MODELING AGRICULTURAL IMPACTS OF LONGWALL MINE SUBSIDENCE: A GIS APPROACH[1]

Robert G. Darmody and Scott L. Vance[2]

Abstract: Illinois is both a major agricultural State and one of the leading coal-producing States. The future of coal mining in Illinois is longwall mining. One of the advantages of longwall mining, and the most noticeable consequence, is immediate subsidence. Mitigation of subsidence effects is the responsibility of the coal company. Research has shown that mitigation is usually effective, but may be difficult in many cases. Minimizing subsidence impact by avoiding sensitive soils in the mine plan is a possibility that should be considered. Predicting agricultural impacts of subsidence would give mine designers and regulating agencies an additional tool to use when evaluating mine plans. This paper reports on the development and an application of a predictive model of agricultural soil subsidence sensitivity (SSS). The SSS model involves integration of selected soil properties in a GIS (geographical information system) to assign a subsidence sensitivity class to a given area. Predicted crop yield losses at a proposed longwall mine in southern Illinois, using corn (*Zea mays* L.) as a reference, were 6.8% for the longwall panel area but ranged from 4.1% to 9.5% for the individual panels. The model also predicted that mitigation of the affected areas would reduce yield losses to 1.2% for the longwall area and to 0.5% to 1.7% for the individual panels.

Additional Key Words: underground coal mining, environmental impact, crop production, corn yields, mitigation.

Introduction

Longwall mining in Illinois has a deleterious effect on crop yields. Subsidence subsequent to mining forms depressions that may cause ponding in agricultural fields. Ponded areas pose several problems to agriculture, which may include difficult cultivation, poor stand establishment, loss of nutrients, poor root development, and increased diseases. These problems can be quantified by measuring yield reduction at harvest. In an earlier study, crop yield reduction, as estimated using actual corn yields at subsidence sites selected from aerial photographs, was 4.7% (Darmody et al. 1988a, 1989a). This estimate was for the entire mine area, individual sites identified as having severe subsidence effects had an average loss of 95%. Sites identified as having moderate effects had 43% reduction and sites with slight effects had 2% yield reduction. Coal companies are required to mitigate subsidence effects to restore land use. There are no crop yield requirements as with surface mining. Research indicates that mitigation is successful in restoring land use and soybean (*Glycine max* L.) yields, but not corn (*Zea mays* L.) yields (Hetzler and Darmody 1992). Corn yields in mitigated sites that had severe impact of subsidence average 19% lower than on adjacent undisturbed sites (Darmody et al. 1992).

Soil properties that contribute to deleterious effects of longwall mining are primarily related to hydrologic aspects of the soil (Darmody et al. 1988b, 1989b). These include water table depth, flooding probability, slope, natural drainage, and hydraulic conductivity. Unfortunately, many soils in Illinois, particularly those on the Illinoian till plain, have many of these properties that make them sensitive to subsidence (Fehrenbacher et al. 1984). Longwall mining to date has been largely in the portion of the State that includes soils that are relatively insensitive to the deleterious effects of subsidence. The work reported here involves the development of a predictive model for determining the sensitivity of agricultural soils to subsidence. This

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model should be helpful both to the industry and to regulatory agencies. It is particularly important as longwall mining moves into the extensive areas of highly subsidence sensitive soils on the Illinoian till.

The objectives of this research were to (1) develop a predictive model of agricultural soil sensitivity to subsidence (SSS) associated with longwall mining and (2) apply the model to a proposed longwall mine plan.

Methods and Materials

Subsidence Yield Reduction Computation

Soil properties that influence sensitivity to subsidence were given a weight to assign an SSS score to each soil map unit in the county (table 1). The soil properties used (table 2) were depth to seasonally high water table, slope, probability of flooding, natural soil drainage, and hydrologic group (Drablos and Moe 1984, Darmody et al. 1989b, Hodges 1990, Darmody et al. 1988b). SSS scores ranged from 0 to 20. SSS classes were assigned to soil mapping units based on the sum of their scores. An SSS score of <6 was assigned to SSS class

Table 1. Properties used to assign subsidence sensitive scores to soils.[1]

Slope class	Drainage group	Flooding		Hydrology group	Water table depth (cm)		Subsidence score
		Frequency	Duration		Perched	Apparent	
A	3A, 4A, 4B	Frequent	Brief and longer	D	<0	<30	4
	2A, 3B, 3C, 4C	Frequent	Very brief	C		30-60	3
B	2C, 2B	Occasional	Brief	B	0-30	60-180	2
	1C	Occasional	Very brief	A	31-180		1
C		None	---		>180	>180	0
D							-3
>D							-4

[1] See table 2 for property definitions.

Table 2. Definitions of soil property criteria classes.

Slope class	Drainage group		Hydrology (runoff)	Flooding frequency
	Drainage	Permeability (in/h)		
A= 0-2%	A = Poorly	1=Rapid (>2)	A= Low	Occasional= <50%
B= 2-5%	B = Somewhat poorly	2= Moderate (0.6-2)	B= Low moderate	Frequent= ≥50%
C= 5-10%	C = Well + moderately well	3=Mod. slow (0.2-0.6)	C= High moderate	Very brief= <2 days
D= 10-15%		4=Slowly (<0.2)	D= High	Brief= ≥2 days

A, none to slight subsidence hazard; 6 to 10 was class B, slight hazard; 11 to 15 was class C, moderate hazard; >15 was class D, severe subsidence hazard.

The crop yield impact associated with each SSS class was determined from previous research on the impact of longwall subsidence on corn yields (Darmody et al. 1988b). The proportion of the yield reduction found in that earlier study associated with each SSS class was determined (table 3). The effectiveness of subsidence mitigation for restoring corn yields was estimated from the results of a previous research project (Darmody et al. 1992). Reference corn yields for each soil map unit were taken from the Soil Survey of Macoupin County (Hodges 1990).

Table 3. Generalized impact of subsidence on crop yields.[1]

Subsidence risk class	Yield reduction, %		Extent (%) of soils in each class				Average yield loss, %	
	Subsided	Mitigated	None-slight	Slight	Moderate	Severe	Subsided	Mitigated
None-slight	0	0	90	10	0	0	0.2	0.0
Slight	2	0.4	82	15	3	0	1.6	0.3
Moderate	43	8.6	56	35	8	1	5.1	1.0
Severe	95	19	47	40	6	7	10.0	2.0
Average	35	7	69	25	4	2	4.2	0.8

[1] Data derived from Darmody et al. 1988b and Darmody et al. 1992.

GIS Software

The geographical information system (GIS) software package GRASS (USACERL 1991) was used to generate the maps and tabular data of soil properties, SSS information, and crop yields. The Soil Conservation Service (Tom D'Avello, personal communication 1993) provided the digital soil map that was used as a base map and from which the other maps were derived. The mine plan map was hand-digitized with a digitizing board.

Research Area

The study area was a proposed longwall permit area in Macoupin County, IL (fig. 1). It was in the Honey Creek watershed which includes many of the county soils (Hodges 1990). However, because of the proximity of the creek, it was more sloping than much of the county (fig. 2). The physiography of the southern portion of the study area is dominated by the creek valley and its associated sloping soils; the northern portion of the study area is on the nearly level, poorly drained Illinoian till plain (Fehrenbacher et al. 1984).

The proposed longwall mine plan was provided by the Illinois State Geological Survey (Robert Bauer, personal communication 1993). The plan consists of a longwall permit area of 2,044 ha (5,048 acres) with 17 longwall panels. The panels are approximately

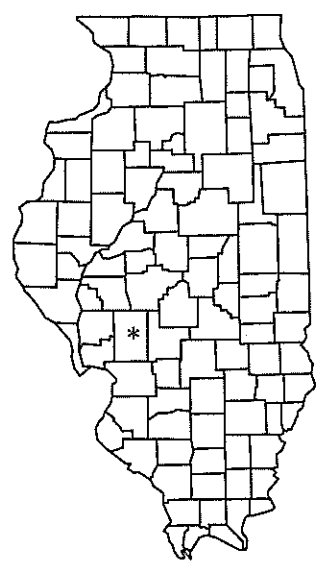

Figure 1. Location (*) of longwall mine subsidence modeling study in Illinois.

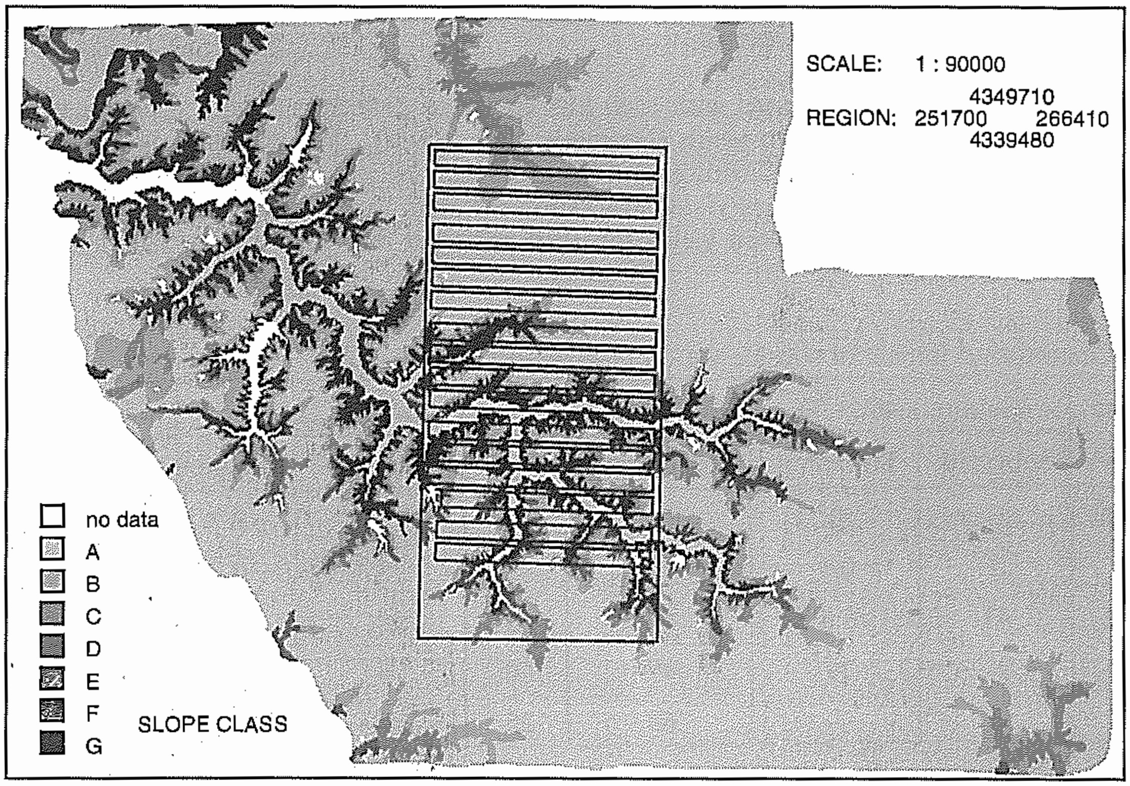

Figure 2. Soil slope classes of Honey Creek watershed, longwall permit area is outlined in black.

3,000 m (10,000 ft) long and 200 m (600 ft) wide and are oriented east-west. They are numbered for research purposes from 1 to 17, south to north.

Results and Discussion

SSS scores for the soils of the study area ranged from 1 to 18, with a weighted average score of 12.3. The scores tended to be higher in the northern portion of the study area, away from the creek valley and towards the Illinoian till plain (fig. 3). Severe was the most extensive SSS class generated from the SSS scores, it covered 37% of the study area (table 4). The northern portions of the study area on the Illinoian till plain are primarily in the moderate and severe classes, the southern portion of the study area includes some none-slight and slight classed land (fig. 3). If the mine were located more to the north or east on the nearly level Illinoian till plain, the SSS scores would be higher and unmitigated subsidence would pose a greater hazard to agriculture.

Table 4. Soil subsidence sensitivity (SSS) classes for the longwall permit area.

SSS class	Area Acres	Hectares	%
None..........	842	341	17
Slight.........	1,043	422	21
Moderate..	1,278	518	25
Severe.......	1,886	764	37
Total..........	5,048	2,045	100

Most of the soils in the study area are well suited for corn growth. The weighted average corn yield for the study area is 112 bu/ac (table 5). The most productive soils have a predicted yield of 141 bu/ac and are in the northern part of the study area (fig. 4). Some soils, particularly on the steeply sloping valley walls in the southern portion of the study area,

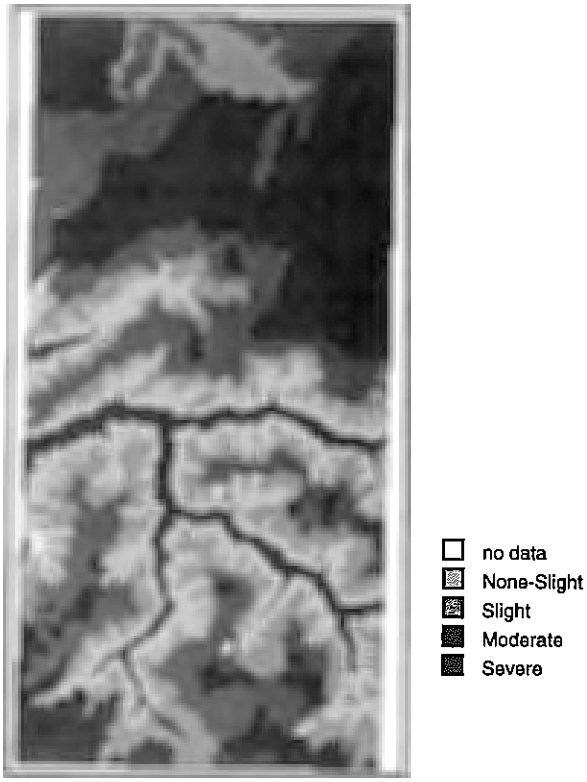

Figure 3. Soil subsidence sensitivity (SSS) classes for the longwall permit study area.

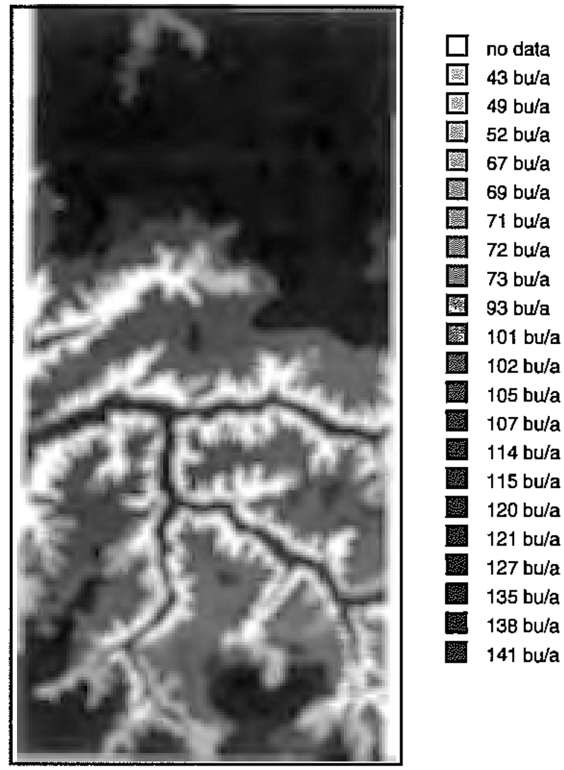

Figure 4. Predicted premining corn yields for the study area.

Table 5. Predicted corn yields for the total longwall permit area.

Condition	Total corn yield		Weighted average corn yield		
	Bushels	Kilograms	bu/ac	kg/ha	%
Unmined......	488,031	14,400,298	112	7,049	100.0
Subsided.......	454,931	13,426,612	105	6,572	93.2
Mitigated.....	482,216	14,233,746	111	6,967	98.8

are not suitable for corn growth and are shown in white in figure 4. The predicted impact of subsidence in the longwall permit area, based upon the weighted average of all of the soils of the study area, is a 5.4% reduction in crop yields (table 6). If the portion of the study area unsuitable for corn production is excluded from the analyses, the predicted corn yield after subsidence is 105 bu/ac (table 5). This is a reduction of 6.8%. This estimate includes the entire area under consideration. Previous reports of corn yield reductions of 95% referred to those limited portions of the mine area that were most highly affected (Darmody et al. 1989a). Figure 5 displays the generalized distribution of predicted corn yields,

Table 6. Predicted subsidence impact on crop yield for the longwall permit area by SSS class.

SSS class	Yield loss, %	Area		
		Acres	Hectares	%
None........	0.2	842	341	16.7
Slight........	1.6	1,043	422	20.7
Moderate	5.1	1,278	517	25.3
Severe......	10.0	1,886	763	37.3

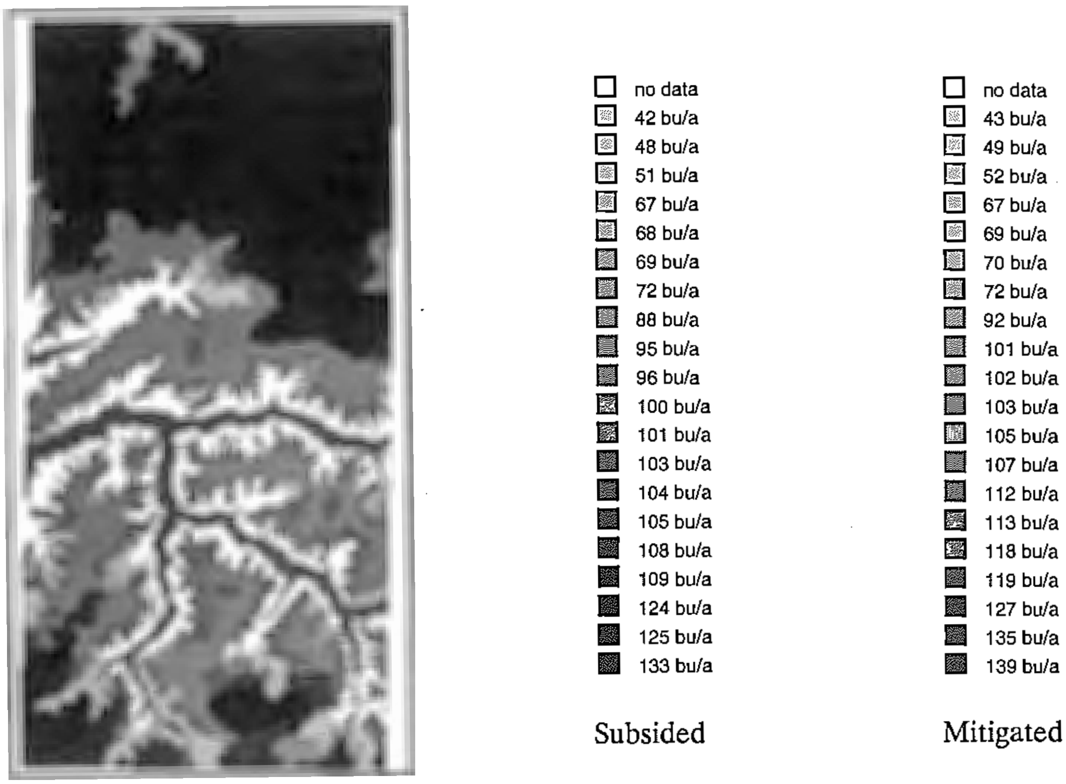

Figure 5. Predicted corn yields for the study area, after longwall mining.

which range from 42 to 133 bu/ac, for the study area after subsidence.

Subsidence impact would not be expected to be uniformly distributed over a given panel as shown in the model. The resolution of the available topographic data would not permit displaying individual portions of a panel. This apparent deficiency in the model is, however, accommodated by adjusting the impact over the entire panel according to known impact distributions from previous studies (table 3).

Mitigation of the subsidence effects is predicted to lessen the impact on crop yields. The weighted average loss in corn yields after subsidence mitigation, when all the soils in the study area are included, is predicted to be 1.2% (table 5). Figure 5 shows the generalized distribution of predicted corn yields, which range from 43 to 139 bu/ac, for the study area after subsidence mitigation.

Because the northern and southern portions of the proposed mine are so different, the subsidence

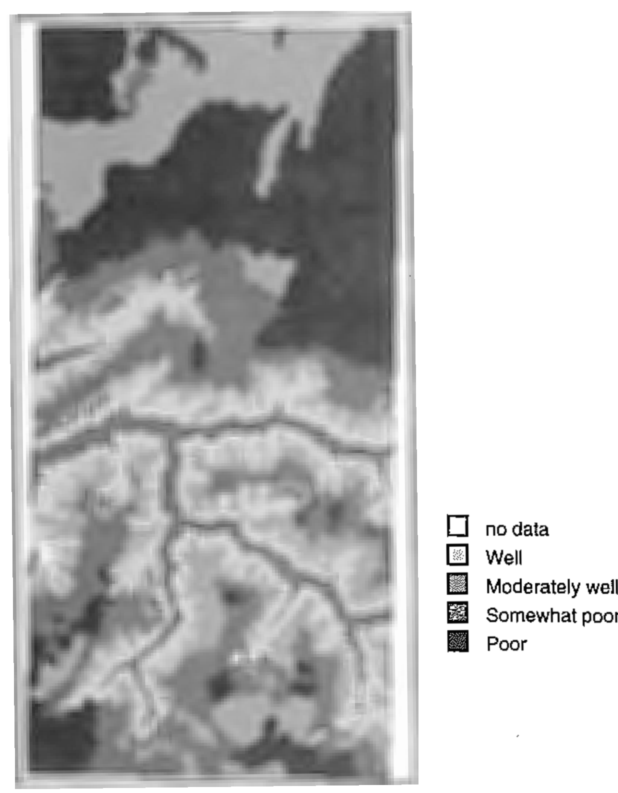

Figure 6. Soil drainage classes of the soils of the longwall mine permit study area.

impact on individual panels varies considerably. The southern panels are in the more sloping soils near Honey Creek and the northern panels are on the nearly level Illinoian till plain (fig. 2). Sloping ground tends to be less sensitive to subsidence because closed depressions that can accumulate runoff are less likely to form (Darmody et al. 1989b). Another way the two areas differ is in natural soil drainage (fig. 6). In the north, soils tend to be poorly drained and to have shallow water tables. In the southern portion of the permit area, drainage is generally better and water tables are deeper. Poorly drained soils are more sensitive to subsidence because they routinely suffer from excessive water and tend to have slow hydraulic conductivity. Drain tiles generally are not recommended for slowly permeable soils, especially if an outlet is not available (Drablos and Moe 1984). Subsidence would render existing drain tiles useless, and may even cause them to run backwards, because of the change in gradient subsidence causes. In addition, water tables tend to remain at the same elevation after subsidence, and shallow ones cause a greater sensitivity to subsidence (Darmody et al. 1989b).

The differences in topography and soils among the panels are reflected in different SSS scores (table 7). SSS scores in the southern panels range from 8.6 to 10.7. In the north, SSS scores range from 11.8 to 16.9. These SSS scores result in predicted crop yield losses of 4.1% to 6.5% for the southern panels and of 5.8% to 9.5% for the northern panels. Crop yield reductions after mitigation are predicted to be from 0.5% to 1.1% for the southern panels and from 1.1% to 1.7% for the northern panels.

Summary

The SSS model is a useful tool for predicting the impact that longwall mine subsidence will have on production agriculture. Different mine plans can be tested to predict the impact mining will have on crop yields. This can be done to estimate mitigation costs, to test different mine plans to minimize impact, or to predict loss in crop yields.

Table 7. Predicted corn yields before and after longwall mining in the study area.

	SSS		Initial yield		Subsided yields			Mitigated yields		
Panel	Score	Class	Total bu	bu/ac	Total bu	bu/ac	% loss	Total bu	bu/ac	% loss
1	9.9	3.4	12,241	103	11,653	98	4.8	12,150	102	0.7
2	10.7	4.1	12,854	102	12,136	96	5.6	12,740	101	0.9
3	8.7	2.9	10,531	101	10,042	96	4.6	10,460	100	0.7
4	10.4	3.6	13,712	105	13,019	99	5.1	13,611	104	0.7
5	8.9	2.5	11,047	100	10,590	96	4.1	10,988	99	0.5
6	8.6	2.7	10,590	105	10,091	100	4.7	10,521	104	0.6
7	8.9	3.6	10,186	106	9,526	99	6.5	10,078	105	1.1
8	10.0	2.9	12,611	101	12,086	97	4.2	12,540	100	0.6
9	12.9	5.6	15,477	108	14,393	101	7.0	15,300	107	1.1
10	11.8	4.9	13,590	103	12,664	96	6.8	13,444	102	1.1
11	15.1	7.5	18,733	114	17,245	105	7.9	18,464	112	1.4
12	16.9	9.3	19,952	122	18,060	111	9.5	19,607	120	1.7
13	16.5	9.0	20,751	128	18,853	116	9.1	20,394	126	1.7
14	16.0	8.4	21,664	130	19,812	119	8.5	21,301	128	1.7
15	15.7	8.3	21,019	128	19,256	118	8.4	20,683	126	1.6
16	13.4	5.7	20,760	129	19,555	121	5.8	20,542	127	1.1
17	13.6	6.1	18,144	124	17,012	116	6.2	17,923	123	1.2
All	12.3	5.3	263,861	114	245,993	106	6.8	260,746	113	1.2
Permit	12.3	5.4	488,031	112	454,931	105	6.8	482,216	111	1.2

The predicted impact, as measured by corn yield loss, for the proposed mine in Macoupin County, IL is 6.8% for the permit area and ranges from 4.1% to 9.5% for the individual panels. These estimates include the entire area under consideration. Mitigation is predicted to lessen the impact to 1.2% loss of corn yield for the permit area and to 0.5% to 1.7% for the individual panels.

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