

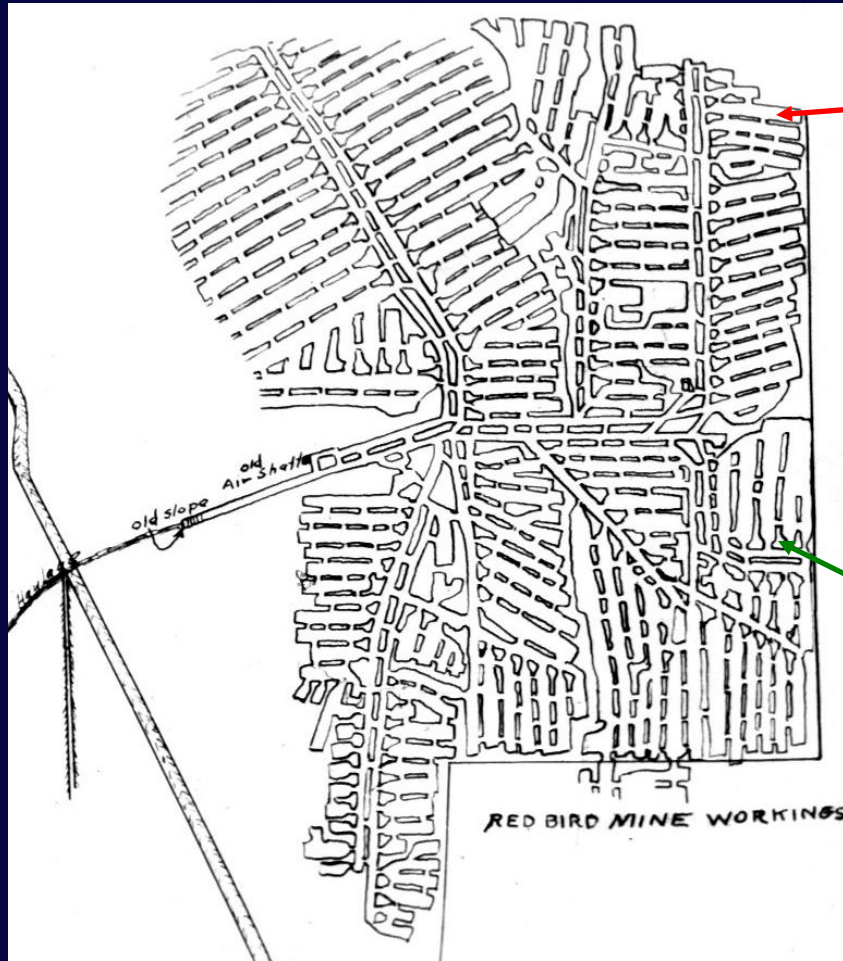
# Using GIS to Identify Subsidence-Prone Areas and High-Priority Improvements for Preemptive Mine Void Grouting in Southwest Indiana

Laura Montgrain, Indiana Department of Natural Resources, Division of Reclamation



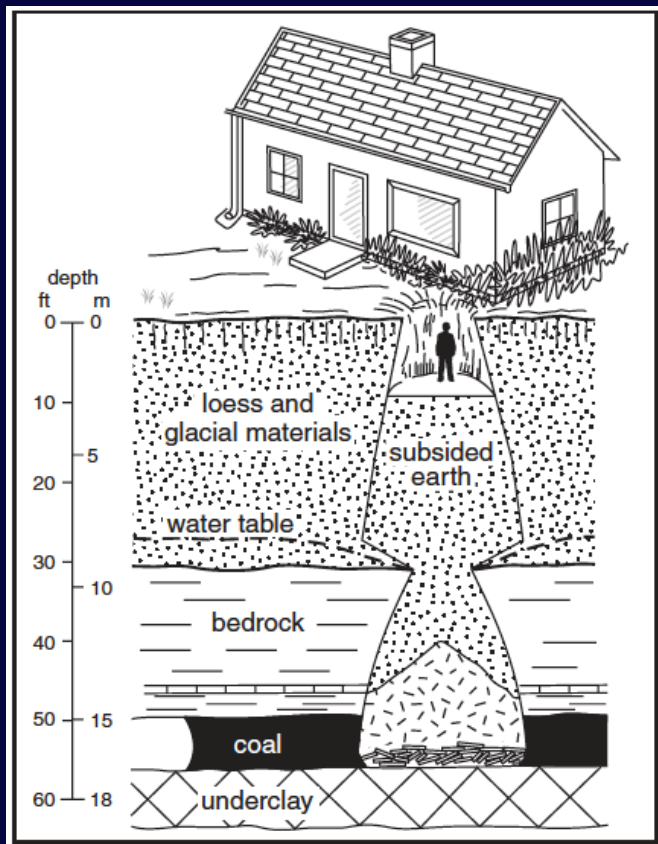
# Background

## Room and Pillar Mining



- Removing coal in tunnels or “rooms”
- Leaving columns or “pillars” of coal behind to support the roof and ground surface

# Subsidence



Illinois Department of Natural Resources



Indiana Dept. of Natural Resources, Division of Reclamation



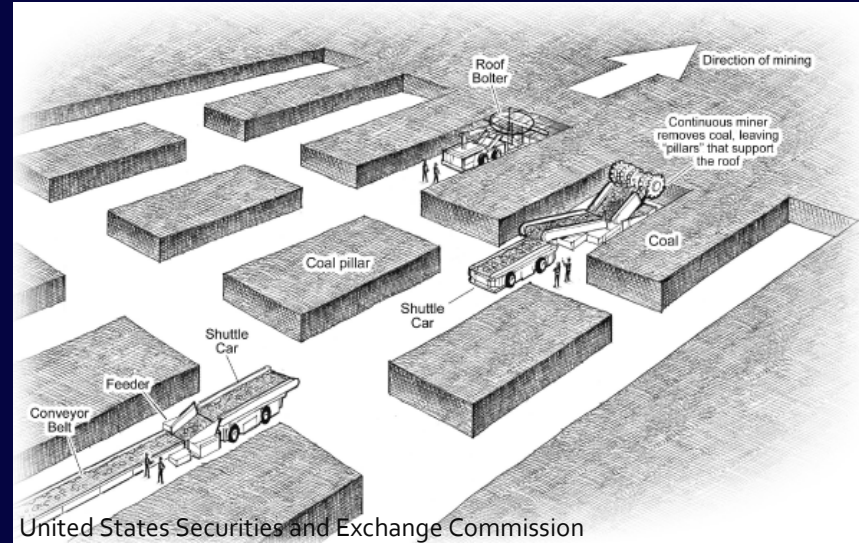
Indiana Dept. of Natural Resources, Division of Reclamation



# Advances in Technology



Arizona Mining Association



United States Securities and Exchange Commission



Coal Leader, Inc.

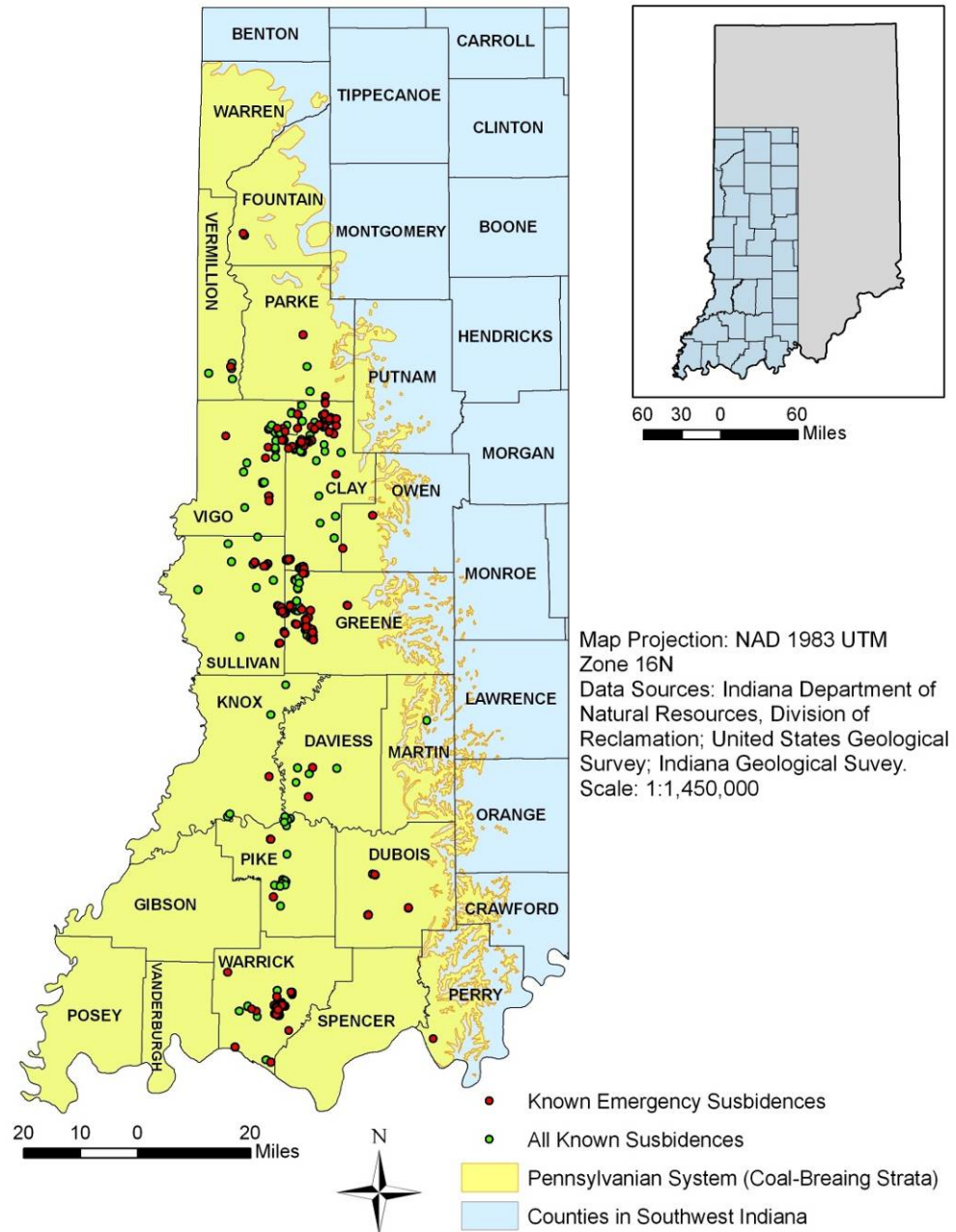
# Abandoned Underground Mines

- Surface Mining Control and Reclamation Act (SMCRA) – 1977
  - Regulation of current mining activities
  - Reclamation of abandoned mines
- Current land use trends



# Addressing Subsidence in Indiana

Locations of Known Subsidence in Southwest Indiana





# Options for Addressing Subsidence



Subsidence backfill



Mine void grouting

# Identifying Subsidence-Prone Areas

- Jim Metzger – Indiana Department of Natural Resources, Division of Reclamation (DOR)
- Nathan Eaton - Indiana Geological Survey (IGS)
- GIS data and analysis
- 11,180 acres of subsidence-prone areas identified



# Purpose

- Expand upon and refine Eaton and Metzger's (2000) procedure
- Identify not only subsidence-prone areas but also high-risk improvements
  - Targets of preemptive mine void grouting efforts

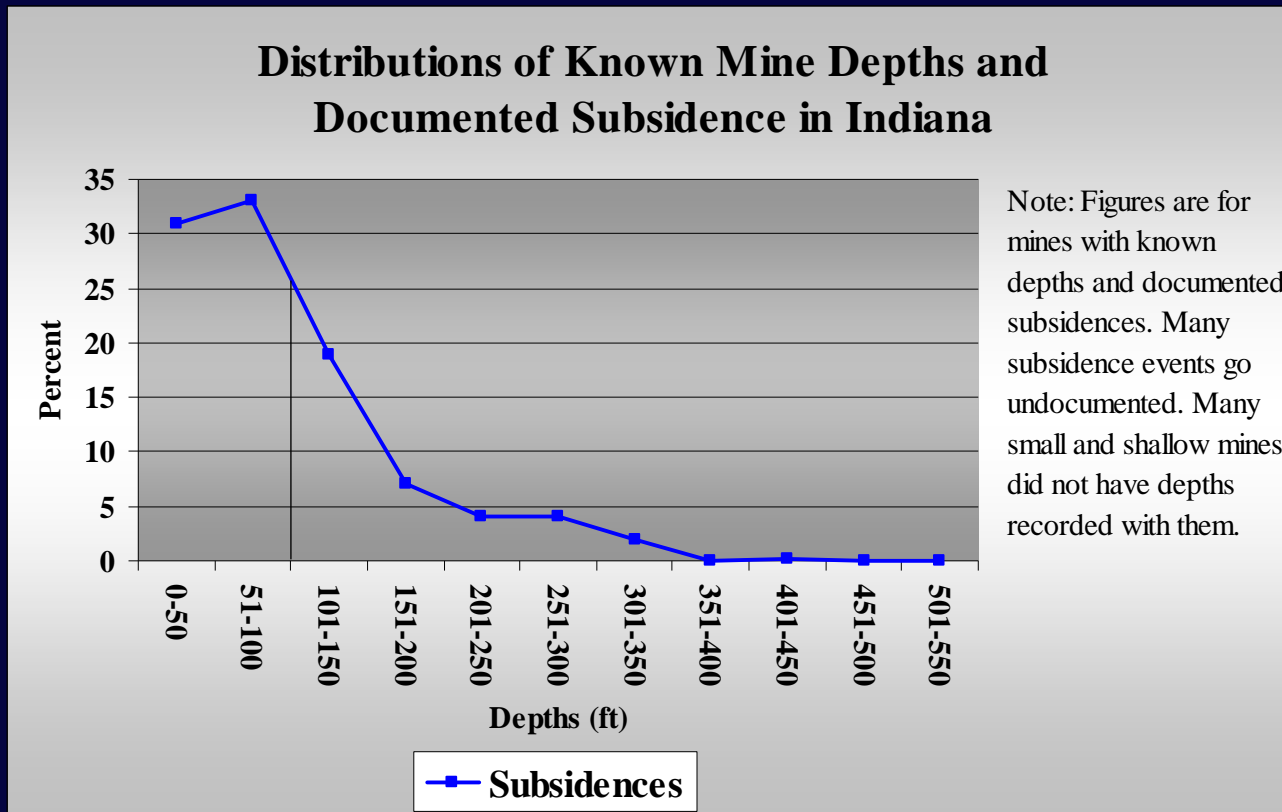
# Methods

## Criteria Selection

- Subsidence-prone mines defined as those that :
  - 1) are less than 100 feet deep,
  - 2) are within  $\frac{1}{4}$  mile of a populated/developed area, and
  - 3) contain or are within 30 feet of a known subsidence event.

# Criteria Selection: Criterion 1

- Mines that are less than 100 feet deep





# Criteria Selection: Criterion 2

- Mines that are within  $\frac{1}{4}$  mile of a populated/developed area
  - Most incidents of catastrophic subsidence have occurred near populated/developed areas
    - Higher concentration of homes, roads, utilities, etc.
    - Higher population

# Criteria Selection: Criterion 3

- Mines that contain or are within 30 feet of a known subsidence event.
- DOR frequently revisits areas with past subsidence to
  - Repair additional subsidence events
  - Address recurring subsidence

# Methods: GIS Procedures

## Criterion 1 Mines (< 100 ft. deep)

- Obtained a shapefile of underground mines (IGS)
- Queried the Indiana Coal Mine Information System (CMIS) database (IGS)
- Related tables in ArcMap 9.3.1
- Selected abandoned mines that were < 100 feet deep



Attributes of Criterion 1 Mines

FID	Shape	MIINEUMB	MAPHUMB	MIINE_TYPE	IMG_AVAIL	YEAR_START	YEAR_END	SOURCE_CON	Shape_area	Shape_len
0	Polygon	800001	342611	U	Y	1917	1918	Primary	24.403366	2748.970425
1	Polygon	800002	342591	U	Y	1909	1922	Primary	29.255713	2654.409809
2	Polygon	800003	342747	U	Y	1906	1906	Primary	45.082576	3645.330578
3	Polygon	800004	342601	U	Y	1894	1921	Primary	3.786688	619.866524
4	Polygon	800005	342688	U	Y	1900	1921	Primary	457.96618	10049.332573
5	Polygon	800006	342572	U	Y	1912	1926	Primary	453.960308	10842.177684
6	Polygon	800010	342069	U	Y	1934	1942	Primary	113.9408	6592.186986
7	Polygon	800011	342704	U	Y	1963	1964	Primary	2.300997	765.308192
8	Polygon	800012	341924	U	Y	1930	1940	Primary	40.101589	2765.354522

Record: 1 Show: All Selected Records (809 out of 809 Selected) Options

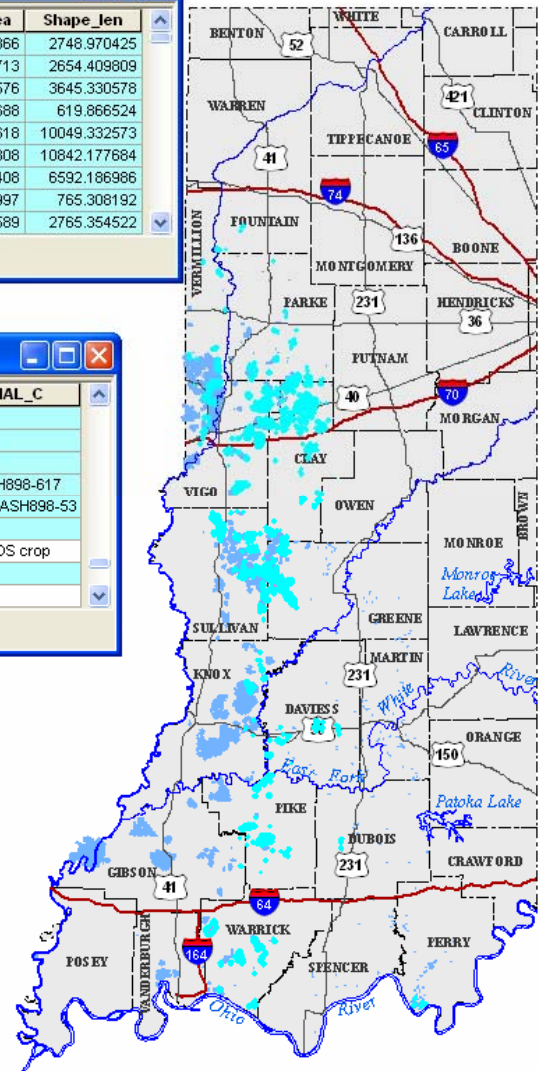
Criterion 1 Mines

Attributes of GEOLOGY

OID	GEOLOGY_ID	MIINEUMB	STRATCODE	AVE_DEPTH	AVE_THICKN	ROOF_LITHO	FLOOR_LITH	ORIGINAL_C
4318	7122	800494	MHL	95	4.08	Fs	Fmmr/Ss	CO-MH
661	1388	800132	SPG	96	4	UNKNOWN	UNKNOWN	CO-5 PCM
693	1439	800010	HYM	96	4.25	UNKNOWN	UNKNOWN	CO-6 SMI
2322	4016	801616	LBK	96	3	Fs	Fmmr	CO-LB ASH898-617
2733	4653	801302	LBK	96	3.7	Fs	Fmmr	CO-LB (3) ASH898-53
616	1308	800084	HYM	97	7.75	Fs	Fmmr	CO-6 PCM
786	1629	810063	BKT	97	5.5	UNKNOWN	UNKNOWN	CO-SB NCRDS crop
788	1632	800758	SPG	97	5.5	UNKNOWN	UNKNOWN	CO-5 PCM
826	1692	801030	SPG	97	-9999	UNKNOWN	UNKNOWN	V PCM

Record: 1 Show: All Selected Records (776 out of 4523 Selected) Options

State\_boundary.shp



# Methods: GIS Procedures

## Criterion 1 Mines (<100 ft. deep)

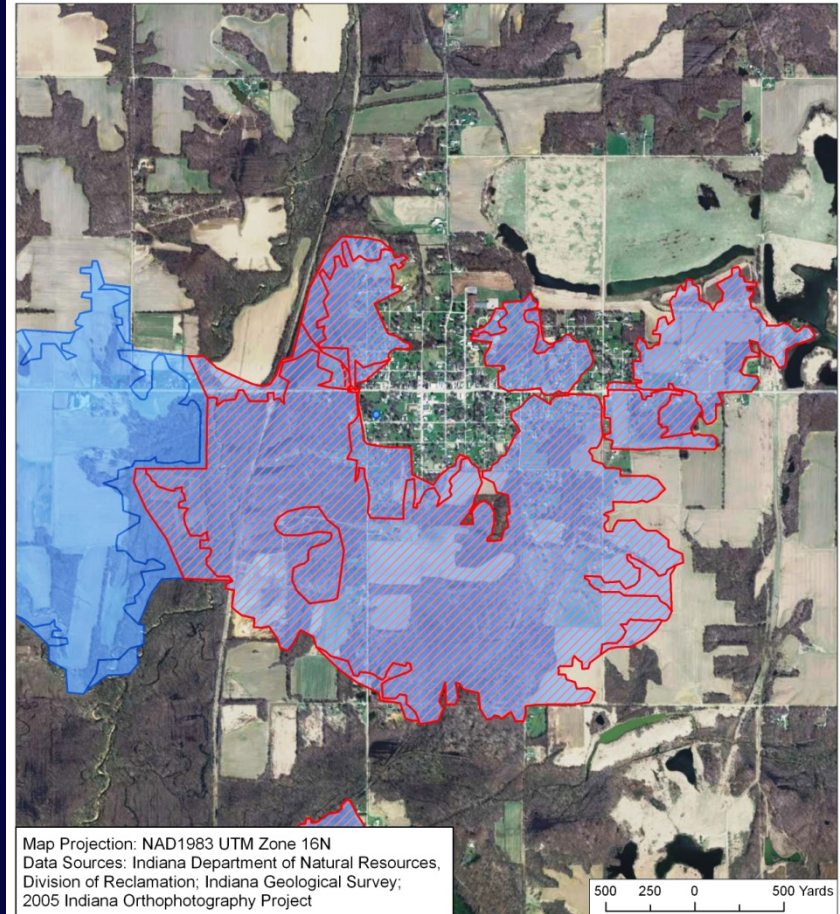
The screenshot shows the ArcMap interface with two data tables and a map of Indiana. The 'Attributes of Criterion 1 Mines' table lists mine details, and the 'Attributes of GEOLOGY' table lists geological data.

FID	Shape	MHSHRMB	MAPHRMB	MINE_TYPE	IMG_AVAIL	YEAR_START	YEAR_END	SOURCE_CON	Shape_area	Shape_len
1	Polygon	800001	342611	U	Y	1917	1918	Primary	24.403368	2745.970425
2	Polygon	800002	342591	U	Y	1909	1922	Primary	29.255713	2654.409609
3	Polygon	800003	342747	U	Y	1906	1908	Primary	48.982676	3845.300878
4	Polygon	800004	342601	U	Y	1894	1921	Primary	3.786688	619.866524
5	Polygon	800005	342688	U	Y	1900	1921	Primary	457.966810	10049.325273
6	Polygon	800006	342672	U	Y	1912	1926	Primary	453.960208	10842.177684
7	Polygon	800010	342009	U	Y	1924	1942	Primary	112.9400	6592.180886
8	Polygon	800011	342704	U	Y	1963	1964	Primary	2.300997	765.300192
9	Polygon	800012	341924	U	Y	1930	1940	Primary	40.101589	2765.354522

IDB	GEOLOGY_ID	MHSHRMB	STRUCODE	AVE_DEPTH	AVE_THICKN	ROOF_LITH	FLOOR_LITH	ORGINAL_C
4318	7122	800498	MLL	95	4.00	Fs	Frmy/Ss	CO-M1
681	1368	801132	SPO	96	4	UNKNOWN	UNKNOWN	CO-S PCM
693	1439	800010	HYM	96	4.25	UNKNOWN	UNKNOWN	CO-S SML
2322	4016	801816	LBR	96	3	Fs	Frmyr	CO-LB ASHBR-617
2733	4653	801302	LDR	97	3.7	Fs	Frmyr	CO-LB (3) ASHBR-53
816	1388	800084	HYM	97	7.75	Fs	Frmyr	CO-S PCM
786	1620	810063	BKT	97	5.5	UNKNOWN	UNKNOWN	CO-SB NCRDG crop
780	1632	800758	SPO	97	5.5	UNKNOWN	UNKNOWN	CO-S PCM
826	1692	801030	SPO	97	-9999	UNKNOWN	UNKNOWN	V PCM

Example of Criterion 1 Mine Selections in Greene County, Indiana



Map Projection: NAD1983 UTM Zone 16N  
 Data Sources: Indiana Department of Natural Resources,  
 Division of Reclamation; Indiana Geological Survey;  
 2005 Indiana Orthophotography Project

- Criterion 1 Mines (Mines less than 100 feet deep)
- Known/Documented Underground Mines



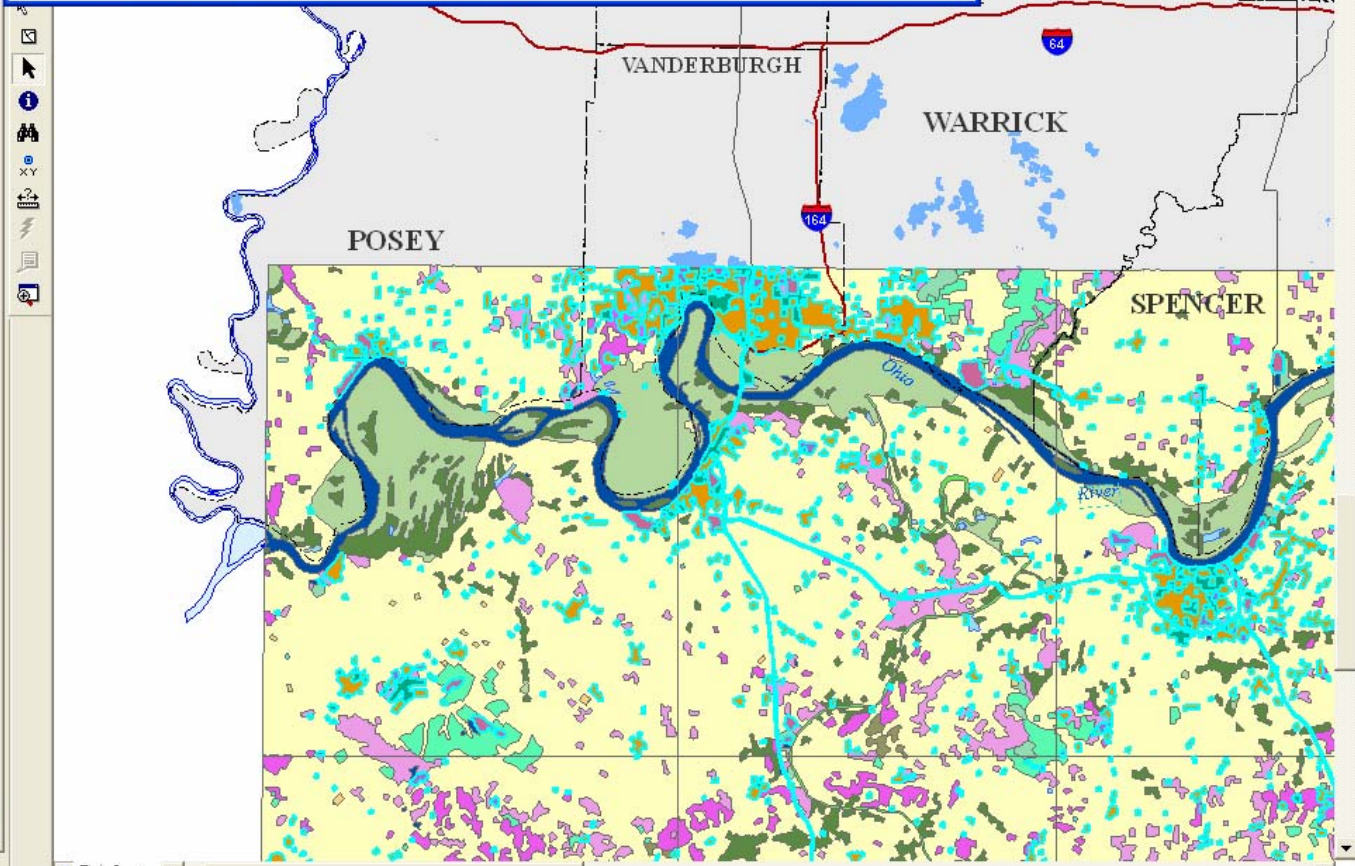


**Selected Attributes of Evansville\_LULC**

FID	Shape	RWID	RWE_INDEX	LUCODE	Code	Class
50	Polygon		0	12	12	12 Commercial and Services
55	Polygon		0	17	17	17 Other Urban or Built-up Land
56	Polygon		0	12	12	12 Commercial and Services
57	Polygon		0	11	11	11 Residential
61	Polygon		0	11	11	11 Residential
62	Polygon		0	13	13	13 Industrial
63	Polygon		0	11	11	11 Residential
67	Polygon		0	11	11	11 Residential
75	Polygon		0	14	14	14 Transportation, Communications, and Utilities

Record: 1 Show: All Selected Records (2351 out of 8415 Selected) Options

- cities2
- Cities
- Emergency Subsidence
- Known Subsidence
- Major\_Rivers\_Clip
- MajorRoads
  - CODE
  - I
  - U
- Southwest\_counties
- Evansville\_LULC
  - Class
  - 11 Residential
  - 12 Commercial and Services
  - 13 Industrial
  - 14 Transportation, Communications, and Utilities
  - 17 Other Urban or Built-up Land
  - 21 Cropland and Pasture
  - 22 Orchards, Groves, Vineyards, Nurseries
  - 23 Confined Feeding Operations
  - 24 Other Agricultural Land
  - 41 Deciduous Forest Land
  - 42 Evergreen Forest Land
  - 43 Mixed Forest Land
  - 51 Streams and Canals
  - 52 Lakes
  - 53 Reservoirs
  - 61 Forested Wetland
  - 62 Nonforested Wetland
  - 75 Strip Mines Quarries, and Gravel Pits
  - 76 Transitional Areas
- Criterion 3 Mines: 6,770 acres
- Criterion 2 Mines: 19,258 acres
- Criteria 1 Mines: 52,285 acres
- Underground Coal Mines
- sw\_water polygon



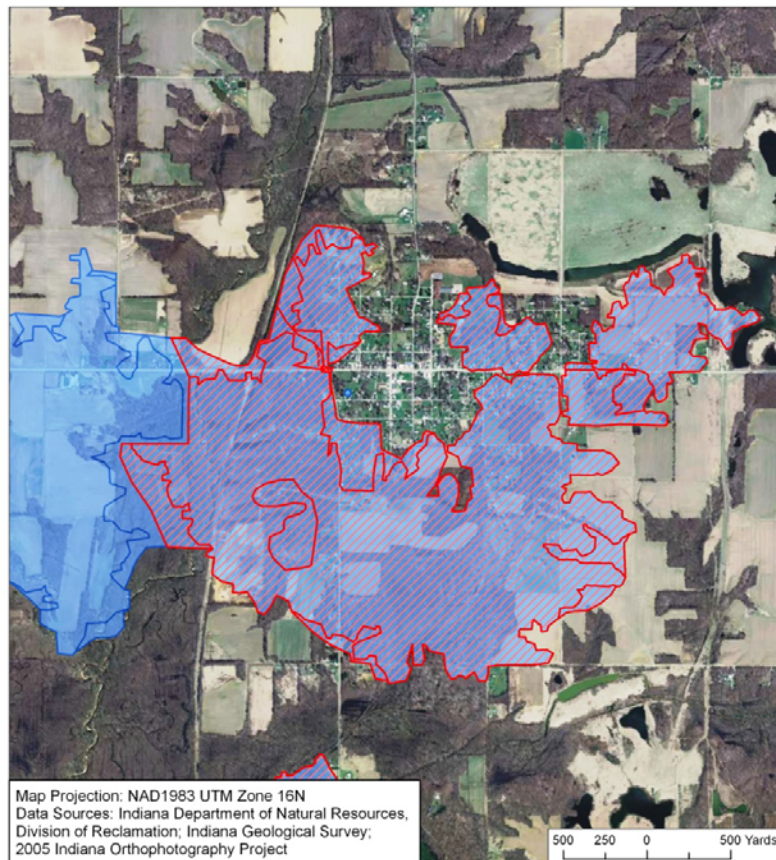


# GIS Procedures

## Criterion 2 Mines

Within 1/4 mile of a populated/developed area

Example of Criterion 1 Mine Selections in Greene County, Indiana

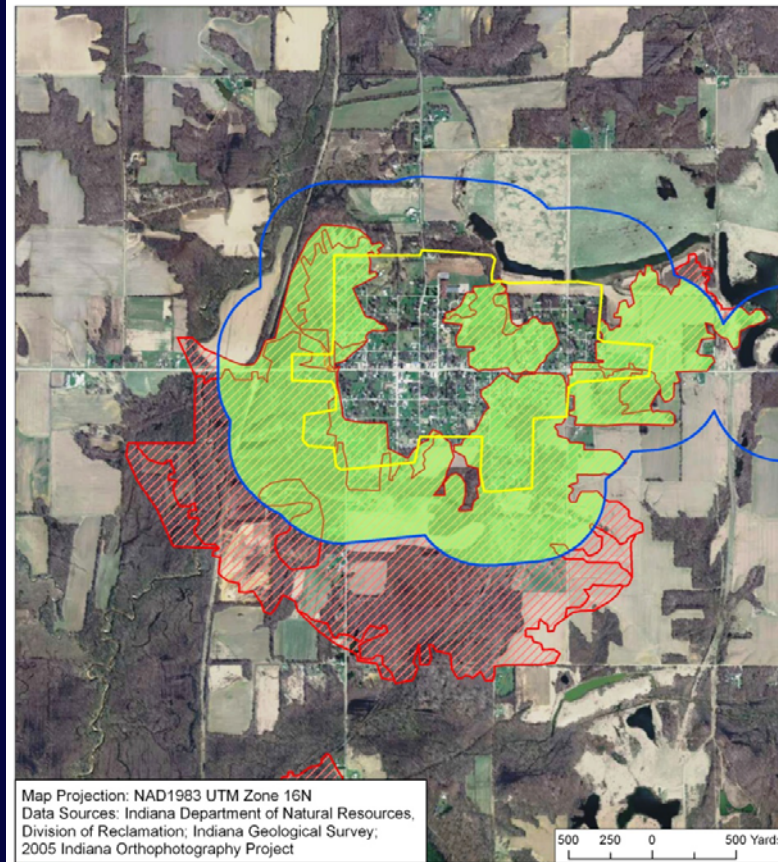


Map Projection: NAD1983 UTM Zone 16N  
Data Sources: Indiana Department of Natural Resources,  
Division of Reclamation; Indiana Geological Survey;  
2005 Indiana Orthophotography Project





-  Criterion 1 Mines (Mines less than 100 feet deep)
-  Known/Documented Underground Mines



Example of Criterion 2 Mine Selections in Greene County, Indiana



Map Projection: NAD1983 UTM Zone 16N  
Data Sources: Indiana Department of Natural Resources,  
Division of Reclamation; Indiana Geological Survey;  
2005 Indiana Orthophotography Project

-  Populated/Developed Area
-  1/4 Mile Buffer Around Populated/Developed Area
-  Criterion 2 Mines (Mines within 1/4 mile of a populated/developed area)
-  Criterion 1 Mines (Mines less than 100 feet deep)



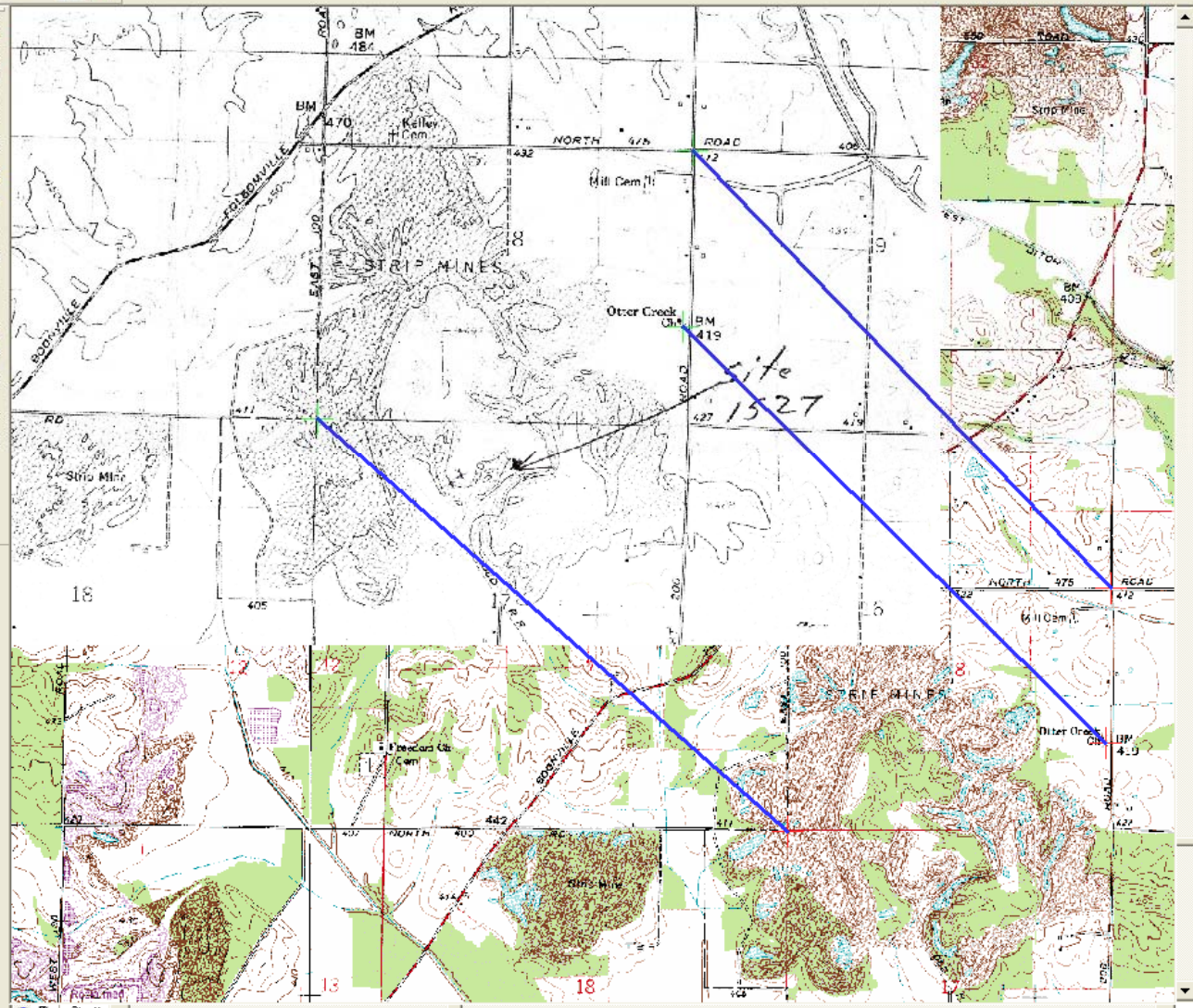


**Layers**

- Major\_Rivers\_ClipAnno2
  - Default
- EmergencySubsidence
- Major\_Rivers\_Clip
- MajorRoads
  - CODE
  - I
  - U
- Criterion 3 Mines
- Criterion 2 Mines
- Criterion 1 Mines
- Total Undermined Area: 205,320 acres
- Southwest\_counties
- sw\_water polygon
- Pennsylvanian System (Coal-bearing strata)
- EmergencySite1527.jpg
  - RGB
  - Red: Band\_1
  - Green: Band\_2
  - Blue: Band\_3
- IN\_250k\_drg
- IN\_100k\_drg
- IN\_24k\_drg
- Southwest\_counties

**New Data Frame**

- Sw\_bndy.shp
- 
- Counties.shp
- 
- State\_boundary.shp
- 



# GIS Procedures

## Criterion 3 Mines

Contain or are within 30 ft. of a known subsidence

- Selected Criterion 2 mines containing a known subsidence, or within 30 feet of a known subsidence
  - Why 30-foot proximity condition?
    - To account for possible errors in mine boundaries, missing data, approximate locations of some subsidences
- Criterion 3 mines = subsidence-prone areas
  - Meet all 3 criteria

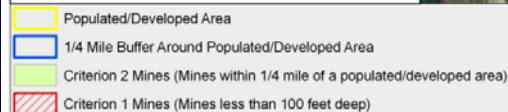
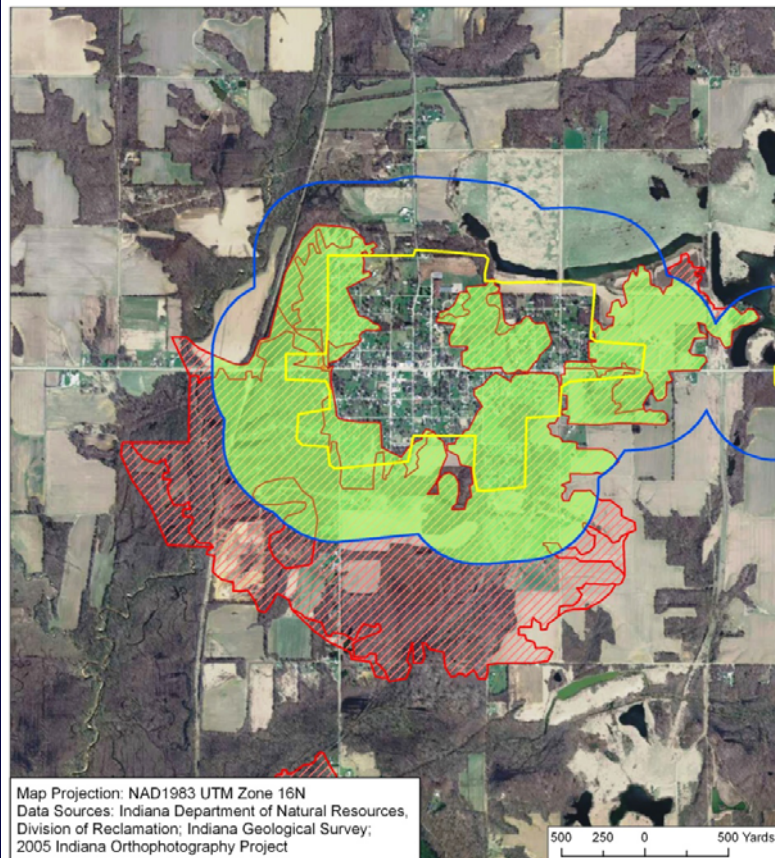


# GIS Procedures

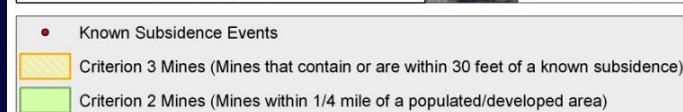
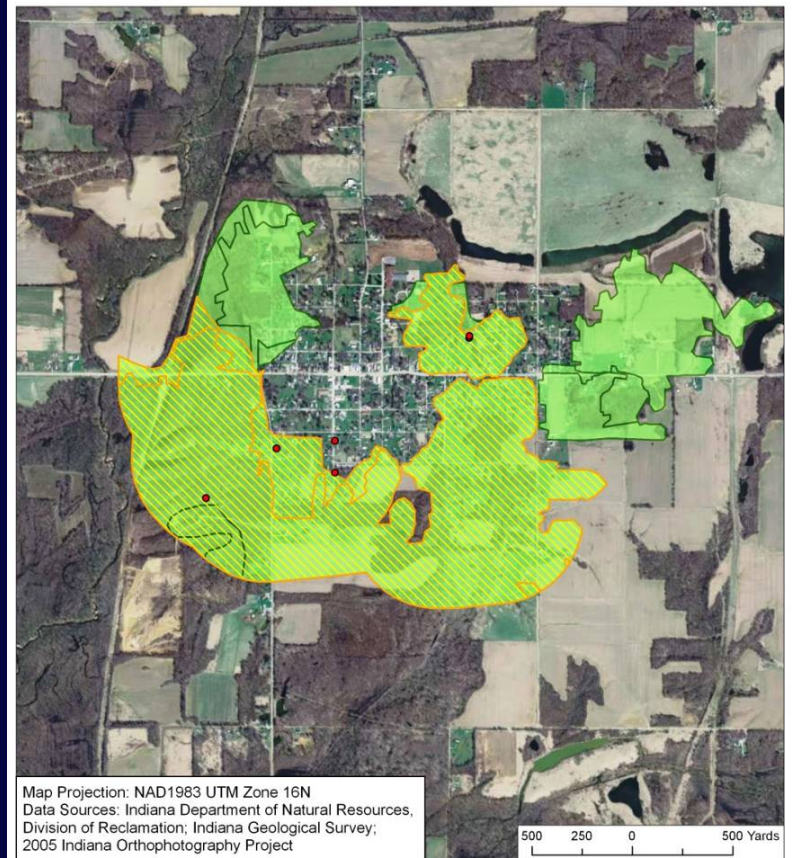
## Criterion 3 Mines

Contain or are within 30 ft. of a known subsidence

Example of Criterion 2 Mine Selections in Greene County, Indiana



Example of Criterion 3 Mine Selections in Greene County, Indiana



# GIS Procedures

## Criteria 1 – 3 Exceptions and Additional Steps

- Underground mines in Dugger are ~105 feet deep. Included in subsequent analyses anyway - high incidence of subsidence in area.
- “Dissolve” tool used on Criteria 1, 2, and 3 mines before acreages were determined

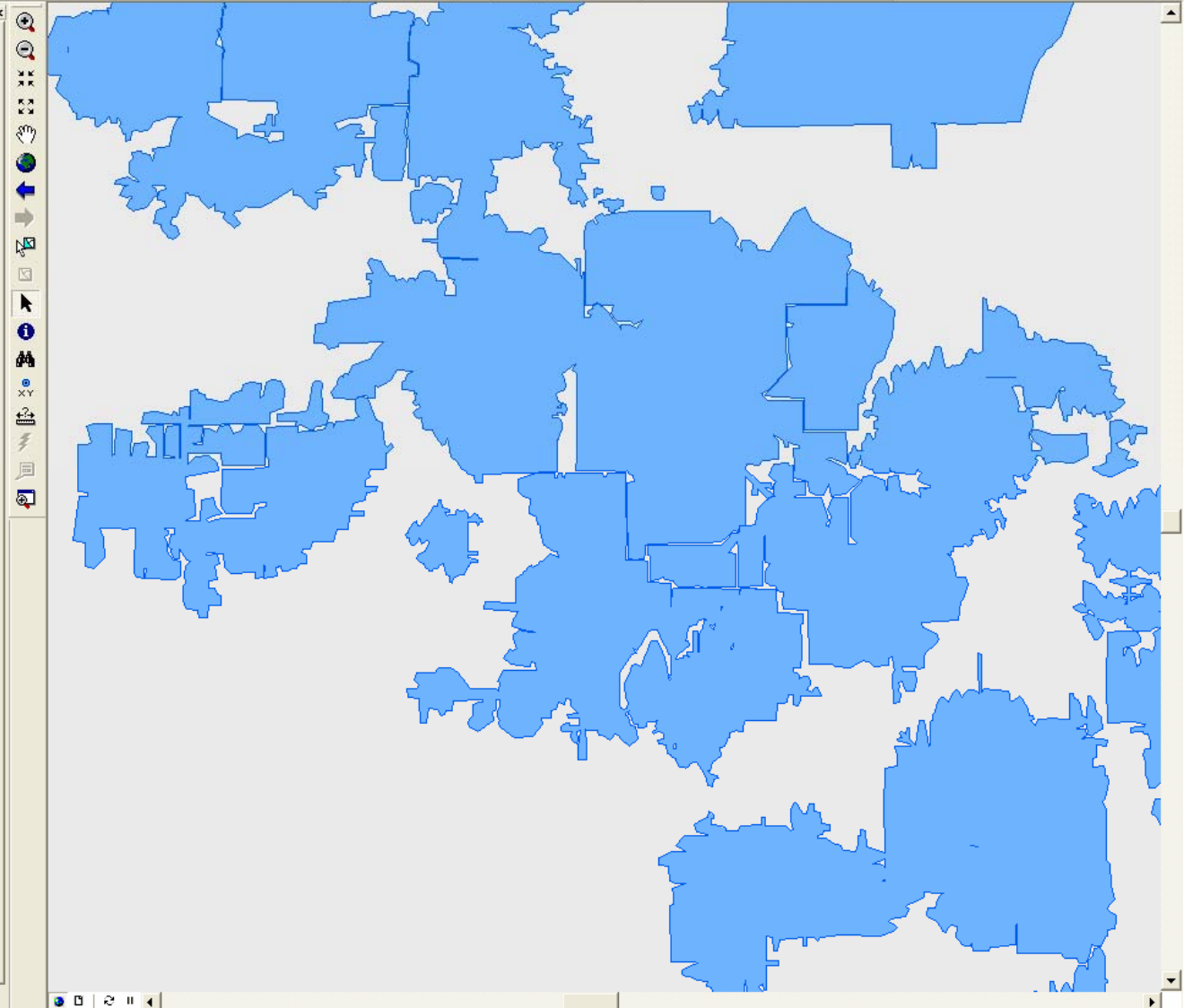


**Layers**

- Major\_Rivers\_ClipAnno2
  - Default
- EmergencySubsidences
- Major\_Rivers\_Clip
- MajorRoads
  - CODE
  - I
  - U
- Criterion 3 Mines
- Criterion 2 Mines
- Criterion 1 Mines
- Underground Mines
- Underground Mines: Dissolved
- Southwest\_counties
- sw\_water polygon
- Pennsylvanian System (Coal-bearing strata)
- Southwest\_counties

**New Data Frame**

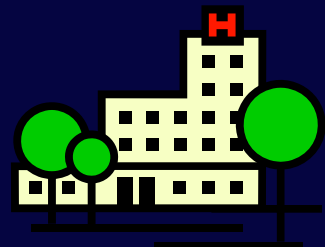
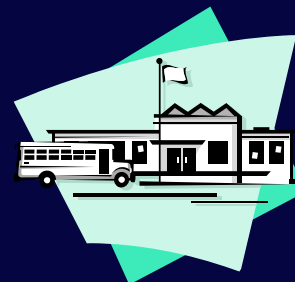
- Sw\_bndy.shp
- Counties.shp
- State\_boundary.shp



# GIS Procedures

## High-Priority Improvements

- High-Priority improvements defined as:
  - 1) Within 300 feet of 2 or more emergency subsidences, and
  - 2) Inside or within  $\frac{1}{4}$  mile of an identified subsidence-prone area
- Socially-important improvements: no 300 foot proximity condition



# GIS Procedures

## High-Priority Improvements

- 1) Within 300 feet of 2 or more emergency subsidences, and
- 2) Inside or within ¼ mile of an identified subsidence-prone area

Priority Documentation Form

DPE, HEF, HWB, P, VO

Page 1 of 2

DPE--DANGEROUS PILE OR EMBANKMENT, HEF--HAZARDOUS EQUIPMENT AND FACILITIES, HWB--HAZARDOUS WATER BODY, P--PORTAL, VO--VERTICAL OPENING

PAD NO.:	DATE:	KEYWORD:	PRIORITY:
----------	-------	----------	-----------

I. HEALTH, SAFETY AND GENERAL WELFARE INFORMATION		Yes	No
1.	Are there any AML-related unstable steep refuse piles or banks (other than landslides), wind-blown refuse fines, radio nuclides, dilapidated equipment or facilities, hazardous water bodies, easily accessible unguarded open mine entries, or unfilled vertical or steeply inclined shafts or openings posing a danger to human life, safety, health, and general welfare?		
2.	Is there any occupied structure, public use facility, improved public road, or public use park or recreational area located within <u>300 feet</u> of the problem area?		
3.	Is there any evidence of either frequent visitation or easy access road capable of carrying vehicles to the problem area?		

Positive answers to Question 1 and Question 2 indicate the problem can qualify to meet Priority 1 criteria with adequate justification included in the narrative description.

Positive answers to Question 1 and Question 3 or a positive answer to Question 4 indicate the problem can qualify to meet Priority 2 criteria with adequate justification included in the narrative description.

**II. RECLAMATION PROBLEM DESCRIPTION (Evidence of Extreme Danger and Health, Safety, and General Welfare Problems):**

5. Narrative description of Priority 1 (Extreme Danger) problems:

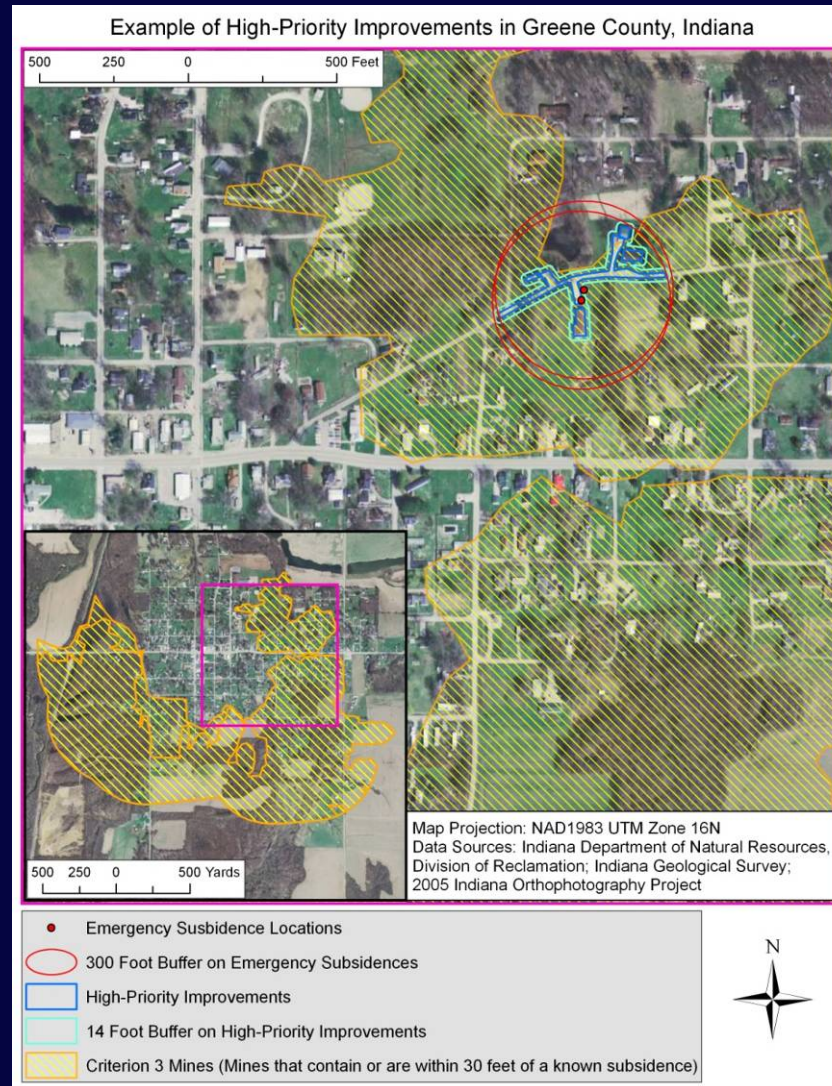
# GIS Procedures

## High-Priority Improvements

- 300 foot buffer drawn around emergency subsidence points
- 1/4 mile buffer drawn around subsidence-prone areas
- Relevant improvements digitized

# GIS Procedures

## High-Priority Improvements





# GIS Procedures

## High-Priority Improvements

### Exceptions

- High-priority improvements in Boonville, Indiana not always limited to those within 300 feet of two or more emergency subsidences.

# Results and Discussion

## Locations of Mines Meeting Selection Criteria

-  Total Undermined Area: 205,320 acres
-  Criterion 1 Mines: 52,285 acres
-  Criterion 2 Mines: 19,258 acres
-  Criterion 3 Mines: 6,770 acres



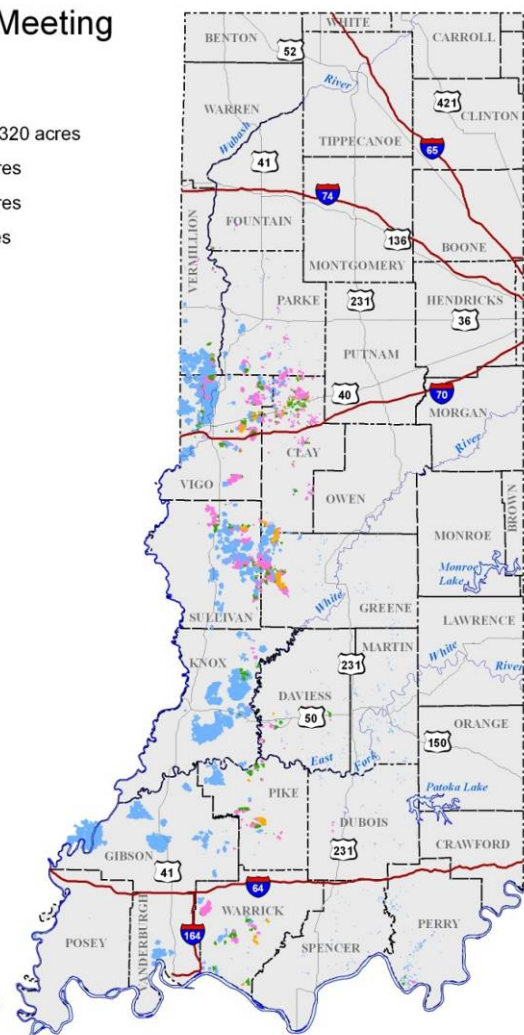
Index map of Indiana showing the location of map area.



Map projection:  
NAD 1983 UTM Zone 16N

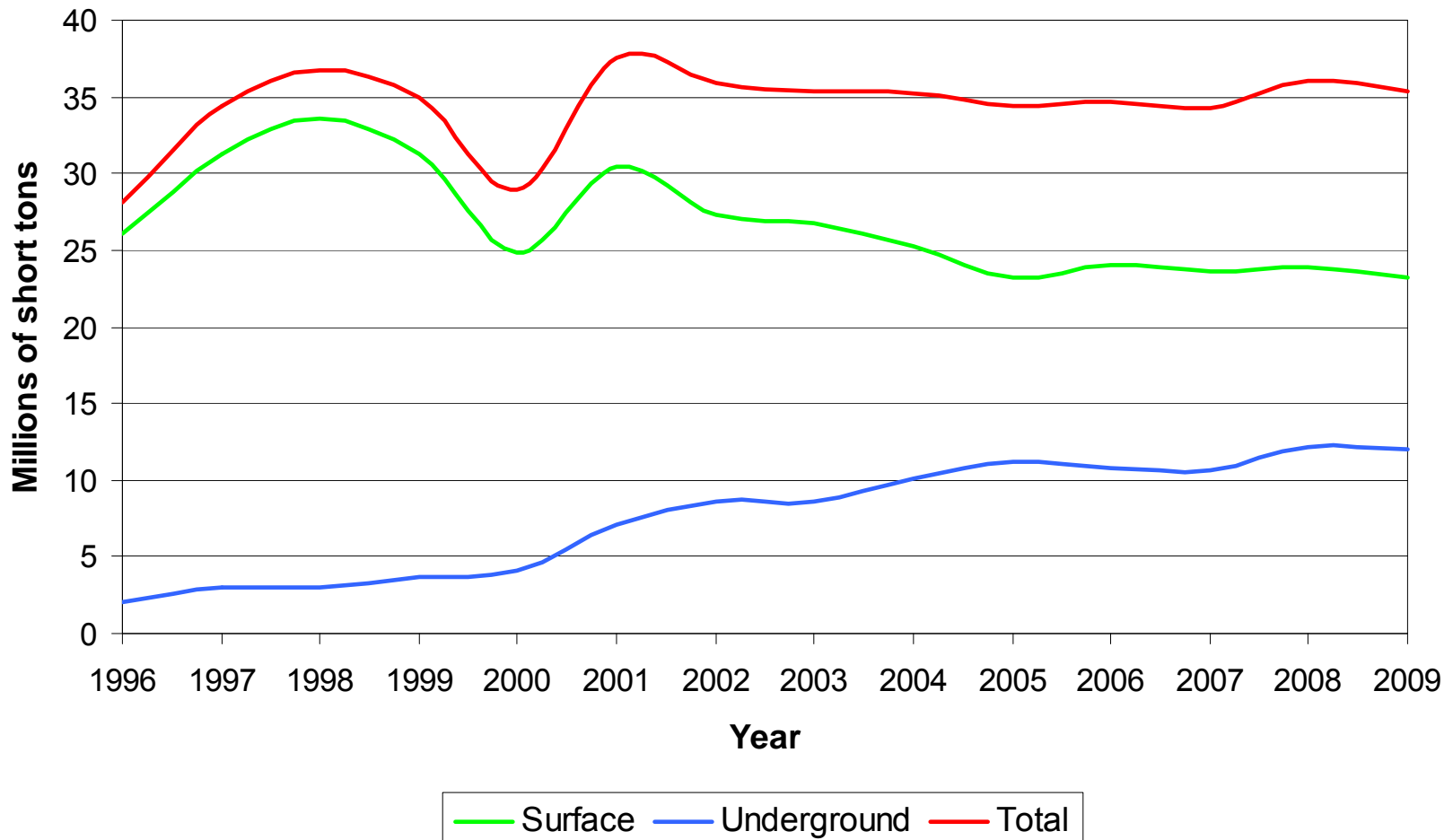
20 10 0 20  
Miles

20 10 0 20  
Kilometers



# Results and Discussion

## Recent Indiana Coal Production



Total  
Acre  
Acre  
Acre  
Acre

000  
547  
368  
042  
30\*  
/A

# Results and Discussion

- 116 acres of high-priority improvements identified
- Results offer a point from which to start evaluating grouting projects
- Narrowing ~7,000 acres to 116 allows case-by-case consideration for grouting
- DOR already using results:
  - Plans in place to grout up to 15 acres at Terre Haute Airport
  - Up to 20 acres in Warrick County



# Acknowledgements

- Jim Metzger (Restoration Technical Supervisor at the DOR)
- Nathan Eaton (Systems Analyst/Programmer at the IGS in 2000)
- Rebecca Meyer (GIS/Database Analyst at the IGS)
- Licia Weber (Geologist at the IGS)
- Steve Herbert (Director of the Restoration Program at the DOR)