ecological studies. These studies are ongoing.

Atrazine's potential effects on human health have been exhaustively studied. In 2000 and 2001, SAPs and then the full USEPA concluded that atrazine is not likely to cause cancer. Previously, based on one animal study, it was considered to be a possible human carcinogen, causing extra safety margins to be used in calculating the 3 ppb drinking water standard.

In 2006, USEPA released the Triazine Cumulative Risk Assessment, finding triazine herbicides (one of which is atrazine) pose "no harm that would result to the general U.S. population, infants, children or other…consumers."

Even though atrazine has passed all the regulatory hurdles, activists have continued to press for its elimination. Following a series of newspaper articles on a Natural Resources Defense Council (NRDC) report about atrazine in drinking water from surface water sources, USEPA in 2009 announced an unprecedented "re-review" of atrazine and acknowledged that it was based on the newspaper stories. The first SAP convened to this re-review was understandably confused as to the reason for the review, as atrazine had just finished an exhaustive review. It is evident to many that the reason for USEPA's re-review is not based on any new scientific developments that would warrant regulatory changes, but rather appears to be due to politics and activist pressure. Four SAP meetings have been held and more are scheduled.

To understand the charges of risk from atrazine in drinking water made by NRDC, one needs to understand how current drinking water standards are applied. The drinking water standard applied through the Safe Drinking Water Act is called the Maximum Contaminant Level or MCL. For atrazine, the current MCL is 3 ppb. The MCL for atrazine is a chronic standard, based on an annual average exposure over a 70-year lifetime and includes a 1,000-fold safety factor. Most CWS sample four times a year to develop this annual average number. (CWS in Syngenta Atrazine Monitoring Programs sample about 40 times a year). The NRDC report purposely misrepresented data by saying that because certain water supplies exceeded 3 ppb on a single day, they had exceeded the drinking water standard and posed a risk to human health. These supplies were actually well within the standard, as annual averages were in fact below 3 ppb and single day concentrations were well below the single day health advisory. USEPA confirmed this fact.

USEPA has set Health Advisory Levels (HAL) to address these shorter-term exposures to chemicals. Table 3 shows HALs for atrazine. The 1-day and 10-day HAL for a child is 100 ppb, a concentration never seen in drinking water. The occasional increases of atrazine seen in some CWS using surface water do not exceed standards or pose a risk.

Table 3. Health Advisory Levels (HAL) and Maximum Contaminant Level (MCL) for atrazine.

Exposure type	HAL	MCL	Safety factor
	(ppb)	(ppb)	(ppb)
1-Day, Child	100	-	100
10-Day, Child	100	-	100
7-Year,Child	50	-	100
7-Year, Adult	200	-	100
70-Year, Adult	3*	3	1000

*70 year HAL = MCL

The existing MCL and HALs were calculated by USEPA Office of Drinking Water many years ago relying on older data and the assumption that atrazine was a possible carcinogen. Based on many new toxicological studies, atrazine is now classified as “not likely to be a human carcinogen”. If atrazine’s MCL were to be calculated today, it would be a higher number. In fact, in 2010 the World Health Organization raised its former atrazine water standard of 2 ppb, establishing the new standard at 100 ppb (www.who.int/water_sanitation_health/dwq/chemicals/atrazine/en/).

Another branch of USEPA, the Office of Pesticide Programs has, in fact, calculated new “standards” used in the re-registration of atrazine for the water monitoring and mitigation plans described previously. Table 4 shows Drinking Water Levels of Comparisons (DWLOCs) for atrazine and its chlorinated metabolites (TCT). TCT concentrations less than the DWLOCs are considered not to pose risk for human consumption. DWLOCs were calculated for many population subgroups. For infants, considered to be most sensitive, a DWLOC for a 90-day average was set at 12.5 ppb. Annual DWLOCs for other population classes range from 23 to 68 ppb. For females 13 to 50 a one-day DWLOC of 298 ppb was set. In all of the intense monitoring of CWS using surface water, none of these DWLOC standards has ever been exceeded.

Conclusions

Atrazine has provided economic and environmental benefits over the 50 years of its use by economically improving weed control and increasing yields. Despite the introduction of many new active ingredients, atrazine continues to be useful and widely used in Iowa, controlling weeds missed by other actives. Atrazine has recently become even more important in Iowa weed management systems, as it is needed in the management of herbicide-resistant weed biotypes, being an alternative mode of action to glyphosate which is now used repeatedly in both corn and soybeans.

Table 4. Summary of lowest Drinking Water Levels of Comparison (DWLOCs) for atrazine and its chlorinated metabolites from EPA-OPP Interim Registration Eligibility Decision (IRED), January 31, 2003.

Population subgroup	One day exposure (ppb)	90-day exposure (ppb)	Annual exposure (ppb)
General Population	-	-	68
Infants < 1 year old	-	12.5	-
Children 1 to 6	-	-	23
Children 7 to 12	-	-	53
Females 13 to 50	298	-	60
Males 13 to 19	-	-	68
Males 20 ad over	-	-	68
Seniors	-	-	68

Through facilitation of conservation tillage, use of atrazine has helped provide many environmental benefits, from reduced erosion and siltation into surface waters, to reduced runoff of nutrients and pesticides, to improved wildlife habit, to reduced fuel consumption, to sequestration of carbon. Should atrazine not be available, we could expect tillage to increase, reducing these environmental benefits. This would be especially true if weed resistance to glyphosate increases, as it has in some southern states. Farmers in the South have increased tillage where glyphosate-resistant weeds are not adequately controlled.

Prior to the Iowa Department of Agriculture's enactment of the Iowa Atrazine Management Plan in 1989, the Iowa Legislature considered a number of proposed actions on atrazine, including taxes and bans. Over 20 years later it is evident that taxes, bans, or other onerous regulations were not needed to protect Iowa's waters. The Atrazine Management Plan has worked to protect Iowa's most vulnerable groundwater where sinkholes and agricultural drainage wells are common. Commercial pesticide dealers have installed diking and containment which protects town wells. Farmers no longer fill and rinse sprayers at the farm well, but haul water to the field to mix herbicides and rinse in the field, applying the rinse water to the field. Many BMPs have been adopted by Iowa farmers, protecting both ground and surface water. Conservation Compliance provisions of the 1985 Farm Bill resulted in millions of new acres of conservation tillage and thousands of miles of grassed waterways. Conservation tillage is now "conventional" in many areas. Iowa is a leader in the installation of conservation buffers. Through the Continuous Sign-Up provision of the Conservation Reserve Program alone, over 600,000 acres of filter strips have been installed in Iowa as of April 2010 (USDA-FSA 2010). Atrazine remains a valuable tool for Iowa farmers, used on about as many acres as in the past, but used in different ways, reducing its potential impacts on Iowa's waters. Thanks to the efforts of Iowa farmers and agricultural chemical dealers, farmers are able to continue to realize the benefits from atrazine use, while atrazine concentrations in both ground and surface water have declined dramatically, easily meeting conservative drinking water standards.

References

Center for Health Effects of Environmental Contamination. 2009. Iowa statewide rural well survey phase 2(SWRL2). Results and analysis. University of Iowa, Iowa City.

Fawcett, Richard S. 1989a. Big Spring revisited. Agrichemical Age: Oct. pp. 16-19.

Fawcett, Richard S. 1989b. What is Big Spring really telling us. Wallaces Farmer. Nov. 14. pp. 10-13.

Fawcett, Richard S. 1989c. Contamination of wells by pesticides – solving the right problem. Groundwater Mon. Rev. 9:5-8.

Fawcett, Richard S. 1993. Agricultural environmental audits in the United States. Proc. Brighton Crop Prof. Conf. pp. 1107-1113.

Fawcett, Richard S. 2008a. Environmental benefits of triazine use in conservation tillage. In Homer LeBaron, Janis E.

McFarland, and Orvin C. Burnside, eds. The Triazine Herbicides. pp. 519-526. Elsevier, Amsterdam.

Fawcett, Richard S. 2008b. Twenty years of university corn yield data: with and without atrazine. Proc. North Cent. Weed Sci. Soc. 35 pp. www.ncwss.org.

Hartzler, Robert and Wendy Wintersteen. 1991. A survey of pesticides used in Iowa crop production in 1990. Pm 1441. Iowa State University, Ames.

Jennings, Vivan and Harold Stockdale. 1978. Herbicides and soil insecticides used in Iowa corn and soybean production, 1977.

Kolpin, D.W., D.Sneck-Fahrer, G.R. Hallberg, and R.D. Libra. 1997. Temporal trends of selected agricultural chemicals in Iowa's groundwater, 1982-1995: Are things getting better? Journal of Environmental Quality 26:1007-1017.

Kross, B.C. et al. 1990. The Iowa State-Wide Rural Well-Water Survey. Water-quality data: initial analysis. IDNR Technical Information Series 19.

Libra, R.D., G.R. Hallberg, J.P. Littke, B.K. Nations, D.J. Quade, and R.D. Rowden. 1991. Groundwater monitoring in the Big Spring Basin 1988-1989: a summary review. Iowa Geological Survey Bureau publication TIS-21.

Liu, H., R.D. Rowden, and R.D. Libra. 2000. Groundwater and surface water monitoring in Big Spring Basin 1996-1999: A summary review. Iowa Geological Survey Bureau publication TIS-44.

Muller, Gustav. 2008. History of the discovery and development of triazine herbicides. In Homer LeBaron, Janis E. McFarland, and Orvin C. Burnside, eds. The Triazine Herbicides. pp. 13-29. Elsevier, Amsterdam.

Pope, Rich, Mary Skopec, and Jim Ellerhoff. 2005. Pesticide use and water quality. Proc. 2005 Agriculture and Environment Conf. Iowa State University, Ames, IA.

Quade, D.J., M.P. Skopec, and R.D. Libra, 1994. A preliminary evaluation of the atrazine management areas in Floyd and Mitchell Counties, Iowa. Iowa Geological Survey Bureau Special Report to the Iowa Department of Agriculture and Land Stewardship.

Skopec, M.P. and B.E. Hoyer. 1998. Pesticide trends in surface and groundwater in Iowa: 1980-1995. Sixth National Nonpoint-Source Monitoring Workshop. Sept. 21-24, 1998, Cedar Rapids, IA.

Sullivan, Daniel J., Aldo V. Vecchia, David L. Lorenz, Robert J. Gillom, and Jeffrey D. Martin. 2009. Trends in pesticide concentrations in Corn-Belt streams, 1996-2006. U.S. Geological Survey Scientific Investigations Report 2009-5132.

Thurman, E. Michael, and Elisabeth A. Scribner. 2008. A decade of measuring, monitoring, and studying the fate and transport of triazine herbicides and their degradation products in groundwater, surface water, reservoirs, and precipitation by the U.S. Geological Survey. In Homer M. Le Baron, Janis E. McFarland, and Orvin Burnside, eds., The Triazine Herbicides. pp. 451-475. Elsevier, Amsterdam.

USDA-FSA. 2010. Conservation Reserve Program Monthly Summary – April 2010. Farm Service Agency. Washington, D.C..

USDA-NRCS. 2010. Effects of conservation practices on cultivated cropland in the Upper Mississippi River Basin. www.nrcs.usda.gov/technical/nri/ceap.