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TITLE

Probabilistic Risk Assessment of Cotton Pyrethroids: III. A Spatial Analysis of the Mississippi Cotton Landscape

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1 ABSTRACT

2 Estimates of potential aquatic exposure concentrations arising from the use of pyrethroid
3 insecticides on cotton produced using conventional procedures outlined by EPA's Office of Pesticide
4 Programs Environmental Fate and Effects Division (EFED) appear unrealistically high. Accordingly,
5 the assumptions inherent in the pesticide exposure assessment modeling scenarios were examined
6 using remote sensing of a significant Mississippi cotton producing county. Image processing
7 techniques and a Geographic Information System (GIS) were used to investigate the number and
8 size of the water bodies in the county and their proximity to cotton. Variables critical to aquatic
9 exposure modeling were measured for approximately 600 static water bodies in the study area.
10 Quantitative information on the relative spatial orientation of cotton and water, regional soil texture
11 and slope, and the detailed nature of the composition of physical buffers between agricultural fields
12 and water bodies, was also obtained. Results showed that remote sensing and GIS can be used
13 cost effectively to characterize the agricultural landscape and provide verifiable data to refine
14 conservative model assumptions. For example, 68% of all ponds in the region have no cotton within
15 360 m and 92% of the ponds have no cotton within 60 m. Only 2% of ponds have cotton present in
16 all directions around the ponds and within 120 m. These are both significant modifications to
17 conventional pesticide risk assessment exposure modeling assumptions and exemplify the
18 importance of using landscape level risk assessments to better describe the Mississippi cotton
19 agricultural landscape. Incorporating spatially characterized landscape information into pesticide
20 aquatic exposure scenarios is likely to have greater impact on the model output than many other
21 refinements.

22

23 Key words: aquatic exposure, GIS, remote sensing, landscape analysis, pyrethroid

INTRODUCTION

The use of conventional pesticide aquatic exposure assessment procedures to investigate the potential aquatic impact of cotton pyrethroids results in anticipated pond concentrations that suggest there is no hazard for fish. However, the exposure/toxicity ratios for aquatic invertebrates indicate further assessment may be required. Increasingly sophisticated modeling resulted in lower estimated exposure values, but the predicted exposures, decline curves, and impacts on invertebrates still did not reflect results from the extensive series of mesocosm studies conducted by the Pyrethroid Working Group (PWG) companies and others in the 1980s [1]. As a result, the PWG decided to investigate the validity of some of the assumptions inherent in pesticide exposure assessment modeling procedures using what has been termed a “landscape level” analysis. In current pesticide regulatory parlance, a sophisticated analysis of this type should be described as a Tier 3 or Tier 4 risk assessment [2].

The approach taken by the PWG was to examine the probability that some of the key conservative modeling assumptions co-occur within a Mississippi cotton agricultural landscape. Although many of the underlying assumptions merit more detailed consideration, this analysis focused in particular on the following:

- A 10-ha watershed is 100% cropped with cotton which drains to a 1-ha pond;
- The runoff “slope/length” factor is 0.4 (equivalent in Mississippi to slopes $\geq 3\%$);
- All soils are of high erodibility;
- Cropping and treatment occurs up to the edge of the pond (i.e., no physical buffers exist between crops and water);
- Drift towards the pond occurs from all applications (i.e., the wind is always blowing to the pond);
- There is no marginal vegetation present to reduce spray drift deposition from a field to the water body.

To investigate these factors, a relevant cotton producing county was selected via a progressive approach from the universe of all cotton producing US counties. Remotely sensed Landsat Thematic

1 Mapper (TM) imagery was spectrally classified to identify water bodies and land cover composition.
2 This information was combined with many other data sets to permit a detailed analysis of the
3 proximity between water bodies and cotton as well as the other factors listed above. Data on each of
4 the approximately 600 ponds in this county was used as input to PRZM-EXAMS modeling to produce
5 a probabilistic distribution of anticipated exposures reflecting the true cotton landscape [3].
6

7 MATERIALS AND METHODS

8 To investigate modeling assumptions, remotely sensed satellite imagery was spectrally classified
9 to identify cotton, water bodies, and other land cover categories. This classification was combined
10 with USGS digital line graph hydrology and transportation data sets. Soil and slope information was
11 also incorporated.
12

13 *Selection of the study area—Yazoo County, MS*

14 Selection of Yazoo County, MS was a result of a process that examined all US cotton producing
15 counties based on cotton cropped acreages, total area of water, and insecticide use. The logic tree
16 was as follows, with the number of counties remaining after each step shown in parentheses.
17 • Select all USA counties producing cotton (449).
18 • Select the top 50% of these based on cotton acres in 1987 (225).
19 • Select the top 50% of the above counties based on acres of water in the county (113).
20 • Select the top 50% of the above counties based on reported insecticide usage (57).
21 • Select the top 50% of the above counties based again on cotton acres (29).
22 • Eliminate counties isolated from typical cotton areas (26).
23 • Eliminate counties where water acres are dominated by marine water types or the Mississippi
24 River (8).
25 • Eliminate counties where probable local cooperation was poor (6).

1 Of the resulting pool of six counties, Yazoo, MS was selected because it represents both Delta
2 (flatland) and upland cotton cropping that will experience suitably worst case rainfall occurrence and
3 intensity. Fortuitously, it has also been the setting for the modeling scenario for both preliminary and
4 more sophisticated cotton exposure assessments for several years. Consequently, an EPA-
5 approved site-specific model input file was available for Yazoo County that proved very valuable in
6 the final step of the pyrethroid exposure estimation and risk assessment [3].

7

8 *Imagery and G/S data sources*

9 The satellite image land use/land cover (LU/LC) classification was the primary data source from
10 which the environmental characterization was conducted. The multispectral data allowed separation
11 of different land cover types. The satellite image was acquired in 1991 from the Landsat satellite
12 utilizing the Thematic Mapper (TM) sensor. The image consists of seven spectral bands, with a
13 ground resolution of 30 m.

14 Hydrology data were used to enhance the water classification generated from the satellite
15 imagery (see “image classification” below). The final water classification used both the spectral
16 characteristics of the satellite imagery and United States Geological Survey (USGS) Digital Line
17 Graph (DLG) hydrology data. These DLG data were provided at 1:100,000 scale for Yazoo County
18 [4].

19 Several of the analyses were performed using high resolution aerial imagery. One hundred water
20 bodies were imaged using true-color 9-inch aerial photography from a camera mounted in the belly
21 of a light aircraft flying at a specified altitude relative to ground level. The 9-inch film positives were
22 scanned and formatted for use by the image processing system. The resulting images had an
23 approximate footprint of 2.4 km per side and a spatial resolution of 1 m.

24 The baseline soil data used for this study were the STATSGO soil data produced by the Natural
25 Resources Conservation Service (NRCS). Larger scale watersheds for analysis of soil/slope
26 characteristics were defined using the USGS 8-digit Hydrologic Cataloging Unit (HUC) Boundaries

1 [5]. The baseline elevation data Digital Elevation Models (DEMs) were acquired at a scale of
2 1:250,000 for Yazoo County [6]. These data consist of a regular array of elevations referenced
3 horizontally on the geographic (latitude/longitude) coordinate system. The unit of coverage of these
4 data is a 1 x 1-degree block and elevations are in meters. The spacing of the elevations along each
5 profile is 3 arc-seconds (approximately 90 m). The elevation data were used to confirm HUC
6 watershed boundaries and to generate slope characteristics for the study area.

7

8 *Image Classification*

9 The spectral information contained in the satellite image permitted the identification of different
10 land cover types. Cotton was classified using a two-step process. The first step was to identify cotton
11 in the study area using the spectral characteristics of the imagery. A series of image processing
12 functions were used to group image pixels with similar spectral characteristics. Once identified,
13 cotton field boundaries were visually delineated around each field and “stray” pixels within the field
14 were then reassigned to cotton.

15 The water classification utilized both the spectral characteristics of the satellite imagery and the
16 DLG hydrology data. The DLG hydrology data consist of lines and polygons that have attributes
17 specifying the type of water body represented. DLG data were combined with the satellite
18 classification and the attributes in the DLGs were used to identify all types of water. Due to the 30-m
19 resolution of the satellite imagery, it was not possible to identify small or narrow water bodies (<30
20 m) using spectral characteristics of the satellite imagery alone. For these special case features, the
21 DLG hydrology information was used to provide the location and type of hydrology in the final
22 classification. All classes that comprise other agriculture and vegetative land cover were identified
23 using only the spectral characteristics of the satellite imagery. The final LU/LC classes generated for
24 this study were cotton, other agriculture/bare soil, forest, pasture/brush, catfish ponds,
25 rivers/streams, lakes/ponds, drainage ditches, irrigation canals, wetlands, and roads.

1 Figure 1 is a low resolution representation of the LU/LC coverage showing the Delta (western)
2 half of the county and also the escarpment that separates the Delta from the uplands. Interesting
3 findings were that the largest water bodies were oxbow lakes (lakes arising from historical river
4 meanders which became isolated from the main river channel as a result of natural sedimentation
5 and flow changes) and that cotton appears to be frequently grown on the coarser materials
6 deposited adjacent to old river courses.

7

8 *Assumptions inherent in the data*

9 The following assumptions are inherent in the data used for this study and should be considered
10 when interpreting the results:

- 11 • Although all values in the report are quoted “for Yazoo county,” the Landsat image did not
12 include the entire county—a small portion of the northeastern corner was not included in any of
13 the analyses.
- 14 • The resolution of the satellite classification is 30 m. As a result, land cover types not generated
15 from separate data sets (e.g. rivers, streams, canals, and roads from the DLGs) and having a
16 minimum dimension less than 30 m were not consistently identified in the classification.
- 17 • Pixels representing cotton mixed with other land cover types were classified so that they would
18 most likely represent cotton land cover. A similar approach was used for water pixel
19 classification. This was a conservative approach to ensure that cotton and water were not missed
20 in the final LU/LC classification. Consequently, the cotton and water assignments overestimated
21 the actual areas present.
- 22 • All roads, streams, and irrigation canals were represented as being 30 m wide (1 pixel) unless
23 they were identified in the satellite imagery as being wider than 30 m. Roads, streams, and
24 irrigation canals less than 30 m wide therefore had exaggerated areas in these analyses. This
25 also contributed to overestimates of water acreages.

1 • It was assumed that all agriculture in the high resolution aerial imagery was cotton, greatly
2 exaggerating the potential interaction between “cotton” and water bodies.

3

4 *Proximity analysis*

5 Proximity analyses were designed to provide information regarding the land cover composition
6 near water bodies by measuring the acreage of various land cover types within specified margin
7 distances of water bodies. For this paper, a *margin* is defined as a notional area created by drawing
8 an imaginary line a fixed distance from the perimeter of a polygon of interest (e.g., a water body or a
9 cotton field). In contrast, the term *buffer* is used in this paper to refer to the physical area between
10 the edge of a water body and the nearest agricultural land.

11 Margins were generated around water bodies at four different widths (60, 120, 180, and 360 m)
12 and the distribution of land covers within each margin was measured for each aquatic habitat type
13 (rivers/streams, lakes/ponds, canals, wetlands, and catfish ponds). Figure 2 is an enlarged view of a
14 portion of a proximity analysis showing the LU/LC classification for a margin of 360 m. The LU/LC
15 classification was then used to identify both the total area of the margin and the total area of each of
16 the land covers within the margin. The distances selected to generate margins around water bodies
17 and cotton fields are multiples of the satellite imagery pixel size (30 m) and were chosen to reflect
18 the likelihood of various levels of spray drift arising from aerial spraying of adjacent cotton.

19 The initial proximity analysis examined all the water bodies of each type within the county as a
20 whole. A second analysis was performed to determine the amount of cotton within the four marginal
21 distances around each individual static water body (597 lakes and ponds). The total margin acreage
22 and the acreage of cotton in the margin for each water body was determined for each margin
23 distance. This second analysis permitted closer, probabilistic assessment of the distribution of cotton
24 near static water bodies in Yazoo County and afforded opportunities to understand how the
25 occurrence of cotton in the margins varied with water body size.

26

1 *Directional analysis*

2 The spatial distribution of cotton near lakes and ponds was also measured to understand the
3 directional relationship between cotton and static water, since this indicates the potential frequency
4 with which spray drift from a cotton application is likely to occur. This information could be combined
5 with wind speed and direction assessment to provide a detailed probabilistic assessment of the
6 anticipated frequency of spray drift impacting water bodies.

7 To determine the spatial distribution of cotton in individual static water body margins, sample
8 points along the perimeter of each water body were assigned, spaced approximately 30 m apart.

9 Each of these points was examined to determine if cotton was present within any of eight different
10 compass directions (N, NE, E, SE, S, SW, W and NW) within each of the four margin distances (60,
11 120, 180 and 360 m). All directions from each sample point were analyzed, even those that crossed
12 water. The results for each perimeter sample point were combined to produce results for the entire
13 water body. Figure 3 shows two sample points on a water body using different margin distances.
14 This water body has cotton located to the W, NW, N, NE, E and SE directions within the 360-m
15 margin, and cotton in the NE, E and SE directions within the 180-m margin.

16

17 *Runoff transport factors by Hydrologic Cataloging Unit*

18 The analyses in this section are designed to provide information on the associations between
19 cotton cropping and key factors influencing pesticide runoff within the four 8-digit hydrologic
20 cataloging units (HUCs) intersecting Yazoo County. Information on the slopes within each HUC was
21 compared with those associated with cotton cropping, as well as the distribution of soil parameters
22 including hydrologic group (a classification used by the US National Resource Conservation Service
23 reflecting soil permeability), K factor (reflecting soil erodibility), texture, and organic matter within
24 each HUC. The resulting watersheds were visually checked with 90-m Digital Elevation Model (DEM)
25 data and hydrology from the final land cover classification for quality control and accuracy.

1 Elevation data were used to generate slope classes for the entire study area. The slope data
2 were then analyzed using only those areas identified as cotton in the LU/LC classification. Cotton
3 fields were grouped by HUC and summarized by slope class.

4 Soil data were obtained by intersecting STATSGO soil polygons with the HUC boundaries to
5 identify soil associations within each watershed. The STATSGO polygons are at the soil association
6 level while the characteristics of interest are at the soil series level. Accordingly, the soil series data
7 were grouped using an area weighted averaging technique to produce values for each soil
8 association.

9

10 *Buffer analysis*

11 Buffer analyses using the aerial imagery provided high resolution information (1 m as opposed to
12 30 m) regarding the land cover composition and widths of buffers separating agricultural lands and
13 aquatic habitats. This analysis was only performed to a distance of 60 m to examine only those
14 areas most likely to present cases of high potential exposure. In this way, the average buffer widths
15 were not skewed by extremely large buffers from cotton found large distances away. These analyses
16 provide information about (1) the composition of buffers associated with each type of aquatic system
17 (flowing, static, and irrigation canals); (2) the total widths of the buffers and the widths of the land
18 cover classes present within the buffers; and (3) the extent to which water bodies are directly
19 adjacent to agriculture with no mitigating buffer.

20 Using the satellite LU/LC classification, all water bodies that were proximate (≤ 360 m) to cotton
21 were identified and a stratified random sample was selected and imaged using aerial photography.
22 Eliminating water bodies further than 360 m from cotton was done to bias the acquisition process
23 towards the “worst-case” scenario for cotton/water proximity. For selection, linear water bodies
24 (rivers/streams and canals) were divided into sub-units based on the mean shoreline length of static
25 water bodies found in the study area. Thus the linear water bodies were incorporated into the
26 stratified random sampling along with the static water bodies. The intent of the aerial imagery

1 sampling methodology was to obtain a sample size large enough to provide 95% confidence that
2 buffer width measurements were within 5 m (approximately 5 aerial image pixels) of the actual
3 widths. Based on these criteria, 50 static and 50 flowing water bodies were selected and imaged.
4 However, many of the images contained multiple water bodies and the final sample size was 169
5 water bodies, providing a 95% confidence interval of 3.4 m for buffer width measurements from
6 aerial photographs.

7 All the area within 60 m of water was classified into a different Land Use/Land Cover (LU/LC)
8 system using visual analysis of the high resolution aerial imagery. Figure 4 illustrates the concept of
9 the buffer analyses. The classes used were static water, flowing water, irrigation canal, agriculture,
10 dense trees, sparse trees, brush, grass/pasture, bare ground, built-up land (buildings), and roads.

11 Buffer widths were measured using transect lines generated at 1-m intervals along the
12 perimeters of agricultural fields within 60 m of water and drawn to the nearest point on the water
13 body being examined. The length of each line segment passing through each LU/LC class within the
14 buffers was measured to generate average buffer width and land cover width statistics. When
15 calculating the overall buffer width mean, zero length transects were included if the field was directly
16 adjacent to water. Over 65,000 transects between agriculture and water were generated and
17 examined for this analysis.

18 The selected water bodies were also examined to identify those that border directly upon
19 agriculture fields. The perimeter length comprising the direct agriculture/water border was recorded.
20

21 RESULTS

22 *Land Use/Land Cover (LU/LC) classification*

23 Statistics generated from the LU/LC classification based on the satellite imagery are reported in
24 Table 1. After adjustments for the missing portion of the county and the exaggerated area of
25 intermittent streams and farm roads arising from the merging of the DLG and remotely sensed
26 coverages, the total acreage of cotton classified is 93% of that reported in the 1991 Mississippi

1 Agricultural Statistics [7]. The intermittent drainage ditches were not included in the reported water
2 analyses since they support no permanent aquatic populations and tend to be dry except
3 immediately following a rainfall event.

4 The ability to distinguish cotton from other agriculture was a critical component of this study. Four
5 areas within the county, representing both lowland and upland cotton mixed with a variety of land
6 cover types, were selected to calculate the accuracy of agricultural classification. Crop maps
7 pertaining to the 1991 growing season were obtained from the Yazoo County Farm Service Agency
8 (FSA) office. The four sample areas totaled over 11,600 acres (4,695 ha) within which the cropping
9 in approximately 90% of the fields was identified by the FSA. Each FSA designated field was
10 compared with the final LU/LC classification. Of the 233 labeled fields, 187 were classified correctly
11 as either cotton or other agriculture, 23 more were classified as cotton when they were actually other
12 agriculture, and 23 were classified as other agriculture that were truly cotton.

13 The USGS LU/LC classification system specifies a minimum interpretation accuracy of 85% [8].
14 For this study, it was considered important to be conservative in the classification of cotton. This
15 means that if doubt existed in the identification of cotton and other agriculture, the field was
16 assumed to be cotton. With this conservative viewpoint, we can consider cases of commission
17 (where other agriculture was classified as cotton) to be acceptable. This results in a 90.1% accuracy
18 (210 acceptably classified fields of a total sample size of 233) in classifying the actual cotton pixels
19 as cotton.

20 Cotton field sizes ranged from less than 10 acres (4 ha) to over 500 acres (200 ha) with the
21 majority of fields between 10 acres (4 ha) and 50 acres (20 ha). All the data reflected a clear division
22 in landscape feature between the Delta areas and the more hilly and dissected terrain toward the
23 east of the county.

1

2 *Water body size and frequency*3 Further analysis focused on static water bodies (ponds and lakes) since they represent the worst
4 case for exposure and are the focus of existing pesticide aquatic risk assessment procedures.5 Exposure in flowing water bodies is mitigated by flow dilution, and wetlands tend to have extensive
6 deposition zones to protect them from runoff entry with heavy foliage to help reduce spray drift.7 The distribution of lakes and ponds by size class is illustrated in Table 2. Over 60% of the
8 pond/lake acres were accounted for by just 42 water bodies larger than 20 acres (8 ha). These water
9 bodies were generally long, narrow oxbow lakes formed by river course changes and occur in the
10 Delta area. Most of the smaller water bodies are found in the upland regions of the eastern portion of
11 the county.

12

13 *Proximity analysis*14 Table 3 summarizes the results of proximity analyses conducted on the entire class of each type
15 of flowing and static water body for 60-, 120-, 180-, and 360-m margins. Using the worst case
16 scenario analyzed (the 360-m margin around the water bodies), 15% of the marginal area was
17 composed of cotton. While a 360-m margin is not exactly equivalent to a watershed, these results
18 differ substantially from the conventional exposure assessment modeling assumption of 100%
19 cropping within the watershed. The 60-m marginal composition for all water bodies is only 7% cotton.
20 Less than 10% of the cotton that occurs in the 360-m margin is within 60 m of a water body.21 Lakes and ponds were analyzed individually to determine the frequency of occurrence and
22 extent of cotton cropping within a specified margin distance for five water body size classes (Table
23 4). The average percent of cotton for each size class was derived using only the water bodies with
24 cotton contained in the margin. Water bodies with no cotton in the margin were not used to compute
25 the class average. For example, 70 of the 255 (27.5%) 1- to 5-acre static water bodies have cotton

1 in the 360-m margin, and that margin is composed, on average, of 15% cotton. The remaining
2 72.5% of the 1- to 5-acre static water bodies (185 ponds) have no cotton in their margins.

3

4 *Directional analysis*

5 Table 5 summarizes the results of cotton directional analysis. These results indicate how often,
6 and to what degree, water bodies are surrounded by cotton. For example, for water bodies with
7 cotton within 360 m, only 17.5% had cotton present in all 8 directions but this represents only 4.2%
8 of the total number of water bodies in the study area (25 of 597). Even this case is not as extreme as
9 it sounds since not every perimeter pixel in these 25 ponds has cotton within 360 m in every
10 direction; it is possible to have cotton within 360 m of only eight separate points, each in a single
11 different direction, to qualify the water body as having potential drift from all eight directions.

12 It should be noted that the number of water bodies with cotton in a given number of directions is
13 not cumulative. For example, a water body with cotton in three directions would not be counted as
14 having cotton in two and one directions as well. Note that the number of water bodies that have
15 cotton contained in their margin is smaller than the same measurement performed for the proximity
16 analysis. This is due to slightly different methods (vector v. raster) of determining the presence of
17 cotton in the water body margin.

18

19 *Runoff analysis by Hydrologic Cataloging Unit (HUC)*

20 Table 6 provides a comparison of slopes for the study area as a whole and for cotton fields. The
21 comparison reveals that 83.9% of the total study area is 3% or less in slope, and 97.3% of cotton is
22 grown on 3% or lower slope. Only 2.7% of all cotton is grown on greater than 3% slope, in contrast
23 to the standard exposure modeling assumption that the “slope/length” factor is 0.4 (slope > 3%) for
24 cotton.

25 Table 7 illustrates results of the analysis of the hydrologic group, texture and soil erosivity “K”
26 factors. Nearly half the soils are of hydrologic group C, with the remainder divided nearly equally

1 between B and D types. The predominant soils are silt loams and silty clay loams with similar
2 distribution across the HUCs.

3

4 *High resolution imagery buffer analysis*

5 Buffer composition (Table 8) describes the type of land cover found between agriculture and
6 water. Dense trees comprise at least 50% of the area between agriculture and water for all three
7 water body types (54%, 69%, and 51% for static, flowing, and canals respectively).

8 Table 9 presents overall buffer width statistics, summarized by water body type and the land
9 covers that comprise those buffers. Overall buffer widths represent the total distance of non-
10 agricultural land use between agriculture and water. Individual land cover widths represent those
11 segments of the overall buffer that correspond to that specific land cover type. For example, an
12 overall buffer transect may be 35 m, but can be composed of 20 m of dense trees, 5 m of sparse
13 trees and 10 m of grass. Since this analysis was based on 1-m aerial imagery, the minimum
14 measured width for individual land cover types is 1 m.

15 A summary of the results for the direct adjacency analysis is presented by water body type in
16 Table 10. These results indicate that of the 85 static water bodies used for this analysis, only 4 were
17 directly adjacent to agriculture, accounting for only 5.1% of the total perimeter.

18

19 **DISCUSSION**

20 A detailed analysis of cotton agriculture in Yazoo County, MS using remote sensing has provided
21 an improved general understanding of this agricultural landscape as well as details describing key
22 regulatory model scenario parameters for each of the 597 static water bodies in the county.

23 The land use/land cover analysis indicated that cotton comprised around 13% of the study area
24 and ground truthing showed this was an accurate assessment. Water represents 4.4% or less of the
25 study area. These data also provided the information necessary to focus further analysis on the
26 static water bodies.

1 Proximity analysis showed that 65% of all cotton acres had no water of any type within 360 m.
2 Analysis of the margins surrounding static water bodies revealed that 68% of all ponds had no
3 cotton within 360 m while 92% of ponds had no cotton within 60 m. Cotton was more prevalent
4 within 360 m of the larger ponds (on average, 9 to 23% of the marginal area for pond size classes
5 >10 acres) than 1 to 10 acre ponds (3 to 5%). For the subset of ponds with cotton within 360 m (190
6 ponds), 58% had no cotton within 120 m. These values show that the potential for spray drift and
7 runoff routes is much lower than assumed in the standard aquatic exposure modeling scenarios.
8 Most importantly, approximately 66% of static water bodies are unlikely to receive any exposure
9 arising from cotton agriculture and therefore offer refugia with potential to be sources of
10 recolonization.

11 Moreover, analyses of the spatial distribution of cotton around static water bodies showed that
12 only 4% of ponds had the potential for wind from every direction to deposit spray drift on the water
13 surface. Only 2% of ponds had cotton in all directions *and* within 120 m of the water. Only 43% of
14 ponds with cotton within 360 m would receive drift from more than half the wind directions (assuming
15 the wind speed was sufficient to cause drift).

16 The last set of model scenario parameters investigated in this study examined slope and factors
17 influencing soil erosivity in areas defined by the 8-digit hydrologic unit. Only 2.7% of the fields
18 cropped to cotton had slopes $\geq 3\%$; 92.5% had slopes $\leq 2\%$. Similarly, although the soil erodibility
19 “K” value selected using conventional exposure assessment modeling procedures would be 0.49,
20 this value applies to only 24% of Yazoo County, while for the remaining 76% a value of 0.43 or 0.37
21 is appropriate.

22 Finally, high resolution imagery provided detailed information on the buffers that separate water
23 from agricultural fields. The results showed that ponds were infrequently (<5%) directly adjacent to
24 agriculture, and of those ponds that did have direct adjacency, only 5% of their shoreline met this
25 criterion. Additionally, 54% of static water body buffers were composed of dense trees with a mean
26 buffer width of 24 m (± 12). 90% of the pond perimeters had buffers at least 13 m wide.

1 This analysis generated detailed numeric values for replacing some of the standard factors in
2 regulatory aquatic exposure assessments. However, it is instructive to analyze some of the
3 underlying assumptions that make even this analysis conservative. One example is in the proximity
4 analysis. While the assessment of the composition indicates how much of the notional marginal area
5 is cotton, it does not reflect the fact that much of the area of the water body may be considerably
6 further away than the notional value, especially with the long, linear water bodies in this county.
7 Similarly, the directionality algorithm assesses the vulnerability of each pixel around the perimeter
8 and although that spot might be subject to spray drift from cotton from a given wind direction, it does
9 not necessarily mean that significant portions of the pond area will receive drift from that direction. It
10 should also be remembered that the directionality assessment indicates the potential for drift; actual
11 drift can only occur if the wind speed at the time of spraying is sufficient to cause drift. A significant
12 approximation associated with this technique with currently unknown impact on the results is the use
13 of a uniform notional margin around the water margins rather than an actual watershed based on
14 topography.

15 The study shows that remotely sensed imagery coupled with GIS can be used cost effectively to
16 characterize an agricultural landscape and provide verifiable data to refine conventional model
17 assumptions. These tools can be usefully employed for regional analyses. In addition, information on
18 the individual ponds within a region permits a detailed assessment of the distribution of landscape
19 compositions for use in probabilistic risk assessment. This study shows that regulatory model
20 scenarios would benefit from incorporation of agricultural landscape information.

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1 Table 1. Study area Land Use/Land Cover acreage.

Class	Acres	Percentage
Cotton	77,297	12.93%
Other Ag/ Bare Soil	134,917	22.57%
Forest	236,451	39.56%
Pasture/ Brush	87,452	14.63%
Catfish Ponds	6,972	1.17%
Rivers/ Streams	7,231	1.21%
Lakes/ Ponds	5,177	0.87%
Drainage ditches	14,562	2.44%
Irrigation canals	2,448	0.41%
Wetlands	4,4,96	0.75%
Roads	20,690	3.46%
TOTALS	597,695	100.00%

1 Table 2. Static water body acreages and occurrence.

Size Class (acres)	Surface Acreage of Water Bodies	% of Total Acreage of Water Bodies	No. of Water Bodies	% of total number of Lakes and Ponds
<1	80	2%	172	29%
1 to < 5	606	12%	255	43%
5 to <10	490	9%	68	11%
10 to <20	858	17%	60	10%
20 +	3,143	61%	42	7%
Sub-total	5,177	100%	597	100%

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1 Table 3. Acres of cotton in various margins around water bodies in Yazoo County, MS.

Class	60-m Margin		120-m Margin		180-m Margin		360-m Margin	
	Acres ¹	% ²						
Rivers/ Streams	910	6%	2,976	10%	5,452	12%	13,852	17%
Lakes < 1 acre	6	1%	47	2%	116	2%	608	4%
Lakes 1 -5 acres	21	1%	119	2%	298	3%	1,377	5%
Lakes 5 - 10 acres	13	1%	38	1%	92	2%	505	5%
Lakes 10 - 20 acres	24	2%	106	4%	229	5%	835	7%
Lakes 20 + acres	300	10%	1,025	17%	1,767	19%	4,191	22%
Catfish Ponds	135	7%	361	10%	636	12%	1,750	16%
Canals	867	12%	2,011	14%	3,144	15%	6,633	17%
Wetlands	21	2%	80	3%	136	3%	415	5%
Total Area of Cotton	2,288	7%	6,673	10%	11,558	12%	27,224	15%
Total Area of Margin	34,245		68,199		98,827		186,907	

2 1 - Total acres of cotton within the aquatic margin

3 2 - Percent of aquatic margin composed of cotton

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1 Table 4. Cotton in margins of individual static water bodies in Yazoo County, MS.

Water body size (acres)	Total Number ¹	60-m margin				120-m margin				180-m margin				360-m margin			
		Number with cotton ²	% with cotton ³	Avg. % cotton ⁴	Number with cotton ²	% with cotton ³	Avg. % cotton ⁴	Number with cotton ²	% with cotton ³	Avg. % cotton ⁴	Number with cotton ²	% with cotton ³	Avg. % cotton ⁴	Number with cotton ²	% with cotton ³	Avg. % cotton ⁴	
< 1	172	7	4.1%	15%	13	7.6%	20%	19	11.0%	18%	43	25.0%	14%				
1 – 5	255	14	5.5%	16%	30	11.8%	16%	45	17.6%	15%	70	27.5%	15%				
5 – 10	68	1	1.5%	97%	7	10.3%	15%	12	17.6%	12%	26	38.2%	11%				
10 – 20	60	8	13.3%	12%	11	18.3%	17%	16	26.7%	15%	26	43.3%	15%				
> 20	42	15	35.7%	19%	19	45.2%	23%	21	50.0%	24%	25	59.5%	25%				
Totals	597	45	7.5%	32%	80	13.4%	18%	113	18.9%	17%	190	31.8%	16%				

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3 ¹Total number of water bodies in the study area4 ²Number of water bodies whose margin contains cotton5 ³Percentage of all water bodies in that size class whose margin contains cotton6 ⁴Average percentage of margin that is cotton (including only water bodies whose margin contains cotton)

1 Table 5. Spatial distribution of cotton around static water bodies in Yazoo County, MS.

Directions ¹	60-m margin			120-m margin			180-m margin			360-m margin		
	Number ²	Percent ³	Percent ⁴	Number ²	Percent ³	Percent ⁴	Number ²	Percent ³	Percent ⁴	Number ²	Percent ³	Percent ⁴
0 (no cotton) ⁵	569	95.3%	—	539	90.3%	—	512	85.8%	—	454	76.0%	—
1	9	1.5%	32.1%	5	0.8%	8.6%	5	0.8%	5.9%	11	1.8%	7.7%
2	3	0.5%	10.7%	10	1.7%	17.2%	20	3.4%	23.5%	26	4.4%	18.2%
3	3	0.5%	10.7%	12	2.0%	20.7%	11	1.8%	12.9%	23	3.9%	16.1%
4	5	0.8%	17.9%	8	1.3%	13.8%	12	2.0%	14.1%	22	3.7%	15.4%
5	1	0.2%	3.6%	5	0.8%	8.6%	14	2.3%	16.5%	11	1.8%	7.7%
6	2	0.3%	7.1%	3	0.5%	5.2%	2	0.3%	2.4%	14	2.3%	9.8%
7	1	0.2%	3.6%	3	0.5%	5.2%	4	0.7%	4.7%	11	1.8%	7.7%
8	4	0.7%	14.3%	12	2.0%	20.7%	17	2.8%	20.0%	25	4.2%	17.5%
Totals	597	100%	100%	597	100%	100%	597	100%	100%	597	100%	100%

2 ¹ Number of directions containing cotton3 ² Number of water bodies with cotton in the specified number of directions4 ³ Water bodies with cotton in the specified number of directions, as a percentage of all water bodies5 ⁴ Water bodies with cotton in the specified number of directions, as a percentage of water bodies with cotton in the margin

1 ⁵ Water bodies with zero directions containing cotton indicates that cotton is not present in the water body margin

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1 Table 6. Slope characteristics as a percentage of the entire study area and as a percentage of all
 2 cotton area.

Percentage Slope Class	HUC 1	HUC 2	HUC 3	HUC 4	Total
Percentage of entire study area					
0-1%	18.2%	20.9%	18.8%	3.5%	61.4%
1-2%	1.4%	5.5%	7.3%	0.7%	14.9%
2-3%	0.1%	3.9%	3.3%	0.2%	7.6%
3-4%	0.0%	2.8%	1.7%	0.1%	4.7%
4-5%	0.0%	2.2%	1.0%	0.1%	3.3%
5-7%		3.5%	1.1%	0.3%	4.8%
7-10%		2.2%	0.4%	0.2%	2.8%
10-15%		0.5%	0.0%	0.1%	0.6%
15-20%		0.0%		0.0%	0.0%
20+%		0.0%			0.0%
Total	19.8%	41.5%	33.4%	5.4%	100.0%
Percentage of all cotton area					
0-1%	24%	33%	14%	4%	75%
1-2%	3%	5%	8%	1%	17%
2-3%	0%	1%	3%	0%	5%
3-4%	0%	1%	1%	0%	2%
4-5%		0%	0%	0%	1%
5-7%		0%	0%	0%	0%
7-10%		0%	0%	0%	0%
10-15%		0%		0%	0%

Total	27%	41%	26%	6%	100%
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1 Table 7. Distribution of hydrologic group, surface texture, and erodibility among watersheds.

	HUC 1	HUC 2	HUC 3	HUC 4	Total
Hydrologic Group^a					
A	0%	0.1%	0%	0%	0.2%
B	5.8%	10.6%	5.0%	1.4%	22.7%
C	9.6%	17.6%	18.7%	2.1%	48.0%
D	11.7%	12.7%	2.6%	2.2%	29.1%
Surface Texture^b					
C	6%	5%	0%	1%	11%
FSL	0%	0%	0%	0%	0%
S	0%	0%	0%	0%	0%
SIC	1%	0%	0%	0%	1%
SICL	9%	8%	0%	1%	17%
SIL	9%	22%	24%	3%	58%
SL	0%	0%	2%	0%	3%
VFSL	3%	6%	0%	0%	9%
Erodibility (KFFACT – no rock fragments)					
0.00	4%	2%	0%	0%	6%
0.10	0%	0%	0%	0%	0%
0.24	0%	0%	0%	0%	0%
0.28	0%	0%	2%	0%	3%
0.32	3%	3%	0%	1%	6%
0.37	12%	14%	0%	1%	27%
0.43	9%	17%	4%	3%	33%
0.49	0%	4%	20%	0%	24%
Total	27%	41%	26%	6%	100%

1 ^a Hydrologic group as defined by NRCS [9]: A = high infiltration rates; B = moderate infiltration rates;
2 C = slow infiltration rates; D = very slow infiltration rates.

3 ^b Surface texture: C = clay; FSL = fine sandy loam; S = sand; SIC = silty clay; SICL = silty clay loam;
4 SIL = silt loam; SL = sandy loam; VFSL = very fine sandy loam.

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1 Table 8. Overall buffer acreage and the percent composition of the buffer for each land cover.

Water Body		Overall	Dense	Sparse	Brush	Grass	Bare	Built up	Roads
Type		Trees	Trees	Ground			land		
Static Water	Acres	182.4	98.2	11.9	33.1	29.5	2.8	0.2	6.7
	%	100%	54%	7%	18%	16%	2%	0%	4%
Flowing Water	Acres	406.3	281.9	41.3	32.7	30.9	8.5	0.1	10.9
Irrigation canals	Acres	184.5	93.7	12.9	37.4	26.9	2	0	11.5
	%	100%	51%	7%	20%	15%	1%	0%	6%

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1 Table 9. Overall buffer width and the width of buffer land cover components for each land cover (in
 2 meters).

Water Body Type		Overall	Dense	Sparse	Brush	Grass	Bare	Built up	Roads
Static	Min	0*	Trees		Trees		Ground		Land
			Trees		Trees		Ground		Land
Water	Max	60	60	50	60	60	60	17	46
	Mean	25	24	15	14	11	12	9	8
	SD	16	12	8	10	10	11	4	4
Flowing	Min	0*	1	1	1	1	1	1	1
	Max	60	60	60	60	60	39	12	41
	Mean	29	27	12	14	11	8	6	7
Irrigation	SD	16	13	8	11	10	6	3	4
	Min	0*	1	1	1	1	1	-	1
	Max	60	60	60	60	60	53	-	60
Canals	Mean	19	21	13	11	10	10	-	8
	SD	15	13	9	8	11	10	-	7

3 * A buffer width of 0 indicates that agriculture is directly adjacent to water

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1 Table 10. Number and perimeter of water bodies directly adjacent to agriculture.

	Total	Numbers	Percent	Total	Adjacent	Percent
	Number	Adjacent	Adjacent ¹	Perimeter	Perimeter	Adjacent ²
				(m)	(m)	
Static water	85	4	4.70%	10756.8	552.8	5.10%
Flowing water	-	-	-	5712.6	1410.2	24.70%
Irrigation canals	-	-	-	24006.2	2970.3	12.40%

2 ¹ Percentage of all static water bodies that have at least some direct adjacency with agriculture.3 ² Percentage of total water body perimeter that is directly adjacent to agriculture.

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1 Figure Captions

2 Figure 1. Land Use / Land Cover for western half of study area.

3 Figure 2. Delineation of the 360-m water margins for proximity analyses.

4 Figure 3. Determination of the spatial distribution of cotton in static water margins. The presence of
5 cotton in a particular direction is symbolized by shading in the octant.

6 Figure 4. Example of buffer area and buffer transects between agriculture and water.

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