Priority cropland acres with the highest potential for soil loss, nutrient loss, and soil quality degradation

The purpose of this study is to identify cropland areas of the country that have the highest potential for soil loss and nutrient loss from farm fields, as well as the highest potential for soil quality degradation—areas of the country that would likely benefit the most from conservation practices. Eight onsite (field level) environmental outcomes were used to identify critical cropland acres:

- sediment loss from water erosion (ton/a/yr, not including gully erosion)
- wind erosion rate (ton/a/yr)
- nitrogen lost with waterborne sediment (lb/a/yr)
- nitrogen dissolved in surface water runoff (lb/a/yr)
- nitrogen dissolved in leachate (lb/a/yr)
- phosphorus lost with waterborne sediment (lb/a/yr)
- phosphorus dissolved in surface water runoff (lb/a/yr)
- soil quality degradation indicator

Previous sections discuss cropland areas that are potentially the most vulnerable for each of the eight onsite environmental outcomes and define critical acres for each outcome for five categories representing different degrees of severity.

Priority acres are those designated as critical acres for one or more of the eight onsite environmental outcomes. Five categories of priority acres, each representing different thresholds of severity, are defined following directly from the approach used to identify critical acres for each outcome:

- most critical 5-percent category—consists of critical acres for sediment and nutrient loss estimates in the top 5 percent nationally (95th percentile), wind erosion rates in the top 2 percent nationally (98th percentile), and soil quality degradation indicator scores in the bottom 5 percent nationally (5th percentile)
- most critical 10-percent category—consists of critical acres for sediment and nutrient loss estimates in the top 10 percent nationally (90th percentile), wind erosion rates in the top 4 percent nationally (96th percentile), and soil quality degradation indicator scores in the bottom 10 percent nationally (10th percentile)
- most critical 15-percent category—consists of critical acres for sediment and nutrient loss estimates in the top 15 percent nationally (85th percentile), wind erosion rates in the top 6 percent nationally (94th percentile), and soil quality degradation indicator scores in the bottom 15 percent nationally (15th percentile)
- most critical 20-percent category—consists of critical acres for sediment and nutrient loss estimates in the top 20 percent nationally (80th percentile), wind erosion rates in the top 8 percent nationally (92nd percentile), and soil quality degradation indicator scores in the bottom 20 percent nationally (20th percentile)
- most critical 25-percent category—consists of critical acres for sediment and nutrient loss estimates in the top 25 percent nationally (75th percentile), wind erosion rates in the top 10 percent nationally (90th percentile), and soil quality degradation indicator scores in the bottom 25 percent nationally (25th percentile)

The most critical 5-percent category accounted for about 23 percent of the cropland acres included in the study (table 71). Thus, according to these model simulations, one or more of the eight onsite environmental outcomes was in the worst 5 percentile nationally (2 percentile for wind erosion) for 23 percent of the cropland acres. For perspective, note that if all of these acres met the critical acre criterion exclusively for only one environmental outcome, the top 5-percent category would represent 37 percent of the cropland acres—seven outcome categories times 5 percent of the acres for each plus 2 percent for wind erosion. The most critical 10-percent category included about 40 percent of the acres included in the study, the most critical 15-percent category included 52 percent of the acres, the most critical 20-percent category included 62 percent of the acres, and the most critical 25-percent category included 71 percent of the acres.

Table 71 Priority cropland acres with the highest potential for sediment loss, wind erosion, nutrient loss, or soil quality degradation

	Non-critical acres (1,000s)	Number of onsite environmental outcome categories meeting criteria for critical acres							Total critical acres (1,000s)	Percent critical acres
		1 (1,000 acres)	2 (1,000 acres)	3 (1,000 acres)	4 (1,000 acres)	5 (1,000 acres)	6 (1,000 acres)	7* (1,000 acres)		
Most critical 5% category										
Northeast	7,673	2,774	902	1,184	782	311	17	0	5,969	43.8
Northern Great Plains	69,703	2,177	483	32	0	0	2	0	2,694	3.7
South Central	25,404	12,315	4,605	1,522	1,021	417	56	11	19,946	44.0
Southeast	6,635	4,905	1,072	348	385	35	12	3	6,760	50.5
Southern Great Plains	24,294	4,849	2,922	31	0	0	0	0	7,802	24.3
Upper Midwest	93,021	10,124	4,783	3,858	716	55	23	0	19,560	17.4
West	4,151	3,519	1,254	78	1	17	0	0	4,868	54.0
All regions	230,880	40,662	16,021	7,053	2,906	834	109	14	67,598	22.6
Most critical 10% category										
Northeast	4,861	4,091	955	974	1,661	857	201	42	8,781	64.4
Northern Great Plains	65,316	5,409	1,275	333	61	2	2	0	7,081	9.8
South Central	14,580	14,188	7,351	4,644	2,150	1,703	692	42	30,770	67.8
Southeast	3,720	5,785	2,217	739	623	159	143	9	9,675	72.2
Southern Great Plains	18,223	8,187	5,460	217	10	0	0	0	13,873	43.2
Upper Midwest	69,683	22,767	7,756	8,145	3,109	856	259	6	42,898	38.1
West	3,474	3,270	1,950	288	9	15	13	0	5,545	61.5
All regions	179,856	63,696	26,964	15,340	7,623	3,591	1,309	99	118,622	39.7
Most critical 15% category										
Northeast	3,266	4,100	1,714	793	1,496	1,519	577	178	10,376	76.1
Northern Great Plains	58,346	9,240	2,908	1,123	666	112	0	2	14,051	19.4
South Central	10,901	10,115	8,309	6,684	3,998	3,156	1,833	355	34,449	76.0
Southeast	2,233	4,853	3,667	1,183	725	427	256	51	11,162	83.3
Southern Great Plains	15,437	7,984	7,832	786	51	5	0	0	16,659	51.9
Upper Midwest	49,903	28,808	12,962	11,195	6,673	2,207	753	79	62,678	55.7
West	3,222	3,108	2,036	560	59	10	24	0	5,797	64.3
All regions	143,307	68,208	39,427	22,324	13,668	7,436	3,443	664	155,171	52.0
Most critical 20% category										
Northeast	1,517	4,882	1,724	890	1,191	1,804	1,236	399	12,125	88.9
Northern Great Plains	51,511	11,848	5,219	2,063	1,140	610	4	2	20,886	28.8
South Central	7,835	7,993	6,776	7,140	5,921	4,191	4,510	984	37,515	82.7
Southeast	1,521	4,018	3,779	1,829	1,105	559	462	123	11,874	88.6
Southern Great Plains	12,198	8,867	8,486	2,367	161	18	0	0	19,898	62.0
Upper Midwest	36,835	30,675	14,263	14,699	9,470	4,280	1,605	754	75,746	67.3
West	2,888	2,991	2,301	724	44	48	24	0	6,131	68.0
All regions	114,304	71,273	42,547	29,710	19,031	11,509	7,841	2,262	184,174	61.7

Table 71 Priority cropland acres with the highest potential for sediment loss, wind erosion, nutrient loss, or soil quality degradation—Continued

	Non-critical acres (1,000s)	Number of onsite environmental outcome categories meeting criteria for critical acres							Total critical acres (1,000s)	Percent critical acres
		1 (1,000 acres)	2 (1,000 acres)	3 (1,000 acres)	4 (1,000 acres)	5 (1,000 acres)	6 (1,000 acres)	7* (1,000 acres)		
Most critical 25% category										
Northeast	584	5,043	1,862	815	1,011	1,985	1,611	732	13,058	95.7
Northern Great Plains	44,007	16,273	5,227	3,827	2,004	983	74	2	28,390	39.2
South Central	5,484	5,964	6,684	6,519	6,060	6,049	6,053	2,537	39,866	87.9
Southeast	1,227	3,430	3,622	1,790	1,508	860	697	261	12,168	90.8
Southern Great Plains	10,124	8,712	9,190	3,491	490	84	5	0	21,972	68.5
Upper Midwest	24,220	31,277	14,673	18,098	13,413	6,745	2,669	1,486	88,361	78.5
West	2,422	2,925	2,476	775	310	63	48	0	6,597	73.1
All regions	88,067	73,624	43,734	35,314	24,796	16,769	11,156	5,018	210,411	70.5

Note: The most critical 5 percent category includes critical acres for sediment and nutrient loss estimates in the top 5 percent nationally, wind erosion rates in the top 2 percent nationally, and soil quality degradation indicator scores in the bottom 5 percent nationally. The higher percent categories were constructed in an analogous manner, using the top 4-, 6-, 8-, and 10-percent wind erosion rates.
* Includes less than 10,000 acres with eight onsite environmental outcomes for the most critical 25 percent category

Cropland acres were often critical for more than one onsite environmental outcome, also shown in table 71. Of the 68 million cropland acres meeting criteria for critical acres in the most critical 5-percent category, 40 percent met criteria for more than one outcome. Most of these met criteria for just two outcomes, but a significant number met criteria for three or four outcomes. Multiple outcomes were less prevalent in the Northern Great Plains, Southern Great Plains, and West regions. As the criteria for critical acres expanded to include less severe outcomes, critical acres meeting criteria for multiple outcomes increased. About 56 percent of the priority acres met criteria for more than one outcome in the most critical 15-percent category and 65 percent met criteria for more than one outcome in the most critical 25-percent category. These cropland acres that are critical for multiple onsite environmental outcomes are potentially in the greatest need of conservation treatment, and, if treated, would provide the most overall environmental protection for the least effort.

The spatial distribution of priority acres is shown in maps 41–44 for the most critical 5-percent, most critical 10-percent, most critical 15-percent, and most critical 20-percent categories. The color scheme in these maps reflects the number of onsite environmental outcomes that met the criteria for critical acres. A blue cell in the maps, for example, has an average cell value for one of the eight onsite environmental outcomes that meets the criteria for critical acres on the basis of the NRI acreage represented by the 25-square-mile cells used to construct the maps. Green represents critical acres for two onsite environmental outcomes, orange represents critical acres for three or four outcomes, and red represents acres for five or more outcomes that met criteria for critical acres. For perspective, map 45 shows the areas of the country with the greatest concentration of cropland acres.

For maps 41–44, thresholds were based on the average values for the 25-mi^2 cells, rather than on the estimates for individual NRI sample points. For the most critical 5% category (map 41), for example, cells were colored if the average cell value for sediment loss or one of the five nutrient loss outcomes was in the 5% of cropland acres with the highest values, or if the average cell value for wind erosion was in the top 2% of the acres, or if the average cell value of the soil quality degradation indicator was in the bottom 5% of the acres.

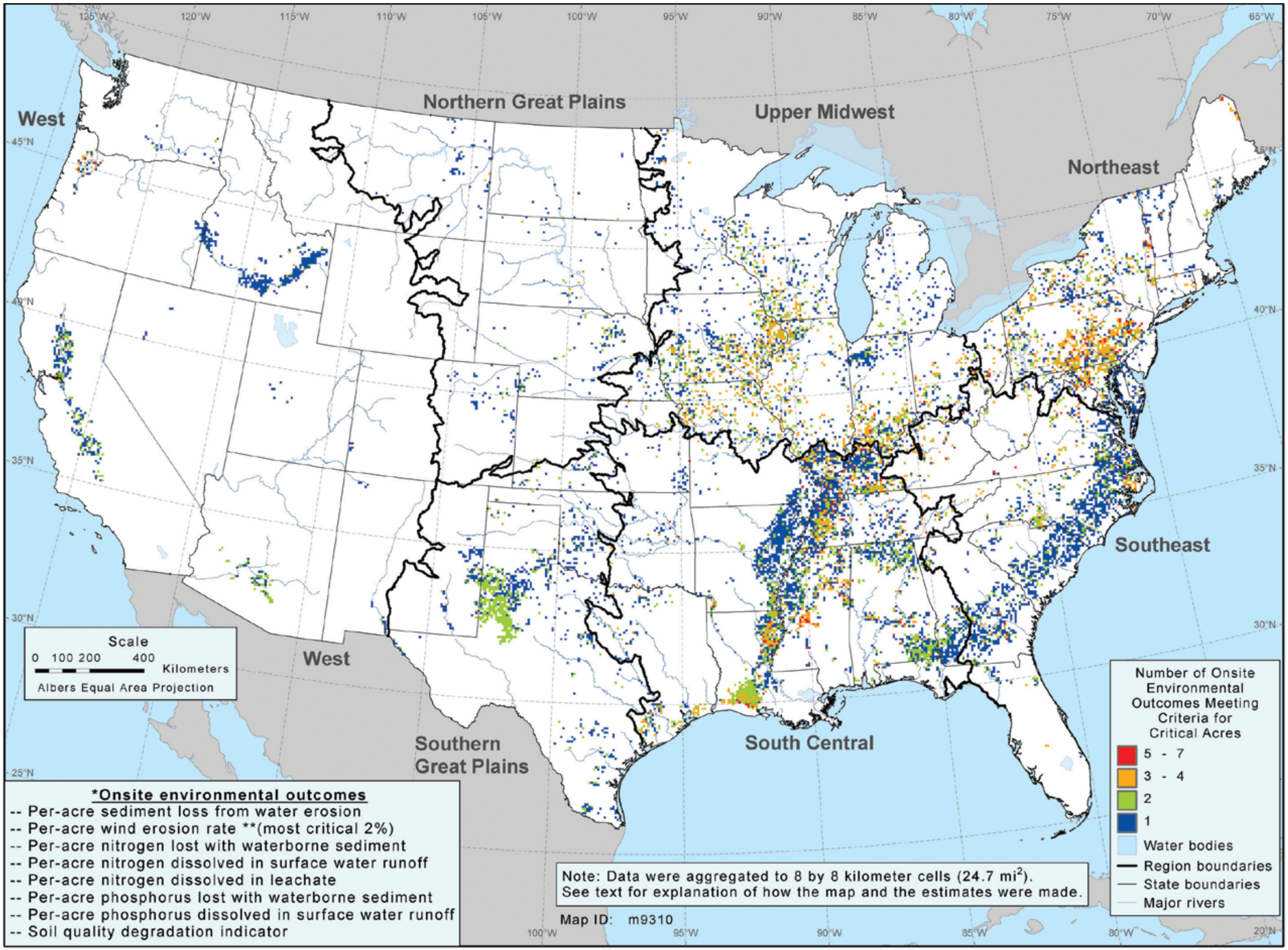
The 68 million potential priority acres shown in map 41 for the most critical 5-percent category are generally distributed throughout most of the cropland areas, as can be seen by comparing map 41 to map 45. However, the priority acres are most concentrated in six areas:

- cropland in the Chesapeake Bay watershed in Maryland and Pennsylvania—area includes the largest concentration of critical acres for multiple outcomes, most of which are critical for three or more outcomes and sometimes five or more
- cropland in the Lower Mississippi River Basin on either side of the Mississippi River below St. Louis, including the lower reaches of the Ohio River, which included several pockets of concentrations of critical acres for multiple outcomes
- cropland along the Atlantic coastal plain stretching from Alabama to southern Virginia
- cropland in northern Texas and western Oklahoma, including a concentration of critical acres in western Texas that met criteria for two outcomes
- cropland in the southern two-thirds of Iowa and parts of Illinois and Missouri adjacent to Iowa, with a significant portion of the critical acres meeting criteria for up to four outcomes
- selected cropland areas in the West

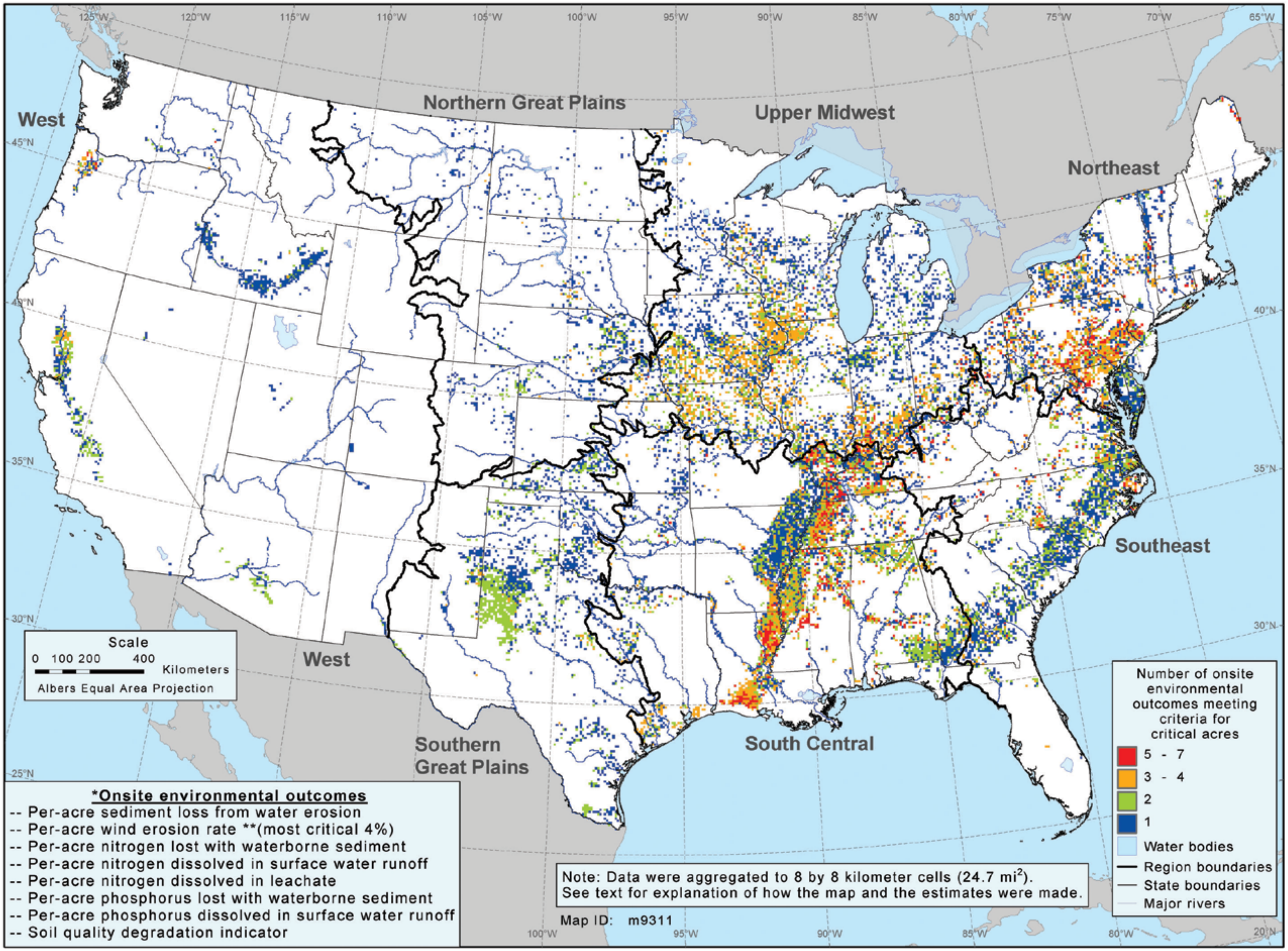
Much of the concentrated cropland area in the Midwest stretching from Ohio through Iowa and eastern Nebraska did not have heavy concentrations of potential priority acres at this level of severity. With the exception of the Lower Mississippi River Basin area, most potential priority acres are found in cropland regions where cropland represents less than 60 percent of the land use.

Relaxing the thresholds for critical acres from the most critical 5-percent category to the most critical 10-percent category increased the number of potential priority acres by 75 percent—from 68 million acres to 119 million acres (map 42). The additional priority acres reinforced the concentration in the six areas identified above, and expanded the number of priority acres in the Midwest region by 23 million acres—more than double the number of priority acres for the 5-percentile category. Priority acres more than doubled in the Northern Great Plains region, as well, although,

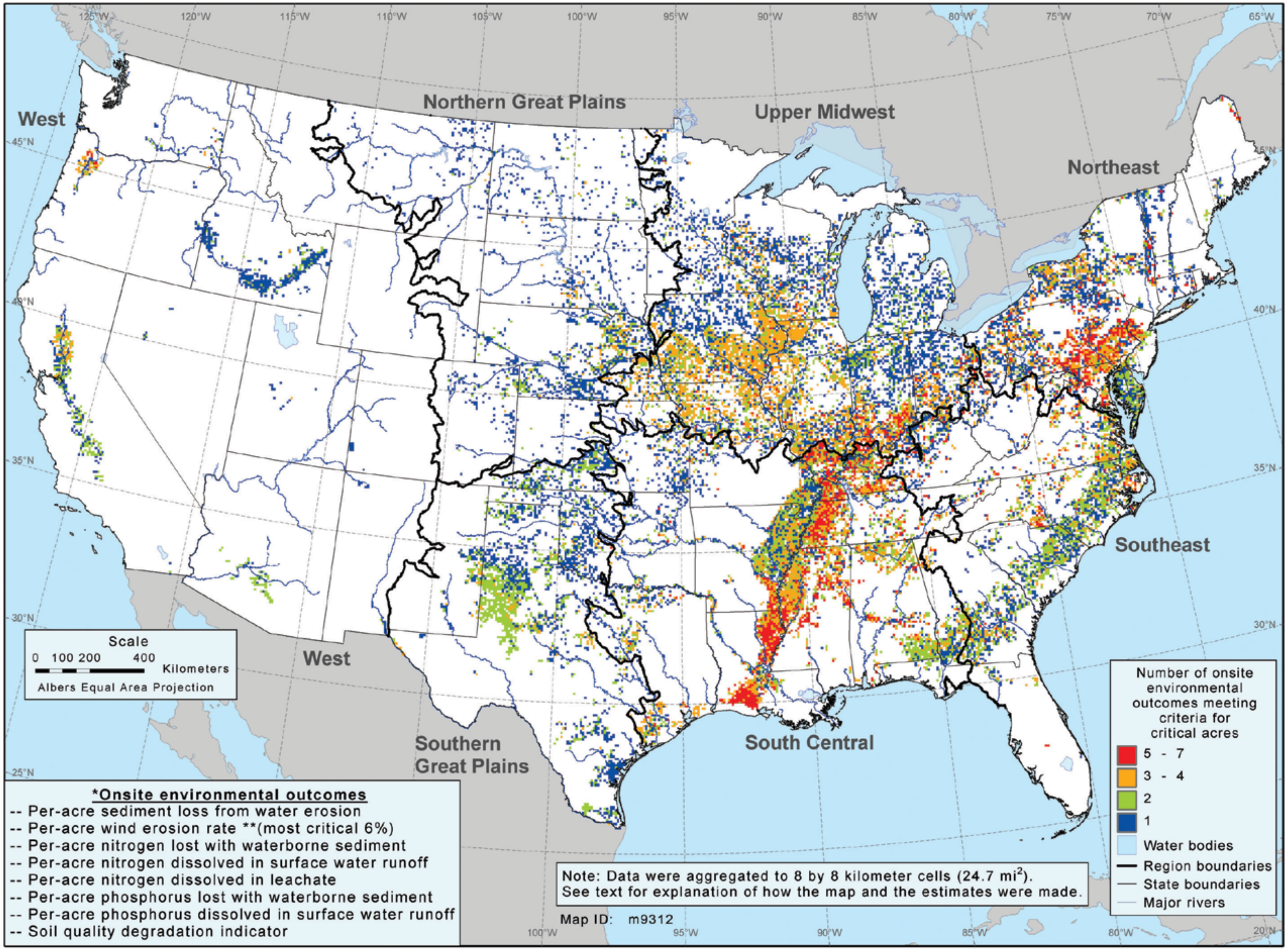
Map 41 Number of onsite environmental outcomes* with most critical 5 percent** of cropland acres for each outcome (most critical 5% category)



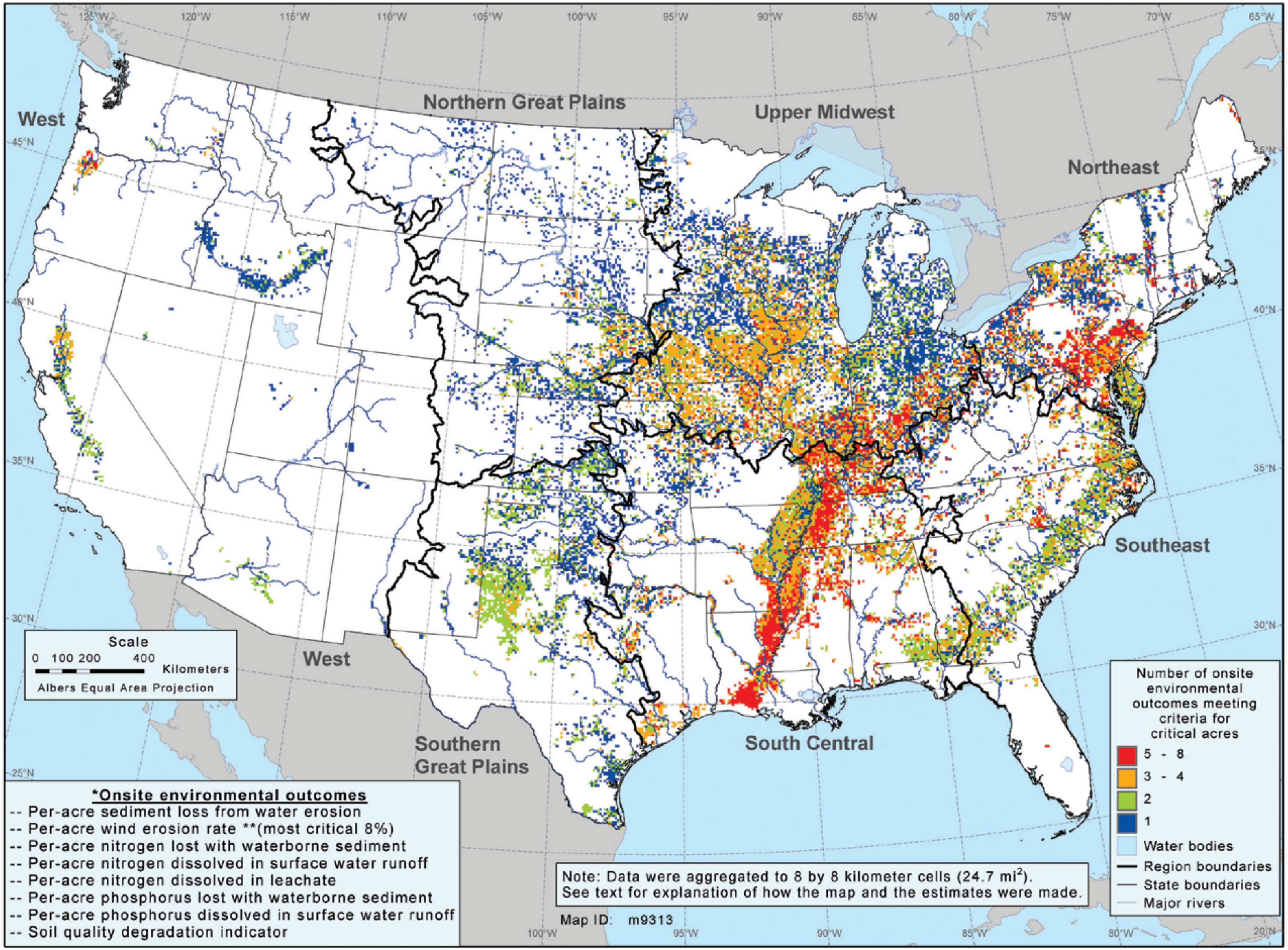
Map 42 Number of onsite environmental outcomes* with most critical 10 percent** of cropland acres for each outcome (most critical 10% category)



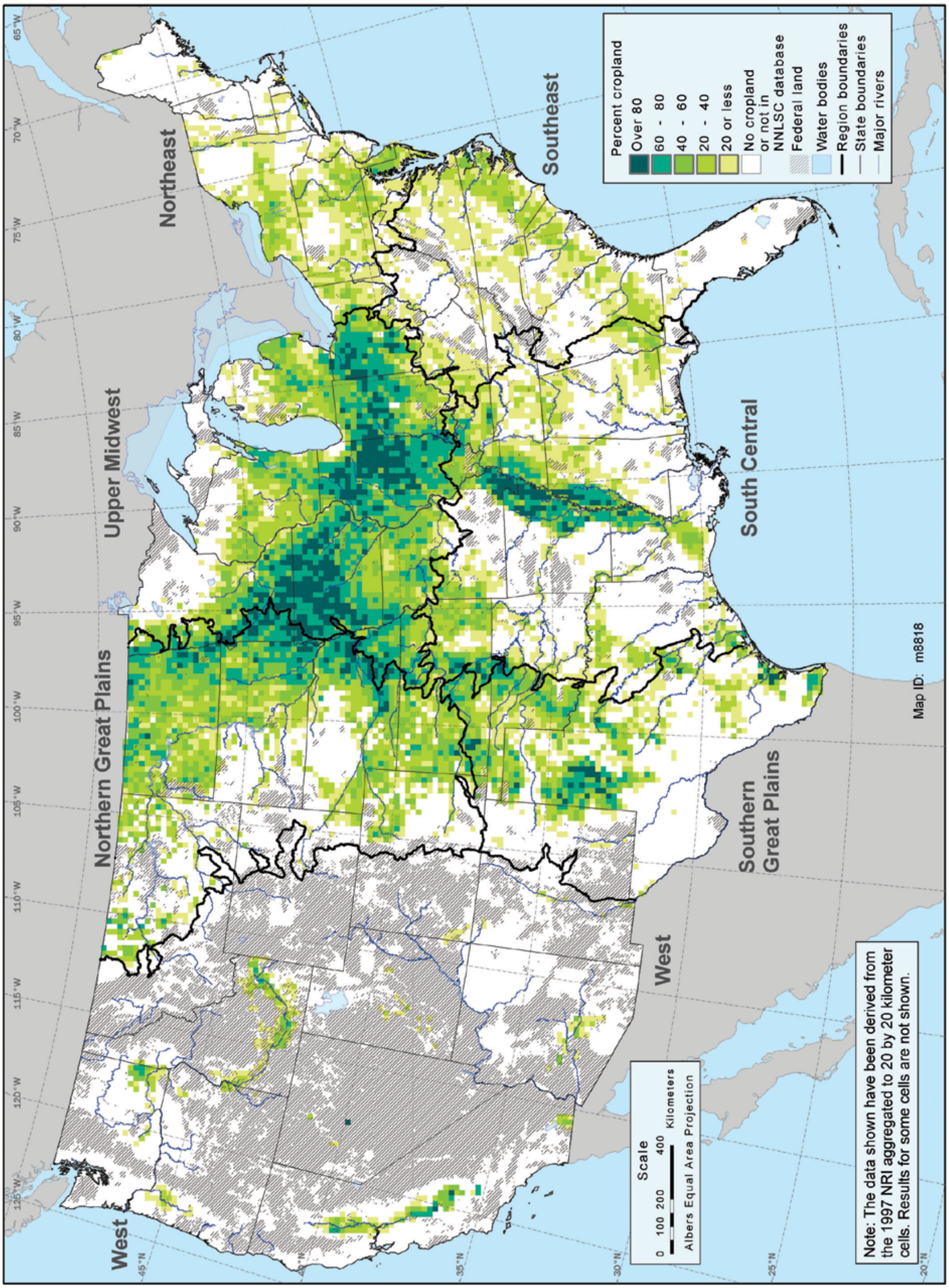
Map 43 Number of onsite environmental outcomes* with most critical 15 percent** of cropland acres for each outcome (most critical 15% category)



Map 44 Number of onsite environmental outcomes* with most critical 20 percent** of cropland acres for each outcome (most critical 20% category)



Map 45 Cropland acres included in the study as a percent of all land uses



they tended to be somewhat evenly spread throughout the cropland acres in the region. The number of priority acres that were critical for multiple onsite environmental outcomes also increased. Acres with three or more outcomes with critical acres (colored orange) more than tripled, and those with five or more (colored red) expanded by more than five times. At the top 10-percent level of severity, two cropland areas had heavy concentrations of priority acres critical for five or more outcomes—the Lower Mississippi River Basin area and the Pennsylvania-Maryland area north of the Chesapeake Bay.

At the severity level of the most critical 15-percent category, about half of the cropland acres were critical acres for one or more onsite environmental outcomes (map 43). The Iowa-Illinois-Missouri area of concentration is more pronounced at this level of severity; most priority acres in this area were critical for three to four outcomes. Most of the priority acres along the Atlantic Coastal Plain are critical for two outcomes, whereas most were critical for only one outcome in the most critical 5-percent category. About 36 million acres were critical for three to four outcomes at this level of severity, and about 12 million acres were critical for five or more outcomes. Nearly all cropland areas had at least some critical acres, but concentrations of critical acres and concentrations of critical acres with multiple outcomes were not always in areas with the highest percentage of cropland. For example, the eastern edge of the Northern Great Plains region is predominately cropland (map 45), but, while it has priority acres scattered throughout most of this area, does not have any areas of concentrated critical acres. The same applies to northern Iowa and southwestern Minnesota, where more than 80 percent of the acres are cropland in some parts.

Expanding the set of priority acres to the most critical 20-percent category (map 44) reinforced the patterns and spatial trends shown in map 43. The Lower Mississippi River Basin and the Pennsylvania-Maryland areas were almost entirely represented by critical acres for five or more outcomes, and the Iowa-Illinois-Missouri area of concentration was largely represented by critical acres for three or four outcomes. Overall, 50 million acres (a sixth of the acres included in the study) were critical for three to four outcomes at this level of severity, and 21 million acres were critical for five or more outcomes. The heaviest concentrations of the highest priority acres—those critical for five or more outcomes—were the Lower Mississippi River Basin and adjacent areas along the lower Ohio River drainage and the Pennsylvania-Maryland region north of the Chesapeake Bay.

An assessment of priority cropland acres, as determined by the per-acre model simulation results presented in this report, leads to the following conclusions:

- Critical cropland acres that are most in need of conservation treatment to manage soil loss, nutrient loss, or soil quality degradation are distributed throughout all the major cropland areas of the country.
- Critical acres are more concentrated in some regions of the country than in other regions.
- The loss pathways and specific treatment needs vary from region to region; for example, the most critical acres for nitrogen runoff loss and nitrogen leaching loss are primarily in different cropland areas.
- Some cropland areas have high concentrations of critical acres for multiple onsite environmental outcomes. These acres represent the highest priority acres for conservation treatment.

Critical acres are identified in this study based only on per-acre losses or soil quality conditions, representing those cropland acres where investment in conservation practices would potentially have the greatest benefits at the field level. Most conservation practices are designed to abate pollution sources at the field level. However, there are other considerations that can also factor into the determination of priority areas for conservation program implementation:

- For some environmental issues, the concern is primarily related to the total amount of sediment or nutrients leaving farm fields and being transported to other areas, impairing water quality in downstream ecosystems. To address these concerns, the areas with the most total loadings would be the highest priority.
- The potential for mitigating impairment of water quality in downstream ecosystems by treating the land is dependent on the potential for the sediment and nutrient losses to be transported from the edge of the field (or through ground water return flow) to a stream or river. It is further

dependent on the existing condition of the water resource, designated uses, and other pollution sources. An evaluation of how effective land treatment would be in ameliorating water quality impairment could lead to identification of a different set of priority acres in some cases.

- Acres that are the most degraded may be the most difficult and expensive to treat. It is possible that treatment of only a few acres with high severity does not provide as much environmental protection as the treatment of more acres that are less severe but easier and cheaper to treat.
- Critical acres in this study were identified on the basis of the annual average amount of nutrients or soil lost from farm fields, averaging over model results for 30 years of different weather conditions. This annual average represents what would be expected under typical weather conditions. For some years in the simulation, however, much higher losses occurred. A somewhat different picture of potential problem areas might be obtained if it was based on the worst case, or near-worst case, outcomes, rather than the average outcome.

Because only tillage and three structural practices were considered in this study, results are presented as potential losses of soil and nutrients from farm fields and the potential for soil quality degradation. Accounting for conservation practices such as nutrient management plans, cover crops, grassed waterways, windbreaks, and buffers, for example, is expected to further reduce sediment and nutrient loss estimates. Moreover, limitations such as incomplete cropland coverage (especially in the West) and the lack of site-specific management practices including crop rotations, as well as various modeling limitations noted previously, are additional reasons to consider the model output as potential losses of soil and nutrients. The priority acres identified are, thus, also potential priority areas. Efforts are currently underway in CEAP to improve the modeling routines, obtain more complete site-specific information, and fully account for conservation practices. Model outputs presented in forthcoming CEAP reports are expected to differ somewhat from results reported in this study and may have some impact on the designation of priority acres.

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Appendix A Example calculation of weighted average EPIC model outputs assigned to NRI sample points

As described in the main body of the report, the NNLSC database consists of EPIC model results for 768,785 model runs providing, on average, about 30 different simulations for each of 25,250 URUs. The results of the EPIC model runs were used to construct model-generated variables for the 178,567 NRI cropland points included in the domain. Variable values for an NRI sample point were obtained by calculating the weighted average over all the management options in the NNLSC database for the URU corresponding to the NRI sample point. Each NRI sample point corresponding to a given URU was assigned the same variable values. The weights represent the probability that a particular option would occur.

The probabilities that a particular management option applies to a URU (and the associated NRI sample points) were estimated based on the frequency of occurrence of each option obtained from national-level databases. For the three tillage options, probabilities were derived from the Crop Residue Management Survey, which is a county-level database that reports the acres for each tillage type by crop (CTIC 2001). The probabilities for the commercial fertilizer application options were derived from the Cropping Practices Survey data by state and crop and were based on the number of observations (farmers surveyed) associated with each of the selected possibilities. The percentage of acres with manure applied as derived from the 1997 Census of Agriculture were used as the probabilities for options with manure applications, calculated for each state and climate zone combination. The probability that the manure was applied on a manure producing farm or on a manure receiving farm was obtained from the same source.

Table A–1 provides an example of how the NRI variable for nitrate loss in runoff was determined for URU 7462. Sprinkler irrigated corn is grown in this URU located in Nebraska within climate cluster 27, which encompasses the northwest portion of the state. The soil is a Blendon fine sandy loam and conservation practices (terraces, contour farming, and stripcropping) are not present. Nutrient management options based on the Cropping Practices database for Nebraska corn consisted of 21 nutrient application time and rate combinations for commercial fertilizer applications (specific options and probabilities of occurrence are shown in table 15 in the main body of the report) and two manure fertilizer options. The 23 nutrient management options were replicated for each of the three tillage systems—conventional-till, mulch-till, and no-till—resulting in a total of 69 management options for the URU. Each management option requires a unique set of field operations to simulate the management option using EPIC. (An example set of field operations for one of the 69 management systems is shown in table 10 in the main body of the report.) Probabilities associated with each tillage type, each manure option, and each commercial fertilizer option are shown in table A–1. The joint probability for the management system is the multiple of the three probabilities, also shown in table A–1. The weighted model output is then calculated for each of the 69 model runs (shown in the last column in table A–1) and summed to obtain the weighted average for the URU. As shown in the last row of table A–1, the weighted estimate of average annual nitrogen lost in runoff is 4.52 pounds per acre for this example. This value was then assigned to each of the 5 NRI sample points associated with this URU.

All model results were calculated in this same manner for each URU and assigned to NRI cropland sample points associated with each URU.

Table A–1 Example of how EPIC-generated variables were estimated for NRI cropland sample points

Tillage	Application time	Fertilizer application rate		Manure application	Average annual nitrogen lost in runoff (lb/a)*	Commercial fertilizer option probability	Manure application option probability	Tillage option probability	Joint probability of management system	Weighted model output for nitrogen runoff
Conventional	Fall	High N	Average P	No manure	6.45	0.0173	0.8921	0.5066	0.00782	0.0504
Conventional	Spring	High N	Average P	No manure	8.48	0.0370	0.8921	0.5066	0.01672	0.1418
Conventional	Fall and at plant	High N	Average P	No manure	6.65	0.0379	0.8921	0.5066	0.01713	0.1140
Conventional	Spring and at plant	High N	Average P	No manure	7.81	0.0864	0.8921	0.5066	0.03905	0.3048
Conventional	At plant and after plant	High N	Average P	No manure	14.50	0.0996	0.8921	0.5066	0.04502	0.6528
Conventional	Fall	High N	Zero P	No manure	6.45	0.0123	0.8921	0.5066	0.00556	0.0359
Conventional	Spring	High N	Zero P	No manure	5.22	0.0428	0.8921	0.5066	0.01934	0.1010
Conventional	Fall	Medium N	Average P	No manure	6.04	0.0099	0.8921	0.5066	0.00447	0.0270
Conventional	Spring	Medium N	Average P	No manure	5.50	0.0379	0.8921	0.5066	0.01713	0.0942
Conventional	Fall and at plant	Medium N	Average P	No manure	4.92	0.0428	0.8921	0.5066	0.01934	0.0952
Conventional	Spring and at plant	Medium N	Average P	No manure	5.47	0.0864	0.8921	0.5066	0.03905	0.2135
Conventional	At plant and after plant	Medium N	Average P	No manure	6.22	0.1012	0.8921	0.5066	0.04574	0.2847
Conventional	Fall	Medium N	Zero P	No manure	6.65	0.0263	0.8921	0.5066	0.01189	0.0790
Conventional	Spring	Medium N	Zero P	No manure	2.43	0.0395	0.8921	0.5066	0.01785	0.0434
Conventional	Fall	Low N	Average P	No manure	1.54	0.0132	0.8921	0.5066	0.00597	0.0092
Conventional	Spring	Low N	Average P	No manure	2.06	0.0247	0.8921	0.5066	0.01116	0.0230
Conventional	Fall and at plant	Low N	Average P	No manure	2.39	0.0370	0.8921	0.5066	0.01672	0.0399
Conventional	Spring and at plant	Low N	Average P	No manure	2.54	0.0872	0.8921	0.5066	0.03941	0.1003
Conventional	At plant and after plant	Low N	Average P	No manure	2.16	0.0955	0.8921	0.5066	0.04316	0.0930
Conventional	Fall	Low N	Zero P	No manure	1.42	0.0189	0.8921	0.5066	0.00854	0.0121
Conventional	Spring	Low N	Zero P	No manure	1.24	0.0461	0.8921	0.5066	0.02084	0.0258
Conventional	At plant	Derived		Manure producer	0.87	1.0000	0.0276	0.5066	0.01400	0.0122
Conventional	At plant	Derived		Manure receiver	1.42	1.0000	0.0803	0.5066	0.04069	0.0580
Mulch	Fall	High N	Average P	No manure	5.70	0.0173	0.8921	0.2787	0.00430	0.0245
Mulch	Spring	High N	Average P	No manure	8.22	0.0370	0.8921	0.2787	0.00920	0.0757
Mulch	Fall and at plant	High N	Average P	No manure	5.73	0.0379	0.8921	0.2787	0.00942	0.0540
Mulch	Spring and at plant	High N	Average P	No manure	6.87	0.0864	0.8921	0.2787	0.02148	0.1476
Mulch	At plant and after plant	High N	Average P	No manure	14.46	0.0996	0.8921	0.2787	0.02476	0.3582
Mulch	Fall	High N	Zero P	No manure	5.53	0.0123	0.8921	0.2787	0.00306	0.0169
Mulch	Spring	High N	Zero P	No manure	3.90	0.0428	0.8921	0.2787	0.01064	0.0415
Mulch	Fall	Medium N	Average P	No manure	5.24	0.0099	0.8921	0.2787	0.00246	0.0129
Mulch	Spring	Medium N	Average P	No manure	4.20	0.0379	0.8921	0.2787	0.00942	0.0395
Mulch	Fall and at plant	Medium N	Average P	No manure	4.13	0.0428	0.8921	0.2787	0.01064	0.0440

Table A–1 Example of how EPIC-generated variables were estimated for NRI cropland sample points—Continued

Tillage	Application time	Fertilizer application rate	Manure application	Average annual nitrogen lost in runoff (lb/a)*	Commercial fertilizer option probability	Manure application option probability	Tillage option probability	Joint probability of management system	Weighted model output for nitrogen runoff
Mulch	Spring and at plant	Medium N Average P	No manure	4.38	0.0864	0.8921	0.2787	0.02148	0.0942
Mulch	At plant and after plant	Medium N Average P	No manure	5.25	0.1012	0.8921	0.2787	0.02516	0.1321
Mulch	Fall	Medium N Zero P	No manure	6.03	0.0263	0.8921	0.2787	0.00654	0.0394
Mulch	Spring	Medium N Zero P	No manure	1.69	0.0395	0.8921	0.2787	0.00982	0.0166
Mulch	Fall	Low N Average P	No manure	1.04	0.0132	0.8921	0.2787	0.00328	0.0034
Mulch	Spring	Low N Average P	No manure	1.36	0.0247	0.8921	0.2787	0.00614	0.0084
Mulch	Fall and at plant	Low N Average P	No manure	1.85	0.0370	0.8921	0.2787	0.00920	0.0170
Mulch	Spring and at plant	Low N Average P	No manure	2.02	0.0872	0.8921	0.2787	0.02168	0.0438
Mulch	At plant and after plant	Low N Average P	No manure	2.29	0.0955	0.8921	0.2787	0.02375	0.0543
Mulch	Fall	Low N Zero P	No manure	0.92	0.0189	0.8921	0.2787	0.00470	0.0043
Mulch	Spring	Low N Zero P	No manure	0.83	0.0461	0.8921	0.2787	0.01146	0.0095
Mulch	At plant	Derived	Manure producer	0.80	1.0000	0.0276	0.2787	0.00770	0.0062
Mulch	At plant	Derived	Manure receiver	1.32	1.0000	0.0803	0.2787	0.02238	0.0296
No-till	Fall	High N Average P	No manure	2.32	0.0173	0.8921	0.2147	0.00331	0.0077
No-till	Spring	High N Average P	No manure	6.83	0.0370	0.8921	0.2147	0.00709	0.0484
No-till	Fall and at plant	High N Average P	No manure	2.36	0.0379	0.8921	0.2147	0.00726	0.0171
No-till	Spring and at plant	High N Average P	No manure	3.74	0.0864	0.8921	0.2147	0.01655	0.0619
No-till	At plant and after plant	High N Average P	No manure	13.17	0.0996	0.8921	0.2147	0.01908	0.2512
No-till	Fall	High N Zero P	No manure	2.27	0.0123	0.8921	0.2147	0.00236	0.0053
No-till	Spring	High N Zero P	No manure	1.32	0.0428	0.8921	0.2147	0.00820	0.0108
No-till	Fall	Medium N Average P	No manure	1.89	0.0099	0.8921	0.2147	0.00190	0.0036
No-till	Spring	Medium N Average P	No manure	1.32	0.0379	0.8921	0.2147	0.00726	0.0096
No-till	Fall and at plant	Medium N Average P	No manure	1.44	0.0428	0.8921	0.2147	0.00820	0.0118
No-till	Spring and at plant	Medium N Average P	No manure	2.00	0.0864	0.8921	0.2147	0.01655	0.0332
No-till	At plant and after plant	Medium N Average P	No manure	2.47	0.1012	0.8921	0.2147	0.01938	0.0479
No-till	Fall	Medium N Zero P	No manure	6.33	0.0263	0.8921	0.2147	0.00504	0.0319
No-till	Spring	Medium N Zero P	No manure	0.58	0.0395	0.8921	0.2147	0.00757	0.0044
No-till	Fall	Low N Average P	No manure	0.74	0.0132	0.8921	0.2147	0.00253	0.0019
No-till	Spring	Low N Average P	No manure	0.67	0.0247	0.8921	0.2147	0.00473	0.0032
No-till	Fall and At Plant	Low N Average P	No manure	1.18	0.0370	0.8921	0.2147	0.00709	0.0084
No-till	Spring and at plant	Low N Average P	No manure	1.30	0.0872	0.8921	0.2147	0.01670	0.0217
No-till	At Plant and after plant	Low N Average P	No manure	1.49	0.0955	0.8921	0.2147	0.01829	0.0272

Table A–1 Example of how EPIC-generated variables were estimated for NRI cropland sample points—Continued

Tillage	Application time	Fertilizer application rate		Manure application	Average annual nitrogen lost in runoff (lb/a)*	Commercial fertilizer option probability	Manure application option probability	Tillage option probability	Joint probability of management system	Weighted model output for nitrogen runoff
No-till	Fall	Low N	Zero P	No manure	0.59	0.0189	0.8921	0.2147	0.00362	0.0021
No-till	Spring	Low N	Zero P	No manure	0.40	0.0461	0.8921	0.2147	0.00883	0.0036
No-till	At plant	Derived		Manure producer	0.68	1.0000	0.0276	0.2147	0.00593	0.0040
No-till	At plant	Derived		Manure receiver	0.99	1.0000	0.0803	0.2147	0.01724	0.0170
		Totals for URU 7462							1.00	4.52

* Average of 30 annual estimates obtained for each of the 69 EPIC model simulations.

Appendix B Summary of EPIC application and performance literature

The complexity of the natural environment modeled by EPIC and the comprehensive accounting of soil and weather properties and management alternatives allowed by the model preclude any simple summary statement about the prediction error of EPIC model output. Validating environmental effects such as nutrient leaching and runoff is difficult because these and other endpoints are seldom measured at the field level. Actual weather events, which drive the model outputs, are highly variable, further complicating validation efforts. A complete validation of EPIC would require that field-level measurements be taken on a variety of soil types in several climatic zones, each with several crops grown using a variety of production technologies. Moreover, the validation study would need to be repeated each time the model was updated. The cost of conducting such a study is clearly prohibitive.

Over the years, however, various researchers have conducted partial validation studies in conjunction with the study of specific issues. There are more than 150 journal articles and reports documenting the use of EPIC in a wide variety of situations. Results from a selection of these studies are listed in table B–1. Findings from some of these studies are summarized below. It is important to note that these studies were for older versions of EPIC than used in the present study.

Williams et al. (1989) evaluated EPIC's ability to simulate yields of maize, wheat, rice, sunflower, barley, and soybeans using a total of 227 measured yields reported by independent research groups around the world. For these crops, mean simulated yields were within 7 percent of mean measured yields. For 118 comparisons of measured and simulated maize yields, mean measured yield and its standard deviation were 103 bushels per acre and 49 bushels per acre, respectively. The measured and simulated means were not significantly different at the 95 percent confidence level. This study also demonstrated that EPIC can accurately simulate maize responses to irrigation at locations in the western United States and to nitrogen fertilizer in Hawaii.

Dyke et al. (1990) compared simulated and measured yields for a total of 204 treatment years for the Southern Coastal Plain and Southern High Plains of Texas. Crops included maize, grain sorghum, and cotton. Tillage systems, irrigation, and crop rotations also varied. Simulated yields were within 20 percent of mean measured yields for 70 and 90 percent of treatment-years for the Coastal Plain and High Plains, respectively. Simulated yields were within the 95 percent confidence interval of measured yields for 69 and 88 percent of the treatment-years for the two sites.

Bryant et al. (1992) examined the ability of the EPIC model to simulate the controlled field experiments on the impact of alternative irrigation management strategies on corn yields for corn grown in the Southern High Plains. Data for comparison to model results was for the period of 1975–1977. Bryant et al. found that the mean of simulated yields was not significantly different (P=0.05) from the mean of the measured yields. The standard deviation of simulated yields exceeded that of measured yields. Yield trends over the period were similar. The EPIC model was able to explain from 72 to 86 percent of the variance in measured yields depending on the year of comparison.

Cabelguenne et al. (1990) evaluated the ability of EPIC to simulate the effects of management of complex crop rotations in southern France, including the effects of irrigation, nitrogen fertilization, and the previous crop on crop growth and yield. For three levels of fertilizer application and a complex four-crop rotation, the differences between simulated yields and measured yields varied from 1 to 17 percent depending on the year, crop, and the fertilizer level.

Chung et al. (1999) validated EPIC against measured hydrologic and environmental quality indicators for two tillage systems (conventional and ridge till) in two watersheds in Southwest Iowa that had been under continuous corn cropping. The model was first calibrated using 1988 to 1994 data for surface runoff, seepage flow, and evapotranspiration (ET), and then validated for those variables plus NO_3 losses, soil erosion, and crop yields using 1976–1987 data. The percent errors for the EPIC model simulations are summarized:

	Watershed 1	Watershed 2
Validation period (1976–1987)		
Surface runoff	+2.1%	+0.2%
Seepage flow	+10.0	-3.2
ET	-0.6	+1.3
NO_3-N leached	-8.8	+4.7
NO_3-N runoff	+43.8	0.0
Crop yield	+4.1	-1.3

Edwards et al. (1994) tested the ability of the EPIC model to simulate non-point source pollution arising from the application of animal waste to agricultural land in Arkansas (four pasture fields). Model predictions of runoff, sediment yield, nitrate losses, organic N losses, soluble P losses, and total P (TP) losses were compared with measured data over a 20-month period and model performance was assessed both for storm events and on a calendar year basis. The correlation between observed and predicted events was significant (P=0.05) for each field. Observed and predicted event TP were significantly correlated for three fields, and there was a significant correlation between observed soluble P and sediment losses for two fields. The overall performance of EPIC on a calendar year basis was very good for all parameters except nitrate losses.

The ability of EPIC to simulate soil carbon changes due to land use and crop management changes was tested by Izaurralde et al. (2001) by comparing actual field test plot measurements to EPIC model results for the same situations. For five sites where cropland had been converted to perennial grass cover in the CRP program in Kansas, Nebraska, and Texas, the EPIC estimate of final soil organic carbon ranged from 80.7 to 139.5 percent of the observed measured value. For a 60-year wheat/fallow rotation experiment at Breton, Canada, the EPIC estimate of soil carbon ranged from 89.5 to 105.6 percent of observed for the control treatment, 93.6 to 199.3 percent of observed for the applied fertilizer treatment, and 74.7 to 99.4 percent of observed for the manured treatment.

Wang et al. (2005) conducted the sensitivity and uncertainty analyses of corn yields and soil organic carbon (SOC) simulated with the EPIC for a 34-year experiment at the University of Wisconsin Arlington Agricultural Research Station in south central Wisconsin. The long-term experiment was established in 1958 with the purpose of evaluating the response of continuous corn to different N fertilization treatments (Vanotti et al., 1997). The study demonstrated EPIC is dependable and accurate from a statistical point of view in simulating corn yields and SOC. The measured average corn yields fell well within the 5 percent and 95 percent confidence limits. The width of 90 percent confidence interval bands for corn yields ranged from 0.31 to 1.6 milligauss hectare^{-1}, while predicted and observed means were 3.26 to 6.37 milligauss hectare^{-1} and 3.28 to 6.4 milligauss hectare^{-1}, respectively, for the 5 nitrogen treatments. The 90 percent confidence width for SOC was 0.97 to 2.13 gram kilogram^{-1}, while predicted means and observed SOC were 17.4 to 22.3 gram kilogram^{-1} and 19.2 to 22.9 gram kilogram^{-1}, respectively. The optimal parameter set for the study site gave an R^2 of 0.96 for mean corn yield predictions, with errors ranging from -8.5 to 8.2 percent, and an R^2 of 0.89 for yearly SOC predictions, with errors ranging from -8.3 to 2.4 percent.

King et al. (1996) applied the EPIC model to estimate runoff, sediment yield, nutrient transport, and crop growth for six small watersheds for which measured data was available. Crop yield predictions were in the range of observed values for the region. The comparison for environmental quality indicators was as follows:

	Measured	EPIC
Runoff to precipitation ratio	12.99–19.89%	13.84–17.8%
Sediment loss—no-till	0.19 ton/ha	0.16 ton/ha
Sediment loss—conventional till	1.87 ton/ha	1.92 ton/ha
NO_3-N in runoff—no-till	3.15 kg/ha	3.43 kg/ha
NO_3-N in runoff—conventional till	6.60 kg/ha	5.43 kg/ha

Kiniry et al. (1997) tested the ability of the ALMANAC version of EPIC and a similar model to simulate long-term mean corn yields for one county in each of the following nine states (MN, NY, IA, IL, NE, MO, KS, LA, and TX). For each county, simulated corn grain yields for representative soil, weather, and management situations were compared to the county average yield for the period 1983 to 1992 as reported by the National Agricultural Statistics Service. Kiniry et al. reported that "Mean simulated grain yield for each county was always within 5 percent of the mean measured grain yield for the location. Within locations, measured grain yield was regressed on simulated grain yields and tested to see if the slope was significantly different from 1.0 and if the y-intercept was significantly different from 0.0, both at the 95 percent confidence level." For the EPIC version, the slope or the intercept was significantly different from the hypothesized values only for Minnesota, New York, and Nebraska, and the coefficient of variation of simulated grain yields were similar to those of measured yields at most sites.

A recent paper by Gassman et al. (2004) reviews the historical development and applications of the EPIC model.

Table B–1 Summary of selected EPIC application, evaluation, and validation studies

Author	Year	Focus	Scope
Hajek and Williams	1987	Erosion productivity effects	AL Coastal Plain and TN Valley
Williams et al.	1989	Yields: evaluation of EPIC crop growth sub-model	Barley, corn, rice, sorghum, sunflower, and wheat, various location in United States and France
Williams	1990	A case history of early EPIC development	Not applicable
Cabelguenne et al.	1990	Yield calibration and validation for rotations	Southern France
Bryant et al.	1992	Yield response to irrigation	Corn in the Southern Plains
Kiniry et al.	1992	Yield calibration for sunflowers	Toulouse, France
Cabelguenne et al.	1993	Irrigation strategy optimization	Corn in SW France
Wallis, T. W. R.	1993	Weather simulator	Five TX locations
Nicks et al.	1994	Erosion prediction equation alternatives	Twenty-two sites across the U.S.
Edwards et al.	1994	Runoff transport of surface applied nutrients	Field level – NW AR forage fields
Potter and Williams	1994	Soil temperature, daily prediction	IA, ND, and TX sites
Sloot et al.	1994	Alternative tillage systems	Secano Interior of Chile
Easterling et al.	1996	Climate change effect, validation of yield response	Seven weather stations in E. NE
King et al.	1996	Sediment and nitrate loss with conservation tillage	Vertisol Blackland Prairie in Central TX
Purveen et al.	1996	Snowmelt and water erosion	Peace River region of Alberta
Kiniry et al.	1997	Yield estimate comparison for corn and other model	Nine locations across the U.S.
Ramanarayanan et al.	1998	Runoff and soil loss	Small watersheds in OK and TX
Chung et al.	1999	Non-point source pollutant loading	Watershed in SW IA
Cavero et al.	Late 90s	Nitrogen cycling in vegetable-grain cropping systems	
Chen et al.	2001	Non-point source water quality	Trinity River Basin in TX
Izaurralde et al.	2001	Soil carbon	Scaling point estimates up to regional and national (U.S. sites)
Izaurralde et al.	2001	Soil carbon, tillage and cover	Canadian and U.S. field plot studies
Tan and Shibasaki	2003	Global warming and crop productivity	Global – various countries and crops
Perez et al.	2003	Yields with precision farming	CA crop and vegetable rotations