Predicting Piping Potential Along Middle Mississippi River Levees

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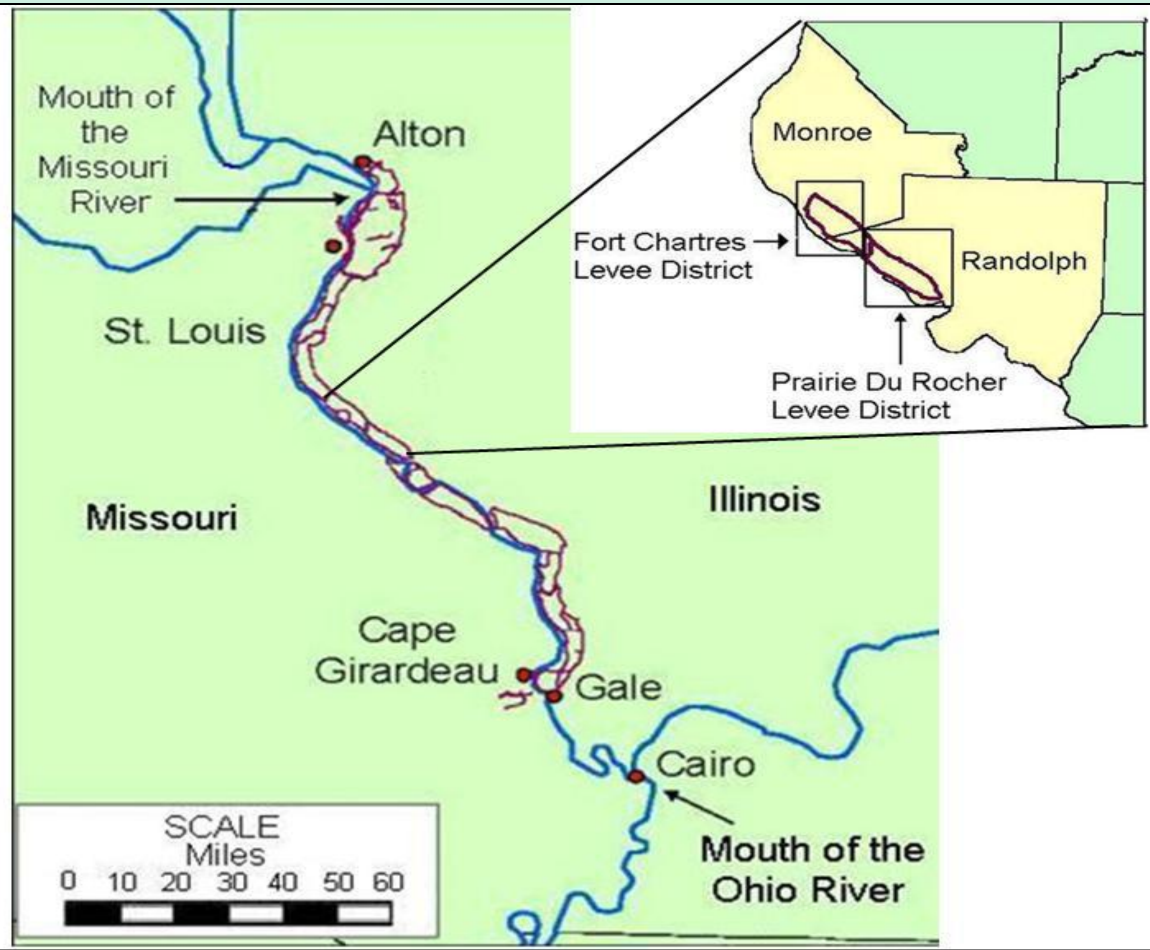
Study Areas:

PRAIRIE DU ROCHER: Developed the model for PDR
FORT CHARTRES: Tested the model on FTC

Middle Mississippi River Valley



Motivation for study of these two areas

- Observed more piping with each flood event in some systems
- Observed new piping developing at lower flood stages

Noted Increase in Piping

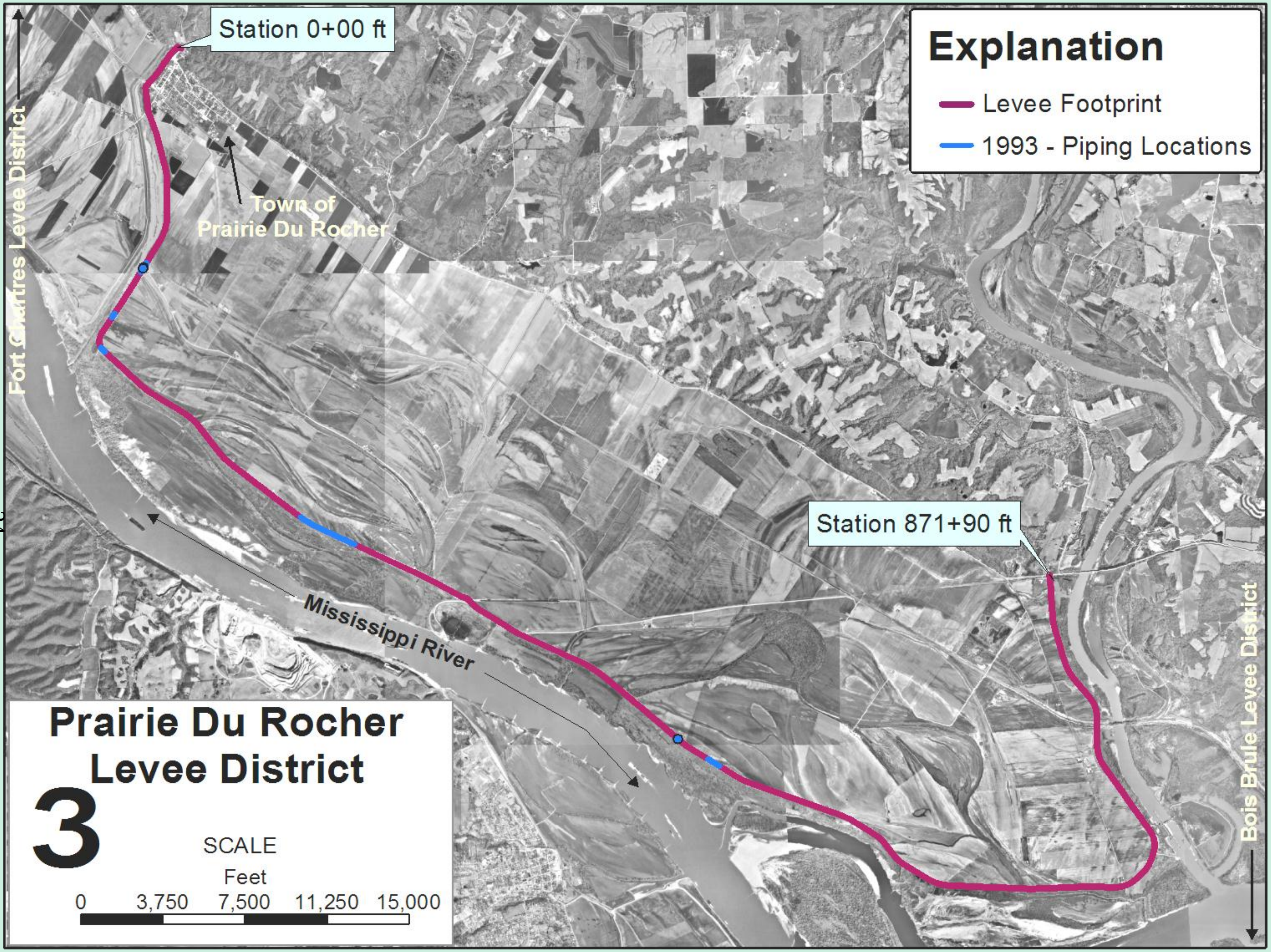
Great Flood of 1993 **Smaller** Flood of 1995

Year	No. days	Average Net Head, (ft)	Percent of Levee Affected by Piping	Levee System
1973	**77**	13	0	**Prairie Du Rocher**
1993	**80**	18	5	
1995	44	10	**14**	16 miles in Length
1973	**77**	13	< 1	**Fort Chartres**
1993	**80**	20	~ 4	
1995	44	11	**~ 5**	11 miles in Length

From these observations AND others, we propose that:

Repeated piping causes **cumulative damage** to the levee foundation

Prairie du Rocher – Piping Location 1993



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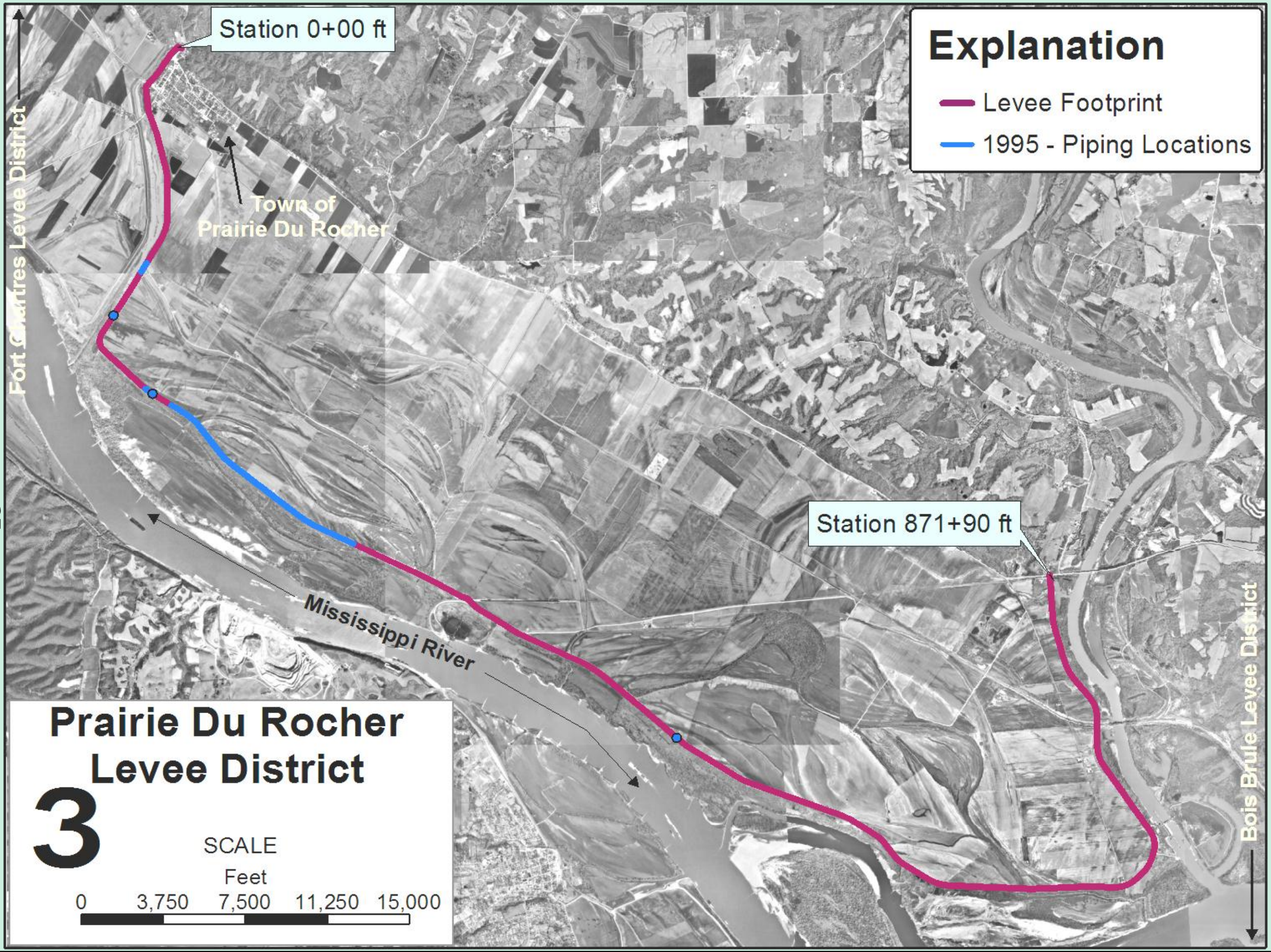
Prairie du Rocher –Piping Location 1995



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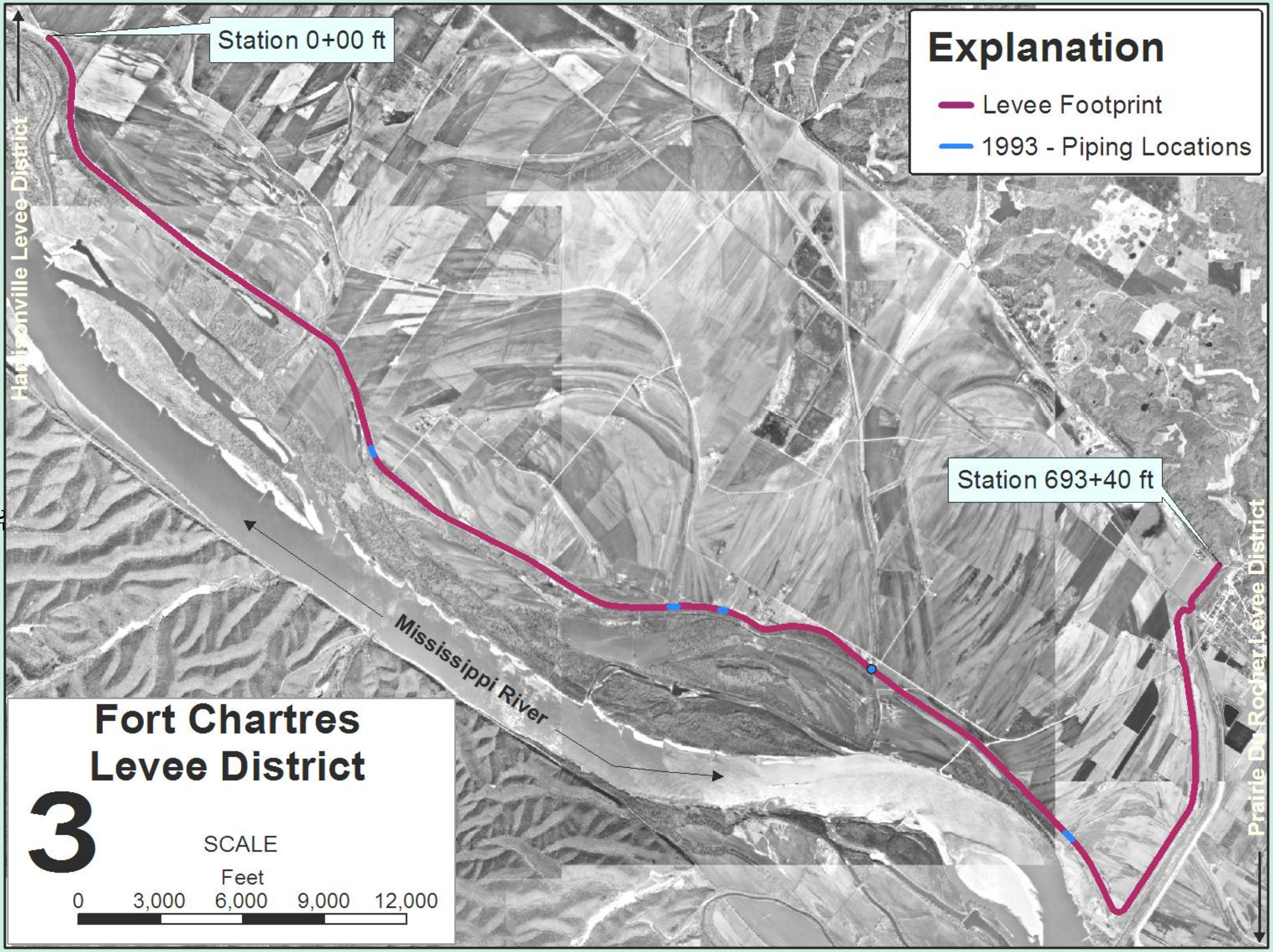
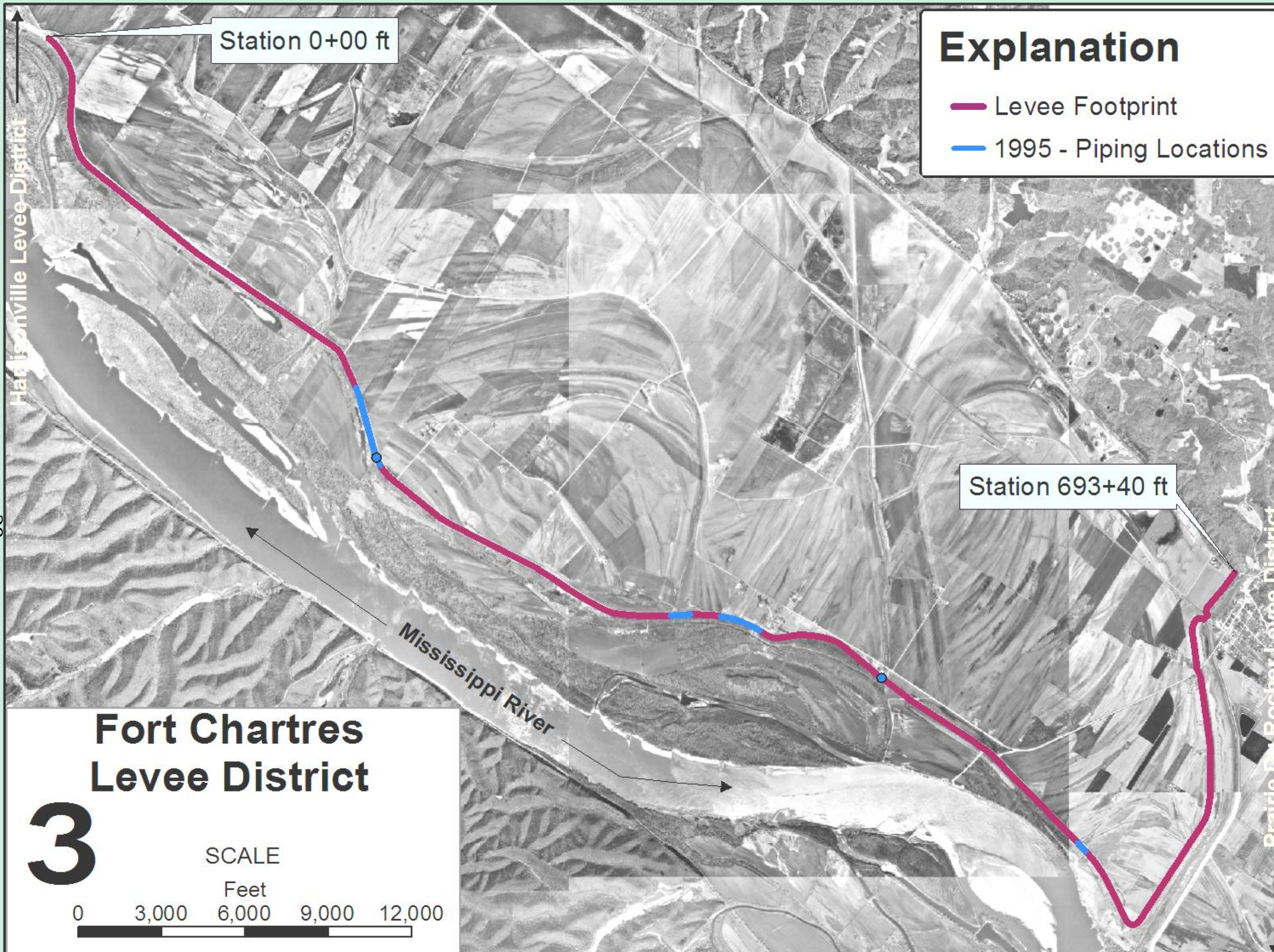
Fort Chartres –Piping Location 1993



Ft. Chartres –Piping Location 1995



Steps taken for Model Development – Using a Spatial Database

- Developed a database of sand boil locations using GIS
- Analyzed the number of sand boils for three flood events, 1973, 1993 and 1995
- Divided the levee footprint into equal segments of 250-ft. for the statistical analyses
- Assigned the available geotechnical data to each 250-ft segment
- Looked for significant correlations between geotechnical parameters and locations of sand boils
- Developed a series of predictive models by logistic regression of significant parameters.

Some of the Data required for spatial database

Data included:

- Levee geometry
- Location and description of sand boils
- Location of Borings< boring logs
- River Geomorphology
- Thickness of the geologic layers (strati)
- Soil properties
- AND many of the seepage parameters used in the Conventional Seepage Analysis developed by USACE (1940s and 1950s) and still used today

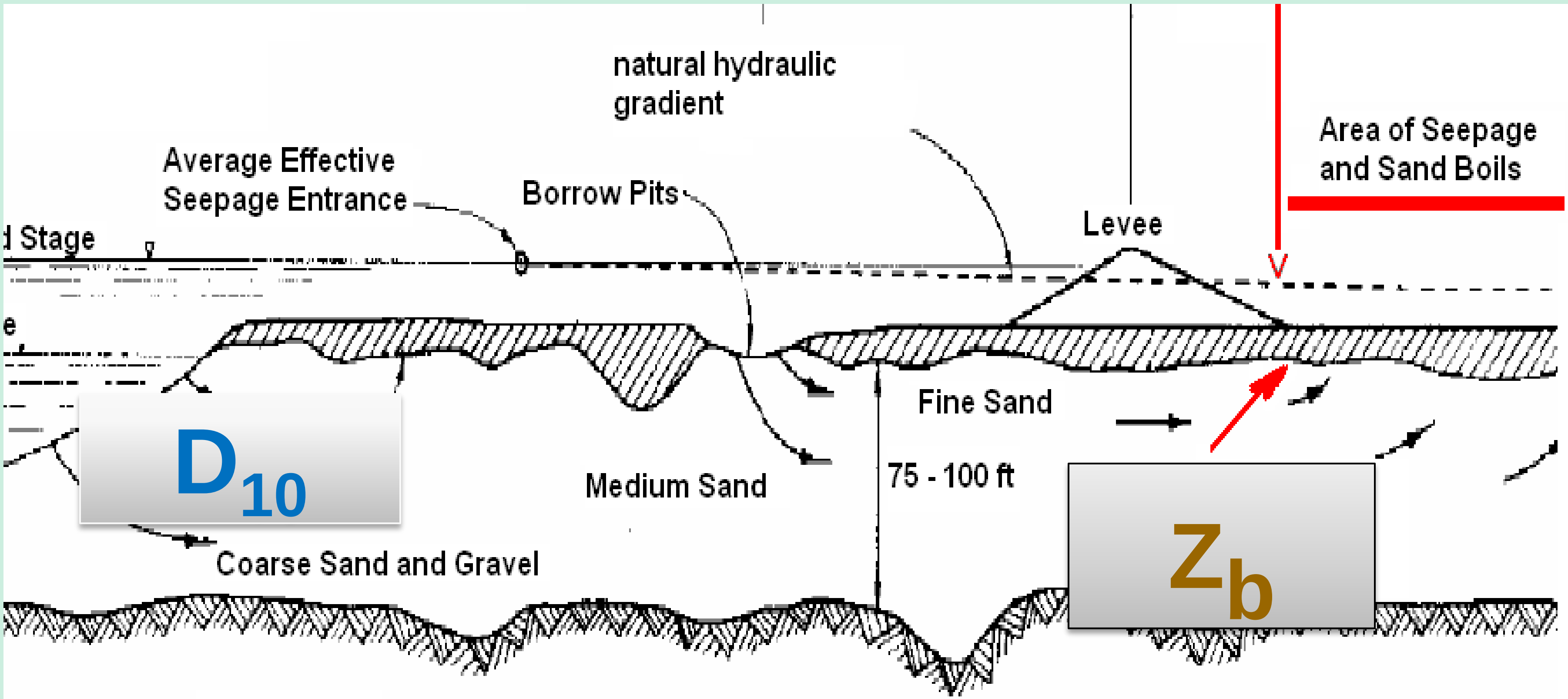
Seepage Parameters used in statistical analyses

No.	Brief Variable Description	Symbol	Noted Previous Investigators
1	Net Head on the levee (ft)	H	USACE (1956a,b)
2	Transformed confining layer thickness (ft)	Z_b	Turnbull and Mansur (1959)
3	Vertical permeability of riverside and landside top blanket (cm/sec2)	k_{br} and k_{bl}	USACE (1956a,b)
4	Effective thickness of the substratum (ft)	d	USACE (1941)
5	Ratio of horizontal permeability of the substratum with vertical permeability of the top stratum	k_h/k_{bl}	USACE (1956a,b)
6	Distance from landside toe of the levee to effective seepage entry (ft)	s	USACE (1956a,b)
7	Distance from landside toe of the levee or berm to effective seepage exit (ft)	x_3	USACE (1956a,b; 1976)
8	Critical gradient through the top stratum landside toe of the levee	i_c	USACE (1941; 1956a,b; 1976)
9	Surface geologic deposit	based on type	Fisk (1945), USACE (1956), Kolb (1975), Smith (1988), Saucier (1994)
10	Surface geologic configuration	based on alignment with the levee	Fisk (1945), USACE (1956a,b), Kolb (1975), Saucier (1994)
11	Blocked exit	based on alignment with the levee	USACE (1976)
12	Effective grain size of aquifer	D_{10}	USACE (1956a)

Top stratum thickness and coefficient of effective grain size (D_{10})

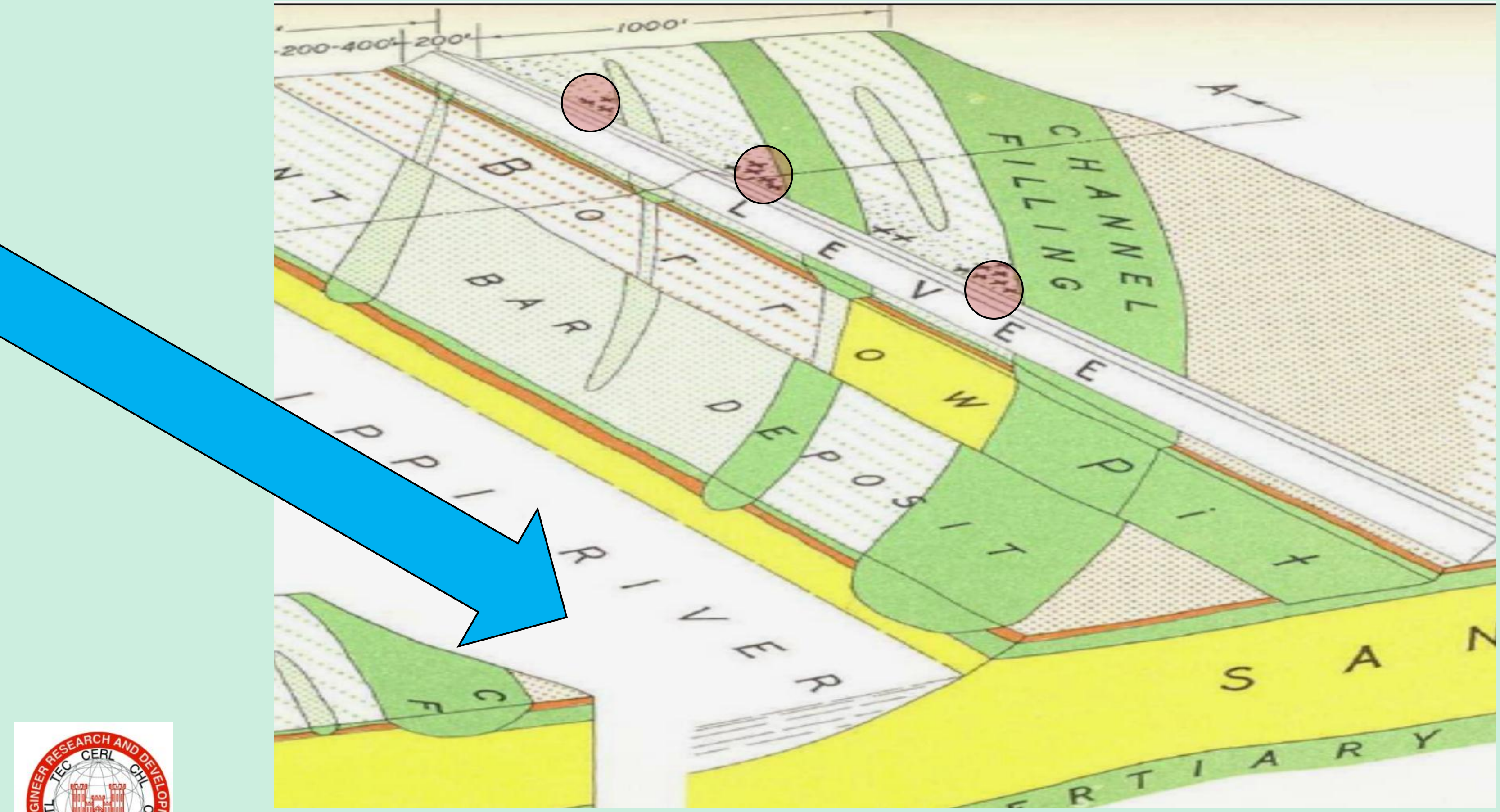
- These variables were obtained from boring logs where borings were located in the segment
- Values were estimated by kriging for segments without boring logs

Most influential parameters are the configuration of the levee with the geomorphology, the thickness of the top-stratum layer (Zb) and the Effective grain size coefficient (D_{10})



Point Bar Deposits

Geologic configuration of the subsurface to the levee



Geomorphic configuration rating

Swales and Abandoned Channels were included if present between 0 -1000 ft from the levee toe

Rank	*Description*
0.00	No unfavorable configuration
0.50	Intersects the levee at an angle > 90 degrees
0.60	Exists parallel to the levee between 500 to 1000 feet landside of levee toe
0.70	Intersects perpendicular with the levee
0.80	Exists parallel to the levee between 250 to 500 feet landside of levee toe
0.90	Exists parallel to the levee with 250 feet landside of levee toe with no overlap
1.00	Intersects the levee at an angle < 90 degrees

Emprical Model to predict piping for 1993 (Wilson 2003)

Logit PDR-93

$$\ln \frac{\pi}{1-\pi} = -7.743 - 0.0526\, Z_b + 26.99\, D_{10} + 1.908\, G$$

- The values for the three parameters were assigned to each of the 250 –ft segments
- The probability of piping for each segment was calculated using the PDR-93 equation
- The results were compared to the piping locations documented during the 1993 flood.

Emprical Model to Predict Piping for 1995 (Wilson 2003)

Logit PDR-95

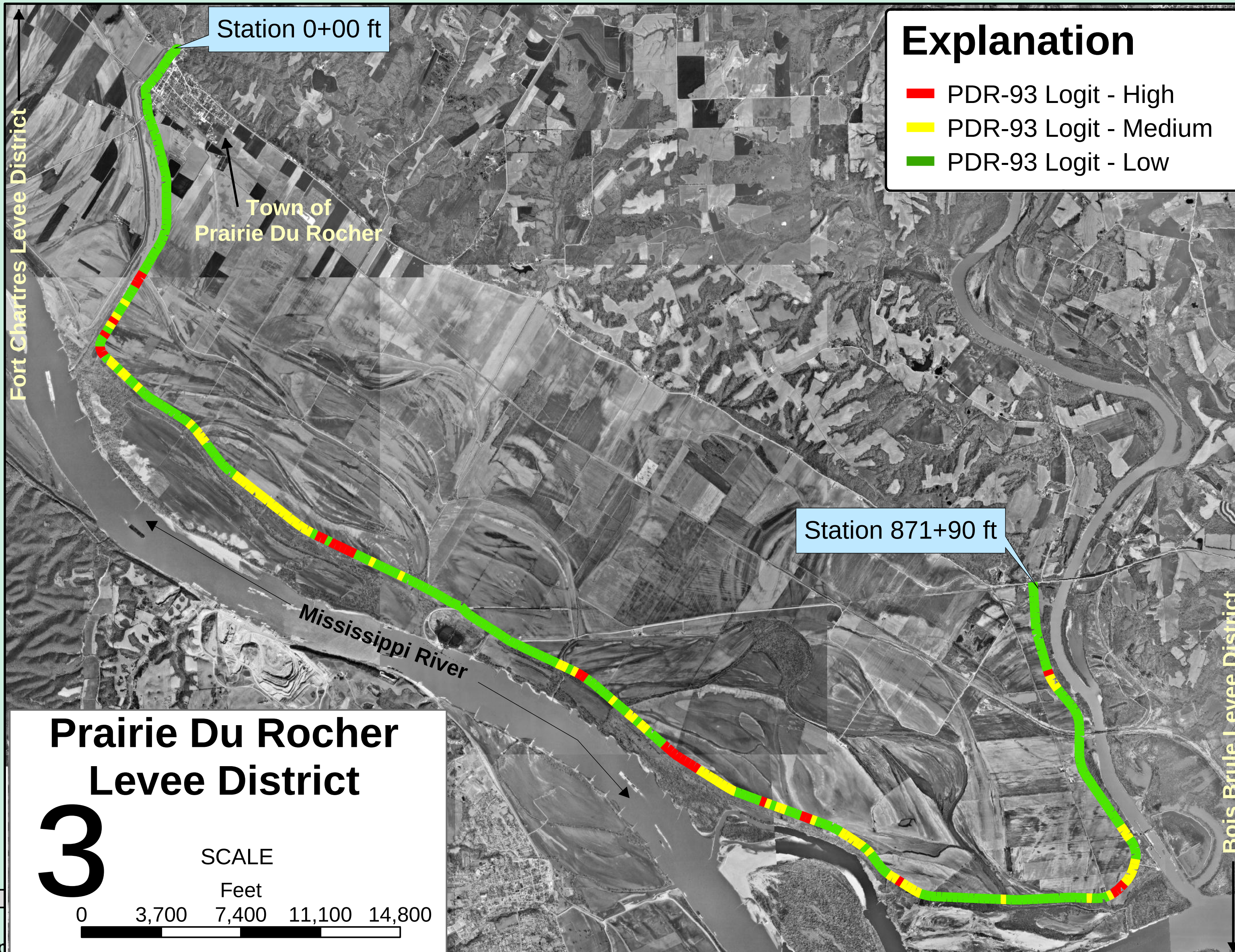
$$\ln \frac{\pi_{95}}{1-\pi_{95}} = -2.353 + 2.988\,\pi_{93} + 2.385\,P_{93}$$

Results from the Logit PDR-93 model were regressed with the binary independent variable P_{93}, where P = 1 for piping and zero for not piping.

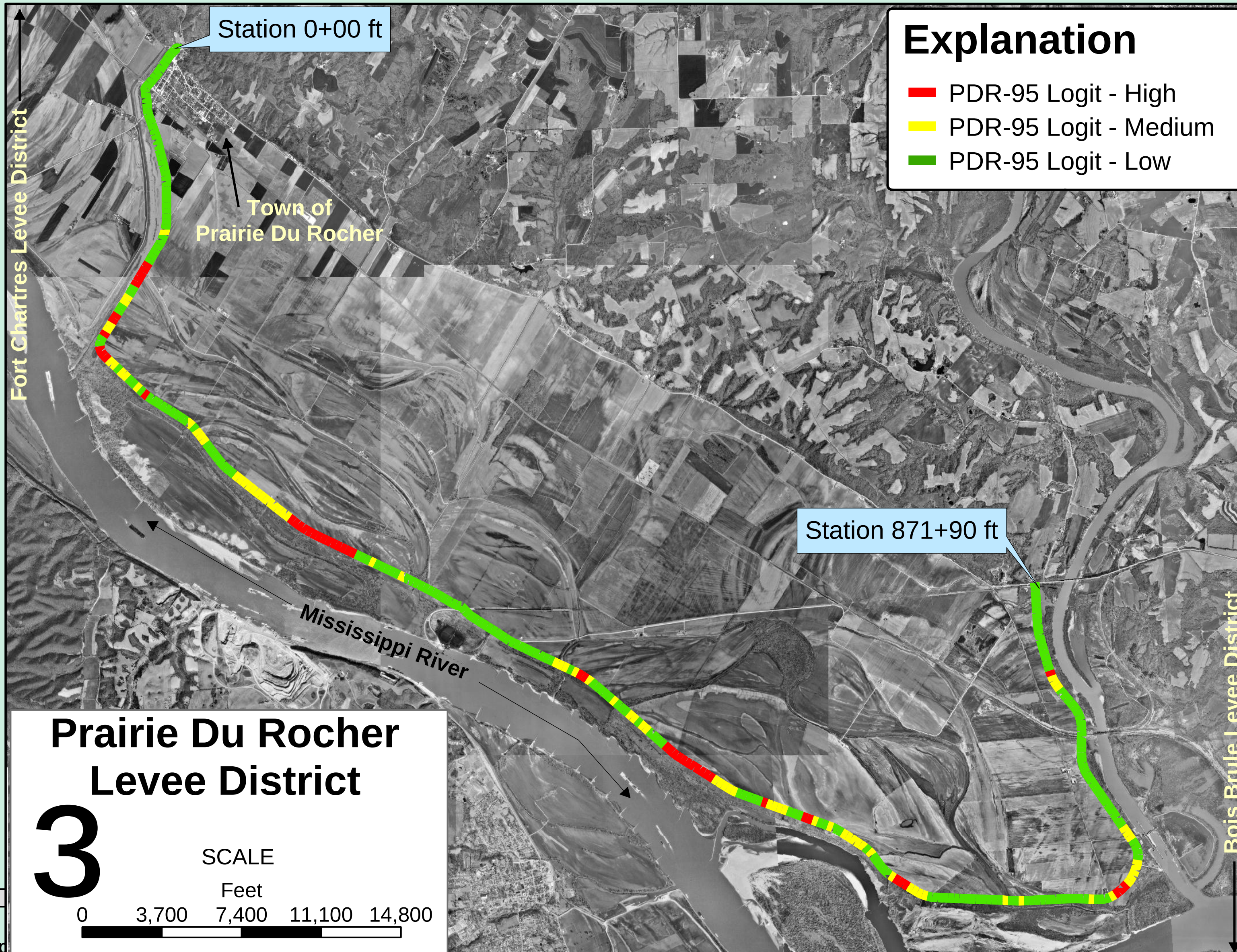
Results

Levee Reach Categories	Threshold	No. of Levee Reaches in Category	Percent of Segments that Piped in this Category	No. of Pipes observed	% of Total Pipes in this Category
PDR-93 Logit					
High	0.1350	61	26.23%	16	66.67%
Medium	0.0330	111	3.60%	4	16.67%
Low	0.0000	177	2.26%	4	16.67%
FTC-93 Logit					
High	0.1350	62	11.29%	7	46.67%
Medium	0.0330	107	6.54%	7	46.67%
Low	0.0000	109	0.92%	1	6.67%
MMR-93 Logit					
High	0.1350	123	18.70%	23	58.97%
Medium	0.0330	218	5.05%	11	28.21%
Low	0.0000	286	1.75%	5	12.82%

PDR-93 Logit

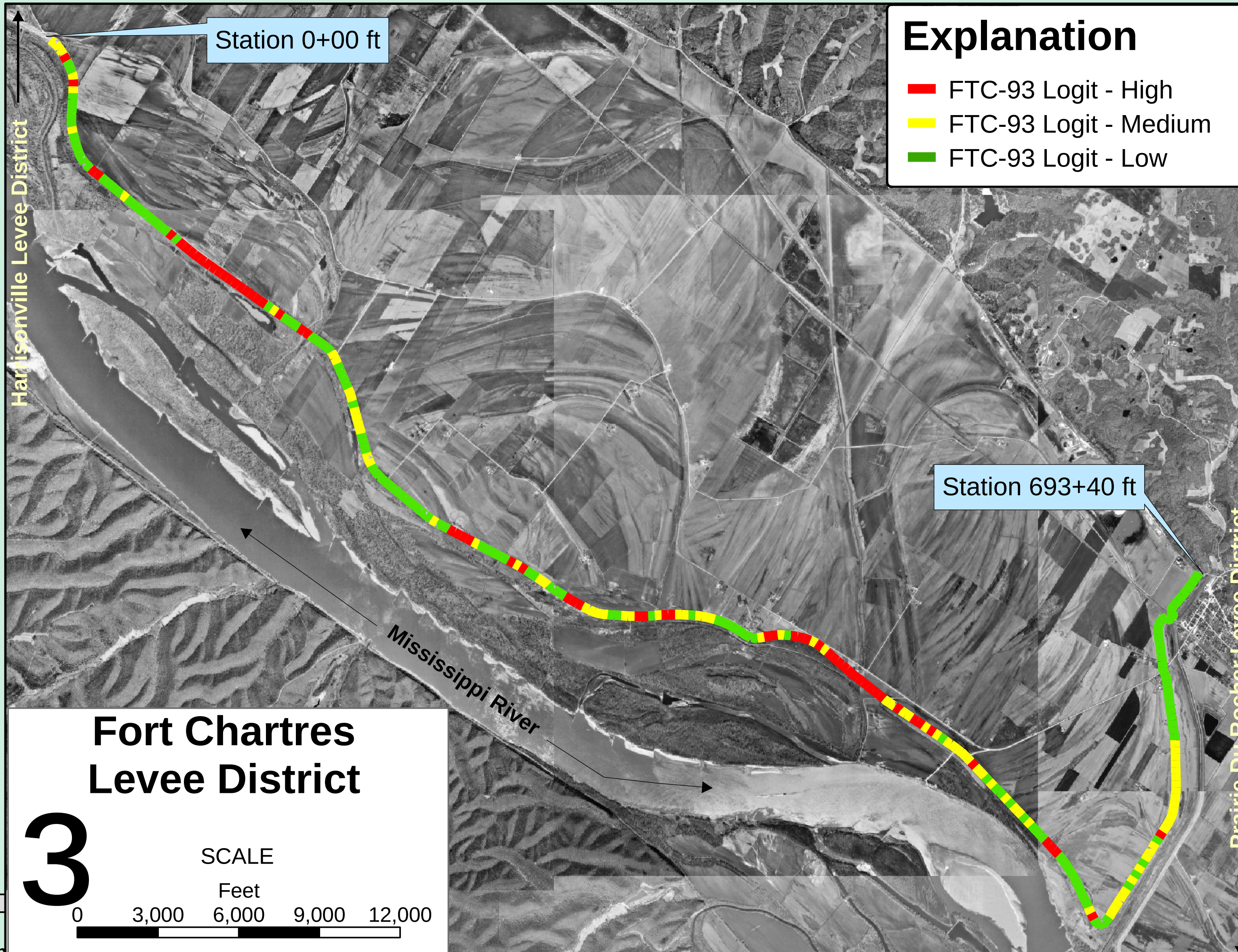

Station 0+00 ft
Explanation
PDR-93 Logit - High
PDR-93 Logit - Medium
PDR-93 Logit - Low
Town of
Prairie Du Rocher
Fort Chartres Levee District
Station 871+90 ft
Mississippi River
Bois Brule Levee District
Prairie Du Rocher
Levee District
3
SCALE
Feet
0
3,700
7,400
11,100
14,800

PDR-95 Logit



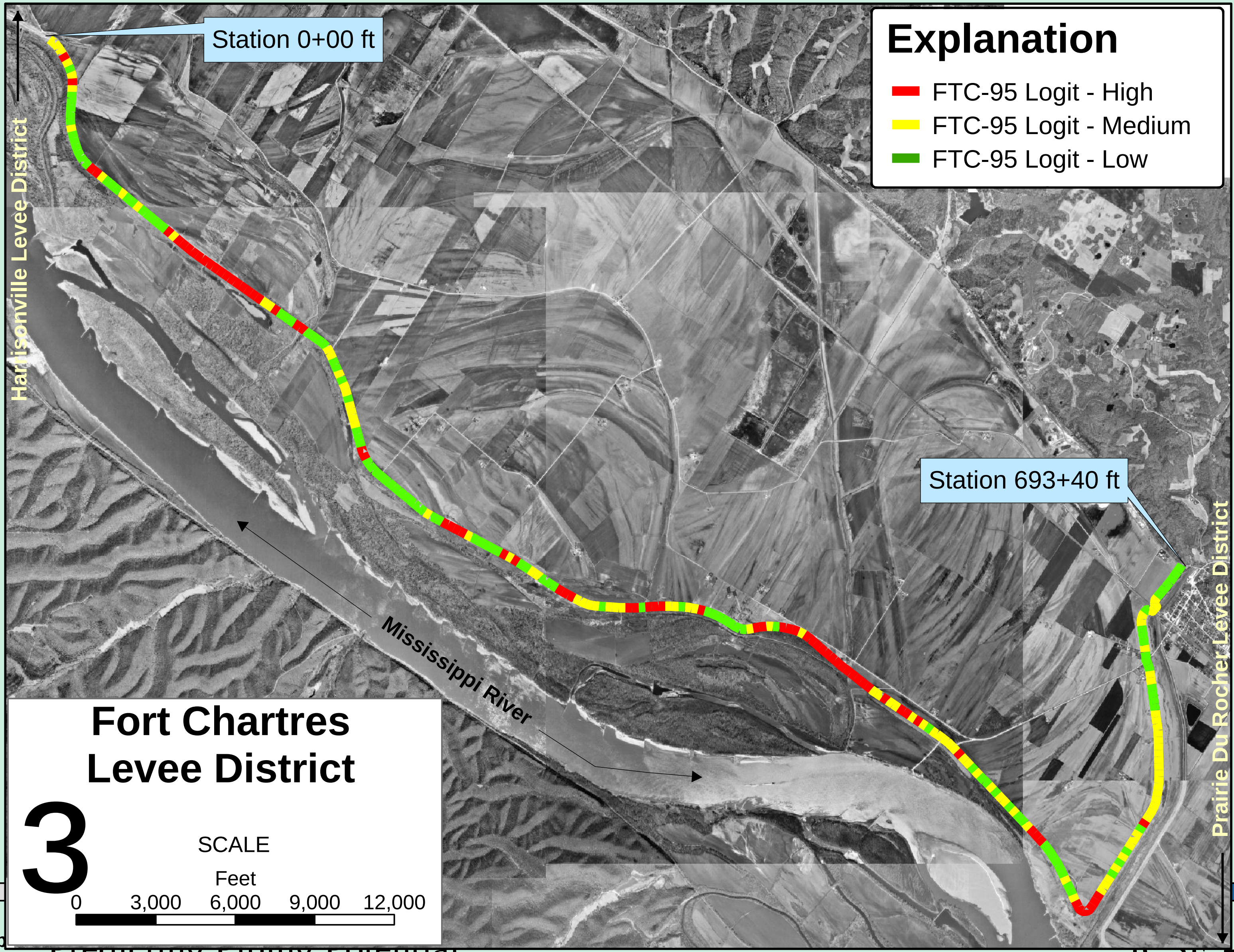
Station 0+00 ft
Explanation
PDR-95 Logit - High
PDR-95 Logit - Medium
PDR-95 Logit - Low
Town of
Prairie Du Rocher
Fort Chartres Levee District
Station 871+90 ft
Mississippi River
Bois Brule Levee District
Prairie Du Rocher
Levee District
3
SCALE
Feet
0
3,700
7,400
11,100
14,800

FTC-93 Logit



Station 0+00 ft
Explanation
FTC-93 Logit - High
FTC-93 Logit - Medium
FTC-93 Logit - Low
Harrisonville Levee District
Station 693+40 ft
Prairie Du Rocher Levee District
Mississippi River
Fort Chartres Levee District
3
SCALE
Feet
0 3,000 6,000 9,000 12,000

FTC-95 Logit


Station 0+00 ft
Explanation
FTC-95 Logit - High
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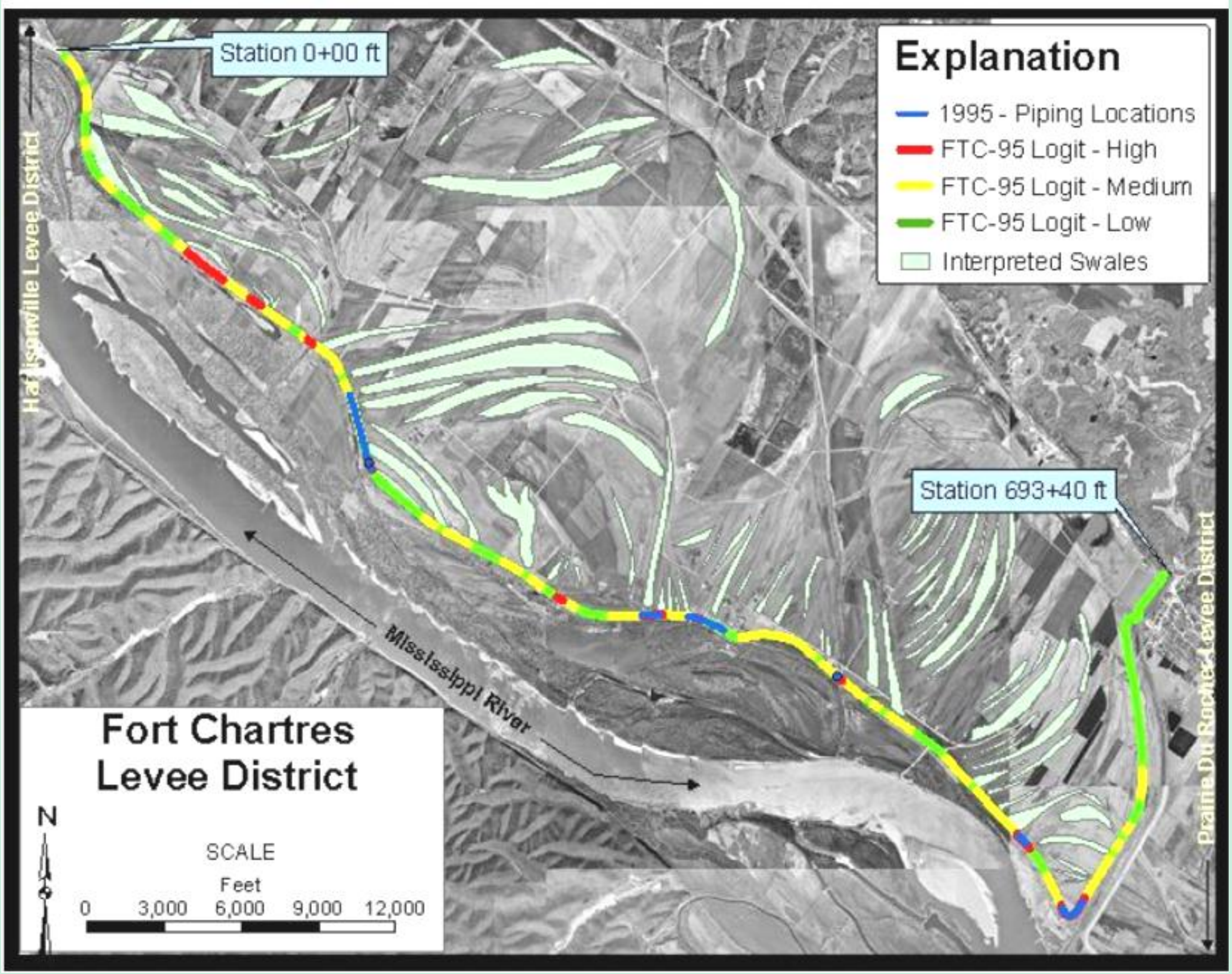
FTC-95 Logit - Low
Harrisonville Levee District
Station 693+40 ft
Prairie Du Rocher Levee District
Mississippi River
Fort Chartres
Levee District
3
SCALE
Feet
0
3,000
6,000
9,000
12,000

RESULTS

- Number of sand boils increased with each flood event
- Three independent variables were determined to be most closely related to piping were
  - Thickness of the top-stratum
  - Effective grain size of the substratum (aquifer)
  - Unfavorable configuration of the geomorphology
- Predictability of the Piping Potential improved when previous piping locations were included as independent variables in the Logit PDr 1995 model

Ft. Chartres Results 1993

Ft. Chartres Results 1995



Conclusions of Piping Study

- Statistical method holds promise as an initial evaluation of where sand boils are likely to appear,
- The model predictability improves if you have previous piping data.
- The statistical method allows the user to find the piping parameters that are significantly related to their specific alluvial regimes
- Main Weakness of this study was the Poor sand boil documentation
  - Location and severity description could be greatly improved if seepage observation sheet were used for standard recording

Predicting Piping Potential - Empirical Modeling References

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Bomar, Joshua. 2007. Assessing the piping potential of individual levee segments along the Sacramento and Feather River Levee Systems in California. MS thesis, University of Mississippi.

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Questions?

6th International Conference
on Scour and Erosion