Assessing U.S. Farm Drainage:

Can GIS Lead to Better Estimates of Subsurface Drainage Extent?

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SUMMARY

Extensive agricultural subsurface tile drainage in the Midwestern U.S. has important implications for nutrient pollution in surface water, notably the "dead zone" in the Gulf of Mexico. However, drainage data limitations have constrained efforts to effectively factor tile drainage into regional economic and environmental impact studies. Improved drainage data would be a valuable addition to future modeling applications. In light of this need, a methodology incorporating a geographic information system (GIS) analysis based on soil and land cover maps was implemented to create a set of county-level tile drainage extent estimates.

- For several leading agricultural drainage states, maps of soil drainage characteristics were created and overlaid with row crops. Areas with row crops and poorly drained soils were calculated, disaggregated to the county level, and reduced by a percentage based on published estimates to approximate subsurface drainage. Results for eight highly-drained Midwest states were compared to previous estimates. A range of tile drainage estimates were compiled, along with a final best-guess county-level database of tile drained area.
- This represents just one set of methods, and without sufficient data for verification it may be difficult to judge its effectiveness compared to others. By demonstrating one method, we hope to encourage further exploration of the use of GIS for predicting and assessing farm drainage. More importantly, we aim to further the dialogue regarding the relationship between drainage and water quality in the U.S. and highlight the need for improved measurement of this key agricultural practice.

CONCLUSIONS & RECOMMENDATIONS

- Map-based GIS analysis using soil and land cover data can provide a good representation of land that would benefit from drainage, and in densely tile-drained regions may be an improvement over previous estimates. Refinements could be made through further exploration of smaller geographic areas using more detailed data and maps.
- Improved drainage data will contribute to a better understanding of the large-scale environmental impacts of tile drainage-related nutrient pollution, and the cost-effectiveness of nutrient abatement strategies. To that end, we offer a range of drainage estimates and a revised national county-level database of agricultural tile drainage for collaborative validation and review.
- Ultimately, without actual measurements, ad hoc efforts to estimate tile drainage extent will only be stop-gap measures in solving the drainage data problem. Pressing water quality concerns such as Gulf hypoxia highlight the need for another large-scale drainage survey, which could be included in the USDA's next agricultural census.

The practice of installing agricultural subsurface tile drainage is pervasive in much of the Midwest Corn Belt, where it has been used for decades to transform poorly drained soils into highly productive cropland. In terms of soil and water quality, tile drainage has both positive and negative effects. For example, while it can help reduce soil erosion and the transport of certain nutrient pollutants, it can also increase nitrate-nitrogen losses to surface water. High levels of nonpoint nutrient pollution, particularly nitrate, from fertilizers used in Midwest agriculture are believed to be an important contributor to the "dead zone" in the Gulf of Mexico, one of the largest hypoxic areas in the world. Because tile drains can accelerate the transfer of nitrate in high concentrations from fields to streams bound for the Mississippi-Atchafalaya River system and ultimately the Gulf, they are a crucial factor in the overall N flux. This constitutes an important consideration for research efforts aimed at improving understanding of the causes of Gulf hypoxia as well as the solutions. Consequently, accurate information on the extent and nature of tile drainage is vital.

The more accurately the current extent of subsurface tile drainage can be quantified, the better its environmental implications can be understood and the more effectively various mitigating policies might be targeted. For example, achieving nutrient load reductions through fertilizer management is one measure that has been demonstrated to be a cost-effective means of improving Gulf hypoxia.[1] However, recent work has shown that nutrient management policies may be somewhat cost-ineffective on non-drained cropland.[2] This indicates that nutrient reductions on tile-drained land probably yield a better bang for the buck, and serves to further highlight the need to discriminate between drained and non-drained land in modeling and other research applications. Making that distinction requires useful, up-to-date data on agricultural tile drainage. Unfortunately, even the best available data are outdated and their degree of precision uncertain due

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to past methodological inconsistencies in data collection. This, coupled with dubious prospects for another survey of drainage in the near-term, has created a sizable data gap that needs to be addressed to the extent possible in order to inform research efforts and policy decisions at all levels.

To begin to address this problem, WRI sought to create a new county-level database of tile drainage using the 1992 National Resources Inventory as a base and incorporating a map-based analysis to investigate the utility of GIS for supplementing or revising existing estimates. The resulting database could then be adjusted and improved over time through ground-truthing and expert review to serve three key functions: address the need for better drainage data, facilitate the validation of the use of GIS for estimating drainage, and provide inputs suitable for regional-scale modeling. WRI is making the data available to further develop assessments of agricultural nonpoint nutrient pollution and inform policies to address this issue. This report describes the methodology used by WRI to create these tile drainage estimates.

DRAINAGE STATUS AND DATA NEEDS

In a 1987 report on drainage status in the U.S., the USDA states that "drainage is the most extensive soil and water management activity in agriculture".[3] According to the report, approximately half of all cropland in both Ohio and Indiana benefits from some type of artificial drainage, whether from surface ditches, subsurface tile lines, or subirrigation-related drainage. In much of the row crop-dominated Upper Midwest, a significant portion of drained cropland is drained by subsurface systems; 85% in both Illinois and Iowa, for example. Coincidentally, 35% of the average total N load going out of the Mississippi River and into the Gulf of Mexico comes from these two states.[4]

Subsurface tile drainage[*] can provide both economic benefits for crop production through the removal of excess water from the soil column, and environmental improvements in soil and water quality through reductions in runoff, erosion, and phosphorous (P) transport.[5] Unfortunately, tile drains can also have the adverse effect of transporting nitrogen (N) from fertilizer and other sources in water-soluble nitrate form more readily from the field to surface water. Excessive agriculture-based nitrate concentration is an established cause of nonpoint pollution and contributor to oxygen depletion in marine ecosystems. Water is considered hypoxic when the dissolved oxygen concentration is less than 2 parts per million. At that point, it can result in stress and mass mortality of bottom-dwellers and the departure of fish and other mobile sea creatures to areas with sufficient oxygen, as happens seasonally in the "dead zone" in the Gulf of Mexico. However, previous regional-scale studies of Gulf hypoxia have been unable to effectively account for the nitrate loading impacts of tile drainage.[6] This is due in part to the unavailability of data on tile drain extent, distribution, and condition at scales larger than the individual watershed or field test-plot.

Federal involvement in drainage projects has declined over the last several decades; the decennial census of drainage was cut by Congress in 1986 and the resulting information gap has gone largely unfilled since the 1978 census. Additionally, inconsistencies in past census and survey methods make the accuracy of existing data difficult to assess and, consequently, past and future trends difficult to establish.

Unfortunately, no truly comprehensive information on the status of agricultural drainage has been published since the aforementioned 1987 USDA report *Farm Drainage in the United States: History, Status, and Prospects*, and those data were not disaggregated to the county level and thus unsuitable for many modeling applications. That report compiled and analyzed drainage information from the 1978 Census of Drainage, drainage specialists, and other government sources current as of 1982, including the 1982 National Resources Inventory (NRI). Although *Farm Drainage* is still regarded as the best available resource on U.S. drainage, there are some key limitations of the source data, many of which are acknowledged in the report. Accuracy and consistency were hampered to some extent in the 1978 Census of Drainage because neither the SCS staff collecting the data nor the farmers always knew how much drained land there was. The 1982 NRI was an improvement, but as a statistical sampling survey it also had limitations: it counted subsurface drainage for each survey point only if it was part of a government-recognized conservation practice, so it is uncertain how much privately installed tile drainage went undetected and uncounted. Additionally, only three practices could be listed for each survey point, so it is also possible that subsurface drainage may have been omitted in favor of other practices. Another limitation is that it was sometimes difficult for the staff who surveyed the sample sites to identify where subsurface drainage was located. The last year that drainage was included in the NRI was 1992, and that survey was based more on remotely-sensed data and aerial photography instead of visits to sample sites. However, this posed another limitation as subsurface drainage can be hard to perceive in such imagery. Although it is unclear how accurate a representation it is of the full extent of tile drainage, the 1992 NRI remains the most recent complete data set at the county level for the continental U.S.

While a lack of more recent data makes it difficult to assess just how much tile has been sold and installed over the last twenty-plus years, it is at least clear that farmers have continued to invest in drainage and that the overall extent of tile has increased. Advances in precision farming and GPS-based yield mapping technology have allowed for more effectively targeted drainage installation, boosting demand for tile beyond what contractors have been able to supply in some areas.[7] Nevertheless, subsurface drainage was not slated for inclusion in USDA's 2007 Census of Agriculture and it may be 5 years or more before another

[*] Although deep surface ditching can provide subsurface drainage, in this report "subsurface drainage" will refer to the use of subsurface tubing or "tile" lines, and will be used interchangeably with "tile drainage."

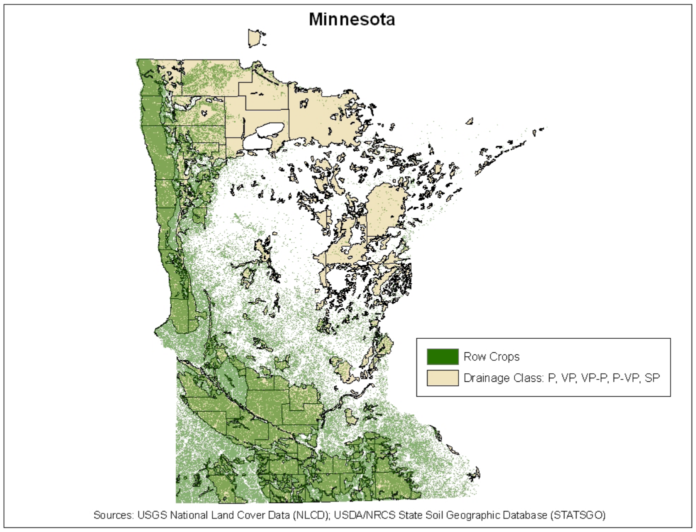
comprehensive assessment could be done that might account for the net increase that has occurred since the last estimates. Thus for the foreseeable future, it appears that information on U.S. drainage will continue to be compiled in a piecemeal fashion just as it has been since the early 1980's.

GIS METHODOLOGY

The GIS methodology described in this paper is based on the simple idea that if row crops are cultivated on a poorly drained soil, then an artificial drainage improvement likely exists on that soil. Therefore, calculating the area of row crops being grown on poorly drained soil should provide an approximation of the extent of artificial drainage improvements. GIS is well-suited for performing this calculation using basic soil, land cover, and administrative map layers. All of the 18 states included in the analysis have at least 10% of all drained land in subsurface drainage as documented in *Farm Drainage in the United States.* Included were the Corn Belt and Great Lake states (Iowa, Illinois, Wisconsin, Minnesota, Indiana, Michigan, Missouri, and Ohio) which are estimated to comprise roughly 51 million acres of drained land.[8] USDA/NRCS State Soil Geographic Database (STATSGO) coverages were used in the analysis. The county-level Soil Survey Geographic Database (SSURGO) would have been preferable due to its higher resolution and more detailed soil information, but would have required the compilation of numerous county data sets, which would have been impractical given the multi-state spatial extent of the analysis and time constraints.

The USDA STATSGO Soils Browser 1.0 was used to query each state based on soil drainage classification to determine the dominant drainage class for each map unit.[9] Soils with a natural soil drainage class of somewhat poor, poor, very poor, poor-to-very poor, or very poor-to-poor (SP, P, VP, P-VP, or VP-P) were extracted from the soil map layer in the GIS, and then overlaid

Figure 1. Poorly drained soils overlaid with row crops for Minnesota.



with row crop grids extracted from 1992 state National Land Cover Dataset (NLCD) grids obtained from USGS.[10] This overlay for Minnesota is shown in Figure 1. The NLCD was selected for geographical completeness, sufficiently detailed land cover classification, and temporal consistency with the 1992 NRI.* After intersecting the soil drainage class maps with county-level administrative boundaries, the area of row crops occurring on the extracted soils was calculated for each county in each of the states. These results were interpreted as general representations of the total area of cropland that would potentially benefit from some type of artificial drainage improvement, but not necessarily tile drainage.

To explore the robustness of the drainage estimates, the GIS analysis was repeated using hydrologic soil groups A/D, B/D, C/D, C, and D instead of soil drainage classification. Soil groups C and D have slow and very slow infiltration rates, respectively, and the dual or "slash" groups A/D, B/D, and C/D represent soils that would be of D classification in their natural (undrained) state but which have the potential for an A, B, or C classification if drained. These soils are most likely to have drainage improvement if row crops are being grown on them.

For each analysis, the individual county data were aggregated to the state level and compared to estimates in *Farm Drainage* and unpublished 2004 results by USDA/ARS National Soil Tilth Lab (NSTL) for six Great Lakes and Corn Belt states.[11] Results are shown in Table 1.

Consultation with soil and drainage scientists at land-grant universities indicated that the USDA 1987 data remains the best available drainage data source, so it was used as a benchmark for comparing the other estimates. Overall, the GIS analysis based on soil drainage class yielded percentages more consistent with the USDA 1987 data than using soil hydrologic group. The GIS estimate by Dan Jaynes (USDA-ARS) incorporated both soil drainage class and hydrologic group but did not include somewhat-poorly drained soils or soils of hydrologic group C. These soils have low infiltration rates when wetted and can remain wet for extended periods, but in terms of this analysis are less likely to require artificial drainage for crop production than other soils with poorer drainage. Of the soils included, they are the least certain to have tile drainage. Using both soil drainage class and soil hydrologic group and including hydrologic soil group C and drainage class "somewhat poorly" as criteria would likely result in higher drainage estimates due to the larger spatial extent of those maps. Further testing is required to determine whether using soil drainage class and/or hydrologic group, and which combination of soil classes yields the most accurate estimates for different areas.

* The 2001 NLCD is now available for the conterminous U.S. but was not complete at the time of this study.

Since there are different types of farm drainage, the estimates of drained cropland using row crops and soil drainage class were not assumed to be exclusively tile-drained. The methods used here cannot distinguish between surface, subsurface, and sub-irrigation drainage practices, and so an adjustment was made based on data in *Farm Drainage* to try to arrive at a closer approximation of the amount of tiled land. Total drained cropland for each state was calculated based on the percent of total drained land given in *Farm Drainage*. Similarly, the amount of subsurface-drained land was calculated. Total subsurface drainage was then taken as a percent of total drained cropland. This percentage of subsurface drainage out of total drained cropland for each state was used to adjust the drainage class results in each of its respective counties. This assumed that the percentage derived from *Farm Drainage* has remained constant over time and that there was an even distribution of drainage type in each state. Some estimates were adjusted based on advice from NRCS specialists. Mapped results are shown in Figure 2.

SUBSURFACE DRAINAGE IN THE 1992 NATIONAL RESOURCES INVENTORY

To further validate the soil drainage class (SDC)-based estimates, another set of tile extent estimates was produced using 1992 NRI data on subsurface drainage implemented as part of a conservation practice. The main advantage of the NRI is that it is complete for all counties in the continental U.S. These data allowed for county-level comparison to the results of the SDC analysis and provided data for states without widespread tile drainage that were not well-suited for the SDC method. An NRI query program was used to select all survey points for which conservation practice 606 (subsurface drainage) was recorded and aggregate them to the county level. Each county figure was multiplied by the NRI's default expansion factor of 1,000 to produce actual acreage. These results are shown in Figure 3.

Figure 2. Estimated drainage per county based on soil drainage class.

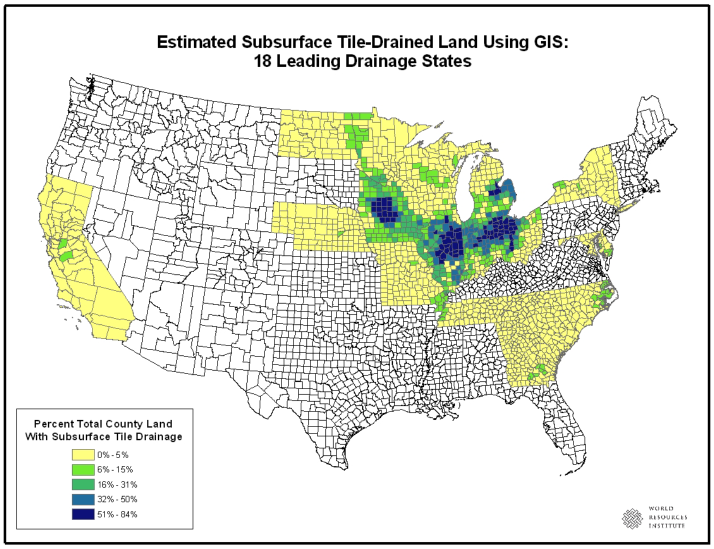


Table 1. Four estimates of drained cropland out of total state area.

Percent Drained Cropland of Total Area for Leading Drainage States

	USDA 1987[1]	National Soil Tilth Lab[2]	WRI GIS[3] (soil drainage class)	WRI GIS[4] (soil hydrologic group)
Indiana	30%	19%	30%	32%
Missouri	10%	11%	11%	12%
Ohio	20%	19%	27%	34%
Iowa	20%	19%	25%	10%
Illinois	30%	22%	35%	17%
Minnesota	15%	18%	18%	15%
Wisconsin	3%	--	4%	7%
North Dakota	5%	--	8%	8%
California	3%	--	0%	2%
North Carolina	8%	--	5%	6%
Tennessee	2%	--	2%	8%
New York	3%	--	2%	3%
South Carolina	5%	--	5%	16%
Georgia	1%	--	2%	4%
Nebraska	2%	--	2%	4%
Maryland	13%	--	5%	6%
Delaware	24%	--	11%	11%

[1] USDA-ERS Misc. Pub. 1455 *Farm Drainage in the United States: History, Status, and Prospects.*
[2] Pers. communication. Drainage class P, VP, P-VP, VP-P; Hydrologic group A/D, B/D, C/D, D
[3] Drainage class SP, P, P-VP, VP-P, VP.
[4] Hydrologic group A/D, B/D, C, C/D, D.

COMPARING THE TWO ESTIMATES

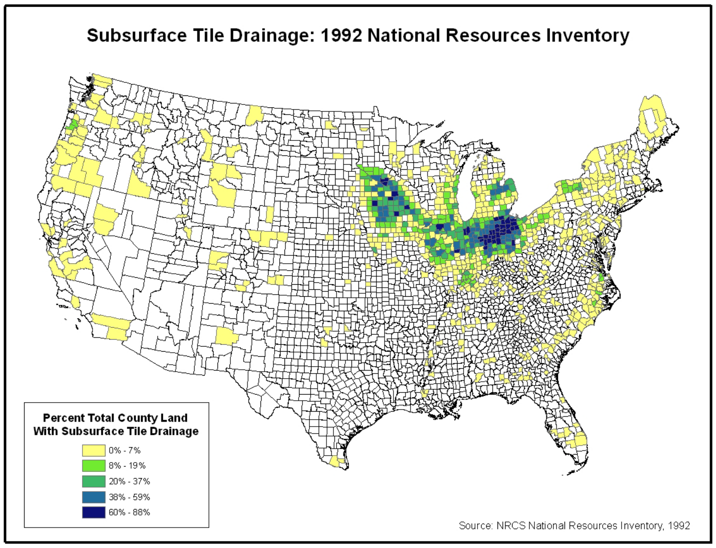
The SDC estimates and NRI county estimates often varied widely in relation to each other; with no recent data other than expert opinion, it was difficult to gain a sense of which dataset was a better representation of the current state of drainage for a given county, or even a given region. Given that subsurface drainage has become more prevalent in many areas since 1992, the NRI data are likely to underestimate the present extent of tile drains. However, neither set of estimates was consistently higher than the other at the state or county level, making it difficult to discern any trend in the data. In some areas, the NRI analysis predicted greater drained acreage than the SDC estimates at both the county and the aggregated state levels. One reason for this could be the existence of subsurface drainage in lands with moderately well-drained soils, which would have been captured in the NRI survey but were not by the SDC method due to the map-based criteria used. In other cases, experts indicated that the SDC estimates were too high. Thus, it was unclear which set of estimates would be more accurate for a given county.

RECONCILING THE NRI AND GIS ESTIMATES

To address this uncertainty in creating a single best-guess set of estimates, the NRI and SDC data sets were reconciled and compiled by incorporating existing state-level data. The NRI was used as the default estimate for most counties because the SDC method did not include all states.

States for which there were SDC estimates and a very high percentage of subsurface-drained cropland out of total drained cropland (80% or higher) according to *Farm Drainage* were treated individually. The states selected were Ohio, Illinois, Indiana, Michigan, Iowa, Missouri, Minnesota, and Wisconsin. A basic set of criteria were developed in order to choose which data to use for each of these states.

Figure 3. Subsurface tile drainage per county, 1992 NRI.



Estimates of cropland with subsurface drainage for each of these states were calculated from drained cropland and total cropland data The percent drained cropland of total cropland was taken from the most recent source available, which was either *Farm Drainage* or, if available, a version of that same data updated based on expert opinion in 1998 found in *Ohio State University Extension Bulletin 871-98*. State cropland totals for 1992 were from USDA/ERS. Total cropland was multiplied by percent drained cropland to produce actual drained cropland. Drained cropland was then multiplied by percent subsurface-drained land of drained cropland to produce actual subsurface-drained land. This total was then taken as a percent of total cropland (see results for Indiana in Table 2).

These "target percentages," which represent the percent subsurface drainage out of total cropland for each state, were then compared to the same percentages calculated using the totals from the other sets of estimates. The state target percentage was used as the common means of comparison across the different types of estimates for each state. A third set of slightly different estimates was created from the raw SDC results by adjusting some counties based on expert advice. Also, if for a given county the SDC value was zero and the NRI non-zero, the NRI was used because its survey methodology makes it unlikely to overestimate subsurface drainage. These adjustments were generally not significant at the state level. Results for the Corn Belt and Lakes states are shown in Table 3.

The NRI, SDC, and SDC adjusted (as described above) sets of county subsurface drainage estimates were summed for each of these states, the sums were expressed as a percent of total cropland, and these were then compared to determine which percentage was closest to the target percentage. The closest set of tile drainage estimates for each of these states was included in the final output database unless information indicating otherwise was obtained from experts. Estimates for the contiguous U.S. are depicted in Figure 4.

RESULTS

These results could be interpreted as a range of estimates of tile drained acres for each state. For both Iowa and Illinois, the NRI represents a lower bound at roughly 3 million acres lower than the USDA-based estimates. The SDC results for Iowa were very similar to the USDA target. However, for Illinois the SDC and SDC adjusted results were about 3.7 million acres higher than the target figure. This represents an upper bound that could be an overestimate for some counties. Still, it is likely more accurate than the NRI estimate, as it is closer to a figure of about 10 million acres (4 million ha) based on a slightly different derivation from the same *Farm Drainage* data used in this study. That commonly cited estimate (David and Gentry[12]; Sogbedji and McIsaac[13]) is approximately twice as large as the 1992 NRI figure, the least consistent estimate for Illinois. For Ohio and Indiana, the SDC results were very similar to the target, with the adjusted values lower by about 100,000 acres. For both of these states, the NRI was roughly 1 million acres higher and represents a possible upper bound. For Minnesota, the SDC results were closer to the target than the NRI, but the NRI was taken as the final estimate. This was because the SDC analysis counted a significant amount of land as being drained in the Red River Valley area in the northwest part of the state where tile drainage in actuality is not yet widespread.[14] The NRI estimates captured this more accurately. SDC estimates for Michigan and Wisconsin were greater than the target by about 1.6 million acres and 200,000 acres, respectively. The NRI results were closer by comparison. A higher SDC estimate for these states is not unexpected, as they have lower percentages of cropland with subsurface drainage than Iowa, Illinois, Ohio, and Indiana. The higher estimates may be attributable to there being more potential drainage than actual drainage in those states. However, Missouri has the lowest percentage of cropland with subsurface drainage of these eight states and the SDC estimate was actually closer to the target acreage than the NRI. This may warrant further investigation into factors influencing the differences tile drainage extent and density in these states.

Table 2. Estimated percent cropland with subsurface drainage for Indiana.

Indiana	
(A) Total cropland 1992 (ac)	13,370,000
(B) Drained cropland (50% of total cropland)	6,685,000
(C) Drained cropland with subsurface drainage (82% of total drained cropland)	5,481,700
Target percent of all cropland with subsurface drainage*	41%

** Expressed as* ***A * B * C / A * 100%*** *where*

A = total cropland in 1992 (USDA/ERS)
B = percent total cropland with drainage (USDA 1987)
C = percent drained cropland with subsurface drainage (USDA 1987).

Table 3. USDA, NRI, SDC, and SDC adjusted estimates of tile drainage for the eight Corn Belt and Lake states.

	USDA "Target"[1]		NRI 1992		Soil Drainage Class (SDC)		SDC Adjusted[2]	
States	*Total subsurface drainage (million acres)*	*Percent total cropland with subsurface drainage*	*Total subsurface drainage (million acres)*	*Percent total cropland with subsurface drainage*	*Total subsurface drainage (million acres)*	*Percent total cropland with subsurface drainage*	*Total subsurface drainage (million acres)*	*Percent total cropland with subsurface drainage*
Iowa	8.9	32.9%	6.0	21.9%	8.7	32.0%	8.8	32.4%
Illinois	7.9	32.9%	5.0	20.9%	11.6	47.8%	11.6	47.8%
Ohio	5.8	48.8%	6.7	56.2%	5.7	48.1%	5.7	48.3%
Indiana	5.5	41.2%	6.5	48.8%	5.7	42.4%	5.6	42.2%
Minnesota	2.5	10.7%	3.4	14.4%	2.4	10.2%	2.4	10.2%
Michigan	2.1	25.7%	2.3	28.7%	3.7	44.7%	3.7	44.8%
Wisconsin	0.7	6.7%	0.7	5.9%	0.9	8.1%	0.9	8.1%
Missouri	0.7	3.6%	0.1	0.7%	0.6	3.3%	0.6	3.4%

[1] Based on 1992 USDA-ERS total cropland estimates and drained land percentages in *Farm Drainage in the United States,* USDA 1987.
[2] Indicates some county totals were changed to NRI value where SDC = 0 and NRI > 0, or based on expert opinion.

Overall, the SDC analysis produced drainage estimates that were well in line with previous USDA estimates for the highly drained states of Iowa, Ohio, and Indiana, and not unreasonably high for Illinois. They were also similar for Missouri, even though it has a much lower percentage of cropland with subsurface drainage. At a state-level aggregation, estimates for Minnesota seemed to be close to the USDA target, but were not used in the final output due to known inaccuracies for the northwest region of the state. Results are less similar for Wisconsin and Michigan, which are less highly drained than the four leading states. From this it is apparent that the SDC analysis is effective and a legitimate alternative for highly drained areas such as those in the intense row crop lands of Iowa, Ohio, and Indiana, and perhaps Illinois, but will have diminishing accuracy the less drainage there is in a state or county. The different sets of estimates are useful in establishing a range of total tile drainage for each state, but more in-depth, localized analysis of factors influencing drainage and validation is necessary to narrow the ranges and improve estimates for individual counties. The range of estimates considered and the subsurface drainage totals used in the final database (and mapped in Figure 4) are shown in Table 4.

LIMITATIONS AND POTENTIAL IMPROVEMENTS

Comparison at the state level is not ideal because drainage practices are influenced by environmental and economic conditions independent of state borders. However, the information given in *Farm Drainage in the United States* is aggregated to the state level and presents the most useful means of comparison. Used as the final data for most states, the 1992 NRI represents the most recent, and spatially disaggregated, estimate of drainage, but not necessarily the most comprehensive. Within the set of map-based estimates, a higher level of confidence can be attributed to counties where row crop production is extensive and soils are naturally very poorly drained. Ultimately, however, it remains uncertain how well these estimates reflect the current state of tile drainage in U.S. cropland.

In states where subsurface drainage is uncommon compared to surface drainage, it is likely that the GIS method produced inflated numbers. A large amount of "false positives" may appear in areas where row crops were being grown on poorly drained soils, but where tile drainage is actually limited. Examples of such areas include Mississippi Delta rice-producing regions of Arkansas, Mississippi, Missouri, and Louisiana, and the Red River Valley region in northwest Minnesota.

Additionally, existing data sources do not make the distinction between targeted tile drainage installed to drain individual depressions and more extensive pattern tile systems that drain significant areas, even entire fields. Thus, inaccuracies may result from the difference in the effective drained area depending on the extent and type of tiling.

This analysis was unable to account for other factors that have a bearing on whether a plot of land is actually drained or not. There are numerous economic, physical, and geographic factors affecting a farmer's decision to install tile drainage. Certainly, tile drainage is not installed on all agricultural land that would benefit from it while, at the same time, artificial drainage is not strictly limited to poorly drained soils. In some regions, the use of tile drainage in wet soils may be limited due to a lack of research on crop response.[15] Such factors were considered in this analysis to

Figure 4. Final estimated subsurface drainage.

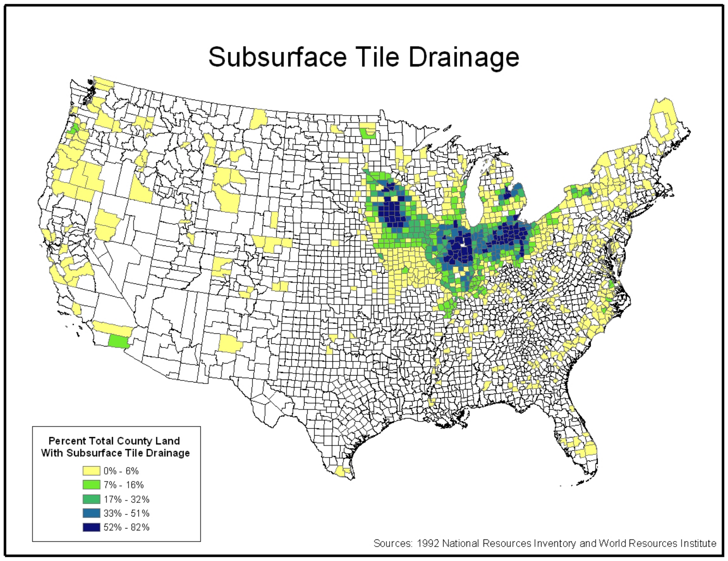


Table 4. Range of subsurface drainage estimates and total used in final database for Corn Belt and Lake states.

	USDA "Target"[1]		Range	Final	
States	*Total subsurface drainage (million acres)*	*Percent total cropland with subsurface drainage*	*Total subsurface drainage (million acres)*	*Total subsurface drainage (million acres)*	*Percent total cropland with subsurface drainage*
Iowa	8.9	32.9%	6 - 8.8	8.8	32.4%
Illinois	7.9	32.9%	5 - 11.6	11.6	47.8%
Ohio	5.8	48.8%	5.7 - 6.7	5.7	48.3%
Indiana	5.5	41.2%	5.5 - 6.5	5.6	42.2%
Minnesota	2.5	10.7%	1.7 - 3.4	3.4	14.4%
Michigan	2.1	25.7%	2.1 - 3.7	2.3	28.7%
Wisconsin	0.7	6.7%	0.7 - 0.9	0.7	5.9%
Missouri	0.7	3.6%	0.1 - 0.7	0.6	3.4%

[1] Based on 1992 USDA-ERS total cropland estimates and drained land percentages in *Farm Drainage in the United States,* USDA 1987.

the extent possible, but not extensively or systematically. Without validation it is extremely difficult to determine just how limiting they may be.

Map-based drainage analysis could be improved in several ways. The use of more detailed, higher-resolution land cover imagery that distinguishes between different types of row crops could significantly reduce the amount of false positives – areas with soils that would benefit from drainage, but where there is little or no subsurface drainage in reality. Such data already exists for some regions. Additionally, use of the more detailed SSURGO digital soil maps would yield more accurate calculations of area likely to be drained. Although not feasible for a large-scale analysis such as this one, it would be appropriate at the county or multi-county level. Finally, further exploration of different combinations of soil classifications and crop types for different areas could lead to sets of region-specific procedures for using GIS to estimate tile drainage.

It is necessary to point out that the ability to test the usefulness of any adjustments to this type of analysis, and indeed the analysis itself, will still be limited by the extent to which the results themselves can be tested. Verification based on the knowledge of soil and drainage specialists may be constructive for the time being, but because it is simply unknown how much drainage has been installed since the last survey, it would seem the best solution for determining the validity of results is a new survey of drainage. If soil characteristics such as soil drainage class could be linked to drainage data within the context of a survey, it could also have the added benefit of facilitating the testing of assumptions made in this study concerning the relationships between artificial drainage, row crops, and soil drainage quality. But until there is another survey, any efforts at estimating drainage will only be a band-aid on the basic problem.

CONCLUSION

Subsurface tile drainage is a widespread practice in agricultural regions of the Midwest U.S. that can have negative implications for surface water quality and Gulf of Mexico hypoxia due to associated higher nitrate loading. Unfortunately, the lack of current and accurate data at useful spatial and administrative scales has made it very difficult to account for this effect in past studies. A thorough assessment of the environmental impacts of agriculture, and of policies to manage those impacts, requires that tile drainage be more fully integrated into future research and modeling efforts. The methodology described here is an attempt to reduce the data gap by establishing ranges for tile drainage extent at the state level for eight Corn Belt and Lakes states, and a base set of subsurface drainage estimates that can be refined and improved through a process of validation. Results indicate that GIS map-based analysis using soil and land cover characteristics can be a useful tool in approximating tile drainage extent in highly drained areas. However, validation is necessary to further assess the effectiveness of estimating farm drainage in this way. The estimates themselves are not intended to be final. In the absence of any actual county-level drainage data more recent than 1992, these results and the range of values presented represent what are essentially educated guesses at the current level of tile-drained acres. This uncertainty serves to highlight the fact that without a new survey of drainage, it will not be possible to know just how much artificially drained agricultural land currently exists. While attempting to assess the accuracy of these or any other drainage estimates with institutional knowledge and existing maps may be useful in the near term, it is only a stop-gap measure in solving the basic data problem. Still, their incorporation into regional-scale modeling analyses will likely lead to an improved understanding of the nutrient pollution impacts of agricultural tile drainage, and a fuller assessment of the cost-effectiveness of different nitrogen-abatement practices and policies in meeting national water quality goals, especially reducing Gulf hypoxia. All estimates are available for review online.[16]

NOTES

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