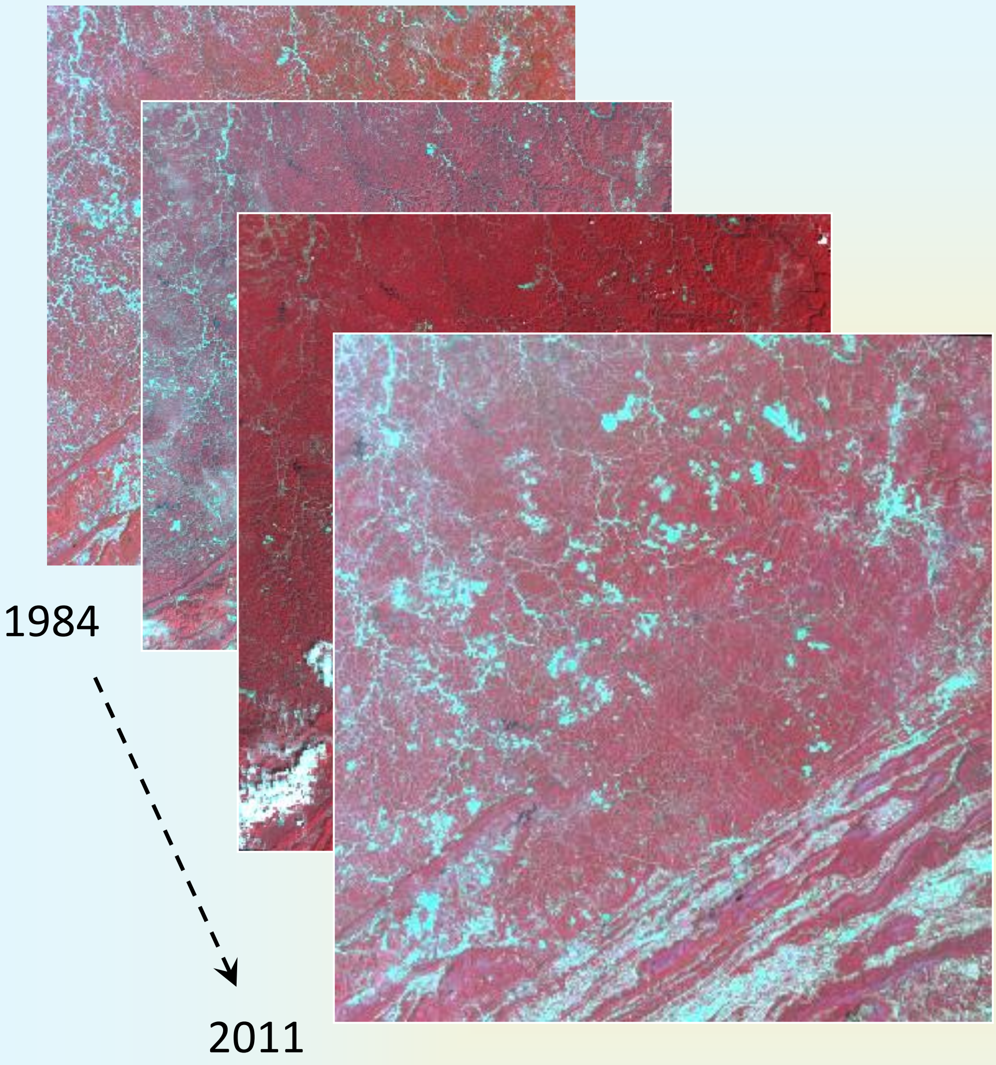

Delineation of Surface Coal Mining and Reclamation History in Appalachia Using Satellite Imagery

ASMR
Lexington KY
11 June 2015

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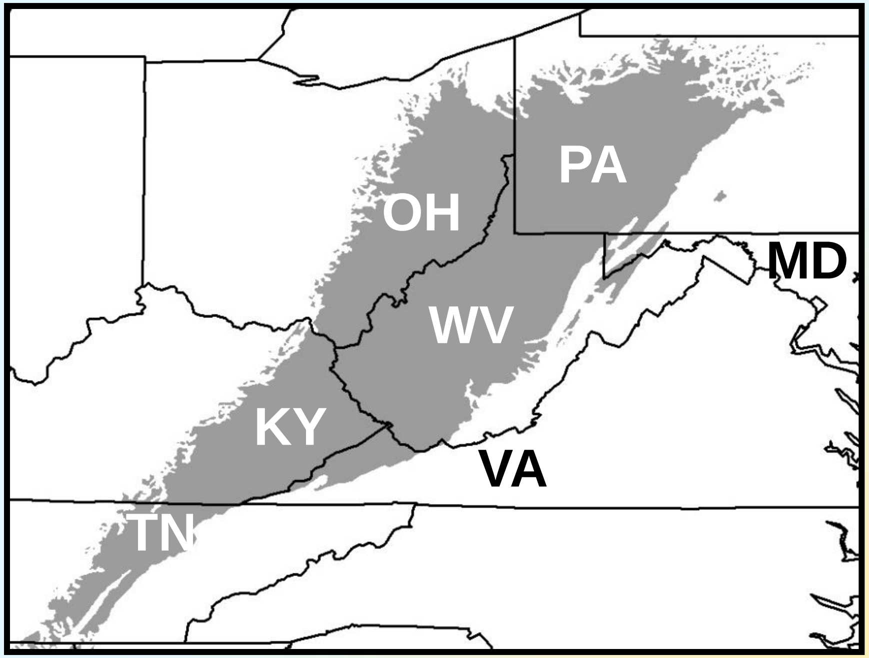
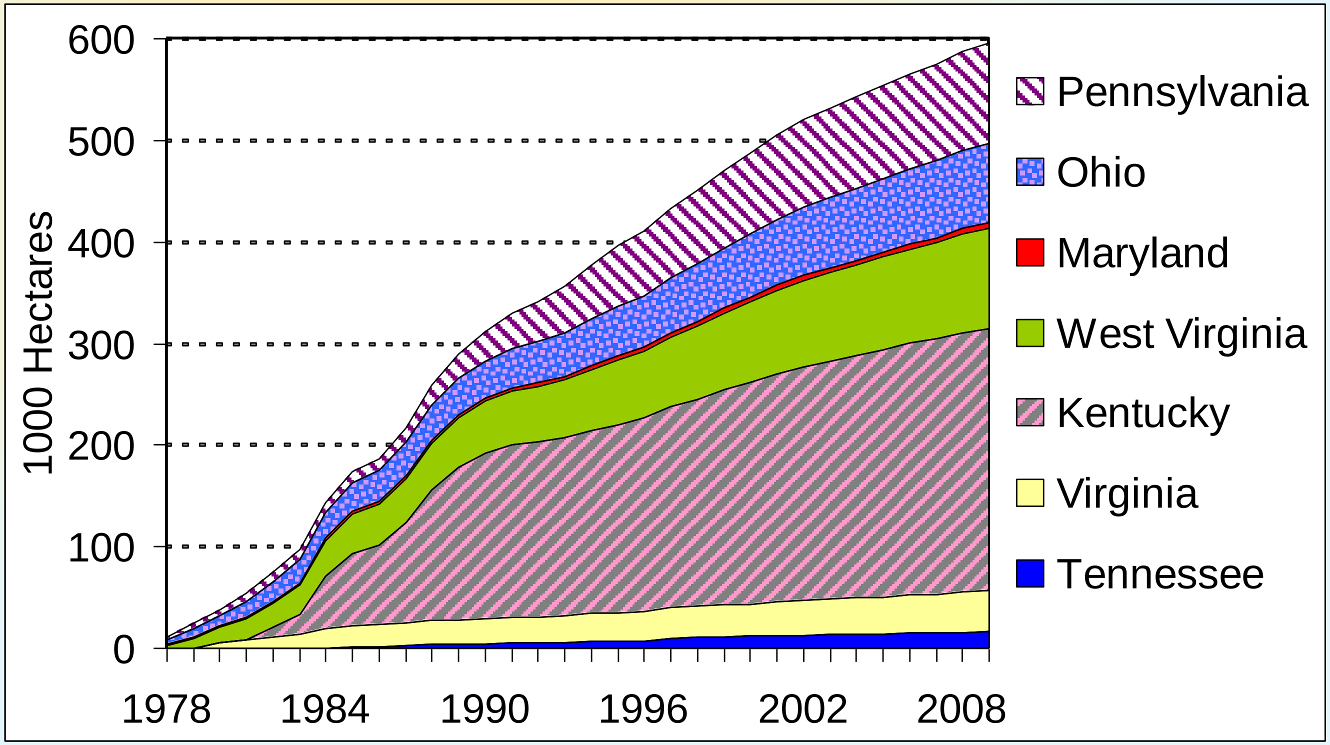
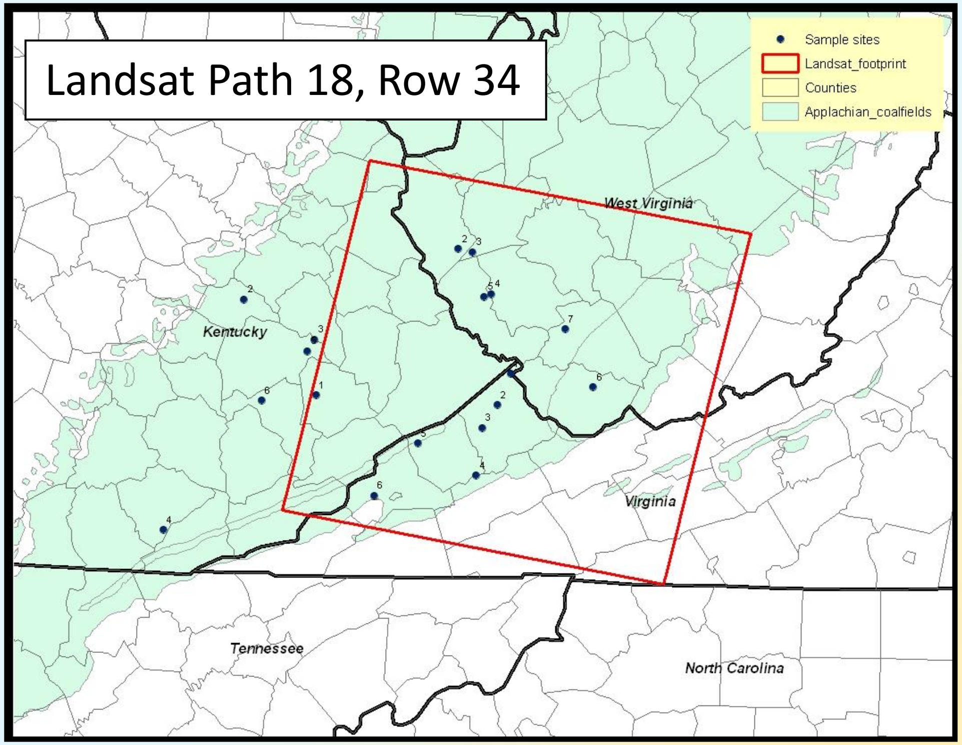
VirginiaTech



Problem: Significant land base in eastern USA mined and reclaimed under SMCRA. Where is it? What are its properties? What are cumulative effects of Appalachian mining?

Lands reclaimed under SMCRA in Appalachia through 2009:
OSM bond release:



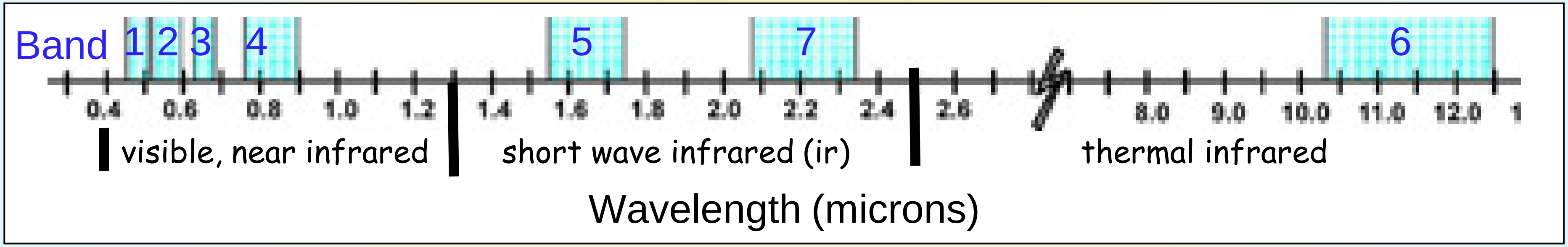


Landsat satellites:

>30 year record of earth observations

30m x 30m pixel resolution

Multispectral data:
7 wavelength bands.



Multispectral data: radiation from earth surface within distinct spectral bands; these data allow construction of metrics that indicate presence/absence of vegetation.

Analysis through time: *"Multitemporal"*

Research Goal

Prepare an inventory of land mined under SMCRA in southwestern Virginia's Appalachian coalfield by mining date, so as to characterize the progressive nature of landscape change over the period of study.

Develop method that can be applied in other areas.

Presentation Outline

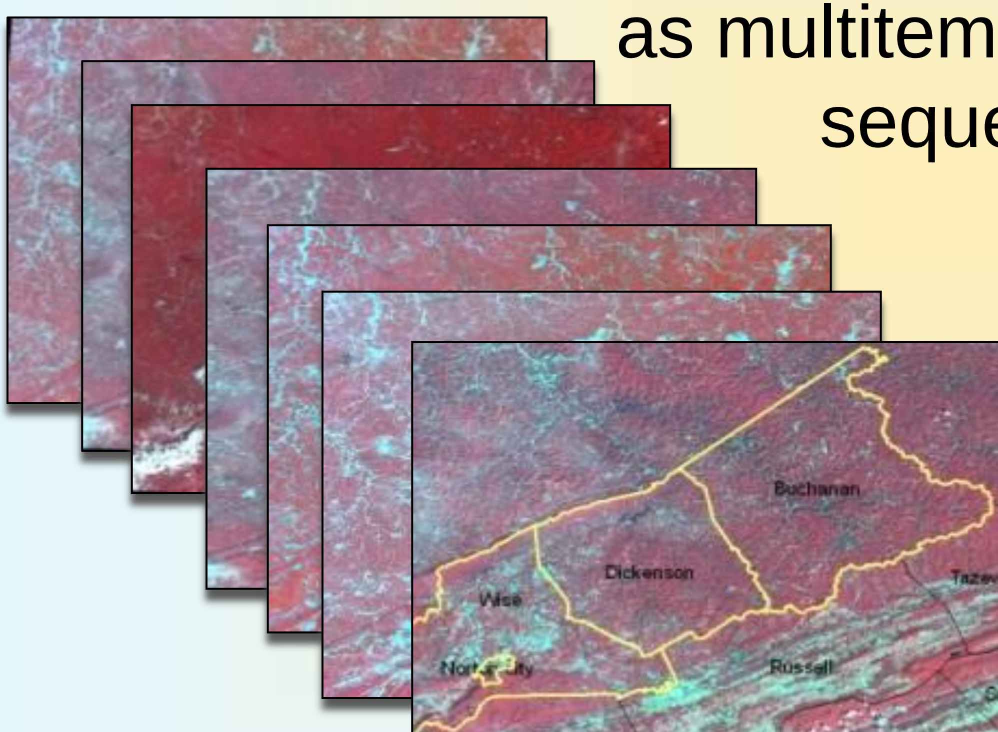
1. Describe research
2. Discuss potential applications of the research product.

Research Methods

Classify each study-area pixel as one of following types:

- ✓ **PV:** Persisting vegetation, vegetated for each image
- ✓ **EM:** “Ever mined”, detected as mined within the 1984-2011 image sequence
- ✓ **OD:** Other disturbances, with subclasses
  - DP: Developed
  - Non-MD: All other disturbances (not OD, not DP).

1. Acquire annual (1984-2011) leaf-on Landsat TM/ETM+ images (Path 18, Row 34): Process†, georectify, and "stack" as multitemporal sequence.



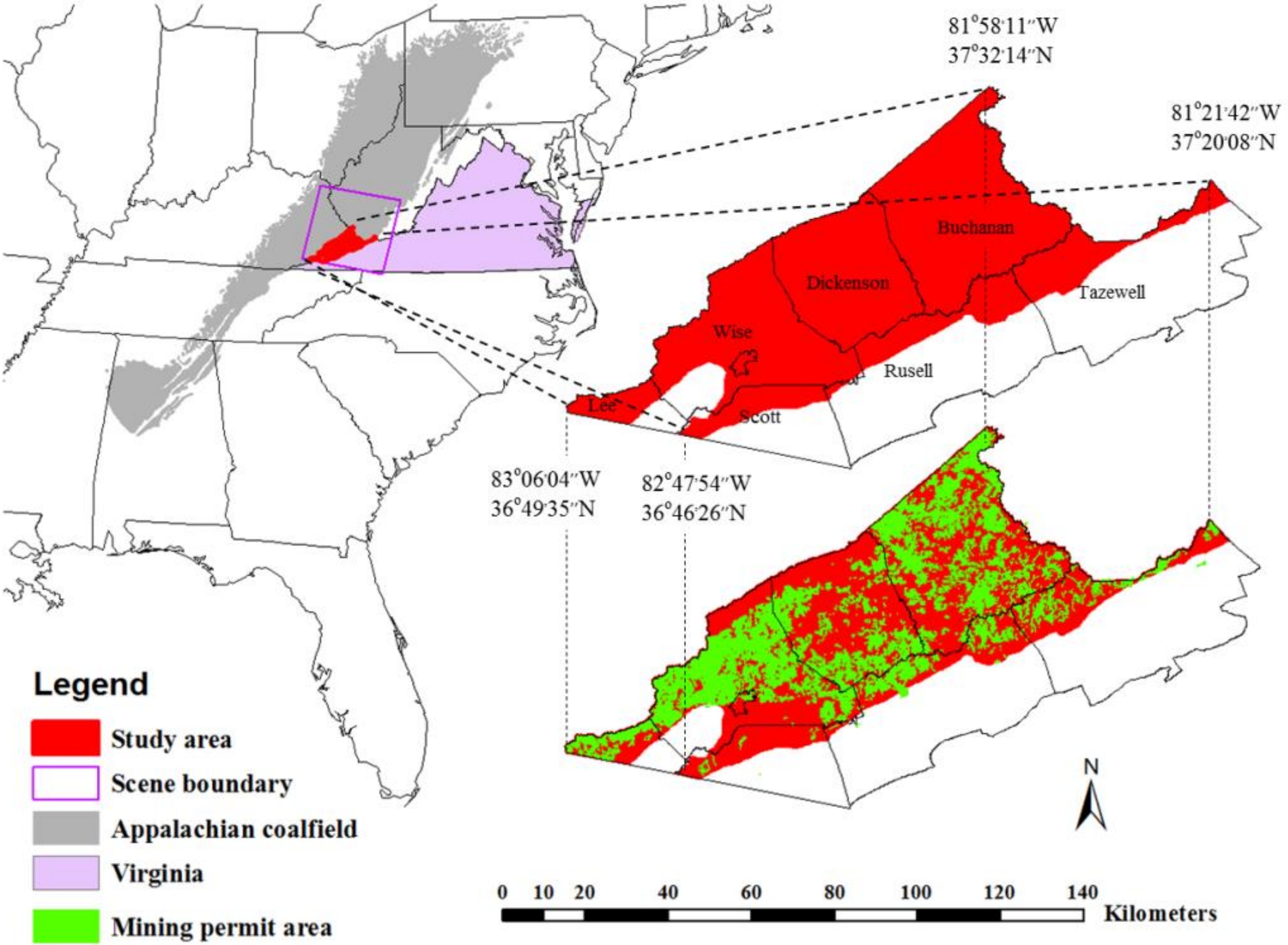
† includes masking clouds & cloud shadows.

4 missing years (no minimum-cloud images)

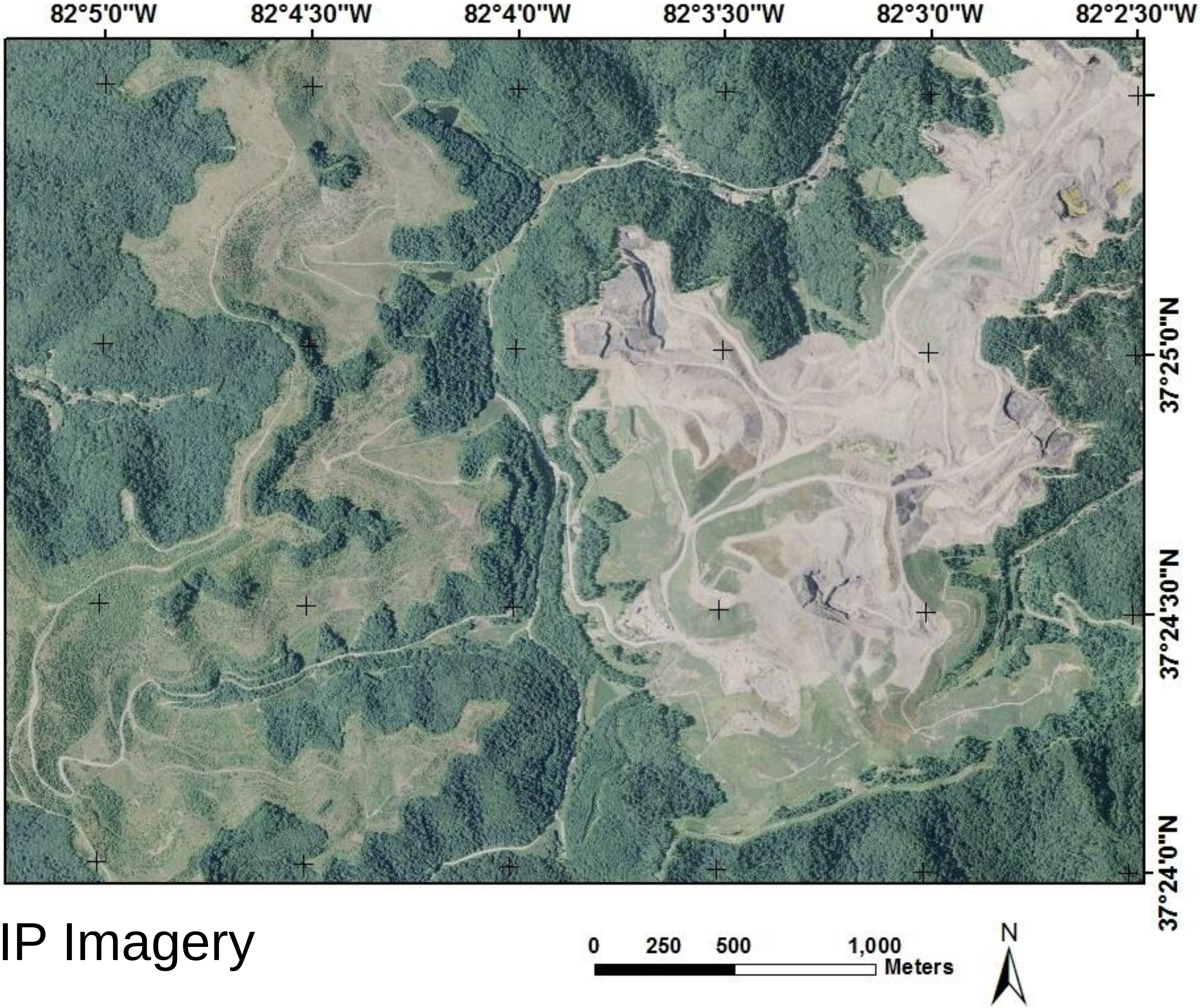
Acquisition Date	Fraction masked as clouds and cloud shadows (% of study area)
9/17/1984	0.22
9/20/1985	0.84
6/19/1986	0
6/6/1987	0.02
8/27/1988	0.02
6/17/1989	1.61
10/20/1990	2.47
10/25/1992	0
6/6/1993	6.14
10/15/1994	0.1
8/31/1995	0.44
9/5/1997	0.01
8/23/1998	0.01
9/3/1999	7.31
6/9/2000	8.83
9/8/2001	0.01
5/22/2002	0.01
6/2/2003	0
9/24/2004	8.27
5/22/2005	6.77
9/17/2007	0.84
9/3/2008	1.14
9/9/2010	3.06
10/30/2011	0.38

2. Obtain ancillary data to assist classification:

- ✓ Virginia DMME mine permit database: geospatial data: pre-SMCRA state permits, interim permits, SMCRA permits (released), active SMCRA permits.
- ✓ High-resolution aerial imagery from National Agricultural Imagery Program (NAIP): 2003, 2004, 2005, 2008, 2009, 2011 and 2012.
- ✓ National Land Cover Database (NLCD).



81°58'11''W
37°32'14''N
81°21'42''W
37°20'08''N
Buchanan
Dickenson
Tazewell
Wise
Rusell
Lee
Scott
83°06'04''W
36°49'35''N
82°47'54''W
36°46'26''N
N
Legend
Study area
Scene boundary
Appalachian coalfield
Virginia
Mining permit area
0 10 20 40 60 80 100 120 140
Kilometers



NAIP Imagery

3. Produce Training data: 509 randomly generated points inside merged permit boundaries, plus additional 50 points outside mine permits in NLCD developed areas.

Classify each point for each image: Bare (b) or Vegetated (v).

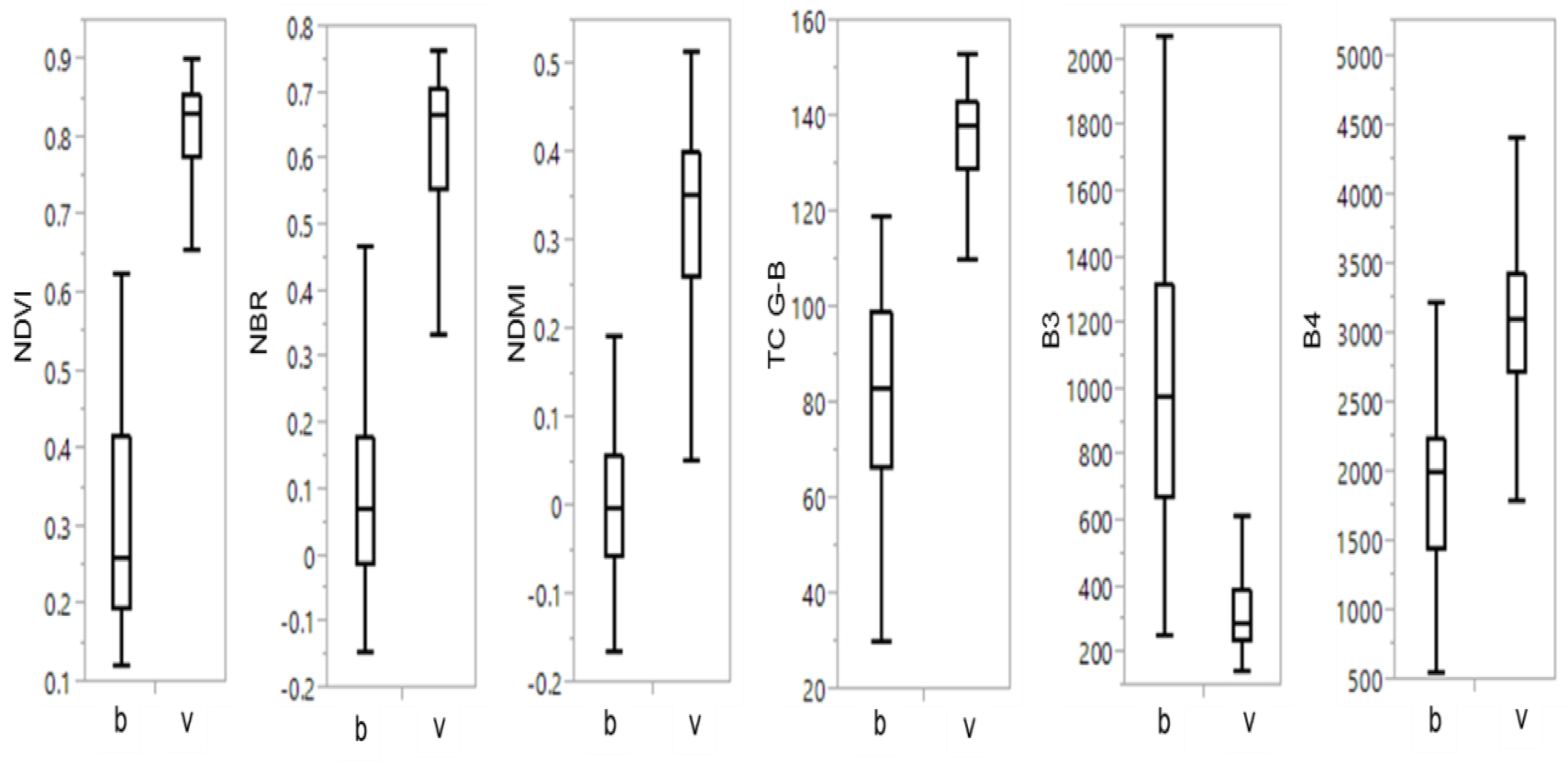
- For Landsat images with NAIP confirmation, use NAIP.

- For other images: Display bands 2-3-4; use NAIP to “learn” image characteristics that correspond with bare ground; then classify training points for pre-NAIP Landsat images.

http://earthobservatory.nasa.gov/Features/MountaintopRemoval/images/hobet_tm_comparison_01-over.jpg

4. Using training data and 2008 image: Select vegetation index

for use in mined land classification by comparing bare (b) vs vegetated (v) pixels.



NDVI works best!

Normalized burn ration

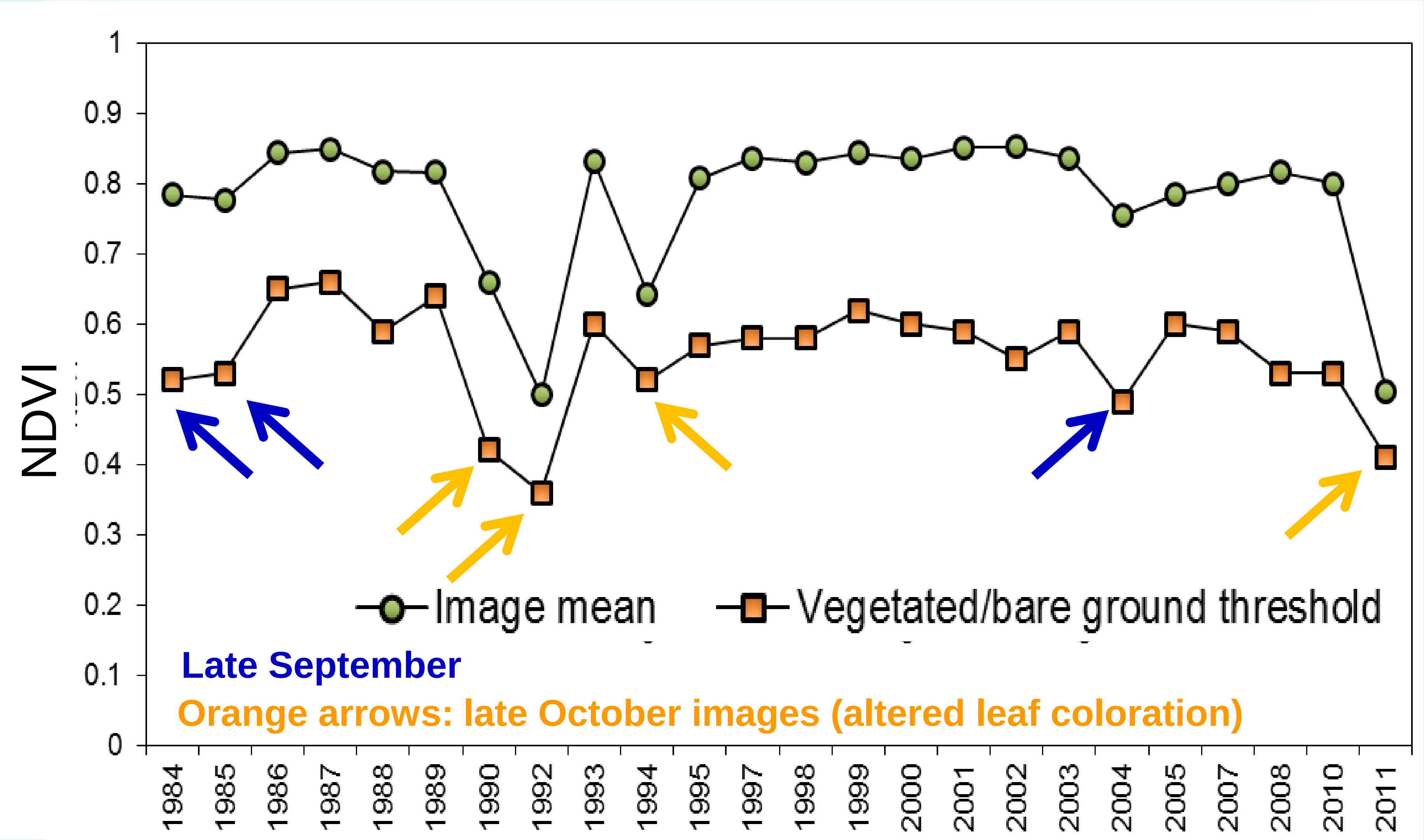
Normalized difference moisture index

Tassled cap greeness-brightness difference

Landsat Band 3

Landsat Band 4

5. Use CART classification to select separate bare-ground threshold for each image.

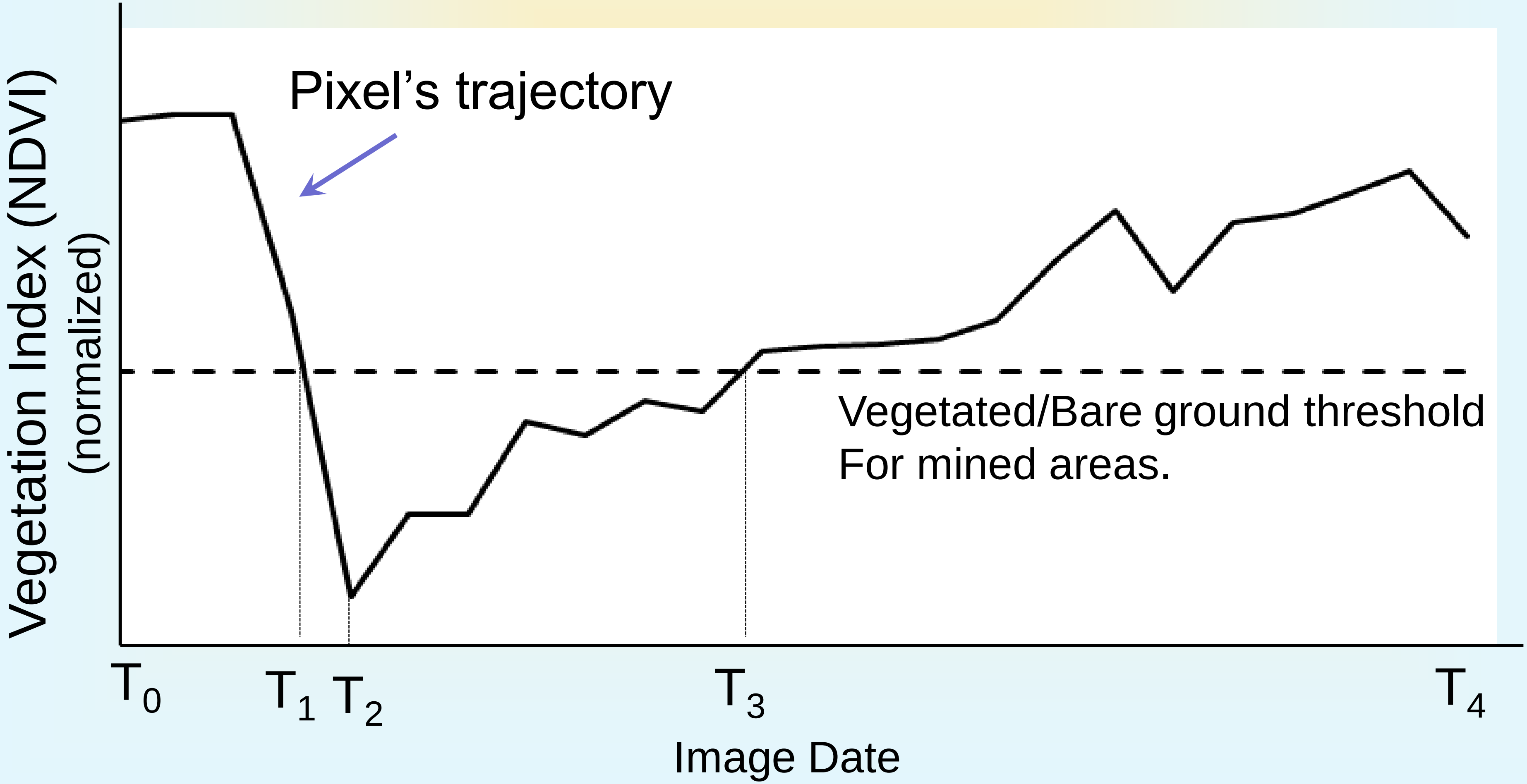


Apply bare-ground thresholds over entire study time/area to classify persisting vegetation (PV) and non-PV (disturbed) areas.

6. Theory: Mining can separated from other disturbances using the “spectral trajectory” model.

Problems with operationalizing that theory:

- Non-mining disturbances also achieve low NDVI values.
- Investigations reveal mine permit spatial extent as incomplete.

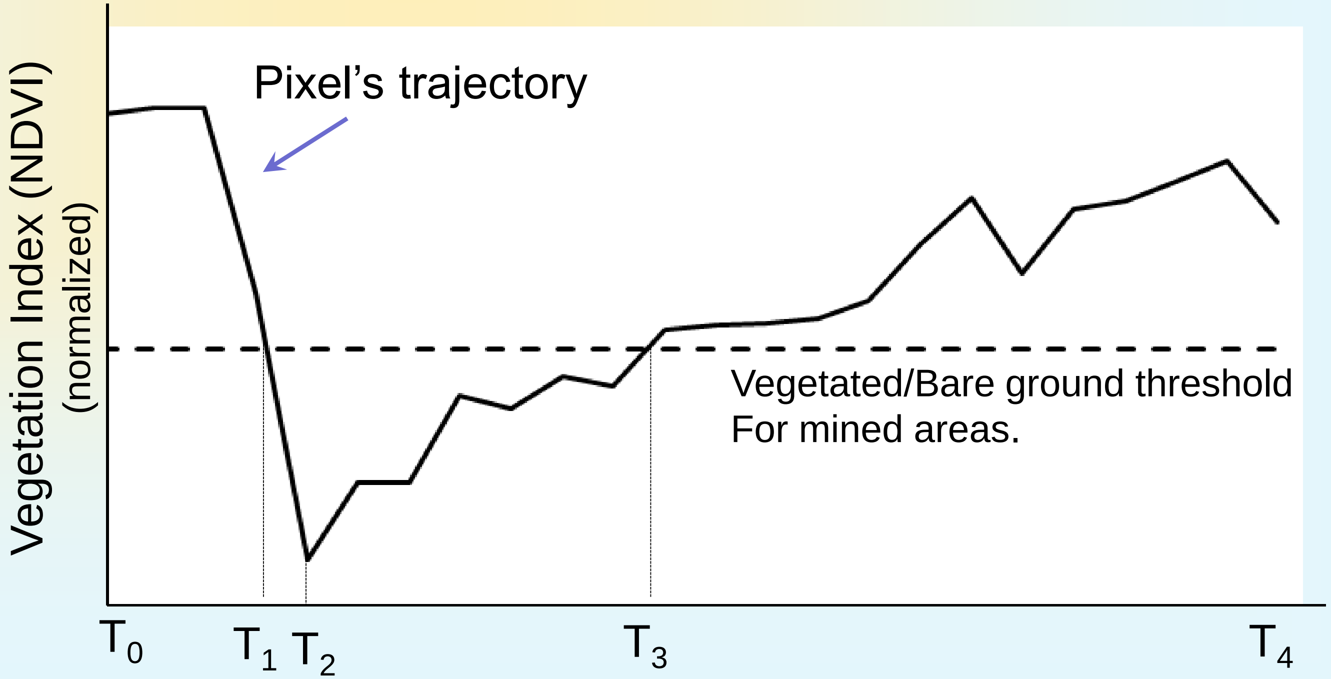


6 (continued): Develop and test two hypotheses:

i. Minimum *NDVI* for mined lands (EM) will generally be lower than the minimum *NDVI* for *Non-MD* lands (non-mining, other disturbances);

ii. Standard deviation of *NDVI* after disturbance will be greater for *EM* (mined lands) than for *DP* (developed) lands.

Hypotheses confirmed - then applied to classify all non-PV (disturbed) lands as EM, non-MD, or DP.



Now: Classification is complete.

Each study-area pixel has been classified as one of following types:

- ✓ **PV:** Persisting vegetation, vegetated for each image
- ✓ **EM:** “Ever mined”, detected as mined within the 1984-2011 image sequence
- ✓ **OD:** Other disturbances, with subclasses
    - DP: Developed
    - Non-MD: All other disturbances (not OD, not DP).

7. Conduct accuracy assessment:

Generate 1193 validation points, randomly distributed within classified categories; visually assess using aerial imagery and Landsat images.

	Reference data																										Row total	User's acc. (%)
	PV	OD	1984	1985	1986	1987	1988	1989	1990	1992	1993	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2007	2008	2010	2011	total	Acc.
PV	**358**	13		1	1	1	1				1			1				1	1	1		2		1			383	93.5
OD	4	**70**	1	1	1					1	3			1	1	1						1	1	1	1		88	79.5
1984			**26**		1					1									1								29	89.7
1985				**23**																							23	100
1986		1			**19**													1									21	90.5
1987		1				**23**																					24	95.8
1988							**29**							1													30	96.7
1989								**26**			1																27	96.3
1990								1	**26**																		27	96.3
1992										**25**	1																26	96.2
1993											**24**																24	100
1994												**20**			1	1		1		1	2	1	1				28	71.4
1995								1					**25**					1									27	92.6
1997														**28**													28	100
1998															**28**												28	100
1999																**31**											31	100
2000		1															**28**										29	96.6
2001		1																**30**									31	96.8
2002		3																	**22**								25	88
2003																				**31**							31	100
2004																					**29**	2					31	93.5
2005		1																				**22**					23	95.7
2007																							**29**				29	100
2008		1																						**29**			30	96.7
2010																									**26**		26	100
2011		1																								**23**	24	95.8
Column total	362	93	27	25	22	24	30	28	26	27	30	20	25	31	30	33	28	34	24	33	31	28	31	31	27	23	1123	
Produc. acc.	98.9	75.3	96.3	92	86.4	95.8	96.7	92.9	100	92.6	80	100	100	90.3	93.3	93.9	100	88.2	91.7	93.9	93.5	78.6	93.5	93.5	96.3	100	**Overall acc.**	**93.5**

"Confusion Matrix"

Results

Results of accuracy assessment: 93.5% overall accuracy.

Mining-by-year accuracy:

- ❑ Users Accuracy (corresponds with errors of commission): 95.4% over all years. 1994 = 71%. All other years: ≥ 88%
- ❑ Producers accuracy (corresponds with errors of omission): 93.3% overall; all years > 78%.

Errors:

- ✓ Along the edges of polygons.
- ✓ Narrow, linear mining features incorrectly classified as OD.
- ✓ Cloud contamination increased time intervals.

- ❑ Visual analysis confirms high accuracy

	Reference data																										Row total	User's acc. (%)
	PV	OD	1984	1985	1986	1987	1988	1989	1990	1992	1993	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2007	2008	2010	2011	total	Acc.
PV	**358**	13		1	1	1	1				1			1				1	1	1		2		1			383	93.5
OD	4	**70**	1	1	1					1	3			1	1	1						1	1	1	1		88	79.5
1984			**26**		1					1									1								29	89.7
1985				**23**																							23	100
1986		1			**19**													1									21	90.5
1987		1				**23**																					24	95.8
1988							**29**							1													30	96.7
1989								**26**			1																27	96.3
1990								1	**26**																		27	96.3
1992										**25**	1																26	96.2
1993											**24**																24	100
1994												**20**			1	1		1		1	2	1	1				28	71.4
1995								1					**25**					1									27	92.6
1997														**28**													28	100
1998															**28**												28	100
1999																**31**											31	100
2000		1															**28**										29	96.6
2001		1																**30**									31	96.8
2002		3																	**22**								25	88
2003																				**31**							31	100
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2007																							**29**				29	100
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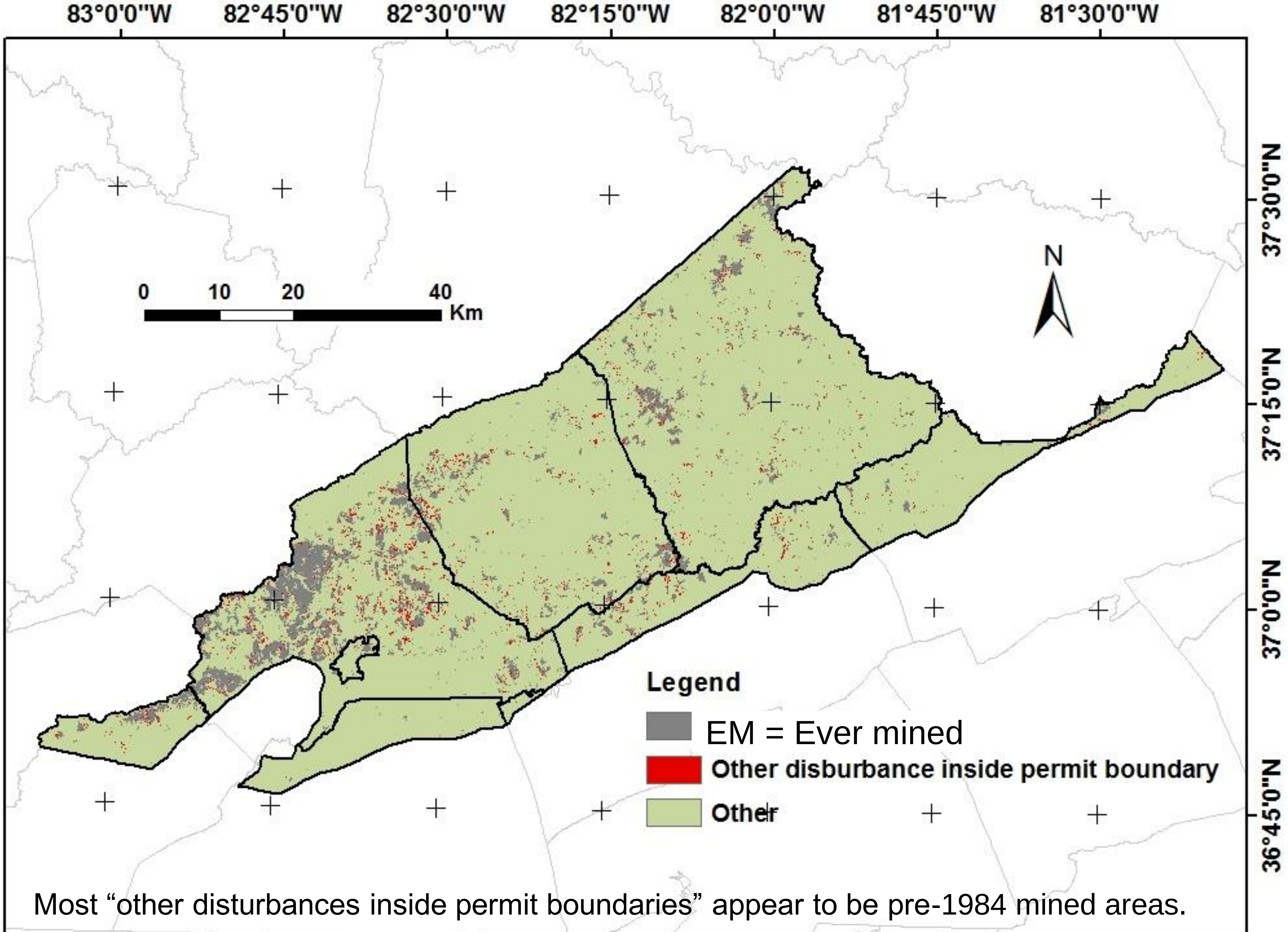
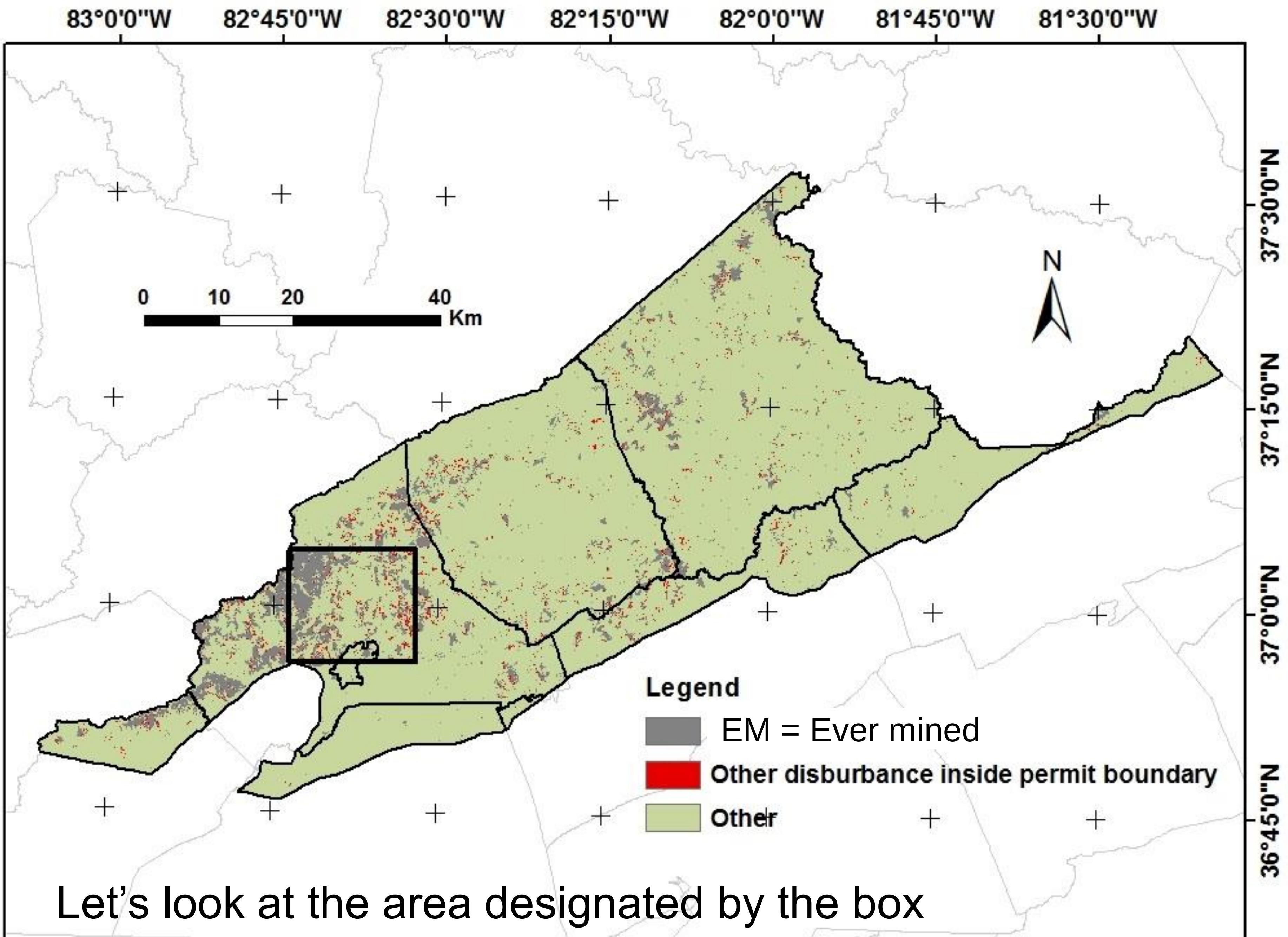
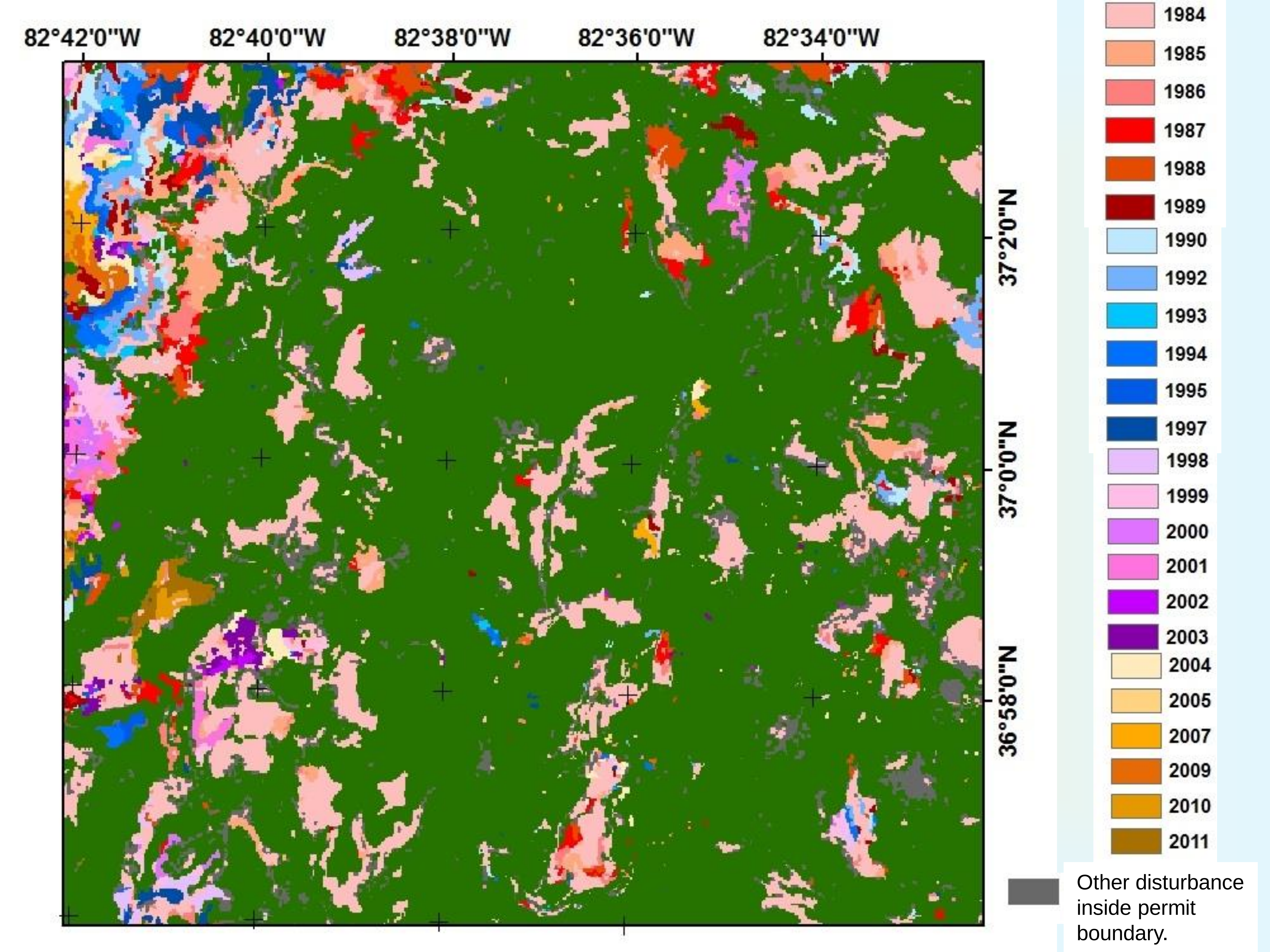
Column total	362	93	27	25	22	24	30	28	26	27	30	20	25	31	30	33	28	34	24	33	31	28	31	31	27	23	1123	
Produc. acc.	98.9	75.3	96.3	92	86.4	95.8	96.7	92.9	100	92.6	80	100	100	90.3	93.3	93.9	100	88.2	91.7	93.9	93.5	78.6	93.5	93.5	96.3	100	**Overall acc.**	**93.5**



Most “other disturbances inside permit boundaries” appear to be pre-1984 mined areas.



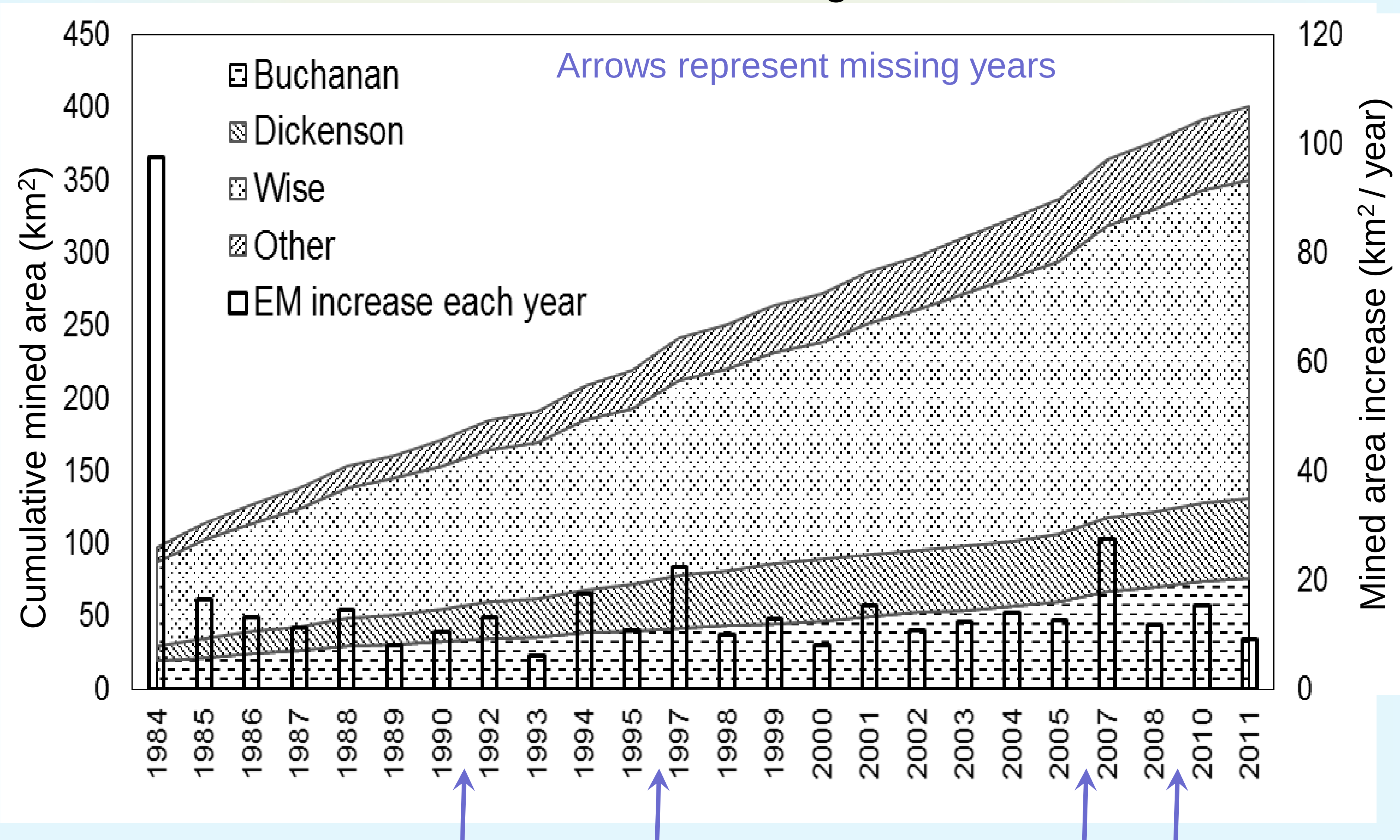
Let's look at the area designated by the box



82°42'0"W
82°40'0"W
82°38'0"W
82°36'0"W
82°34'0"W
37°2'0"N
37°0'0"N
36°58'0"N
1984
1985
1986
1987
1988
1989
1990
1992
1993
1994
1995
1997
1998
1999
2000
2001
2002
2003
2004
2005
2007
2009
2010
2011
Other disturbance inside permit boundary.

Results:

8.2% of Virginia coalfield surface disturbed by mining (1984-2011 detected). ~20% of Wise County's Appalachian coalfield surface: 1984-2011 detected mining disturbance.



Describe Potential Applications

- Terrestrial
- Aquatic

Terrestrial Application

Question: What fraction of mined surface is covered by woody vegetation, native + other?

Hypothesis: Native woody veg increases with ***site age***, varies with landscape position, aspect, and proximity to native forest.

Post-SMCRA mine site from mid-1980s

Terrestrial Application

Use Landsat to define mined lands where autumn olive status enables detection:

- Distinctive coloration in spring season.
- Late leaf-fall in autumn.

Analyze presence via mine site age.

A.J Oliphant thesis: “Mapping *Elaeagnus umbellata* on Coal Surface Mines using Multitemporal Landsat Imagery” (in preparation).

Preliminary results confirm significant autumn olive presence on lands mined 2001 and earlier; and suggest increasing presence with increasing site age for younger mines – but still preliminary.

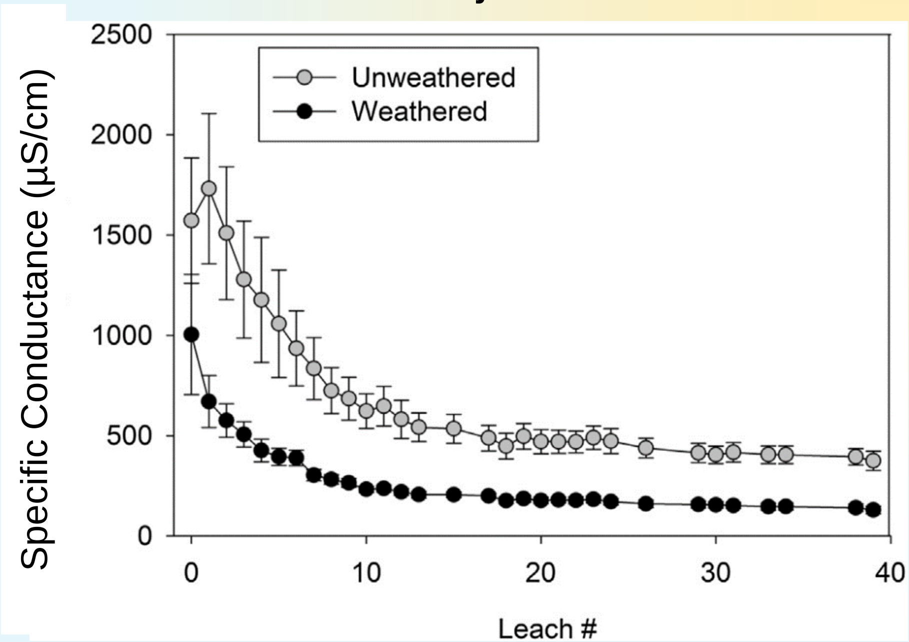
Non-Native Invasive – Autumn Olive

Aquatic Resource Application

Hypothesis: As mining disturbance within a watershed expands through time, total dissolved solids concentrations within the river or stream draining that watershed will increase.

How to evaluate hypothesis?
What do we know?

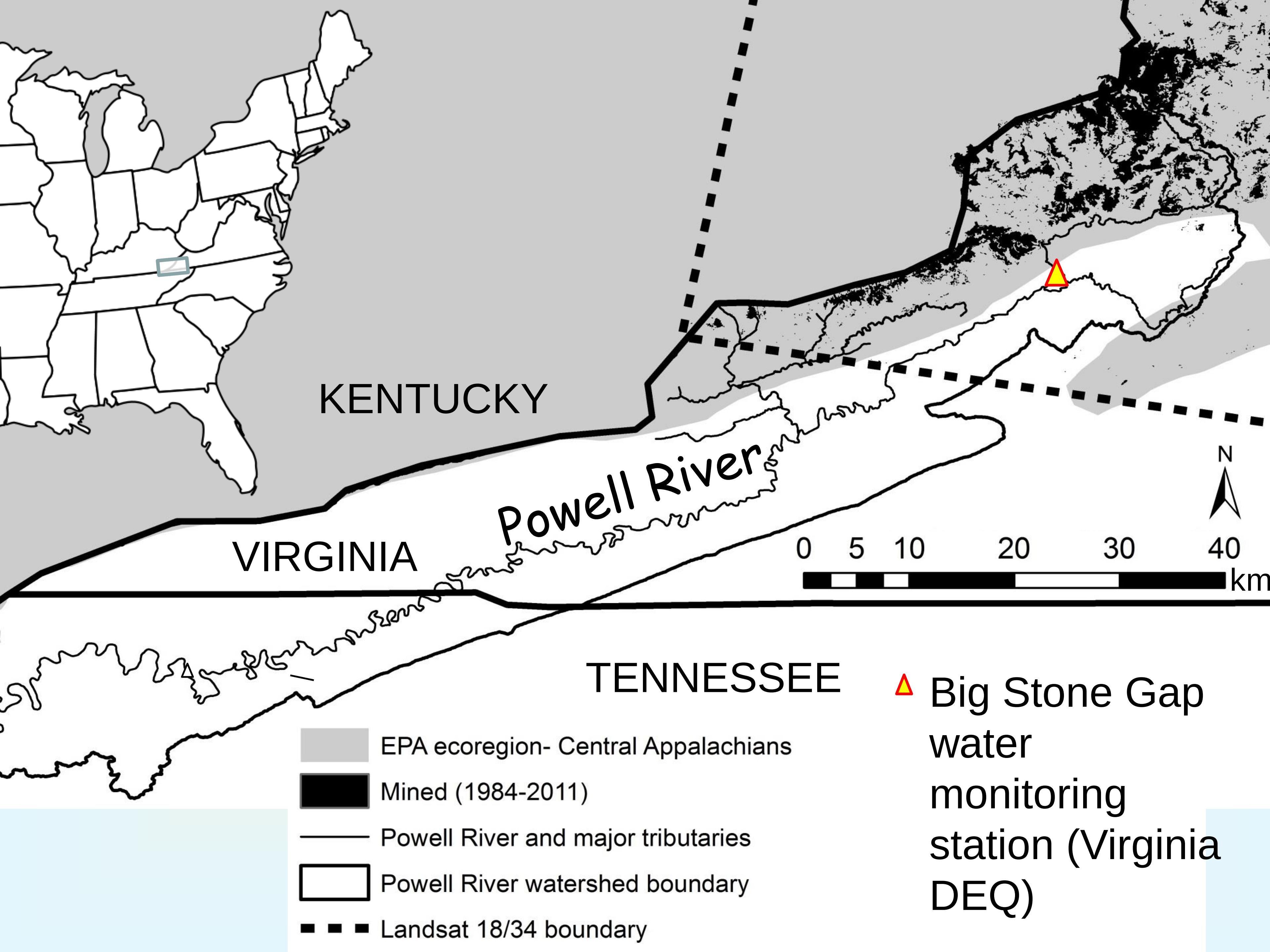
Exposure of unweathered mine spoils to air and water enables major ion release.



Orndorff et al. 2015. Env. Pollution 204:39-47.

Much surface mining activity in Powell River watershed, VA

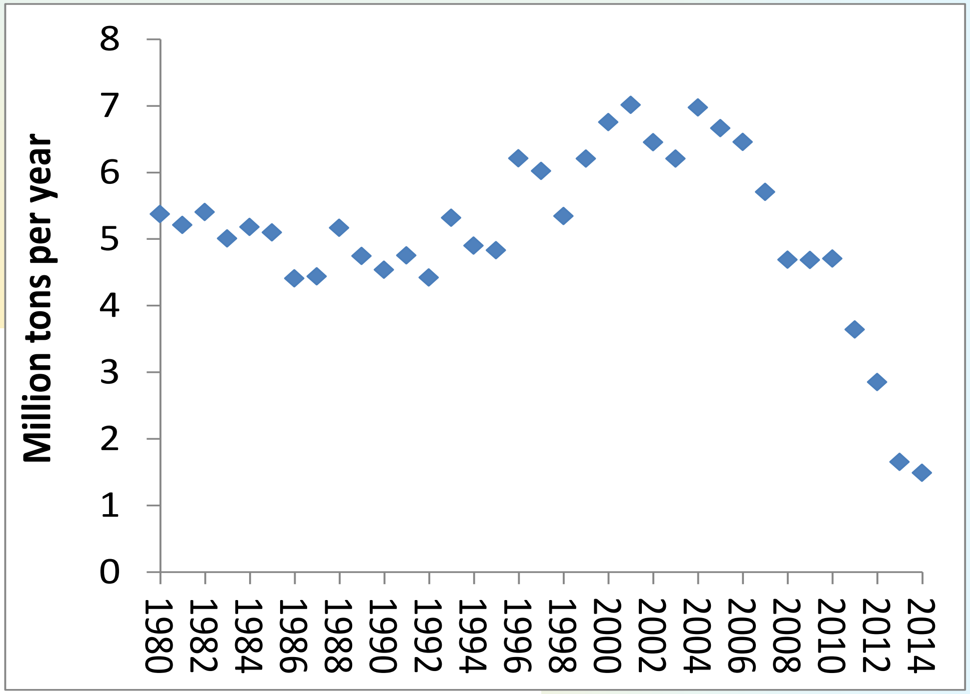
Long-term water quality data for Powell River at Big Stone Gap, VA, are available.

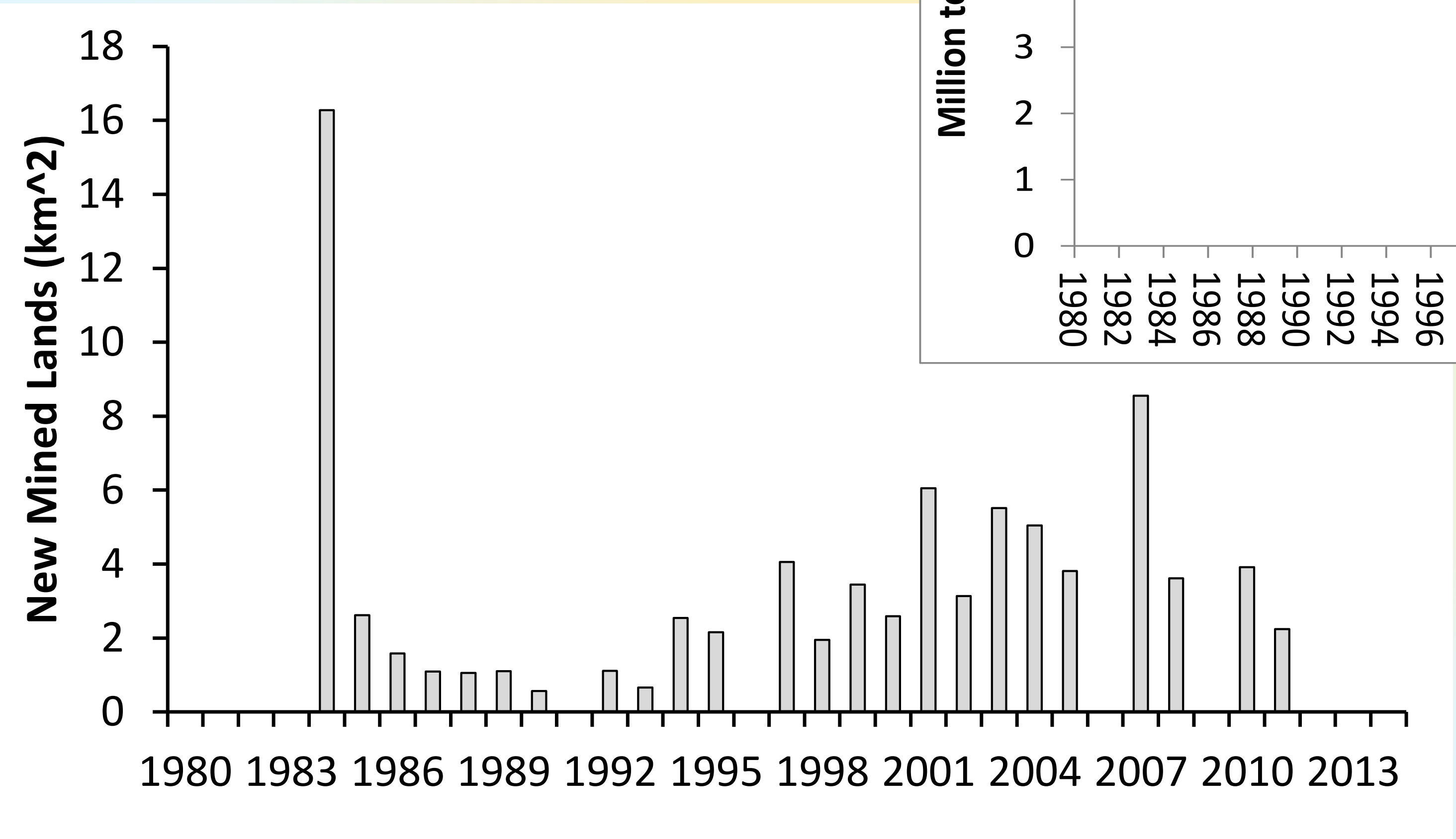


KENTUCKY
VIRGINIA
TENNESSEE
Powell River
N
0 5 10 20 30 40
km
EPA ecoregion- Central Appalachians
Mined (1984-2011)
Powell River and major tributaries
Powell River watershed boundary
Landsat 18/34 boundary
Big Stone Gap water monitoring station (Virginia DEQ)

New mined lands, Powell River watershed above Big Stone Gap (1984-2011, by year of detection).

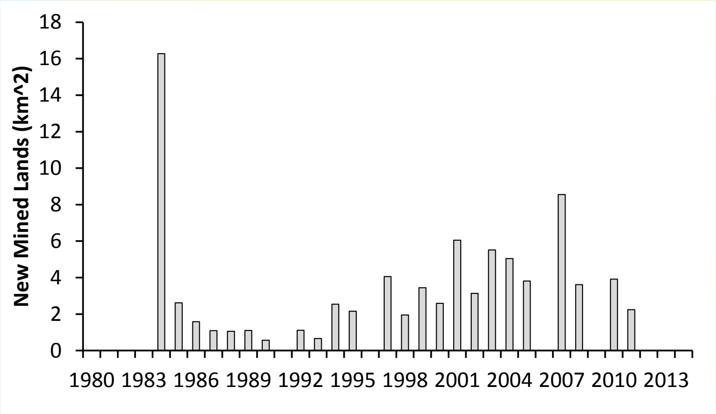
Annual surface-mine coal production for Wise County, 1980-2014 (EIA data)



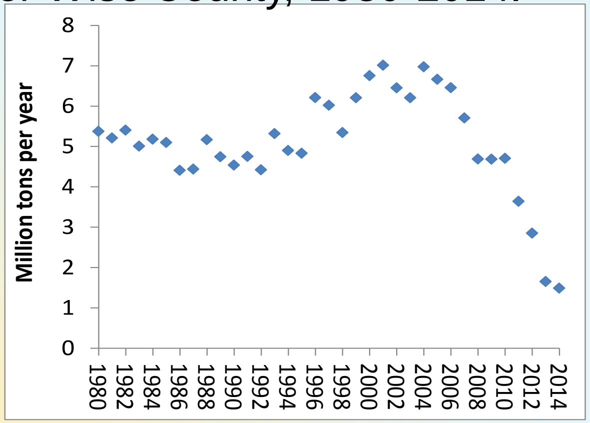


Estimate geologic disturbance through time: Powell River Watershed above Big Stone Gap:

New mined lands, Powell River watershed (1984-2011, by year of detection).



Annual surface-mine coal production for Wise County, 1980-2014.

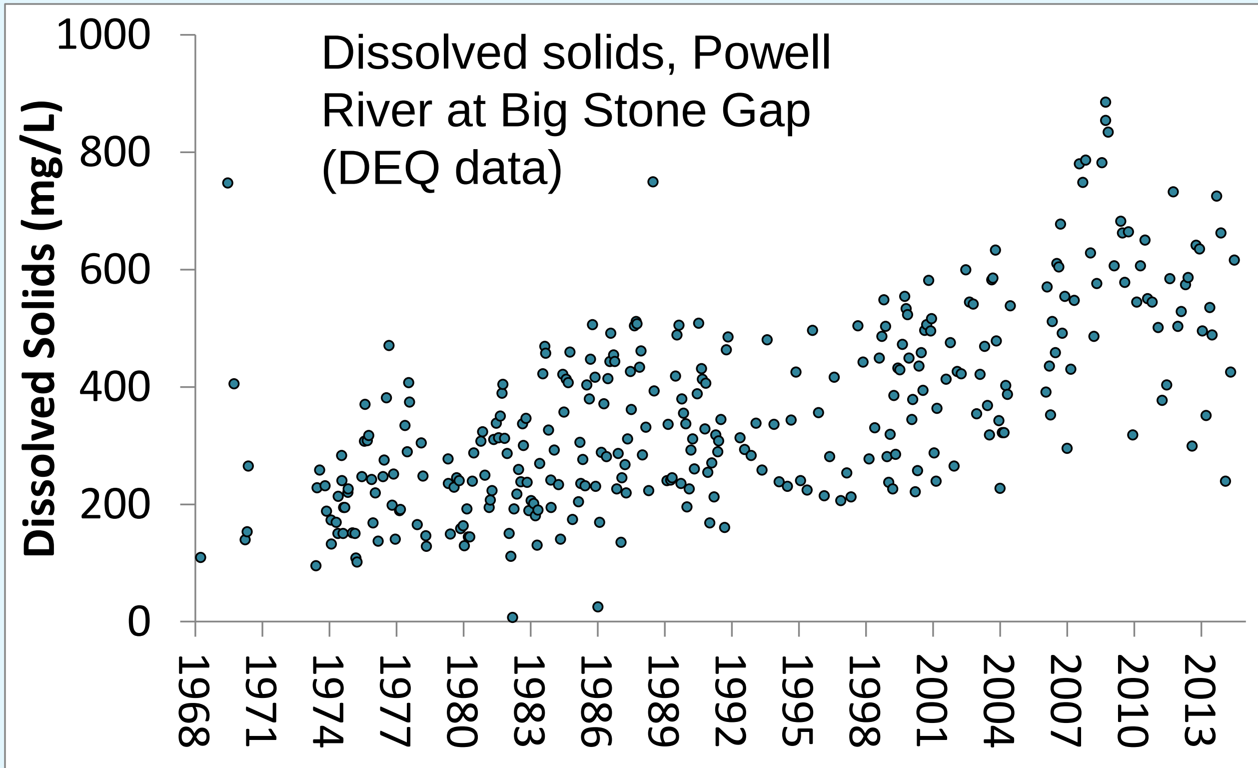


New mined lands, all of Wise County, (1984-2011, by year of detection) – Data not shown.

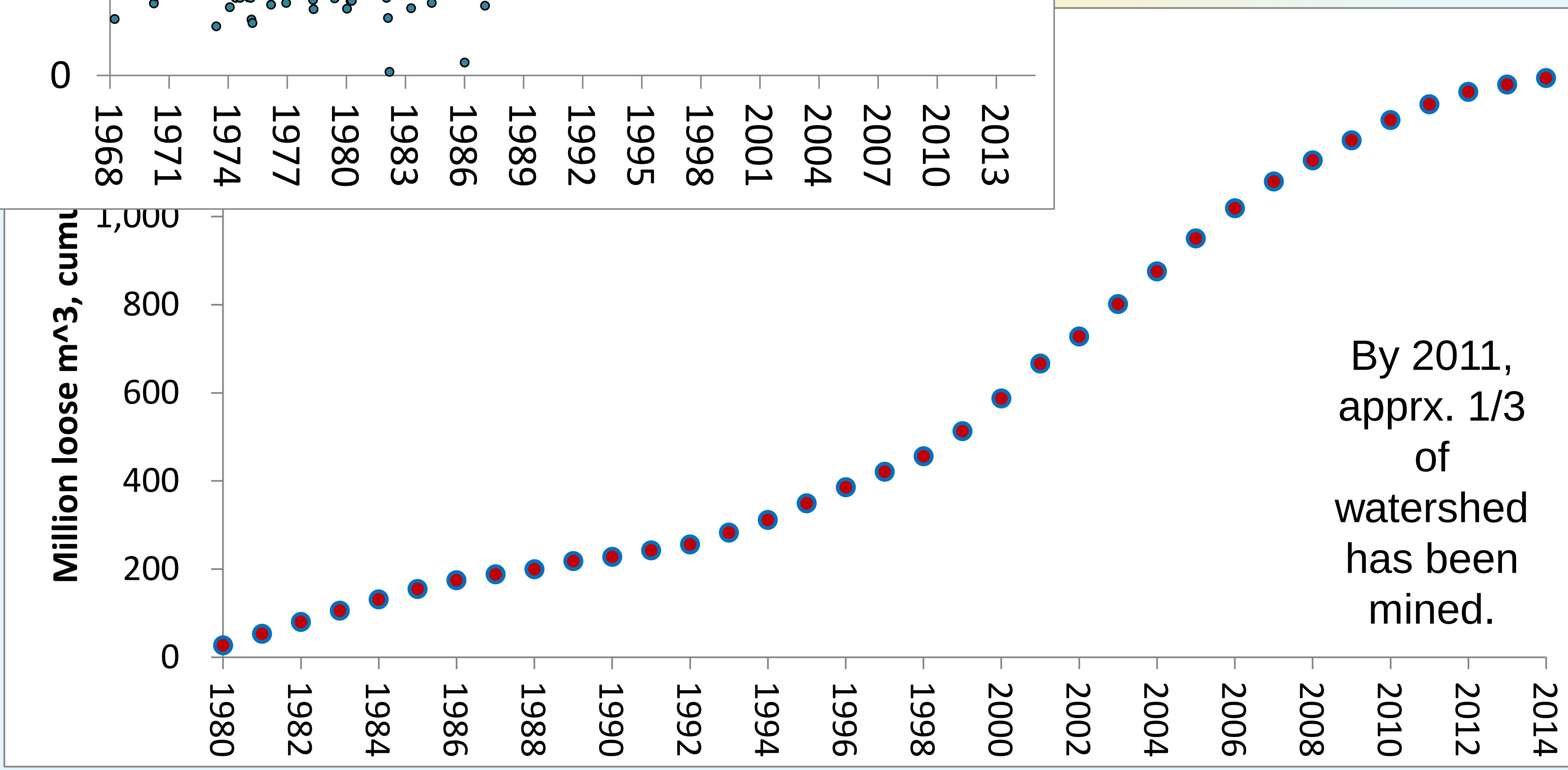
Assumptions:

- ❖ Ratio of surface coal production within vs. outside of watershed (Wise County) varies in proportion to land disturbance.
- ❖ 1984-detected land disturbance reflects 1980-1984 averages.
- ❖ “Missing year” disturbance can be estimated as fixed ratio to the following year.
- ❖ 2012-2014 disturbance occurs in ratios reflected by 2012.
- ❖ Geologic disturbance varies as ratio to coal production (15 bcy†/ton)

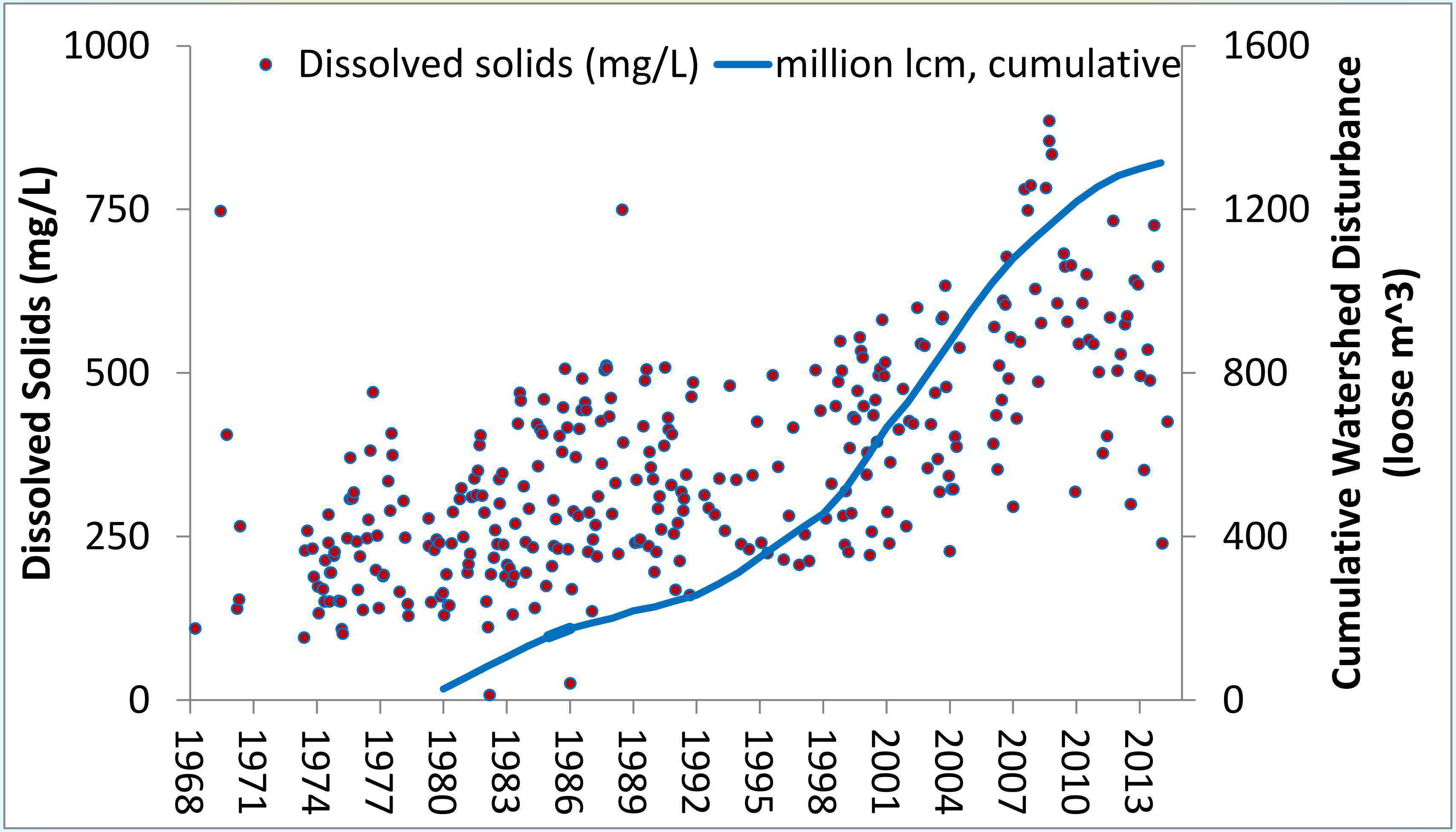
† bcy = bank cubic years



Estimated geologic disturbance,
Powell River watershed above Big Stone Gap, cumulative.



Cumulative Watershed Disturbance (1980-2014) and Dissolved Solids Concentrations (1968-2014), Powell River at Big Stone Gap, Virginia



Conclusions

Time-series analysis of Landsat imagery is well suited for the task of identifying surface coal mining locations, and classifying mining areas by approximate date of initial disturbance.

Resulting data can aid characterization of the natural resources that have been affected by Appalachian mining; and they can aid understanding of recovery processes occurring over extended periods.

Acknowledgements

Thanks to China Scholarship Council for supporting Prof. Jing Li as a visiting scientist at Virginia Tech.

Thanks to colleagues at Virginia Tech and elsewhere for our long-term cooperative and collaborative engagements.