IV. An Index Reservoir for Use in Assessing Drinking Water Exposure

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Office of Pesticide Programs has designed an index reservoir for use with EXAMS as a direct replacement for the farm pond. The reservoir has been designed to mimic drinking water reservoirs in the central Midwest known to be highly vulnerable to contamination from pesticides used in agriculture. The Index Reservoir will then be used in a similar manner to the standard pond, where it is treated as a standard receiving water body and connected with local soils data and weather to define a scenario that reflects local conditions. It would then represent the most vulnerable water bodies that could be used for drinking water in that region.

This chapter is divided into five sections. The first section gives a brief description of the reservoir scenario. Secondly we describe why this represents a vulnerable watershed suitable for assessing drinking water exposure. The third section describes how the EXAMS parameters were developed to describe the Index Reservoir. The fourth section compares results from use of the index watershed to the standard pond scenario and monitoring data. Lastly, we describe how OPP intends to further improve on the Index Reservoir scenario as it is described in this document

The Index Reservoir Scenario

The Index Reservoir was modeled after Shipman City Lake in Shipman, Illinois. Shipman is in west-central Illinois in Macoupin County. Shipman City Lake is a drinking water reservoir that served 365 people according to the Acetochlor Registration Partnership, or ARP, (Hackett,1995). The SDWIS database indicates that the Shipman drinking water facility serves 675 people (USEPA, 1998). Shipman City Lake was chosen because it has been shown to be highly vulnerable to contamination from the corn herbicides used in the basin, particularly atrazine. Shipman City Lake exceeded the MCL for atrazine ($3\ \mu g \bullet L^{-1}$) eleven times from 1991 to 1998. (USEPA, 1998)

Shipman City Lake was constructed in 1968 and covers 5.3 ha (13 acres). It is , on average, 2.7 m deep and the maximum depth is 5.8 m . It was constructed in 1968. The watershed encompasses 178 ha (427 acres) with about 50% Hydrologic Group B soils and 50% C and D soils (Hackett, 1995; Good, 1998). By inference from county level data, about 50% of the watershed is in agriculture production with corn and soybeans occupying about equal portions of the acreage. Shipman City Lake is on the Coop Branch of Macoupin Creek.

One important factor in determining watershed vulnerability is the ratio of the watershed drainage area to the reservoir's normal capacity ratio (DA/NC). The DA/NC for the standard pond currently being used for drinking water exposure assessment is 5 m^2/m^3. DA/NC's for drinking water reservoirs range from 0.5 to 5270 with a median DA/NC. This is based on data from Ruddy and Hitt, 1990 (Figure 1 in previous section). Note that these values are for reservoirs with normal capacities greater than 6,200,000 m^3 or maximum capacities greater than 30,000,000 m^3. These capacities are larger than most of the reservoirs considered in this assessment. (See Table 1.) Hence the standard pond is somewhat less conservative than the median water supply reservoir. The Index Reservoir has a DA/NC of 12 which is greater than approximately 90% of the drinking water reservoirs in Ruddy and Hitt. The reservoirs with very large DA/NC's tend to be in the Midwest and West and are often associated with large cities (Figure 2 in previous section). All other factors being equal, a large DA/NC is associated with higher concentrations in water for the pesticides that are most prone to move to surface water.

Scenario Selection

The Shipman City Lake was selected as the basis for the index reservoir because it is representative of a number of reservoirs in the central Midwest that are known to be vulnerable to pesticide contamination. These reservoirs tend to be small and shallow and to have small watersheds. Many of them frequently have Safe Drinking Water Act compliance problems with atrazine, which is often applied to the corn grown in these watersheds. A number of these reservoirs are listed in Table 1. Shipman is the smallest reservoir in this group, but also has one of the smallest DA/NC's. In 1996 , Shipman City Lake had the greatest atrazine concentration in this group (Hackett, 1996).

Parameter Selection

Geometry Parameters. The geometry parameters describing the Index Reservoir scenario are presented in Table 2. The primary source for the geometry data was an assessment performed by the Acetochlor Registration Partnership (ARP) to support the ARP's drinking water monitoring program for acetochlor. The watershed area is 427 acres (1,728,000 m^2) and the reservoir area is 13 acres. (Note that the watershed area is a PRZM parameter rather than an EXAMS parameter.) The mean depth of the reservoir is estimated to be 9 ft (2.7 m). The Illinois EPA (Good, 1998) has a different estimate, 320 acres, for the watershed area. However, the ARP is better documented and more recent, so this estimate has been used in the scenario. The latitude and longitude were available from several different sources. The length and width of the reservoir estimated from a United States Geological Survey topographical map. The elevation of the reservoir was also estimated from the topographical map.

Hydrology. Data on water flow through the reservoir were not available. Data were available on the mean volume of water used per day by the water supply is 246,000 L day^{-1} (Hackett, 1995). This flow rate accounts for approximately 62% of the reservoir volume in a year. Since there is also some discharge into the stream below the dam, the actual mean annual flow rate through the reservoir is greater than this value. An estimate of the runoff volume entering the reservoir was made using PRZM, assuming that the entire acreage of the watershed was composed of the Clinton silt loam (see below) which is a Hydrologic Group B soil and weather data from

Louisville, Kentucky weather station. Hydrologic Group B soils are the dominant soil in the watershed and, of those present, the least prone to generate runoff. Hence, using the runoff volume from this Hydrologic Group will produce a conservative (underestimated) flow into the reservoir. The flow rate was then estimated by dividing the mean annual runoff volume by the number of hours in a year. The flow rate calculated this way was 25.01 $m^3 \cdot h^{-1}$. For reference, the flow rate resulting in one turnover of the reservoir volume per year is 16.44 $m^3 \cdot h^{-1}$. This flow was effected by setting a stream flow (EXAMS variable STFLO) into the limnic layer of the reservoir. This will result in a discharge from the reservoir of the same volume.

While flow data for Coop Branch and/or Shipman City Lake are not available. There is an estimated flow for Macoupin Creek in Reach File 1 (USEPA, 1998b) of 3100 $m^3 \cdot h^{-1}$ below where Coop Branch enters. This provides an upper bound on the potential flow from Coop Branch since in cannot exceed this value.

The dispersive transport field is described by the parameters in Table 3. The parameters are identical to those for the standard pond except for the characteristic length of dispersion (CHARL) and the turbulent cross section (XSTUR). These two variables were set in accordance with the guidance in the EXAMS manual (Burns, 1997).

Table 1. Selected reservoirs in Illinois and Missouri that are vulnerable to pesticide contamination based on monitoring data (Good, 1998 and Hackett, 1996).

Reservoir	Watershed Drainage Area (m^2)	Reservoir Normal Capacity (m^3)	DA/NC (m^2/m^3)	1996 Mean Atrazine Conc. ($\mu g \bullet L^{-1}$)
Old Gillespie Lake* (Gillespie, IL)	14,832,000	233,313	63	7.6
New Gillespie Lake*, (Gillespie, IL)	18,616,000	2,604,000	7.1	7.6
Silver Lake (Highland, IL)	125,545,000	6,784,200	18	0.59
Lake Lou Yeager (Litchfield, IL)	251,179,000	NA		1.69
Lake Paradise (Mattoon, IL)	46,683,000	1,628,200	29	2.33
Nashville Reservoir** (Nashville, IL)	3,601,700	458,860	7.8	8.21
Washington County** Reservoir (Nashville, IL)	27,519,000	3,238,500	8.5	8.21
East Twin Lake*** (Paris, IL)	51,800,000	204,830	253	5.97
West Twin Lake*** (Paris, IL)	45,584,000	230,800	197	5.97
Salem Reservoir (Salem IL)	10,409,000	640,700	16	2.25
Shipman City Lake (Shipman, IL)	1,728,000	144,320	12	12.29
Lake Springfield (Springfield, IL)	669,921,000	76,742,000	8.7	3.44
White Hall Reservoir (White Hall, IL)	2,464,500	642,040	3.8	5.46
Vandalia Reservoir (Vandalia, MO)	14,787,000	57,262	258	3.35

*New Gillespie and Old Gillespie Lakes serve the Gillespie Water Supply. The same atrazine concentration has been used for both.
** Washington County Reservoir and Nashville City Lake serve the Nashville Water Supply. The same atrazine concentration has been used for both.
*** East Twin and West Twin Lakes serve the Paris Water Supply. The same atrazine concentration has been used for both.

A significant limitation to using EXAMS to represent large water bodies is its limited ability to handle turnover in stratified water bodies. EXAMS is capable of describing stratified water bodies for short periods of time but has limited ability to handle the change in mixing rate and loss of stratification that occurs at turnover in the spring and fall. Larger and deeper water bodies are more prone to stratify than smaller ones, as surface turbulence due to wind tends to keep smaller water bodies (pond-sized) well mixed. A limited temperature data set (1 day) for July 31, 1989 was available for Shipman City Lake from the Illinois EPA (Good, 1998). This data set shows a strong temperature stratification from 29° C at the surface to 11.5 ° C at the 5.8 m depth. The thermocline ranged from1.2 to 2.4 m where the temperature dropped from 28.9 to 19.5° C. While there is no geometry data for Shipman Reservoir that addresses the issue, the deep portions of reservoirs such as Shipman are often restricted to the flooded creek channel with the rest of the reservoir being substantially shallower. Thus, the portion of the reservoir which stratifies may be limited to the flooded creek channel. Since more complete depth profile data are not available, this is a substantial uncertainty in our use of EXAMS to model Shipman City Lake over multiple years.

Table 2. EXAMS II geometry for Index Reservoir.

	Littoral	Benthic	Source
Area (AREA)	52,609 m^2	52,609 m^2	Hackett, 1995
Depth (DEPTH)	2.74 m	0.05 m	Hackett, 1995
Volume (VOL)	144,000 m^3	2630 m^3	Hackett, 1995
Length (LENG)	640 m	640 m	estimated from map
Width (WIDTH)	82.2 m	82.2 m	estimated from map
Stream Flow (STFLO)	25.01 $m^3 \cdot h^{-1}$	0 $m^3 \cdot h^{-1}$	see text

Table 3. EXAMS II dispersive transport parameters between benthic and littoral layers in the Index Reservoir.

Parameter	Path 1*	Source
Turbulent Cross-section (XSTUR)	52609 m^2	Burns, 1997
Characteristic Length (CHARL)	1.395 m	Burns, 1997
Dispersion Coefficient for Eddy Diffusivity (DSP)**	3.0×10^{-5}	standard pond

* JTURB(1) = 1, ITURB(1) = 2; ** each monthly parameter set to this value.

Water and Sediment Properties. The sediment properties chosen are in Table 4 and the variables describing factors external to the pond are in Table 5. The sediment parameters represent those in a Georgia pond. The external variables are those that are recommended as default values in the EXAMS manual. The biological properties are listed in Table 6 and water column chemistry parameters are in Table 7. In all these cases, the parameters are identical to those used for the standard pond. The scenario could be improved by using locally appropriate water and sediment parameters; however, little data has as yet been obtained for Shipman City Lake from which to develop these parameters. It may be possible to develop these values using other similar water bodies as surrogate data sources. However, until these data can be developed, EPA will continue to use the standard pond values to maintain consistency with previous modeling. Since the Index Reservoir will in fact be used across the country, it will be eventually necessary to develop water quality parameters that are regionally appropriate.

Table 4. EXAMS II sediment properties for the Index Reservoir.

Parameter	Littoral	Benthic	Source
Suspended Sediment (SUSED)	30 mg L^{-1}		standard pond
Bulk Density (BULKD)		1.85 g cm^{-3}	standard pond
Per cent Water in Benthic Sediments (PCTWA)		137%	standard pond
Fraction of Organic Matter (FROC)	0.04	0.04	standard pond

Table 5. EXAMS II external environmental and location parameters for the Index Reservoir.

Parameter	Value	Source
Precipitation (RAIN)	0 mm $\cdot month^{-1}$	
Atmospheric Turbulence (ATURB)	2.00 km	standard pond
Evaporation Rate (EVAP)	0 mm $\cdot month^{-1}$	
Wind Speed (WIND)	1 m $\cdot sec^{-1}$	standard pond
Air Mass Type (AMASS)	Rural (R)	
Elevation (ELEV)	54.9 m	USGS map
Latitude (LAT)	39.12º N	USGS map
Longitude (LONG)	90.05º W	USGS map

Table 6. EXAMS II biological characterization parameters for the Index Reservoir.			
Parameter	Limnic	Benthic	Source
Bacterial Plankton Population Density (BACPL)	1 cfu $\cdot cm^{-3}$		see text
Benthic Bacteria Population Density (BNBAC)		37 cfu $\cdot (100\ g)^{-1}$	see text
Bacterial Plankton Biomass (PLMAS)	0.40 mg $\cdot L^{-1}$		standard pond
Benthic Bacteria Biomass (BNMAS)		$6.0x10^{-3}$ g $\cdot m^{-2}$	standard pond

Table 7. EXAMS water quality parameters for the Index Reservoir.		
Parameter	Value	Source
Optical path length distribution factor (DFAC)	1.19	Standard pond
Dissolved organic carbon (DOC)	5 mg $\cdot L^{-1}$	standard pond
chlorophylls and pheophytins (CHL)	$5x10^{-3}$ mg $\cdot L^{-1}$	standard pond
pH (PH)	7	standard pond
pOH (POH)	7	standard pond

Temperature data for the index reservoir are in Table 8. The temperature for each month was estimated by using the mean monthly air temperature data from the M115 meteorology data from PIRANHA (Allen *et al.*, 1992). This weather data is from Meteorological Station W13994 at St. Louis, Missouri. This data set includes 34 years of data ranging from 1950 to 1983. (See Appendix C for information on the data file used.) Macoupin County also contains portions of Major Land Resource Area's M108 and M114. These are represented by weather stations at Burlington, Iowa and Louisville, Kentucky respectively. The St. Louis weather data set was chosen because it is the closest weather station in the PIRANHA data set to Macoupin County. For January, the mean monthly temperature was below -1.66° C, indicating that ice would be expected to be on the reservoir. A value of 0° C was used to represent the temperature of the unfrozen water. When the index reservoir is used to represent reservoirs in other locations, the temperature profile will be modified to reflect local conditions by using the method described here to generate a temperature profile, but with weather data that is appropriate for the new location.

Table 8. EXAMS mean monthly water temperatures (TCEL) for the Index Reservoir. (See text for development of values.)	
Month	Temperature (Celsius)
January	0
February	1.09
March	6.26
April	13.21
May	18.61
June	23.73
July	26.09
August	25.04
September	20.91
October	14.5
November	7.04
December	0.99

Comparison Of Index Reservoir to Standard Pond and Monitoring Data

The Index Reservoir was compared to results generated using the standard scenario of a 10 ha field draining to the standard pond and to monitoring data for Shipman Reservoir collected by Hackett(1996, 1997) and to data for the Shipman Water Supply collected to support the Safe Drinking Water Act. This section describes that comparison.

The simulations were done with PRZM version 3.12 dated May 7, 1998 and EXAMS 2.97.5, dated June 11, 1997. The post-processor Table20, dated May 27, 1998, was used to summarize the results. The simulations were conducted with weather data from the PIRANHA system (Allen *et al.*, 1992) used to represent Major Land Resource Area M114. This data is for the period 1948 to 1983 at Louisville, Kentucky and is from the meteorological station W93821. Three different PRZM simulations were made. Chemical and pesticide parameters are in Table 9. The first run was used to develop the flow in the reservoir (as discussed in the Parameter Development section). The soil data represented a Clinton silt loam, a fine smectitic, mesic Chromic Vertic Hapludalf in SCS Hydrologic Group B. The second run and third runs were identical to each other except that the second run used 10 ha for the field size and the standard pond was used for the water body; the third run used a 178 ha field size and the pesticide loading was directed to the Index Reservoir. The soil used for these two runs was a Keomah silt loam, a fine smectitic mesic Aeric Endoaqualf in SCS Hydrologic Group C. The chemical parameters used to describe atrazine in the simulation are in Table 9. The PRZM scenario parameters, standard pond parameters, and input file names are listed in Appendices A, B, and C respectively.

Table 9. Pesticide and chemical parameters for atrazine used in the Macoupin County corn simulations.		
Parameter	Value	Source
Pesticide Application Rate	2.24 kg•ha^{-1}	
Number of Applications	1	
Application Date	May 10	
Application Method	broadcast, unincorporated	
K_d	0.73 L•kg^{-1}	One-liner Database
Aerobic soil half-life	146 d (k = 1.6 x 10^{-3} d^{-1})	One-liner Database
Molecular Weight	216 g • mol^{-1}	One-liner Database
Vapor Pressure	3 x 10^{-1} torr	One-liner Database
Henry's Law Constant	2.58 x 10^{-9}atm-m^3 • mol^{-1}	One-liner Database
Solubility	33 mg •L^{-1}	One-liner Database

One in ten year values for the peak and annual mean were selected from the modeling runs for comparison purposes. These are the estimates currently being used for drinking water assessment. In addition, the overall mean was also estimated. This value may be useful assessing risk against lifetime endpoints such as some cancers (Table 10). The median and one in ten year value are provided for the peak and annual mean. The one in ten year value is the current regulatory endpoint. The upper 90% confidence bound based on the standard deviation of the annual means is provided for the overall mean. Also in Table 10 are values for the Index Reservoir scenario corrected for the Crop Area Factor, or CAF. The CAF for corn for the Shipman City Lake was estimated from county scale data as 0.25 (Hackett, 1995), meaning that 25% of the watershed was planted in corn. **The Index Reservoir has higher estimates than the standard pond. However, when corrected for the CAF, the values are less than the standard pond.**

Table 10. Atrazine concentrations estimated by PRZM/EXAMS for standard pond scenario and Index Reservoir in Macoupin County, IL with CAF adjusted values for the Index Reservoir. Ninety per cent values are greater than ninety per cent of the annual values.

Scenario	Peak (µg • L^{-1})		Annual Mean (µg • L^{-1})		Overall Mean (µg • L^{-1})	
	Median	90%	Median	90%	Mean	UB 90*
Standard Pond	8.9	56.0	3.5	12.5	5.5	7.2
Index Reservoir	14.7	132	5.4	32.9	11.0	15.3
Index Reservoir, CAF adjusted**	1.2	33.0	1.4	8.2	2.75	3.8

* upper 90% confidence bound
** CAF = 0.25

Monitoring data are available from two sources. Data from the first source (Table 11) is from an acetochlor surface water monitoring study (Hackett, 1996; Hackett, 1997). The data is for finished water from the drinking water facility that uses the reservoir. There were 14 samples taken in both 1995 and 1996 with the means calculated using time weighting. Because this data is for finished water, the concentrations in the raw water from the reservoir would be expected to be somewhat higher than those reported. The finished water and raw water are not equivalent as the water treatment process generally removes some of the pesticides during the treatment process. The 1996 data in particular is in very good agreement with the CAF corrected index reservoir results for the one-in-ten year annual return frequency. Further discussion of the CAF is the Refinements section.

Table 11. Monitoring data for atrazine at Shipman City Lake 1995-1996 in the Acetochlor Surface Water Monitoring Study. Values are for finished drinking water

Year	Annual Peak (µg • L^{-1})	Annual Mean (µg • L^{-1})
1995	2.8	1.5
1996	34.6	12.3

The second data source is compliance data for the Safe Drinking Water Act (SDWA) from the SDWIS database (USEPA, 1998) on the Internet and is current as of April 3, 1998 (Table 12). These values do not represent individual measurements, but they are rolling annual averages based on four samples collected on a quarterly basis. The exact date each sample was collected in each quarter is not reported in the database. If there is no value for any quarter, it means that the annual mean ending in that quarter was below the MCL of 3 µg•L^{-1}. There were 20 quarters of data since the first value in 1993. The rolling annual average exceeded the MCL in 11 of the 20 quarters with the maximum atrazine level reported was 8 $\mu g \bullet L^{-1}$.

There are several substantial uncertainties in this analysis. The greatest uncertainty is connected with the CAF. The CAF used represents the value for the Macoupin County rather than the Shipman City Lake watershed, which may be may be more or less than the county value. In addition, the farmers in the watershed may grow different crops on their fields in any particular year; soybeans are commonly rotated with corn in Illinois. Consequently, the CAF for each year in the watershed is likely to be different. Since the precise annual value for the CAF is not known, it generates uncertainty in the comparison. Because of the limited size of the monitoring data set and the uncertainty in the CAF estimate, comparisons to the modeled results and the monitoring data are imprecise, but there appears to be reasonable agreement between the two sets of values.

Note that there is some overlap in the sampling times for the ARP data set and the SDWA data set. The fact that the two data sets do not provide identical results may be due to several factors. Operators of drinking water facilities have some leeway in the quarter when they sample, and sample timing would be expected to affect the concentration. Consequently, it is possible to have estimates in the SDWA data that are lower than estimates from the ARP despite the fact that the ARP data is for finished water while the SDWA data is for raw water. In addition, there will be some differences due to analytical and sampling methodologies.

Table 12. Safe Drinking Water Act Compliance Data for Atrazine in the Shipman Reservoir .

Date	Contaminant Level ($\mu g \bullet L^{-1}$)
October - December, 1997	6
July - September, 1997	6
April - June, 1997	7
October - December, 1996	6
April - June, 1995	4
January - March, 1995	4
October - December,1994	5
October - December, 1993	5
July - September, 1993	8
April - June, 1993	6
January - March, 1993	6

Refinements

A number of improvements are possible to the Index Reservoir and our modeling approach in general. They can be divided into two groups. The first group are refinements that can be made specifically to the Index Reservoir itself. The second group are refinements that improve the process which uses the Index Reservoir, or replaces the Index Reservoir with an alternative.

Refinements to the Index Reservoir

1. Flow in and out of the reservoir can be more accurately estimated. A better accounting of the contributions from more runoff prone soils can be incorporated. One can also account for precipitation and evaporation.

2. The modeling estimates presented here were based on a single soil, the Keomah silt loam. It is possible to estimate the concentrations using multiple soils for comparison to the monitoring data. This can increase our confidence in the appropriateness of the scenario.

3. Pesticide monitoring data is available for Shipman City Lake and other candidate reservoirs for pesticides other than atrazine. Modeling can be done for these other pesticides as well and compared to the monitoring data. As with point 2, these results would strengthen our confidence in the Index Reservoir Scenario.

4. Soils data were obtained from STATSGO. The level of detail in the STATSGO database did not allow for precise definition of the soils in Shipman Reservoir. We have now obtained county soil maps for Macoupin County that will allow us to more accurately define the soils in the Shipman City Lake watershed.

5. The current water quality data are based on the standard pond and reflects those in a Georgia Pond. This can be improved by locating suitable data for Shipman City Lake or developing data from surrogate reservoirs that are similar to Shipman.

6. We are currently investigating a number of other reservoirs that are similar to Shipman City Lake. After the data are gathered and analyzed, we will reconsider the scenario used for the Index Reservoir. We may continue to use Shipman or may find that one of the other reservoirs may be more appropriate.

Further General Refinements To OPP Modeling Approach

1. This assessment has demonstrated the importance of the CAF for drinking water assessment. The Agency is currently remapping the county level crop data to basins as was recommended by Science Advisory Panel of December 1997. We expect this effort will be completed by the end of the summer, allowing us to routinely consider CAF in these assessments.

2. Efforts are underway in the Agency to upgrade our current scenarios to employ multiple soils when assessing drinking water exposure. These efforts will be discussed in the following paper.

3. The Agency is investigating a variety of higher tier models that work at the basin scale. A basin scale modeling tool is more appropriate for drinking water assessment. The results of these efforts to this point are discussed in the following paper.

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Acknowledgments. The authors would like to thank Deborah Moody for her assistance in preparing some of the materials in this document.