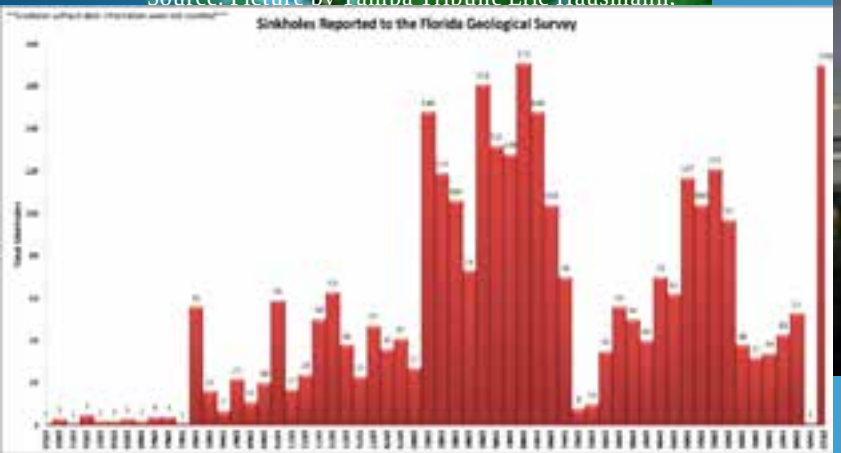
Winter Strawberry Production in West Central Florida, at what cost? A GIS Analysis of the relationship between sinkhole development, dry well complaints and groundwater pumping for frost-freeze protection

Mark D. Aurit, GISP

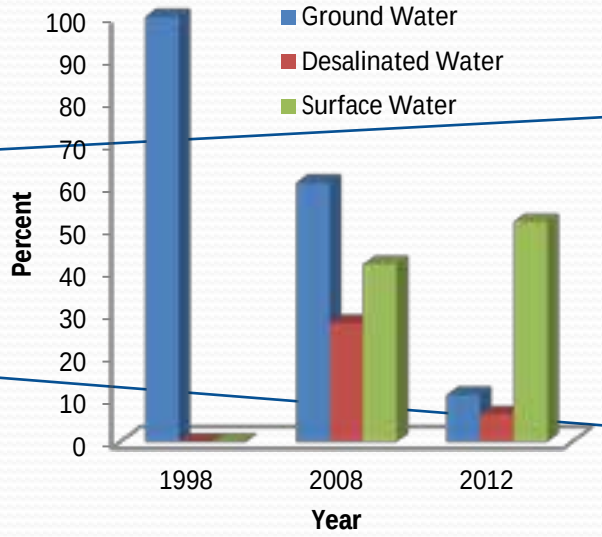
Source: Picture by Tampa Tribune Eric Hausmann.



Source: Picture by Tampa Tribune George Newman

- manages water for SW Florida
- covers 10,000 square miles
- serves > 5 million people.

- 3 cities and 3 counties in the Tampa Bay region.
- provides 186 million gallons drinking water /day



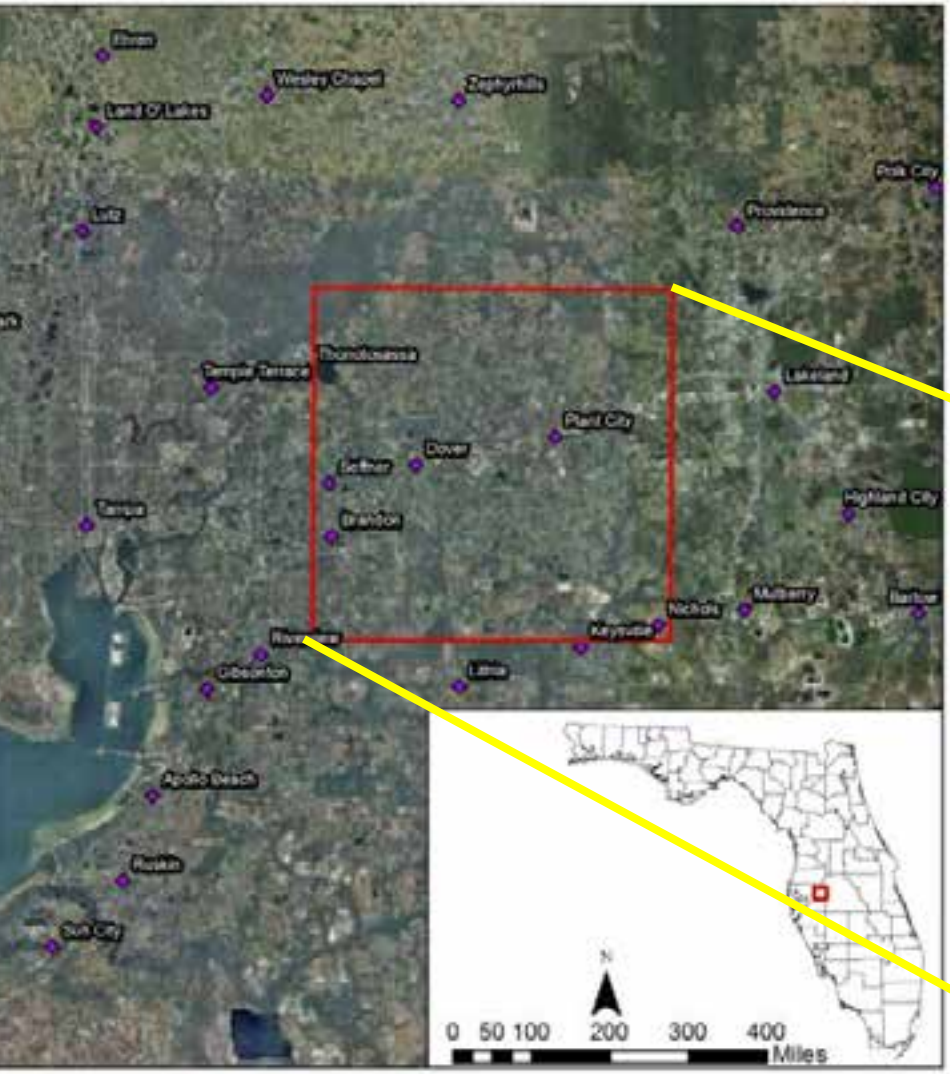
Source: SWFWMD, 2011
http://www.swfwmd.state.fl.us/about/mission/

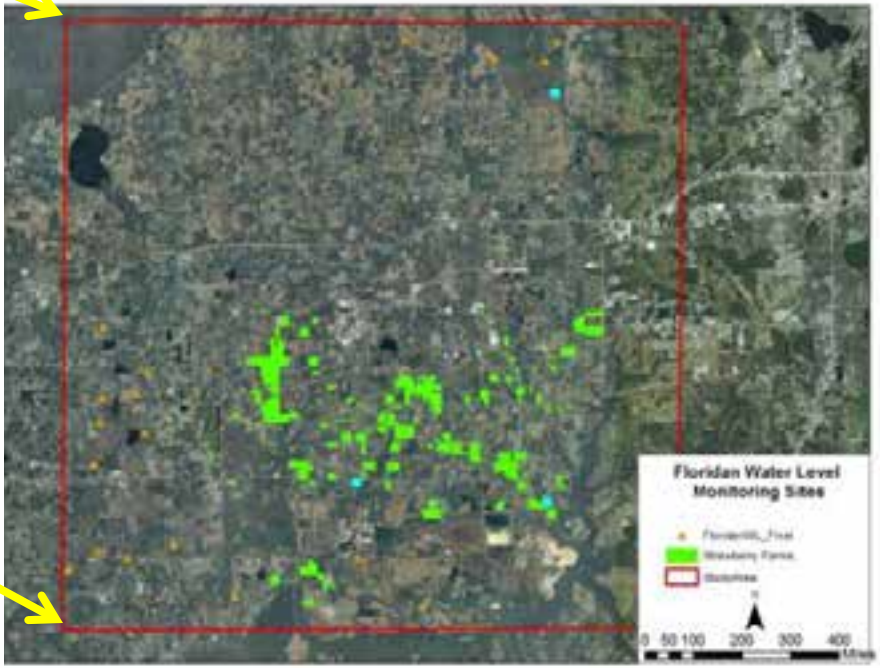
Strawberries: Dover / Plant City

Florida is the main producer of winter strawberries in the USA

Approximately 7000 acres are harvested in SW Florida

Protecting crops from frost-freeze events is important





Crop protection during frost-freeze events

- Passive
  - Site selection
  - Cover
- Active
  - Heaters
  - Wind
  - Water

Table 4. Estimated approximate annual per hectare/hour operating costs (including amortization of investment, but with 0% interest and before taxes) for selected cold temperature (frost) protection systems used 120 hours per year.

Method	Estimated costs/ha/hr
Return Stack Oil Heaters (100/ha)*	$ 93.08
Standard Propane Heaters (154/ha)*	103.98
Wind Machine (130 BHP propane)	33.36
Overcrop Sprinkling	4.10
Under Canopy Sprinkling	4.25
Frost-free site	0.00

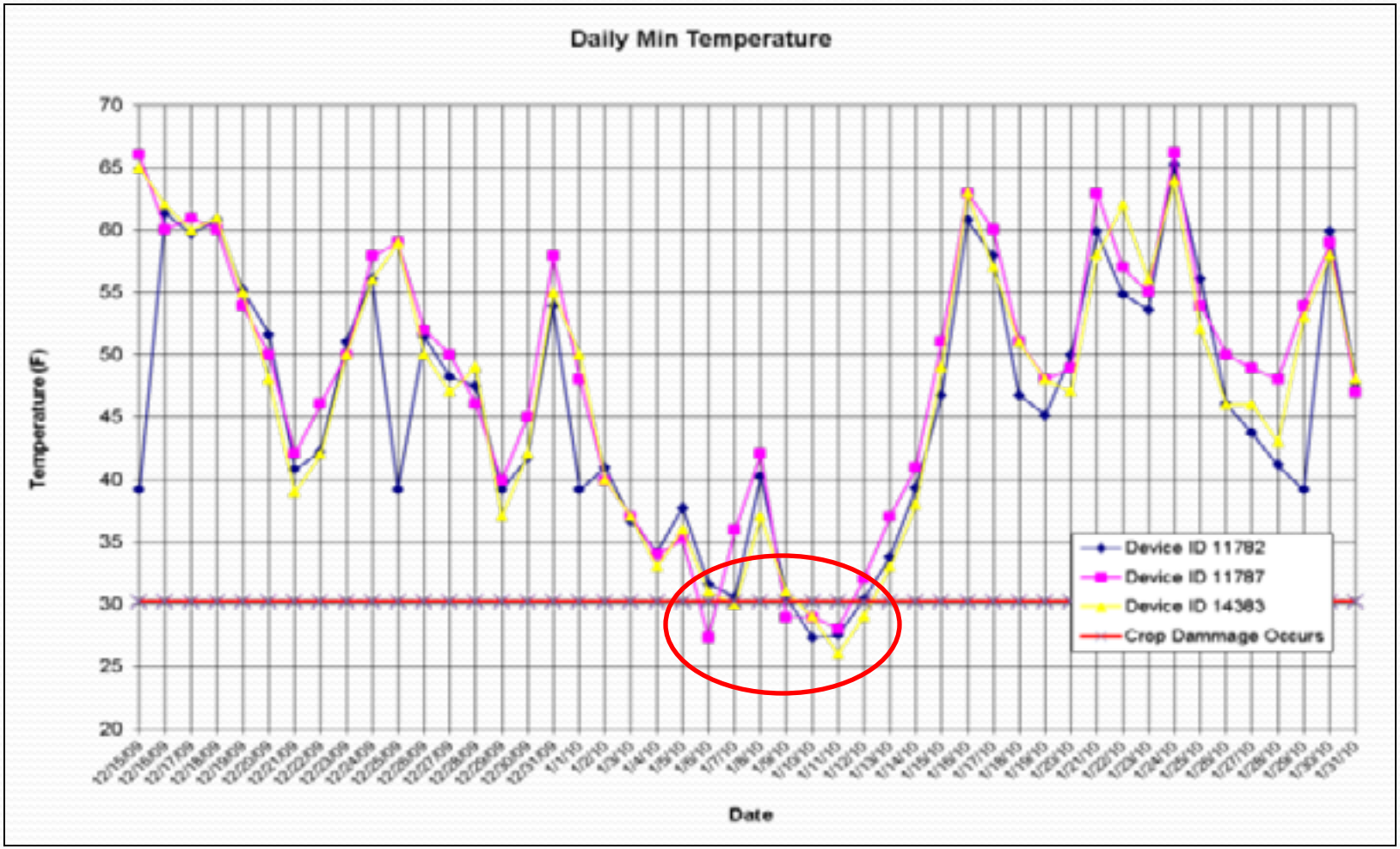
* equal total heat output

Source: Evans (2000) **Proceedings of the ASEV 50th Anniversary Meeting, Seattle, Washington June 19-23, 2000**

Frost-freeze and damage

Floral/Fruit Stage Strawberry	Temperature at which 90%Damage Occurs (F)
Tight bud	22°F or -5.5°C
Tight with white petals	28°F or -2.2°C
Full bloom	32°F or -.5°C
Immature fruit	28 °F or -2.2°C

Source: OMFRA, 2009



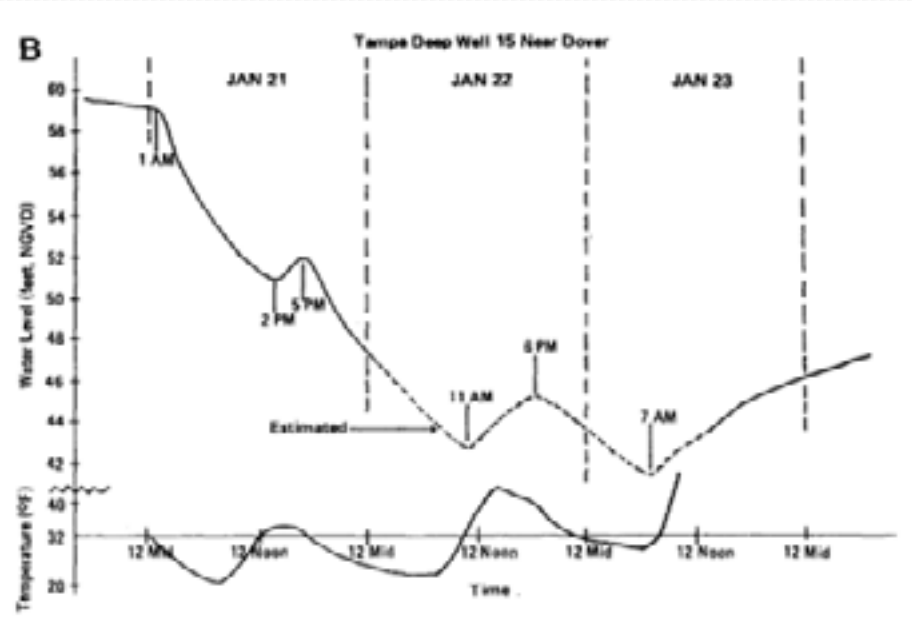
Known effects of water abstraction

Abstraction of water

Rapid reduction in water levels (940 million gallons water/day vs 37 MGD)

Result

- Dry wells
- Sinkhole development



Source: Bengstonn, 1989

Damage during 2010 frost-freeze

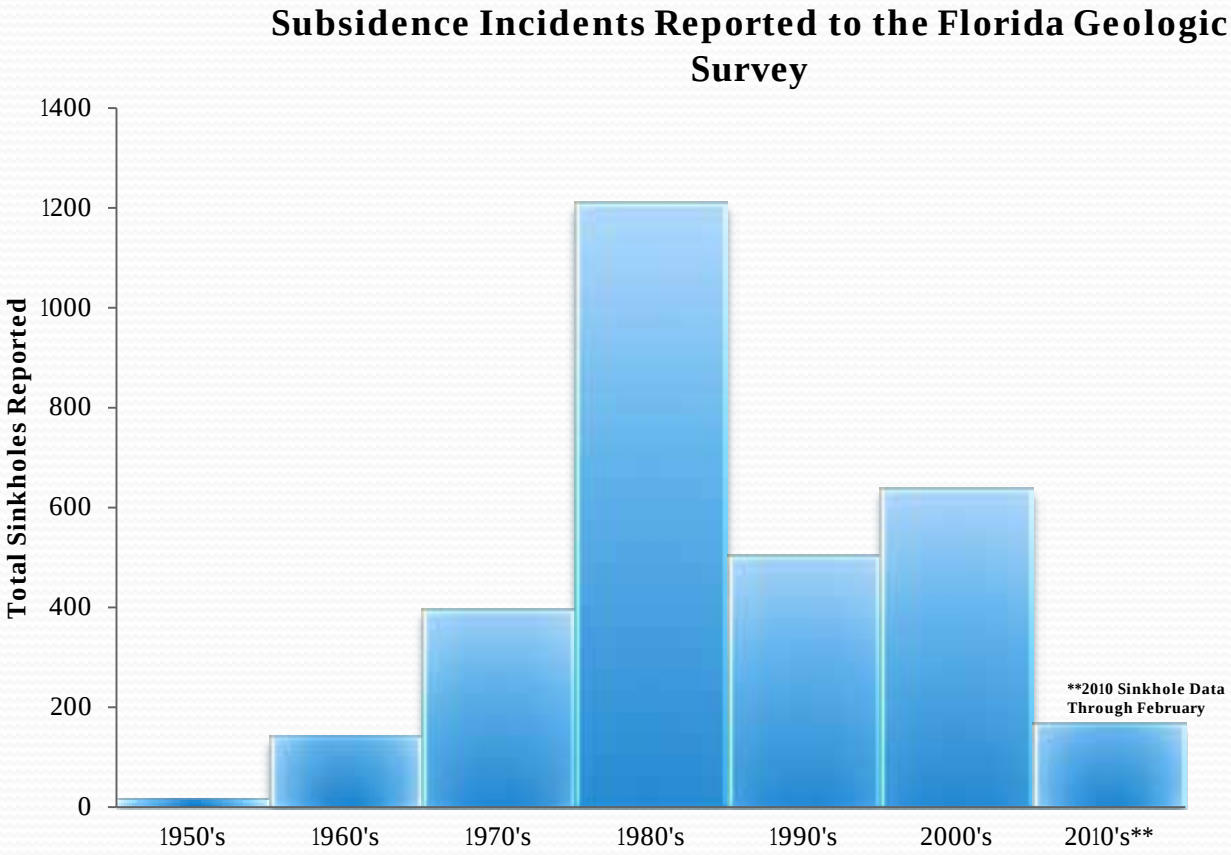
	Plant City Road Repairs	Trapnell Elementary School	Plant City Water Tower	Hillsborough County
Cost	$1,600,000	$900,000	$250,000	$4,900,000
Sinkhole	14	1	1	139

Picture illustrating how a 30 yard wide 40-50 foot deep sinkhole destroyed property in Plant City, FL (Source: Picture by Jay Nolan 2010)

Damage caused by a sinkhole on Highway 27 near Interstate 4 connecting Tampa and Orlando, which resulting in the closure of three of four lanes on January 13, 2010. (Source: Picture by WMG-TV Jacksonville, 2010)

Sinkholes in Florida

Sinkholes without date information in the FGS database were not counted



Damage during 2010 frost-freeze

By GEORGE H. NEWMAN | The Tampa Tribune Dec 31,2010

Sinkhole is 30 ft x 12 ft

Water levels dropped > 20 ft for 3 days

When temperatures dropped below-normal with freezing temperatures

Repairing Florida sinkholes are EXPENSIVE

Costs to repair Dry Wells

- SWFWMD reports costs can range from $1,000-$10,000 per incident
- Tampa Bay Waters costs are similar to repair dry wells

Process	Detailed Description	Average Cost ($)
Investigate Claim	Initial investigation to determine severity of the problem.	$1,000
Option 1: Repair well OR drill new well using complainant vendor	Repair or drill new well using complainant vendor	Repair Well- $5,000 New Well- $14,000
Option 2: Repair Well	Water company repairs or drills new well	$9,000
Well Completion	Final water quality tests to ensure water quality is to federal drinking water standards. Performed by independent consultant	$4,000

Alternative Frost-Freeze Protection

Freeze Cloth

- Estimated Cost for Cloth is $2,000-$2,400 per acre
- Average Labor Cost to apply $300 per acre
- In the Dover/Plant City Area Farmers pay 25% the rest is covered by SWFWMD Facilitating Agricultural Resource Management Systems (FARMS) program

Objectives

1. Analyze how frost-freeze events affected West Central Florida over the past 25 years.

2. Understand the relationship between sinkhole/drywell complaints to a variety of factors (minimum temperatures, ground water level and proximity to strawberry farms).

3. Examine the use of alternative methods through an economic impact analysis

Data Sources

Dataset	Publisher/Source	Published	Data Type	Shape	Measure	Time Component
NOAA Temperature Data	National Oceanic and Atmospheric Administration	2010	Vector	Point	F°-Daily Minimum Temperature	Yes
Sinkhole Location	Florida Geologic Survey	2010	Vector	Point	N/A	Yes/No
Strawberry Farms	SWFWMD	2010	Vector	Polygon	N/A	No
Water Use Permits	Southwest Florida Water Management District	2010	Vector	Point	Maximum Daily Permitted Flow Gallons/Day	No
Floridan Aquifer Monitor Sites	Tampa Bay Water	2010	Vector	Point	Daily Average	Yes/No
Well Complaints	Tampa Bay Water	2010	CSV	Table	Daily Average	Yes/No
SWFWMD 2010 Aerial Photos	Tampa Bay Water	2010	Vector	Point	N/A	Yes
	Southwest Florida Water Management District	2010	Raster	N/A	N/A	No

What Defines a frost freeze event?

- Frost freeze event will be defined when temperature < 32 ° F (0 ° C)

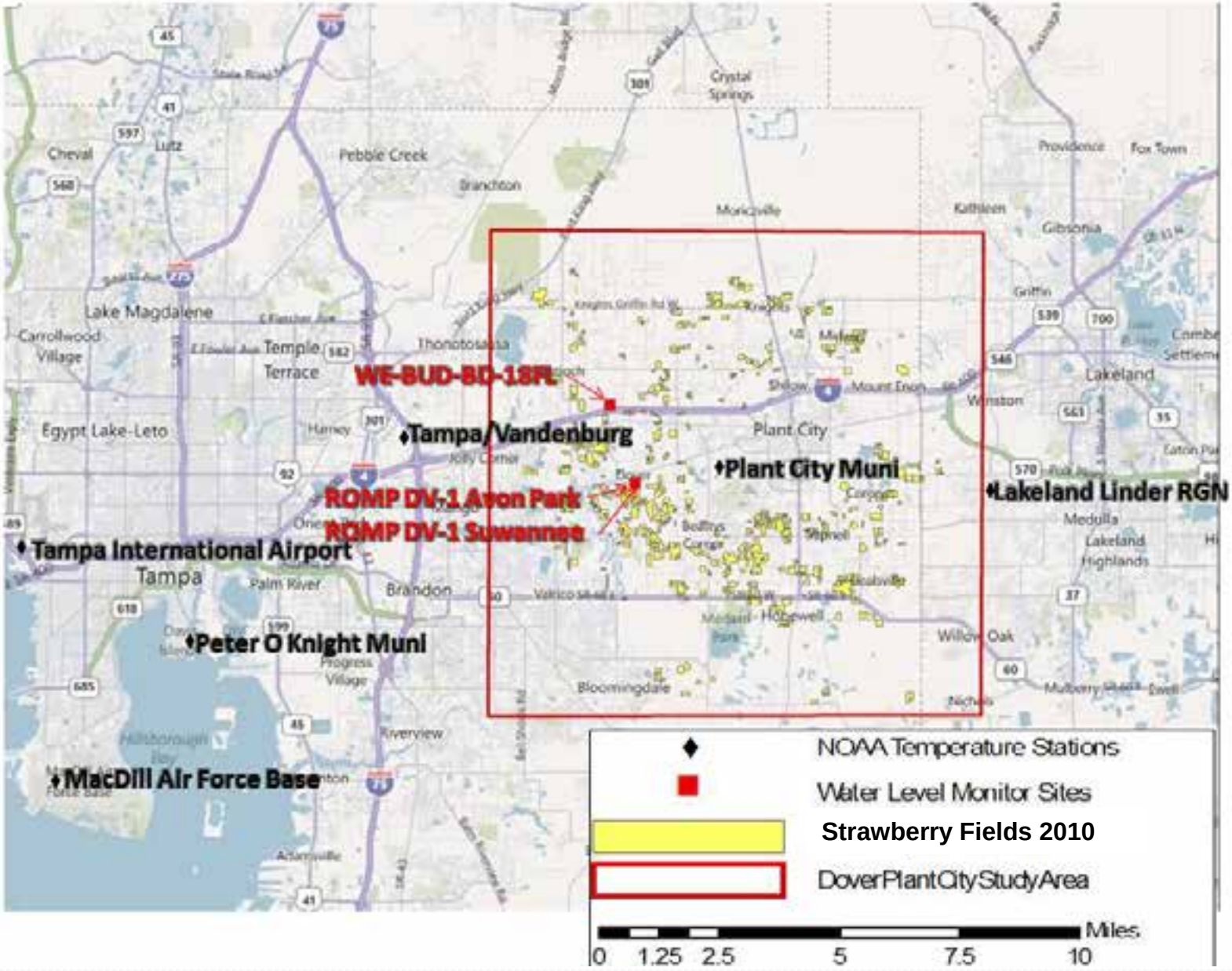
Floral/Fruit Stage Strawberry	Temperature at which Damage Occurs (F)
Tight bud	22°F or -5.5°C *
Tight with white petals or immature fruit	28°F or -2.2°C*
Full bloom	31°F or -0.5°C*
Strawberry	32°F or 0°C

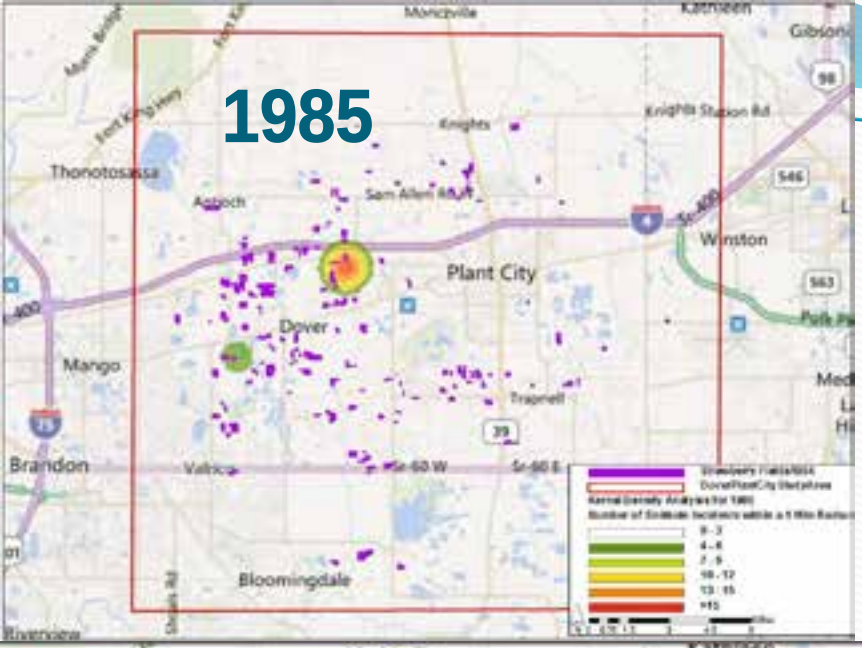
Analysis

- Spatial and temporal analysis
  - Occurrence of sinkholes and dry well complaints over 25 years
  - Occurrence of sinkholes and dry well complaints during two frost-freeze events (1985 and 2010) and a non frost-freeze year (2007)

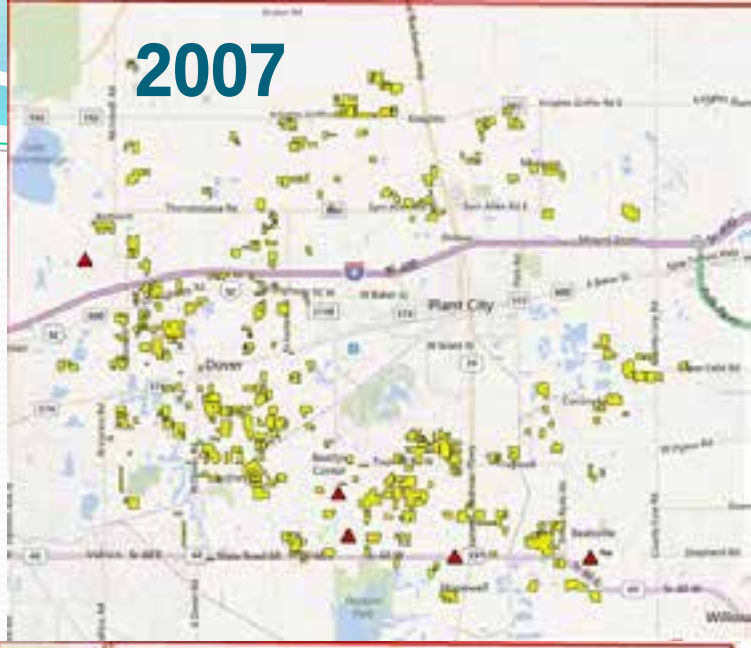
- Hot Spot Analysis
- Exploratory Regression Analysis

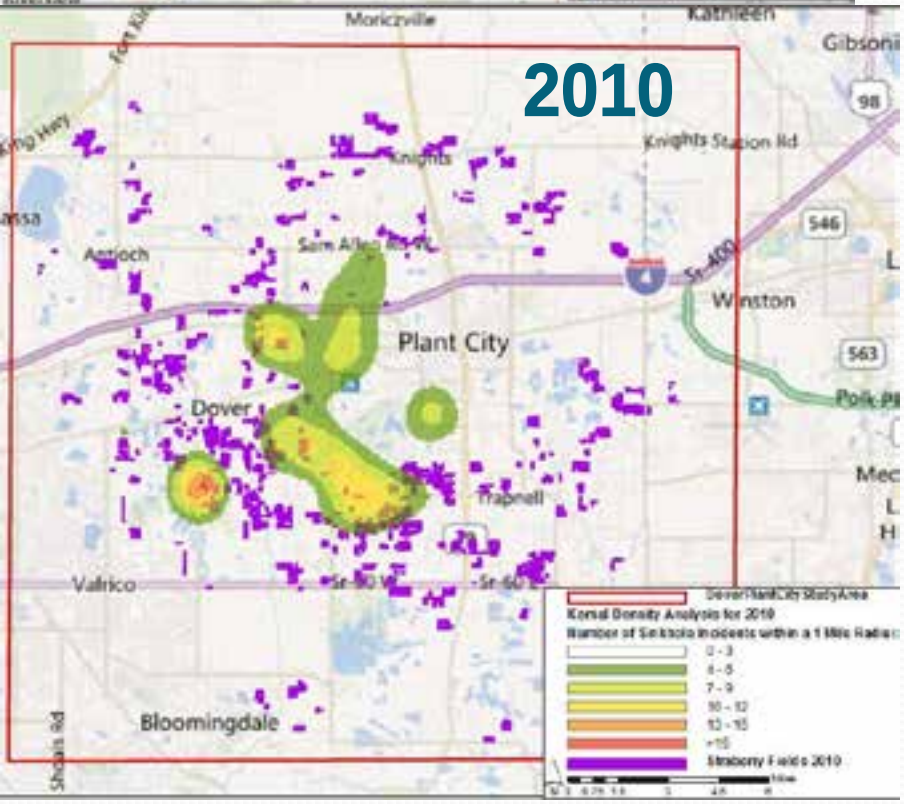
NOAA Temperature Stations and Water Level Monitor Site

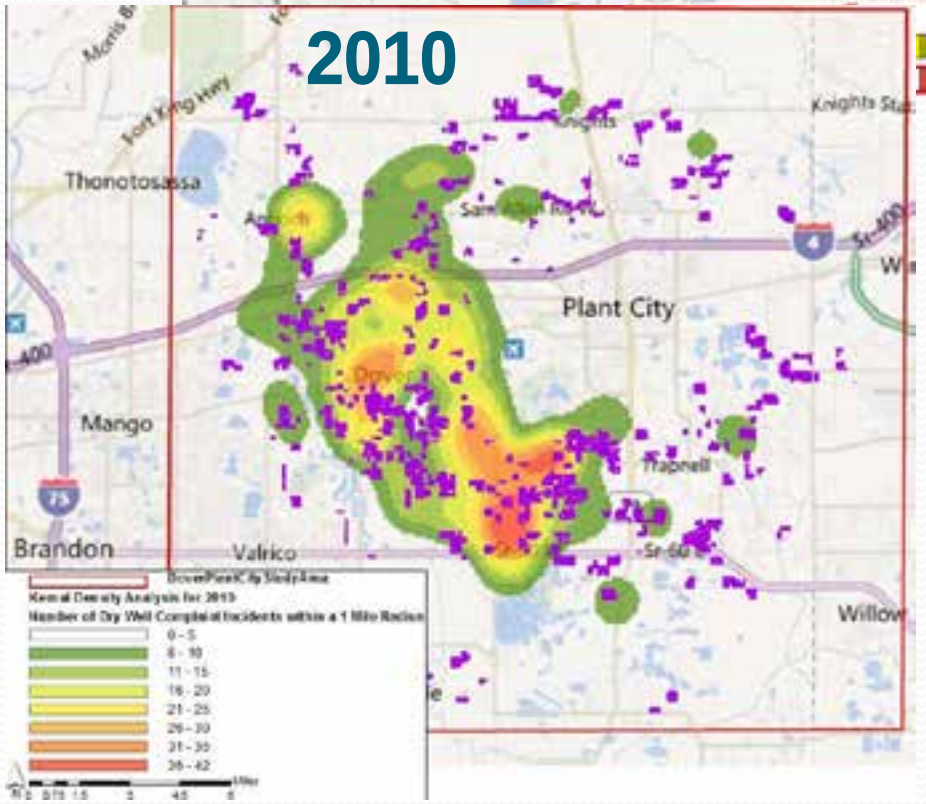



1985
Thonotosassa
Knights
Knights Station Rd
Sam Allen Rd
Antioch
Winston
Plant City
Dover
Mango
Trapnell
Brandon
Valrico
Bloomingdale
Moriczville
Kathleen
Gibsonia

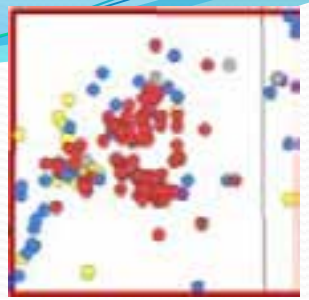
25 year span

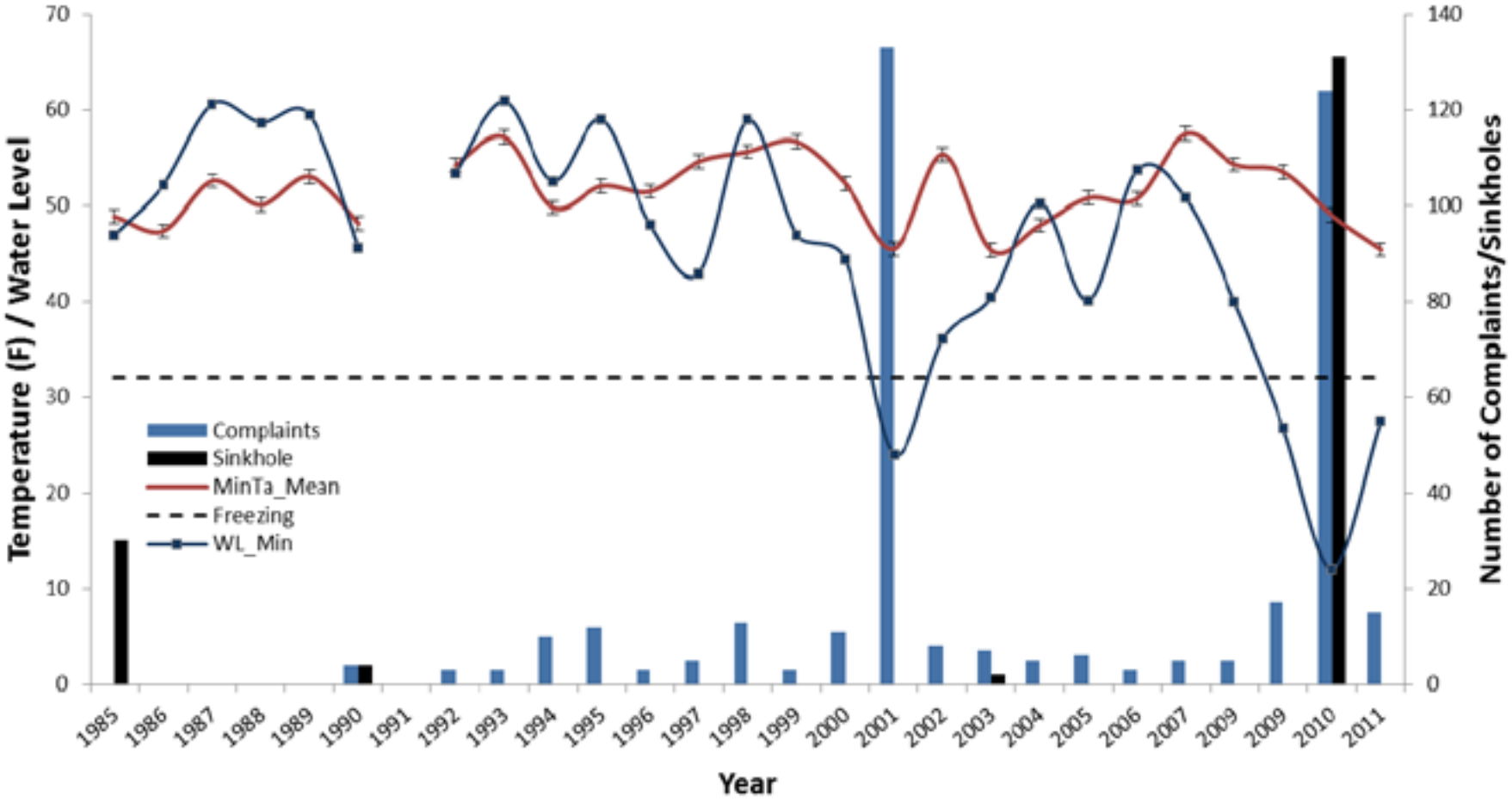

2007
Plant City
Dover


2010
Moriczville
Kathleen
Knights
Knights Station Rd
Sam Allen Rd
Antioch
Winston
Plant City
Dover
Trapnell
Valrico
Bloomingdale
Shoals Rd
Kernal Density Analysis for 2010
Number of Sinkhole incidents within a 1 Mile Radius
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
>15
Strabony Fields 2010

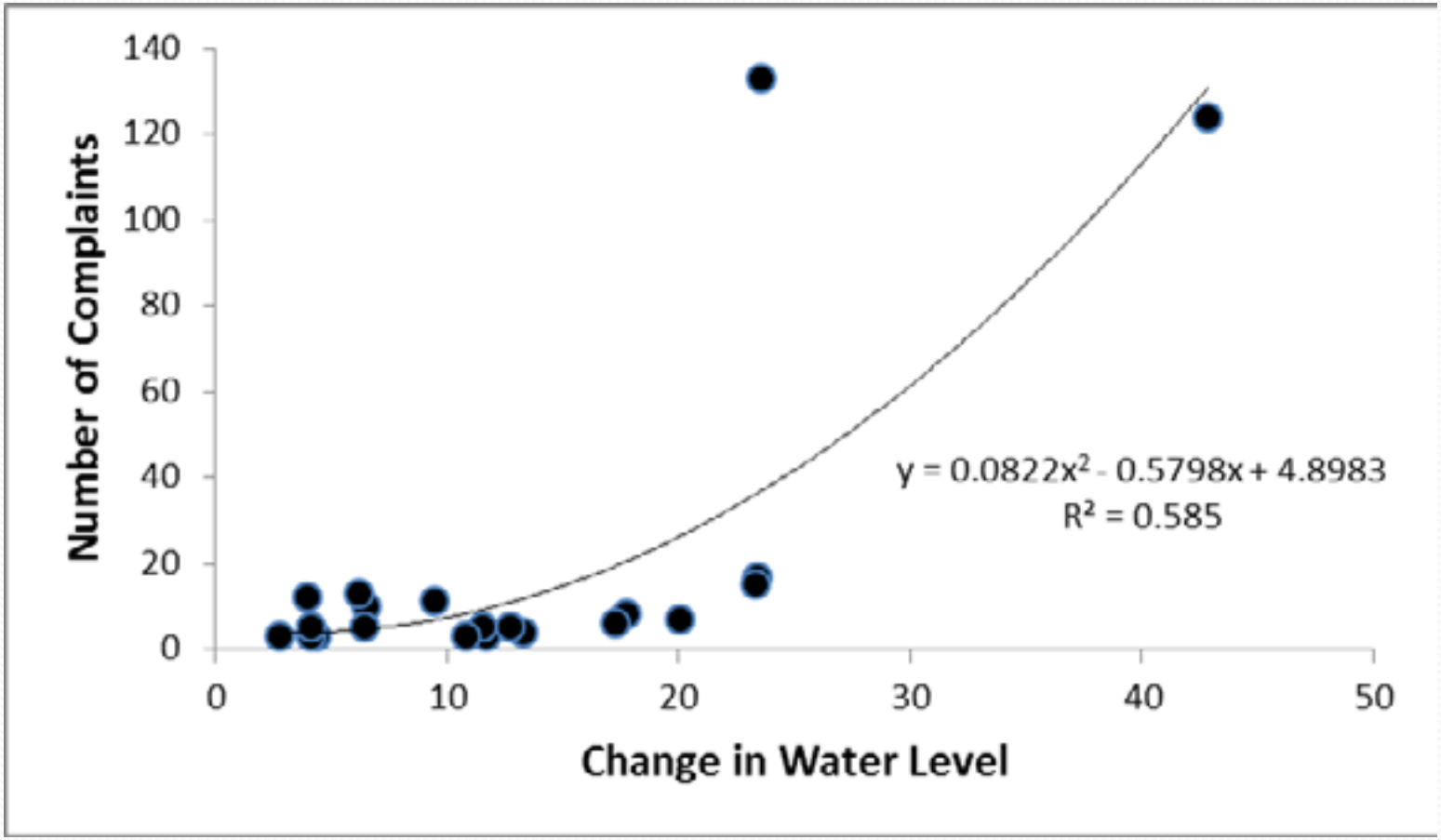

2010
Thonotosassa
Knights
Sam Allen Rd
Plant City
Mango
Trapnell
Brandon
Valrico
Willow
Kernal Density Analysis for 2010
Number of Dry Well Complaint Incidents within a 1 Mile Radius
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 30
31 - 35
36 - 42

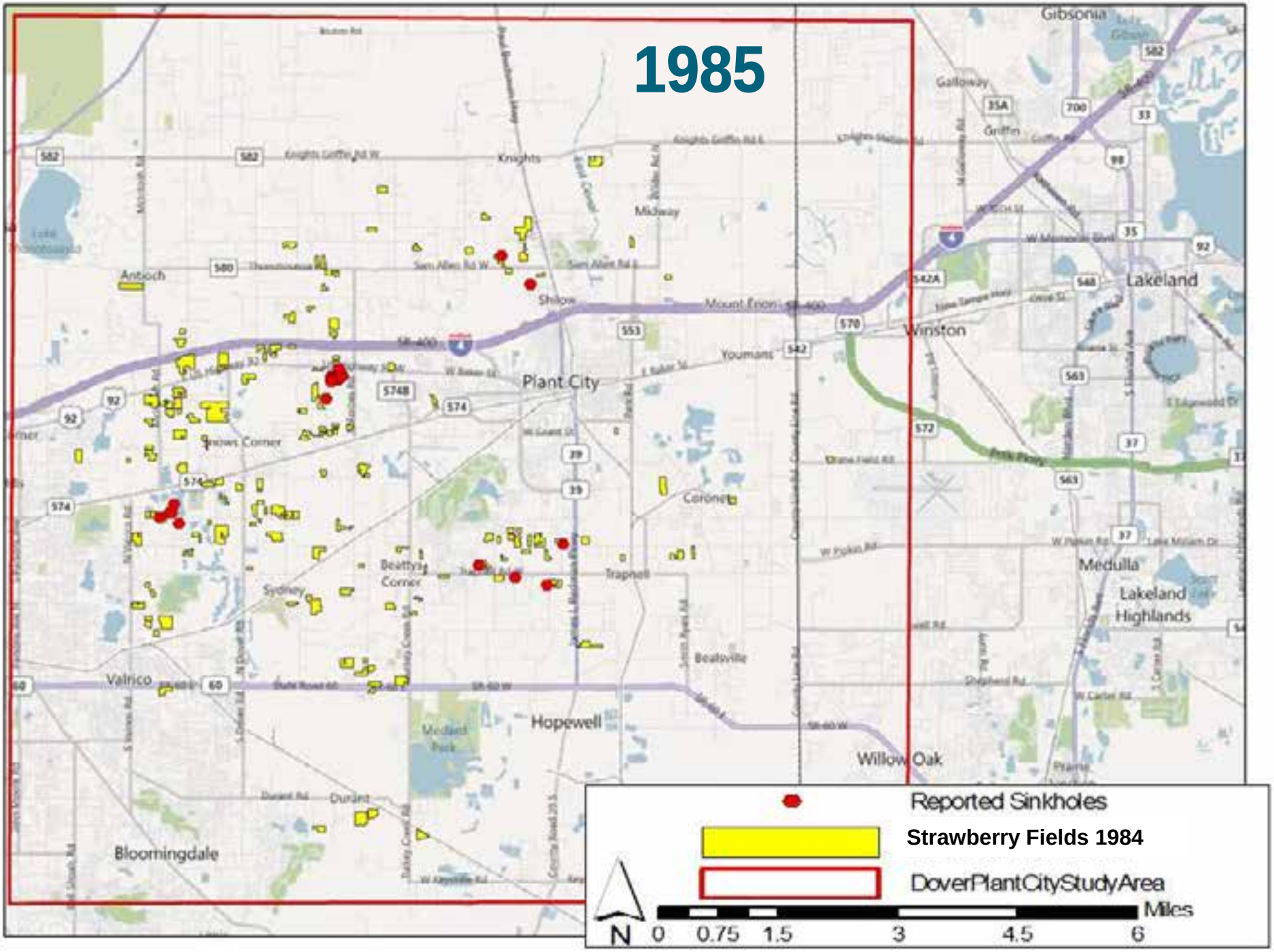
Sinkholes and Dry Well Complaints 1985 - 2010



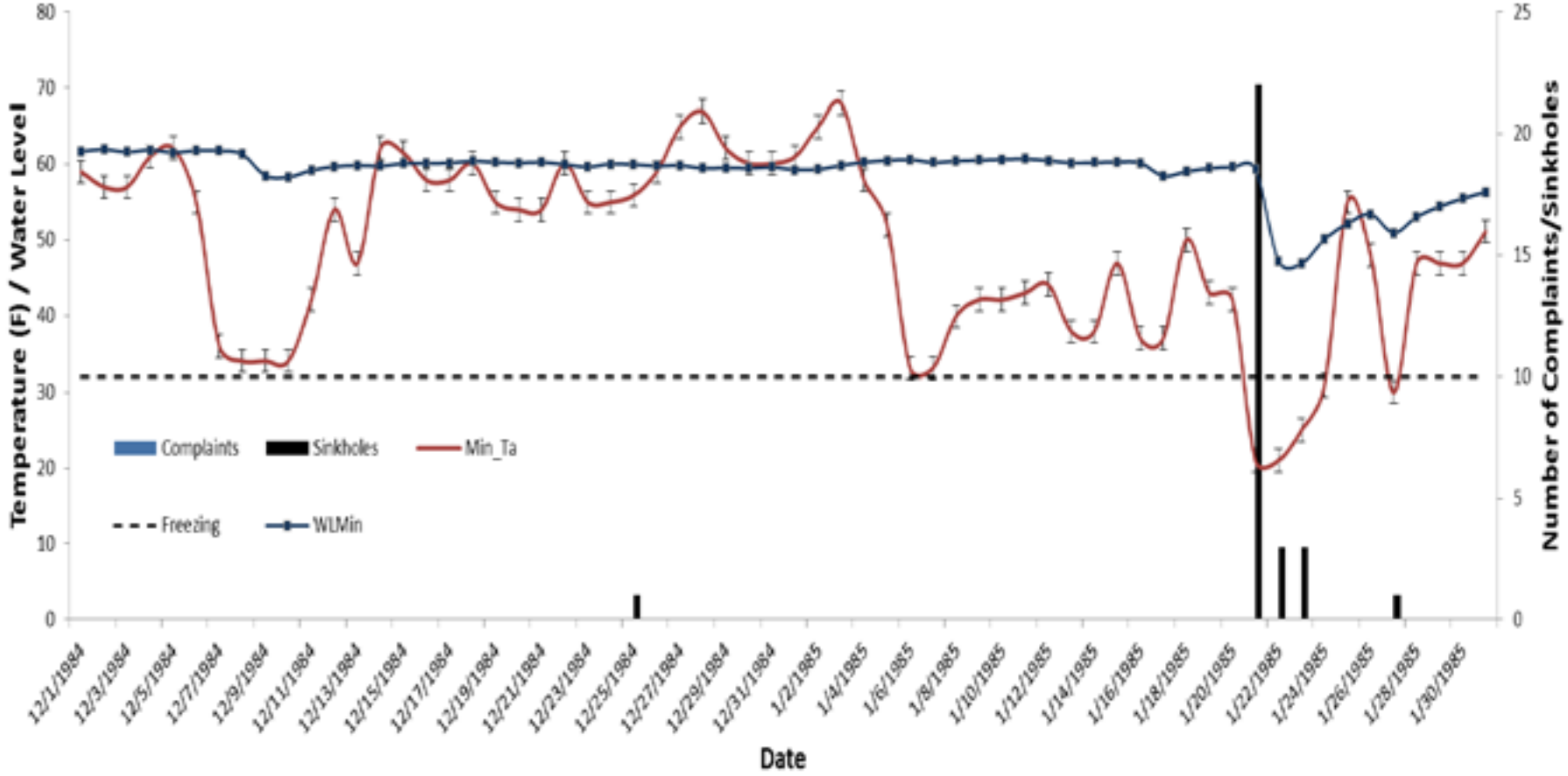


Sinkholes and Dry Well Complaints Relationship to Water Level Change 1985 - 2010




1985
Gibsonia
Galloway
Griffin
Knights
Midway
Antioch
Shiloh
Mount Enon
Youmans
Winston
Lakeland
Plant City
Snows Corner
Corona
Beatty's Corner
Traphell
Sydney
Medulla
Lakeland Highlands
Valrico
Beatsville
Hopewell
Willow Oak
Bloomingdale
Durant
Reported Sinkholes
Strawberry Fields 1984
DoverPlantCityStudyArea
Miles
N
0
0.75
1.5
3
4.5
6

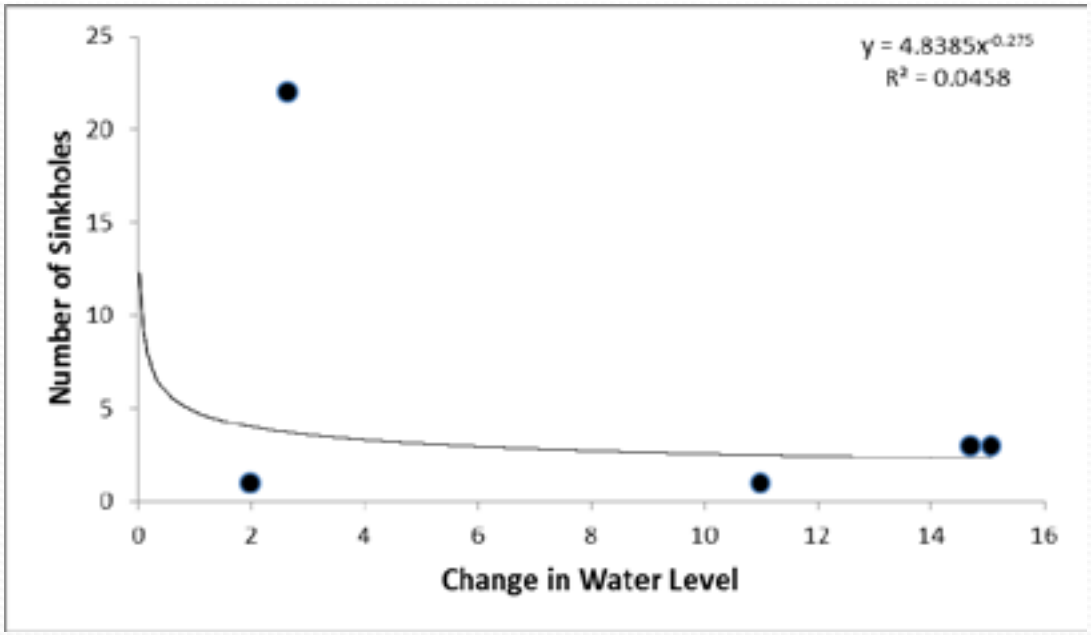
Drop in Water Levels during a Frost-Freeze Event, 1985

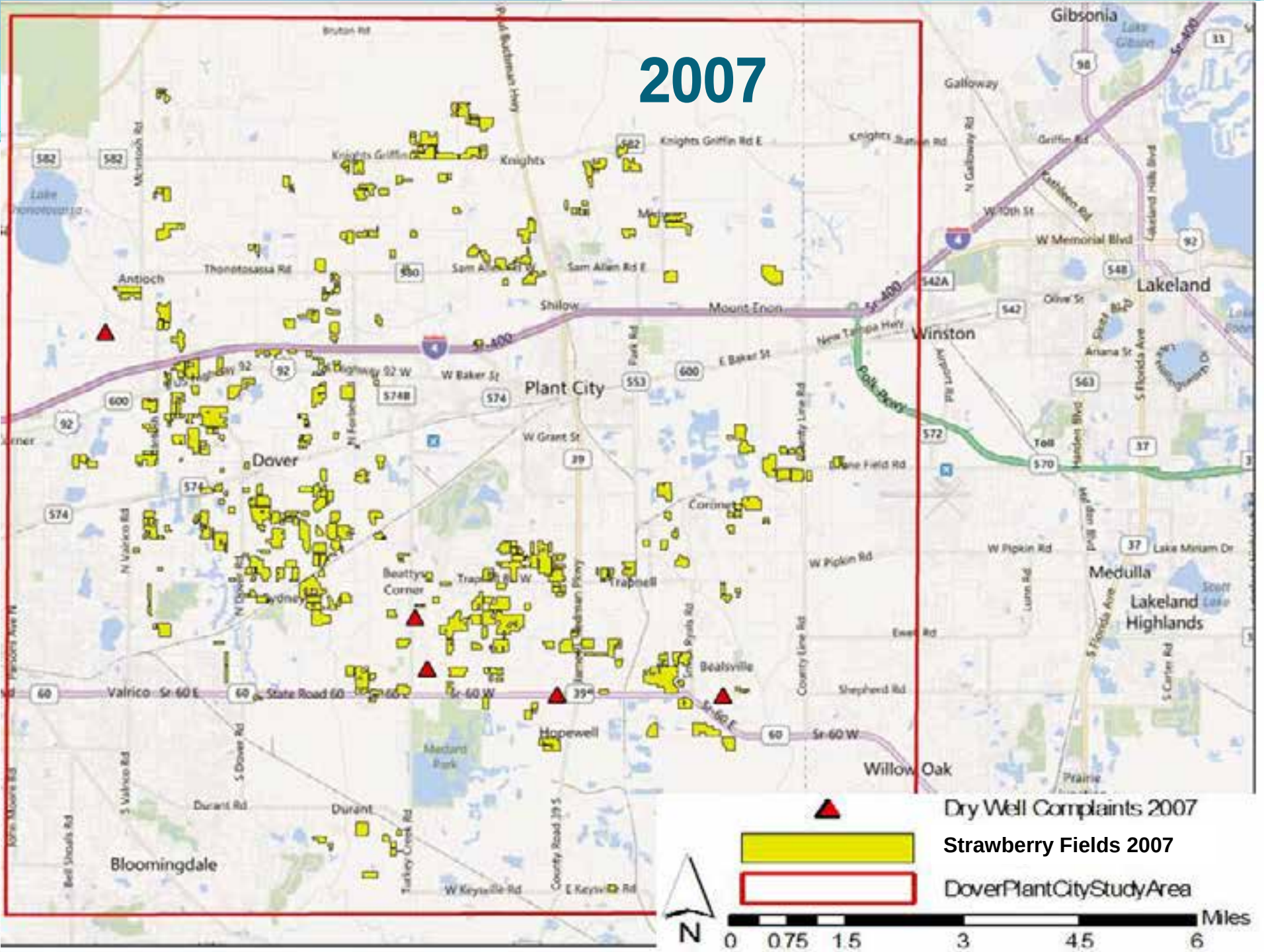


Statistical Correlation between Minimum Temperature and Water Level Change for Sinkholes & Dry Well Complaints during a frost-freeze event, 1985

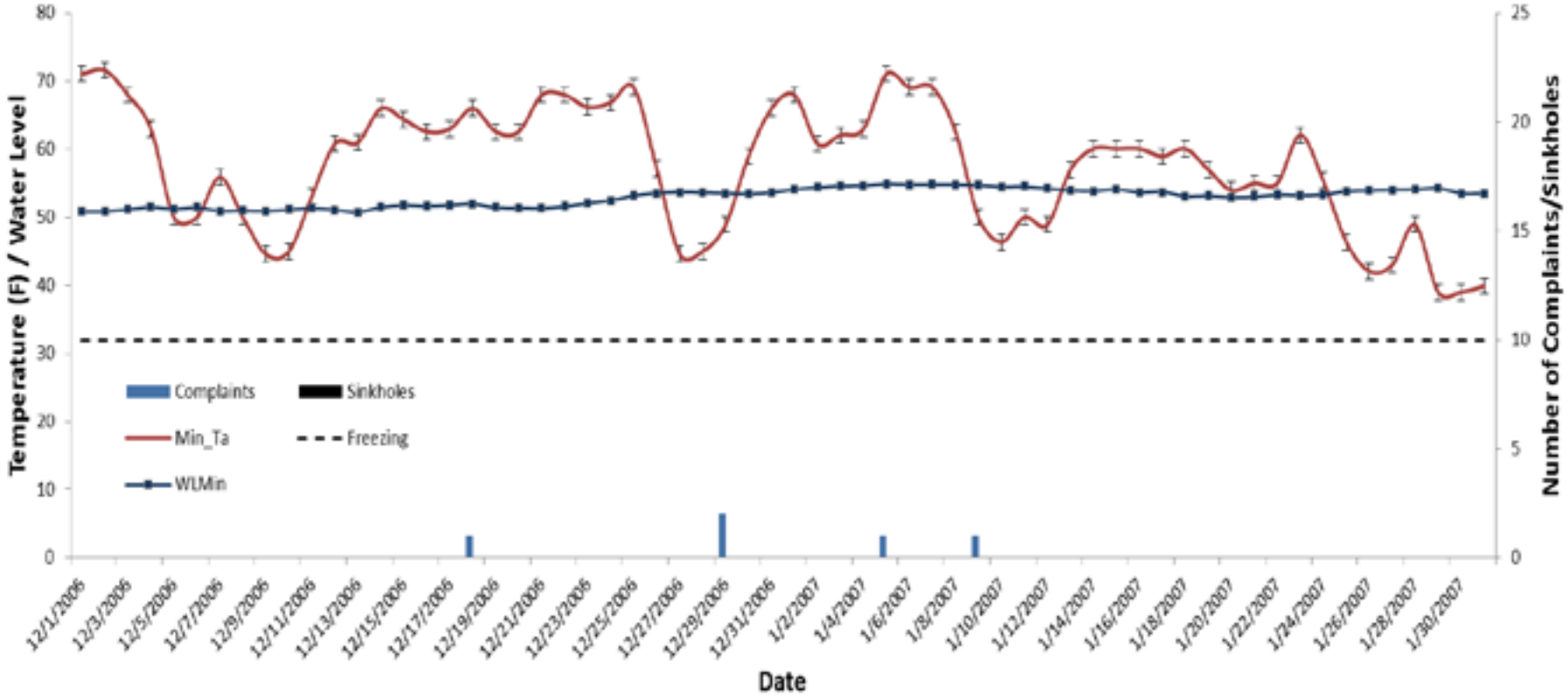
No Correlation

Change in Water Level
(n=5, r= 0.276, $P < 0.05$)




2007
Gibsonia
Galloway
Knights
Knights Griffin Rd E
Antioch
Thonotosassa Rd
Sam Allen Rd E
Shiloh
Mount Enon
Sr 400
Lakeland
Winston
W Memorial Blvd
W Baker St
Plant City
E Baker St
W Grant St
Dover
Corinth
Beatty's Corner
Trapnell
Bealsville
Valrico
State Road 60
Sr 60 W
Hopewell
Willow Oak
Medulla
Lakeland Highlands
W Pipkin Rd
Shepherd Rd
Durant Rd
Durant
Bloomingdale
Dry Well Complaints 2007
Strawberry Fields 2007
DoverPlantCityStudyArea
N
Miles
0 0.75 1.5 3 4.5 6

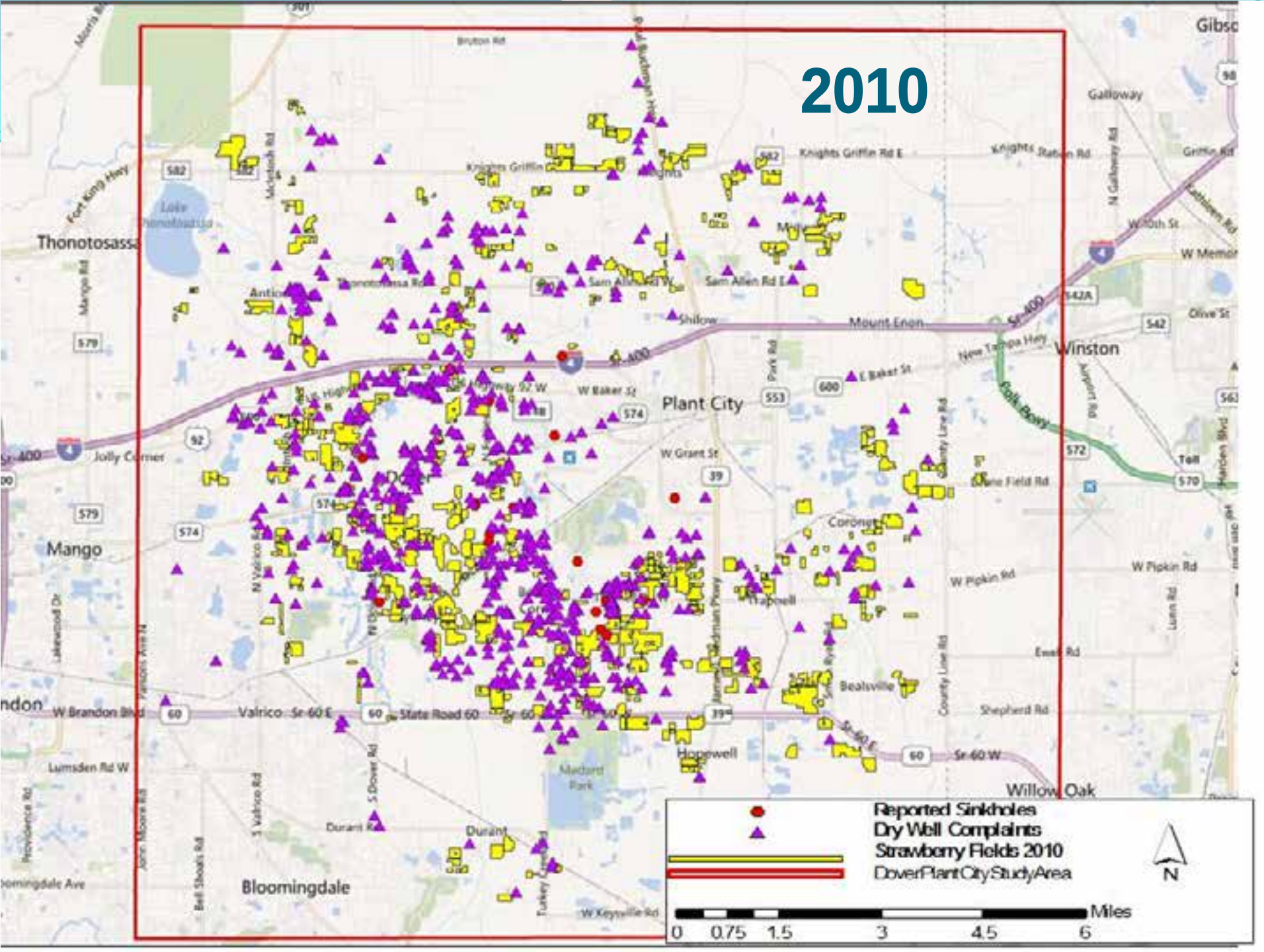
Drop in Water Levels during a Non-Frost-Freeze Event, 2007



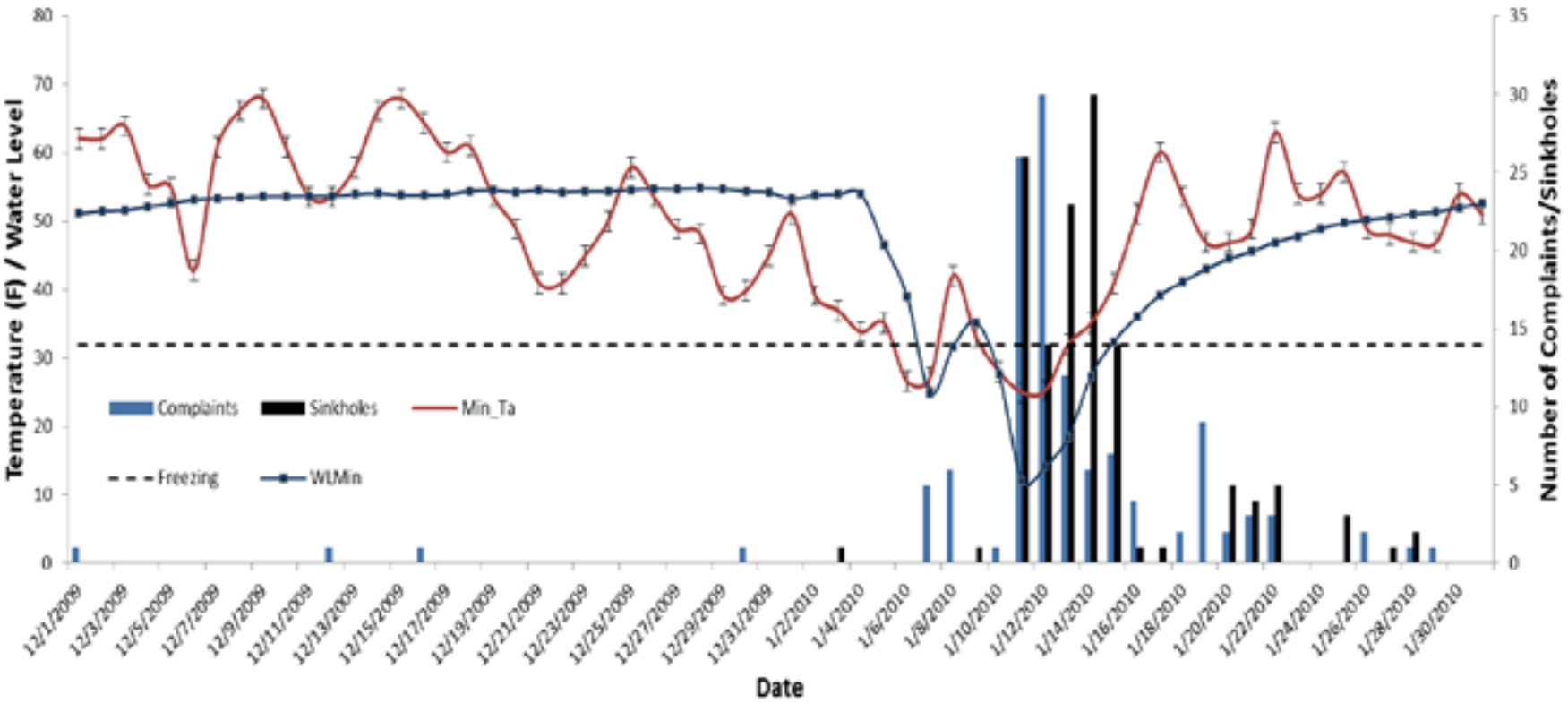
No Correlation

Change in Water Level
(n=5, r= 0.276, $P < 0.05$)

Minimum Temperature
(n=45, r= 0.110, $P < 0.05$).


2010
Reported Sinkholes
Dry Well Complaints
Strawberry Fields 2010
DoverPlantCityStudyArea
N
Miles
0 0.75 1.5 3 4.5 6
Thonotosassa
Mango
Plant City
Winston
Bloomingdale
Willow Oak
Mount Enon
Sr 400
Valrico Sr 60 E
State Road 60
Sr 60 W
Knights Griffin Rd E
Sam Allen Rd E
W Baker St
W Grant St
W Pipkin Rd
Durant
Hopewell
Bealsville
Shepard Rd
Lumsden Rd W
W Brandon Blvd
Galloway
Olive St
Fort King Hwy
Jolly Corner

Drop in water levels during a frost-freeze event, 2010



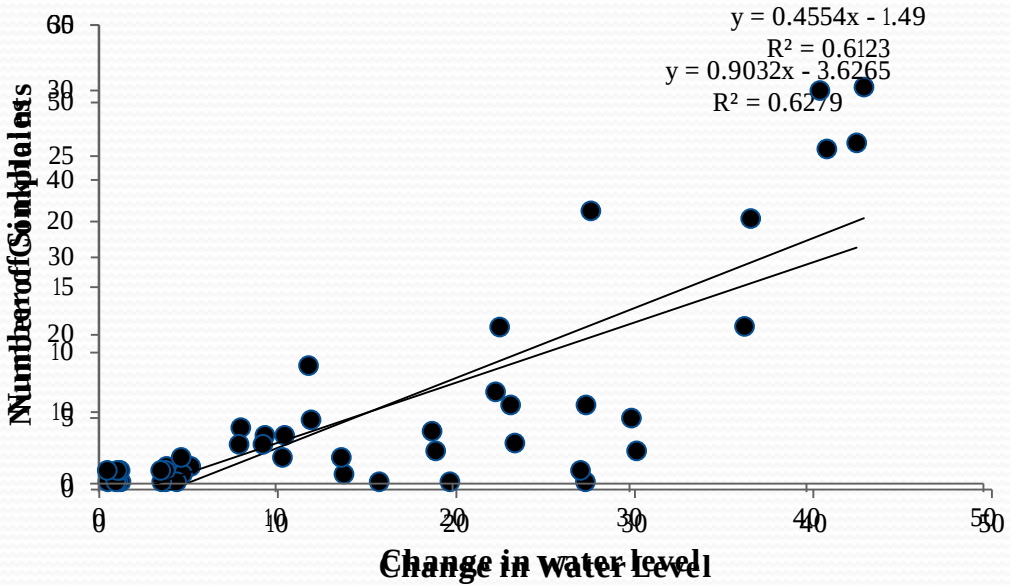
Statistical Correlation between Minimum Temperature and Water Level Change for Sinkholes & Dry Well Complaints water levels during a frost-freeze event, 2010

Correlation between change in water level

Change in Water Level

Sinkhole: (n=15, r= 0.791, P > 0.05).

Dry Well Complaints: (n=22, r= 0.783, P > 0.05).



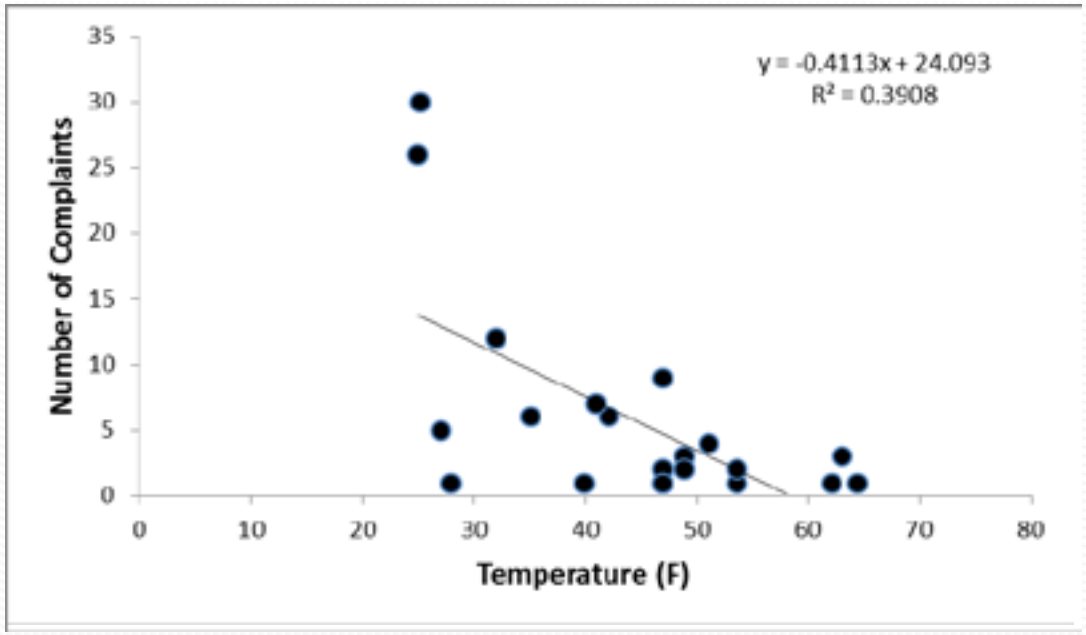
Statistical Correlation between Minimum Temperature and Water Level Change for Sinkholes & Dry Well Complaints water levels during a frost-freeze event, 2010

Correlation between Minimum Temperature

Minimum Temperature

Sinkhole: (n=15, r= 0.632, P > 0.05).

Dry Well Complaints: (n=22, r= 0.625, P > 0.05).



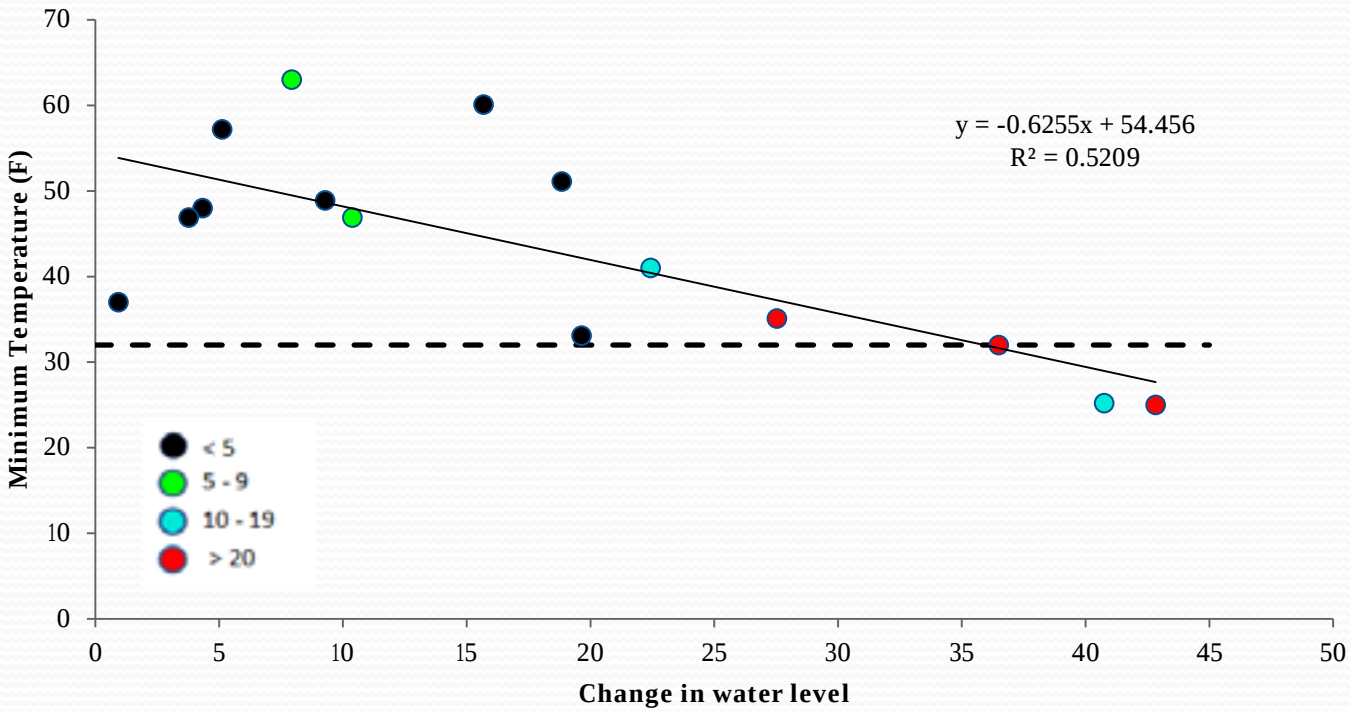
Statistical Correlation between Minimum Temperature and Water Level Change for Sinkholes & Dry Well Complaints water levels during a frost-freeze event, 2010

Correlation between minimum temperature & change in water level

Minimum Temperature & Water Level Change

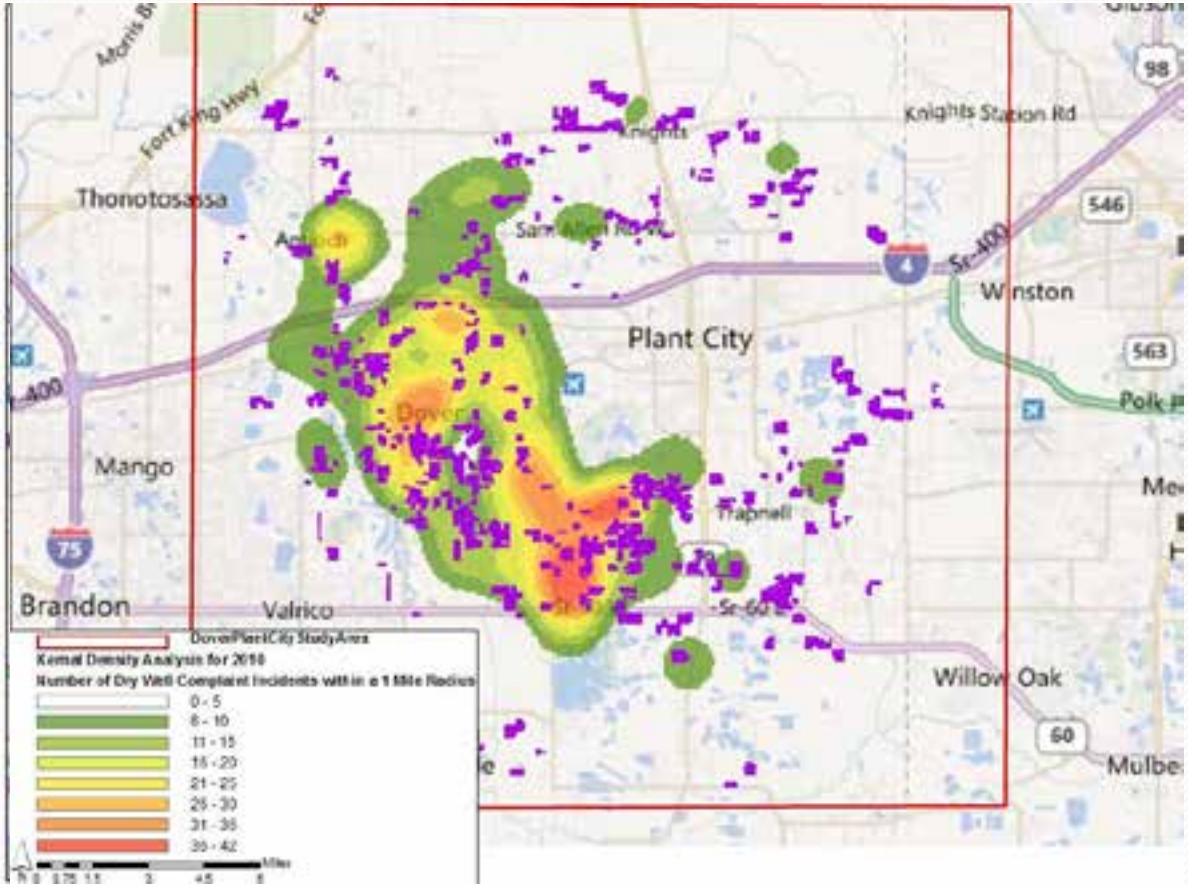
Sinkhole: (n=15, r= 0.721, P > 0.05).

Dry Well Complaints: (n=22, r= 0.823, P > 0.05).



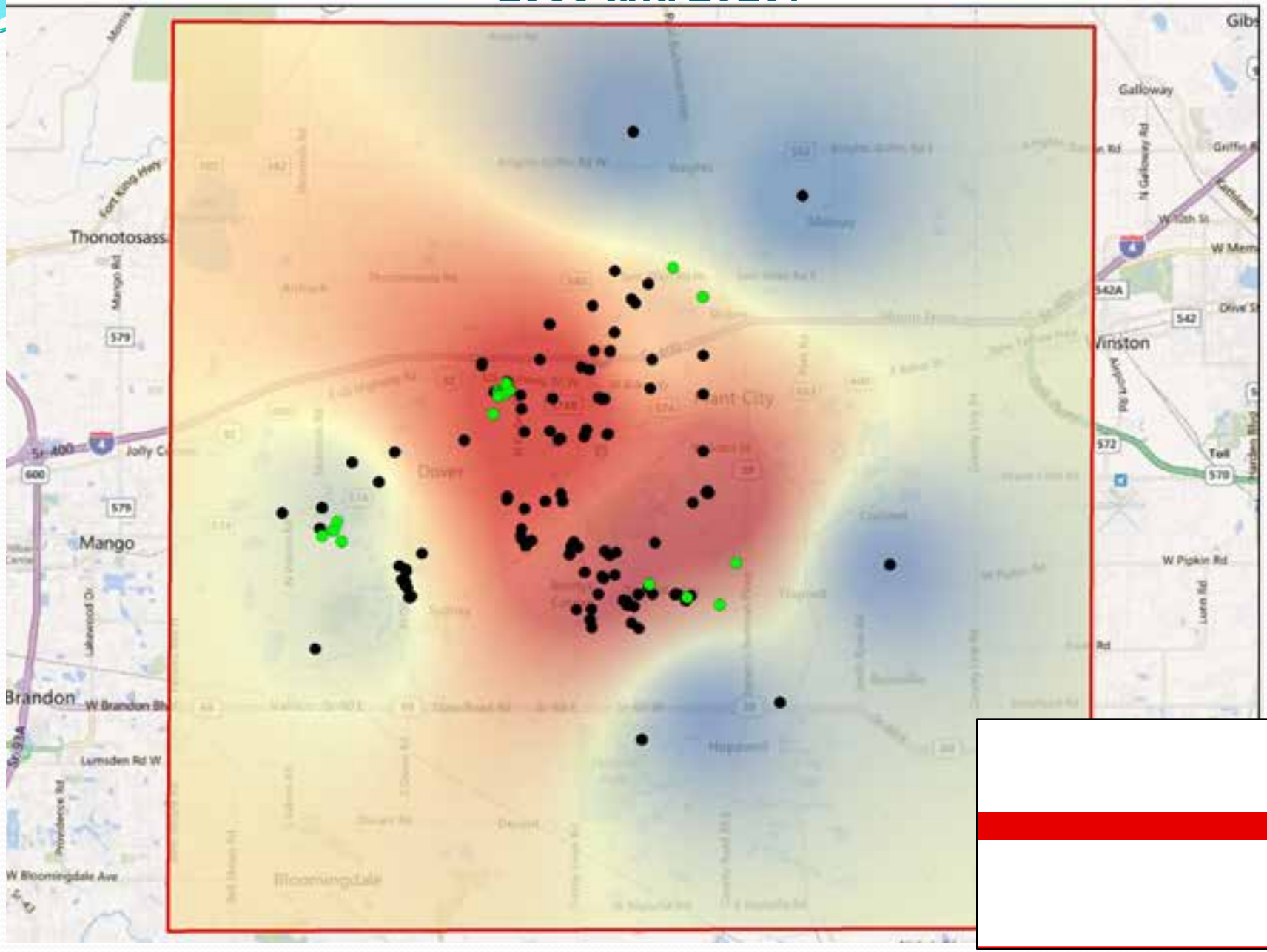
Spatial Analysis of the 1985 and 2010 Frost Freeze Events

Clustering of Sinkholes and Dry Well Complaints 1985, 2007, and 2010?

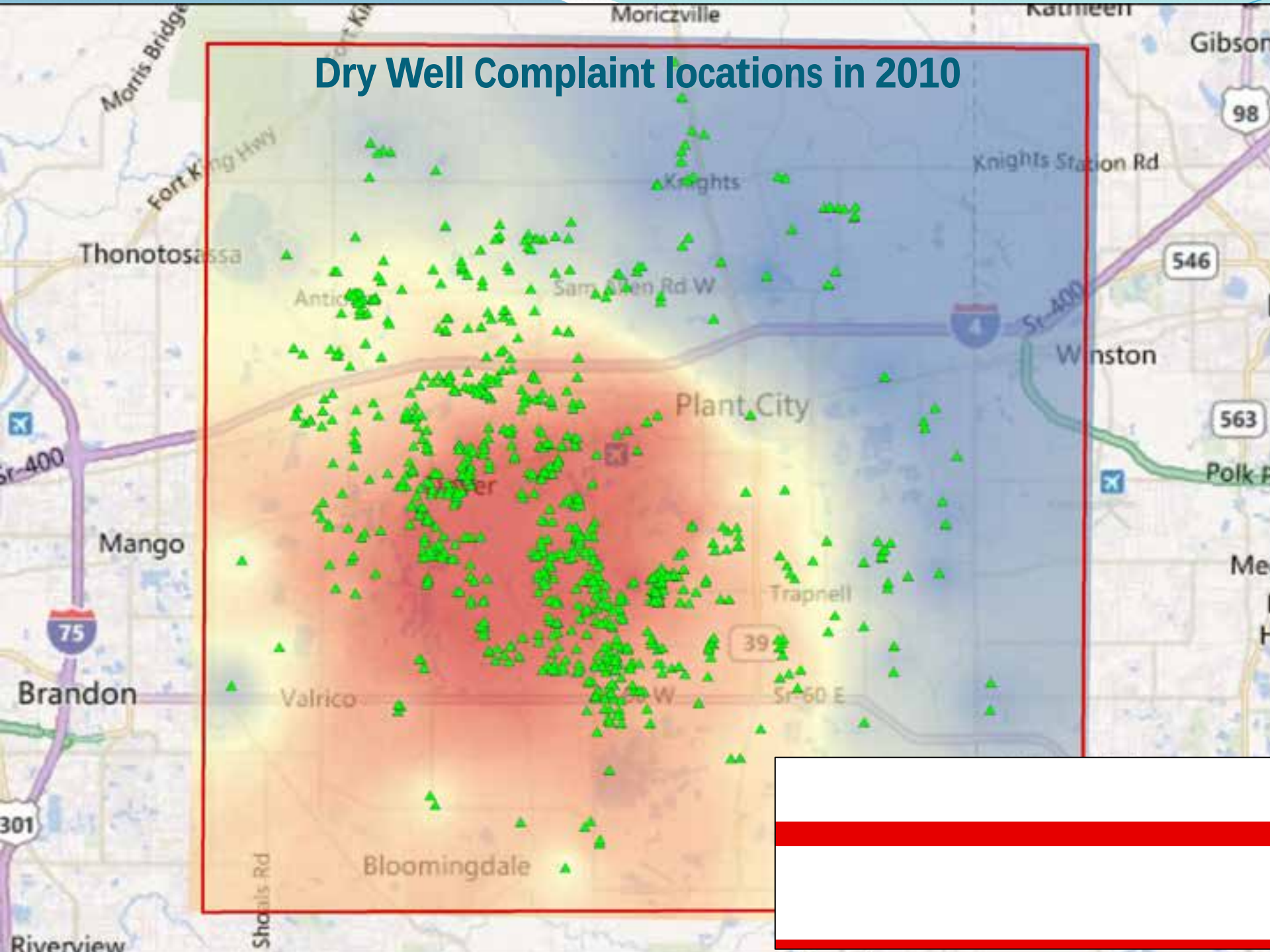


Average Nearest Neighbor							
Year	***Sinkhole***	***Observed Mean Distance***	***Expected Mean Distance***	***Nearest Neighbor Index***	***Z-Score***	***P-value***	
1985	30	253.875442	2362.907813	0.107442	-9.352506	0.000000	Clustered
2010	131	391.749768	1126.472101	0.0347767	-14.335758	0.000000	Clustered
Year	***Dry Well Complaints***	***Observed Mean Distance***	***Expected Mean Distance***	***Nearest Neighbor Index***	***Z-Score***	***P-value***	
2007	5	4730.326943	5787.918451	0.817276	-0.781648	0.433550	Random
2010	812	205.42	1490.73	0.137798	-47	0.000000	Clustered

Have sinkholes and dry wells occurred in the same areas in both 1985 and 2010?

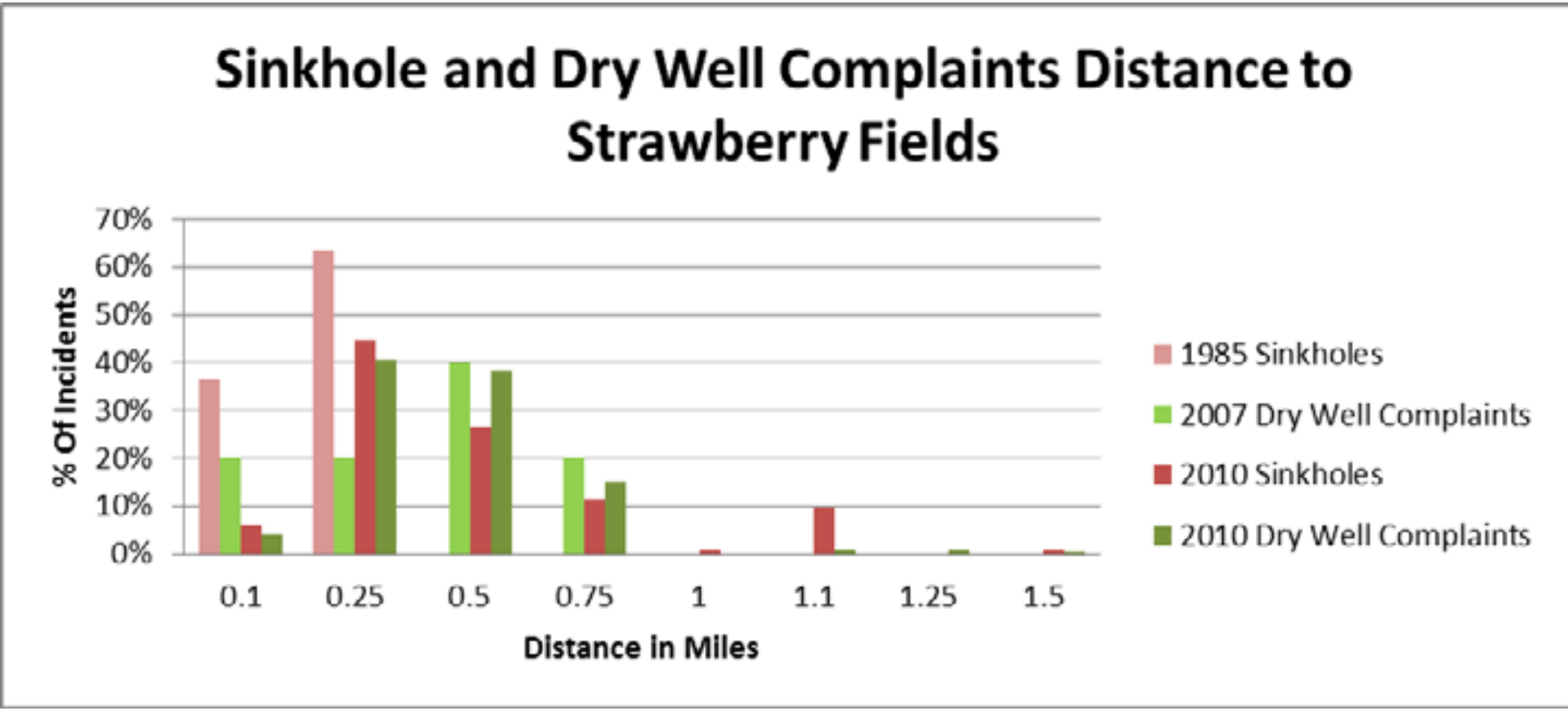


Dry Well Complaint locations in 2010

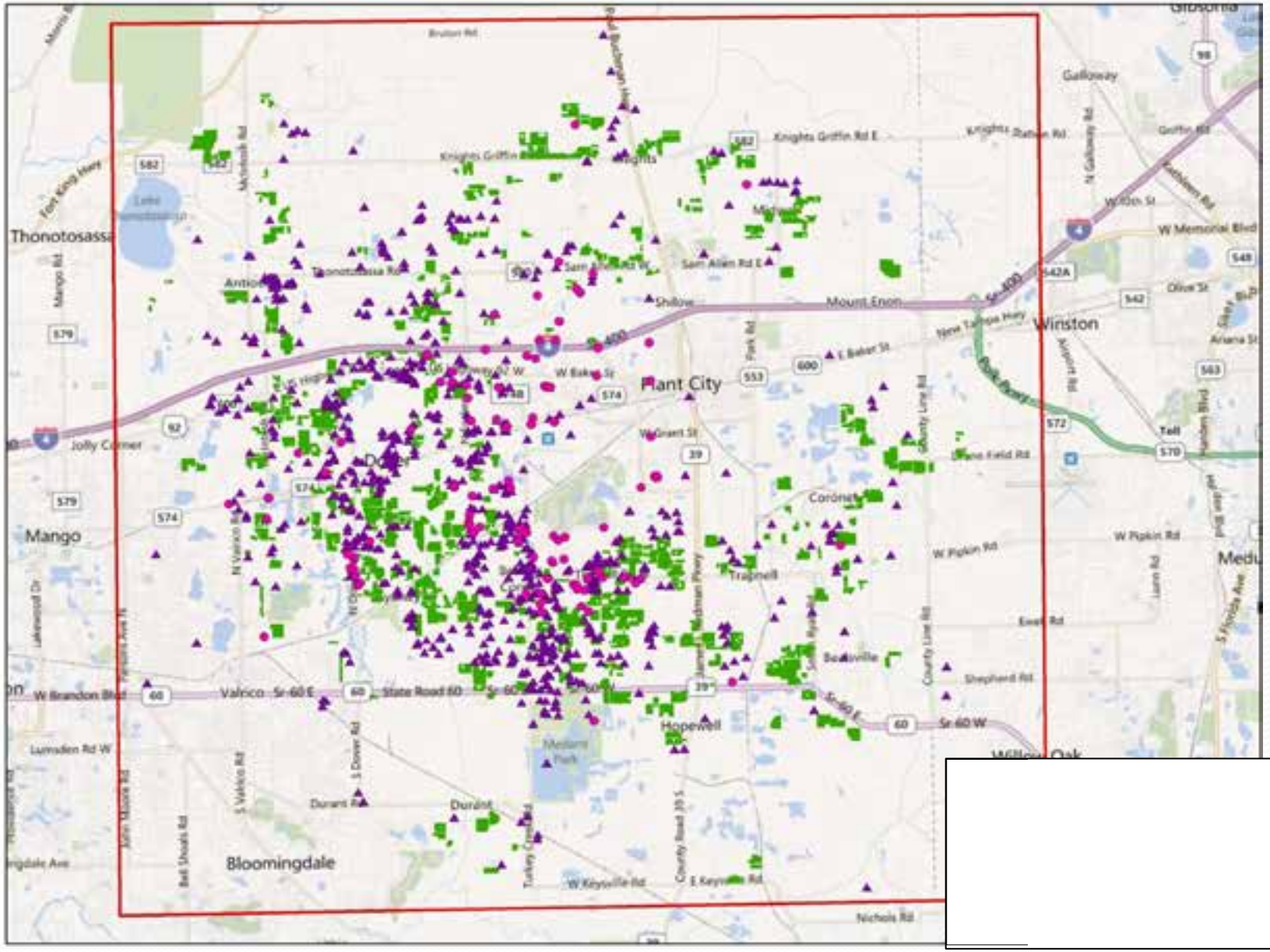


Spatial Regression Analysis

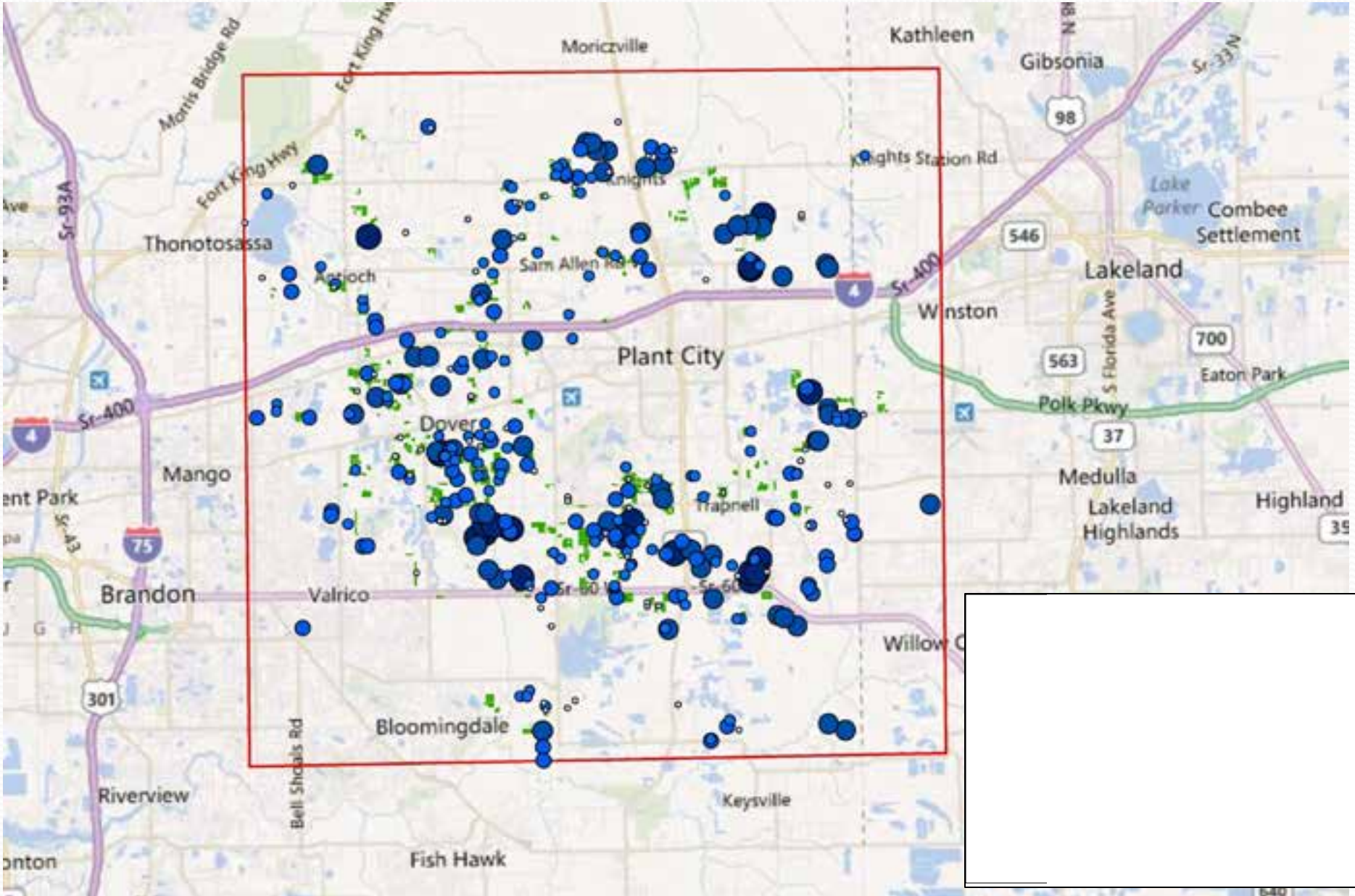
Understanding the relationship between sinkhole/drywell complaints to a variety of factors (minimum temperatures, ground water level and proximity to strawberry farms).


Sinkhole and Dry Well Complaints Distance to Strawberry Fields
% Of Incidents
70%
60%
50%
40%
30%
20%
10%
0%
0.1
0.25
0.5
0.75
1
1.1
1.25
1.5
Distance in Miles
1985 Sinkholes
2007 Dry Well Complaints
2010 Sinkholes
2010 Dry Well Complaints

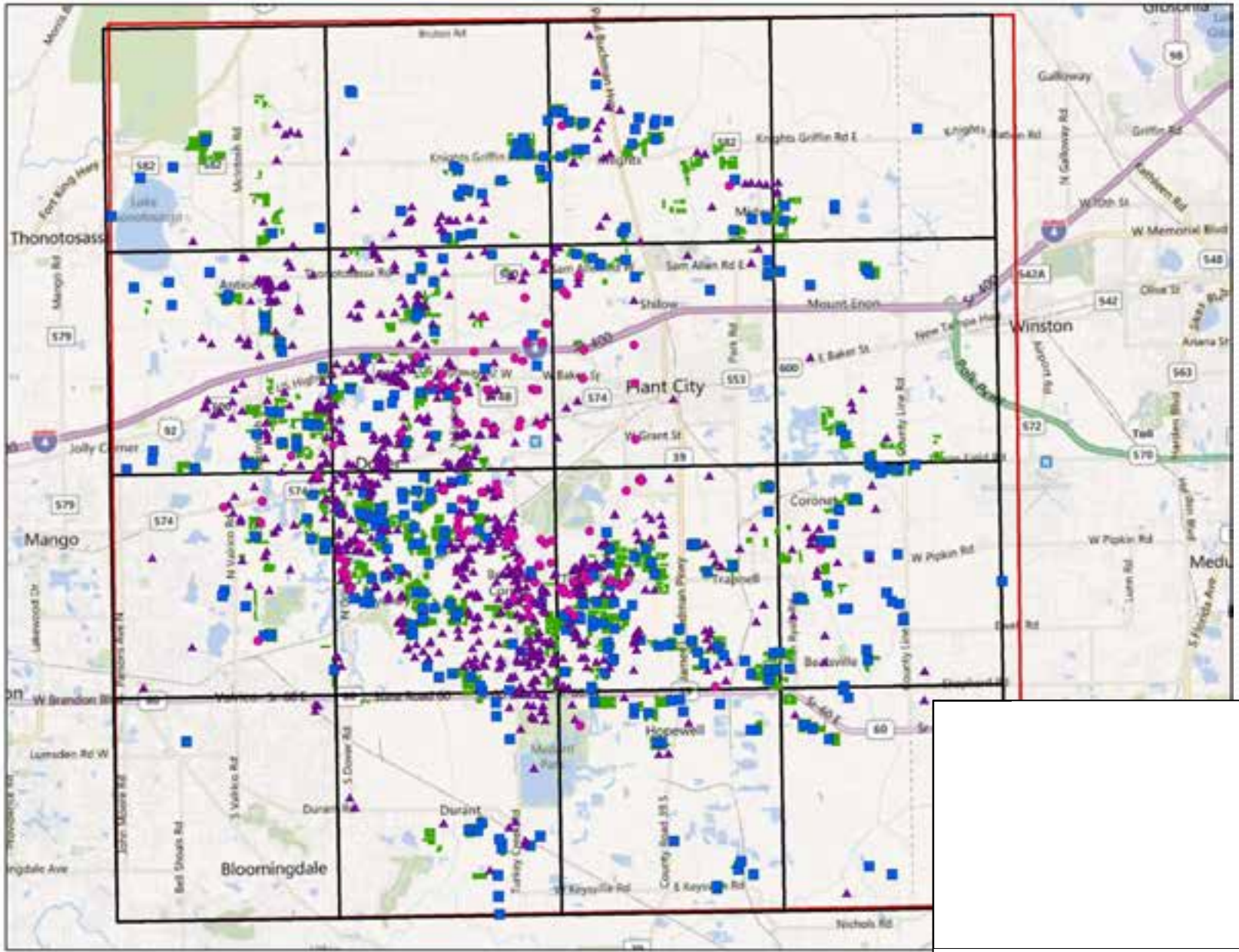
Locations of Sinkholes, Dry Well Complaints and Strawberry Fields in 2010



Water Use Permits Greater Than 1 MGPD in 2010



Exploratory Regression



Exploratory Regression Results

Measuring	Passing Models		Table Abbreviations
	Min Adjusted R-Squared > 0.50		*R2 Adjusted R-Squared*
	Max Coefficient p-value < 0.05		*AICc Akaike's Information Criterion*
	Max VIF Value < 7.50		*JB Jarque-Bera p-value*
	Min Jarque-Bera p-value > 0.10		*BP Koenker (BP) Statistic p-value*
	Min Moran's I p-value > 0.10		*VIF Max Variance Inflation Factor*
			MI Moran's I p-value
			Model Variable sign and significance
			** = 0.10, ** = 0.05, *** = 0.01*

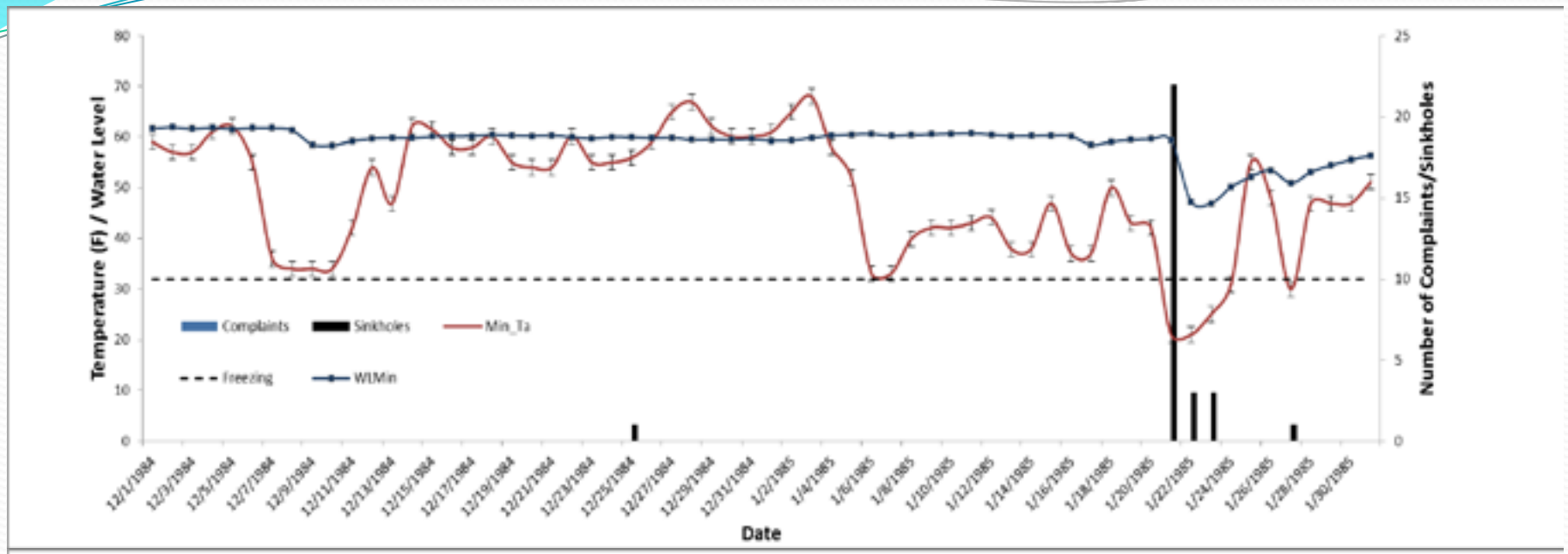
	R2	AICc	JB	BP	VIF	MI	Model
Sinkhole	0.718955	115.0596	0.695553	0.010191	1.849512	0.157826	-SHAVEDISTSF** +SUM_PERM_CROP_**
Dry Well Complaint	0.762637	161.155	0.847513	0.069014	1.53641	0.873654	-DWCAVEDISTSF** +SUM_PERM_CROP_**

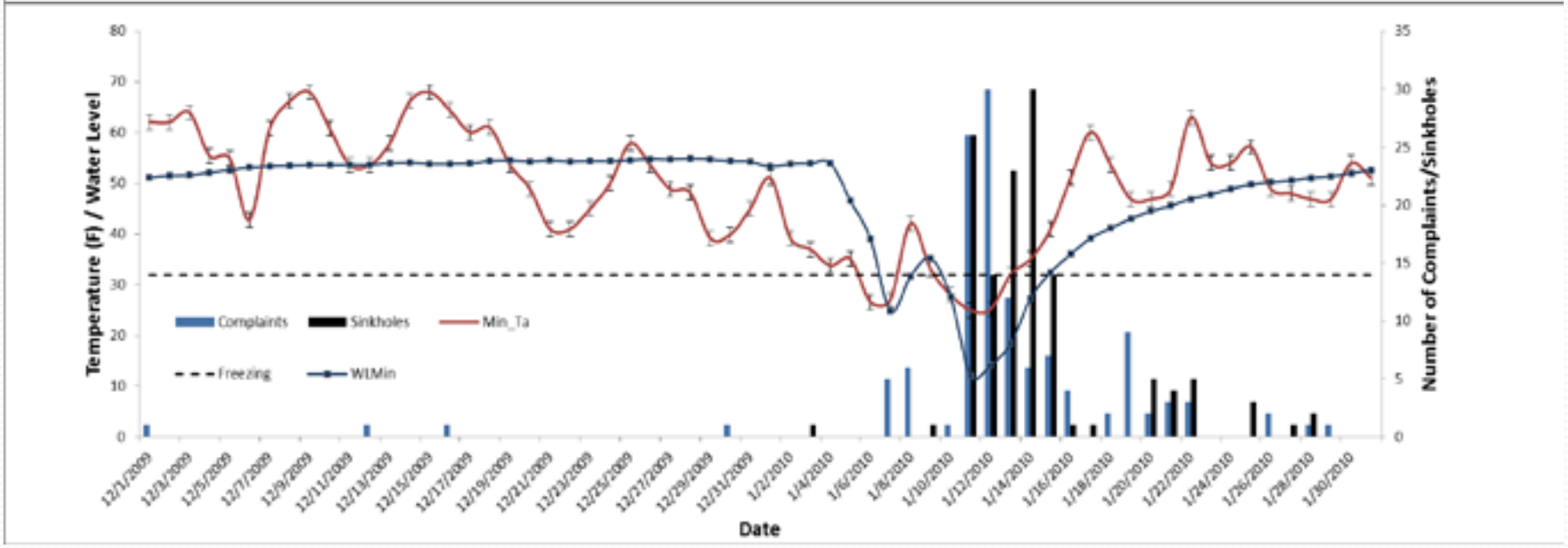
Indicates Model Significance * = 0.10, ** = 0.05, *** = 0.01

NOTE: ***Adjusted R2*** indicates model performance with higher values indicative of better performance, ***AICc*** (Corrected Akaike's Information Criterion) measures model fit with lower values indicative of better fit, the ***Koenker BP Statistic*** measures stationarity with significant p-value indicating non-stationarity, the ***Jarque-Bera Statistic*** assess the distribution of the model residuals with significant p-value indicating non-normal distribution, and ***Moran's Index*** measures spatial autocorrelation with significant p-value indicating non-random spatial distribution.

Time Series Animation of the Frost Freeze Event
January 1, 2010 to January 21, 2010

Comparison of frost-freeze events





Cost of pumping vs cost of using alternative control for 2010

- Cost of investigating and repairing dry wells
  - 2007- total cost was $12,859 (average $2571 per complaint)
  - 2010- total cost was $472,951 (average $2866 per complaint)
- Estimated cost of using the frost freeze cloth
  - Total Cost= $16.5 million ($39,000 per field)
  - FARMS subsides= Farmers pay $4.1 million ($9,750 per field)
  - Farmers pay 25% SWFWMD pays 75%

Conclusion

- **Summary of Findings**
  - A statistically significant correlation between minimum temperatures and change in water level (MinTa < 41 °F and WL Change > 20 ft, number of sinkholes increase (N > 10))
  - Sinkhole occurrence are spatially clustered
  - Dry well complaints are spatially clustered
  - Spatial regression analysis found that distance to strawberry fields and water use permits (total volume) influence development of sinkholes and dry well complaints.
- **Comparison to previous studies**
  - 25 year span, plus 3 individual years
  - Bengtsson (1989) study only analyzed single event in 1985

Conclusion

- **Future/Suggestions**
  - SWFWMDs Dover/Plant City Freeze Management Plan-2010
  - Suggestions and Recommendations from this study

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Robert Peterson

Sr. Professional Geologist

SWFWMD

Questions

Mark D. Aurit GISP
maurit@tampabaywater.org