



Intelligent Compaction and Mechanistic-Empirical Design

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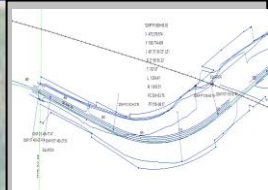
Outline

- ▶ Design, Construction, and Performance Framework
- ▶ Introduction to Intelligent Compaction
- ▶ Intelligent Compaction Data from MnROAD 2008
- ▶ GIS IC Data Analysis
 - ▶ Overall data analysis
 - ▶ Comparison between lifts
- ▶ Lessons Learned
- ▶ Conclusions



Design, Construction, and Performance

Pavement Design



Construction Quality Control



12INP PI 508+60.83
X 473,379.574
Y 189,714.409
40° 37' 06.72" (LT)
D 2° 59' 56.33"
T 707.07'
L 1,354.41'
R 1,910.51'
PC 501+53.76
PT 515+08.17

EQUATION:

12INP PT 515+08.17 = 12INP PCT 515+07.45

490

495

500

505

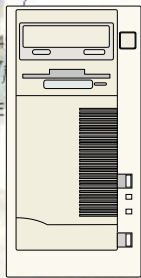
510

12INP CS 4

12INP ST 493+27.47

27.50

135th Ave NE



Performance Management Archive



Construction Quality Assurance

Mechanistic Empirical Pavement Design

- ▶ “MnPAVE” provides the framework for performance based material property inputs
- ▶ Implemented by MnDOT State Aid for County and City Projects (February 1, 2011)
- ▶ Sponsor: Minnesota Local Road Research Board
- ▶ Contact: Bruce.Tanquist@state.mn.us
- ▶ Free download at:
www.dot.state.mn.us/app/mnpave/index.html



Structure

Basic Intermediate Advanced

Confidence Level (50 to 99%)

- View
- Thickness Values
 - Coefficient of Variation
 - Adjusted Thickness

Mill and Overlay

Edit Structure

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	4
<input type="radio"/> 2	Old HMA	4
<input type="radio"/> 3	AggBase	12
<input type="radio"/> 4	EngSoil	24
<input checked="" type="radio"/> 5	UndSoil	

Design Mode:

- Units
- English
 - SI

Finished Structure
Go to
Control Panel

- View
- Test Results
 - Resistance Factors
 - Coefficient of Variation

Check box to enter test data.
Uncheck to use Basic defaults.

- Old HMA Modulus
- Default Values
 - FWD Deflections
-

- Agg. Test Type
- Lab Mr. ksi
 - R-Value
 - DCP, mm/blow

- Soil Test Type
- Lab Mr. ksi
 - R-Value
 - DCP, mm/blow
 - Silt % Clay %

- Other
- Design Modulus, ksi
 - Poisson's Ratio

PG 58-34
PG 58-28

- CL5

- CL
- CL

Why Performance Based Tests?

- ▶ Quantify the performance of alternative materials and construction practices
- ▶ Show the economic benefit of improved materials and construction practices
- ▶ Reward good construction and greater uniformity
- ▶ Achieve agreement between construction quality assurance, pavement design, and performance
- ▶ Implement tools that will strengthen the decisions made by construction inspection personnel



Testing for Compaction

- ▶ **Uniformity is the Priority**
- ▶ **Traditional (Empirical Pavement Design)**
 - ▶ Specify Relative Density (Proctor Test)
 - ▶ Specify Moisture Limits (Proctor Test)
 - ▶ Observation and Test Rolling
- ▶ **Future (Mechanistic Pavement Design, MnPAVE)**
 - ▶ Specify Moisture or Minimum Suction (Cohesion)
 - ▶ Specify Modulus and Strength (LWD and DCP)
 - ▶ Observation, Test Rolling, and Intelligent Compaction



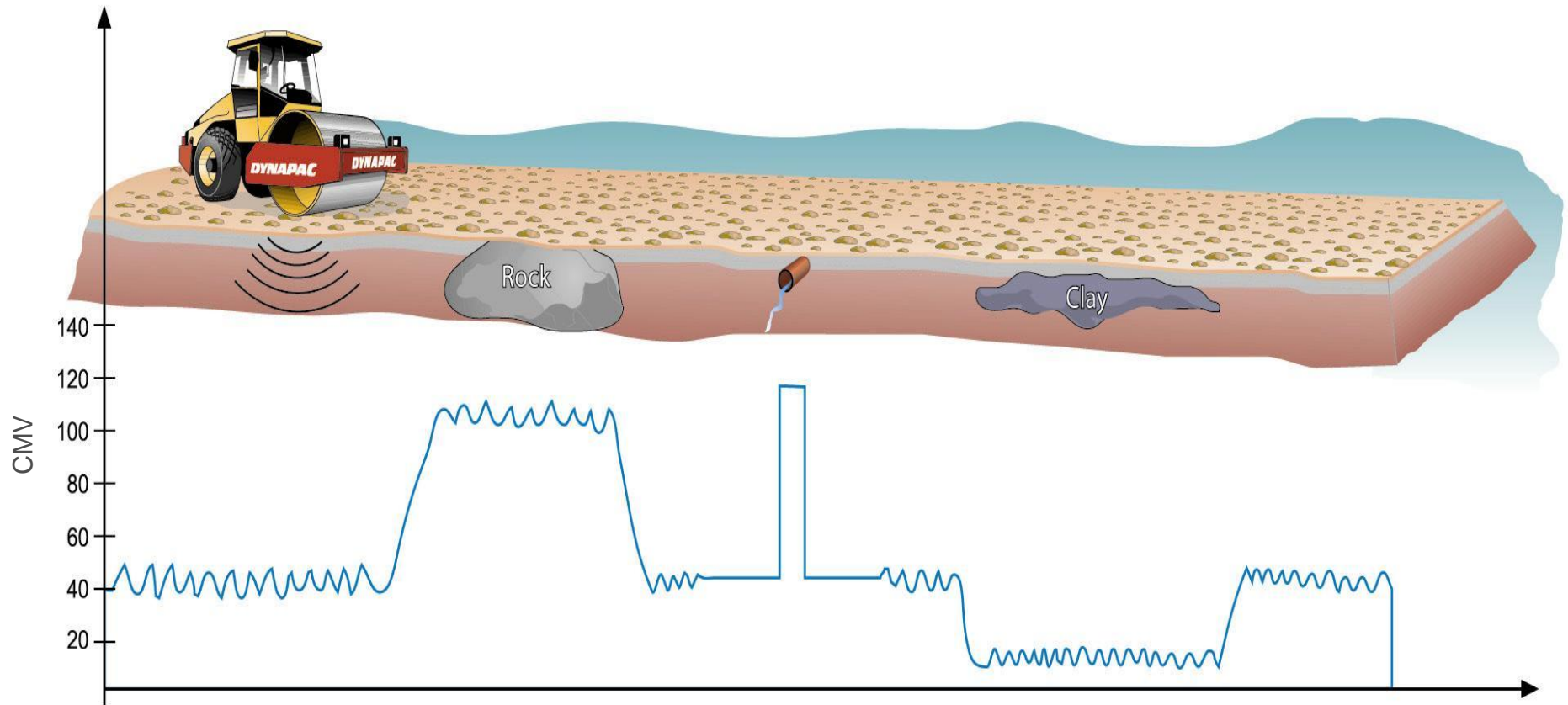
Introduction to Intelligent Compaction

- ▶ **What is Intelligent Compaction?**
 - ▶ Intelligent compaction equipment measures and records the quality of compaction during the compaction process.
 - ▶ The compactor's force changes in real time to increase compaction where needed, while preventing over compaction.
 - ▶ The equipment uses a global positioning system to create an in cab map that shows the quality of compaction across the entire surface of each lift.



Continuous Compaction Control

Measure stiffness – identify soft and stiff areas.



Benefits of Intelligent Compaction

- ▶ Improved quality
- ▶ Reduced compaction costs
- ▶ Reduced life cycle cost
- ▶ Integration of design, construction, and performance



MnROAD 2008 Construction

2	3	4	106	206	113	213	313	413	16	17	18	19	20	21	22	23
1" TBWC 2"64-34	1" TBWC 2"64-34	1" 64-34 2"64-34	2"64-34	2"64-34	5"	5.5"	6"	6.5"	5" WM 58-34	5" WM 58-34	5" WM 58-34	5" WM 58-34	5" 58-28	5" 58-28	5" 58-34	5" WM 58-34
6" FDR + EE	6" FDR + EE	8" FDR + EE	5"	5"	5" CI 1 Stab Agg	5" CI 1 Stab Agg	5" CI 1 Stab Agg	5" CI 1 Stab Agg	12" 100% recycle PCC	12" 50% RePCC 50% Class 5	12" 100% RAP	12" Class 5	12" Class 5	12" Class 5	12" Class 5	12" Mesabi Ballast
6" FDR	2" FDR 2" CI 5	9" FDR + Fly Ash	6" CI 1 Stab Agg	6" CI 1 Stab Agg	5" Class 5	4.5" Class 5	4" Class 5	3.5" Class 5	12" 100% recycle PCC	12" 50% RePCC 50% Class 5	12" 100% RAP	12" Class 5	12" Class 5	12" Class 5	12" Class 5	12" Mesabi Ballast
26" Class 4	33" Class 3	Clay	6" Class 5	6" Class 5	Clay	Clay	Clay	Clay	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3
			Clay	Clay	heavy turf	heavy turf	heavy turf	heavy turf	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3	12" Class 3
			Mesabi 4.75 SuperP	Mesabi 4.75 SuperP	15'x12' 1" dowel	15'x12' no dowels	15'x12'	15'x12'	15'x12'	15'x12'	7" Select Gran	7" Select Gran	7" Select Gran	7" Select Gran	7" Select Gran	7" Select Gran
Clay	Clay							Clay	Clay	Clay	Clay	Clay 30% Non Fract RAP	Clay 30% Fract RAP	Clay 30% Fract RAP	Clay	
Oct 08	Oct 08	Oct 08	Oct 08	Oct 08	Oct 08	Oct 08	Oct 08	Oct 08	Sept 08	Sept 08	Sept 08	Sept 08	Sept 08	Sept 08	Sept 08	Sept 08
Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current





2008 MnROAD Unbound Quality Control Construction Report

Minnesota
Department of
Transportation

**RESEARCH
SERVICES**

Office of
**Policy Analysis,
Research &
Innovation**

D. Lee Petersen, Primary Author
CNA Consulting Engineers

September 2010

Research Project
Final Report #2010-32

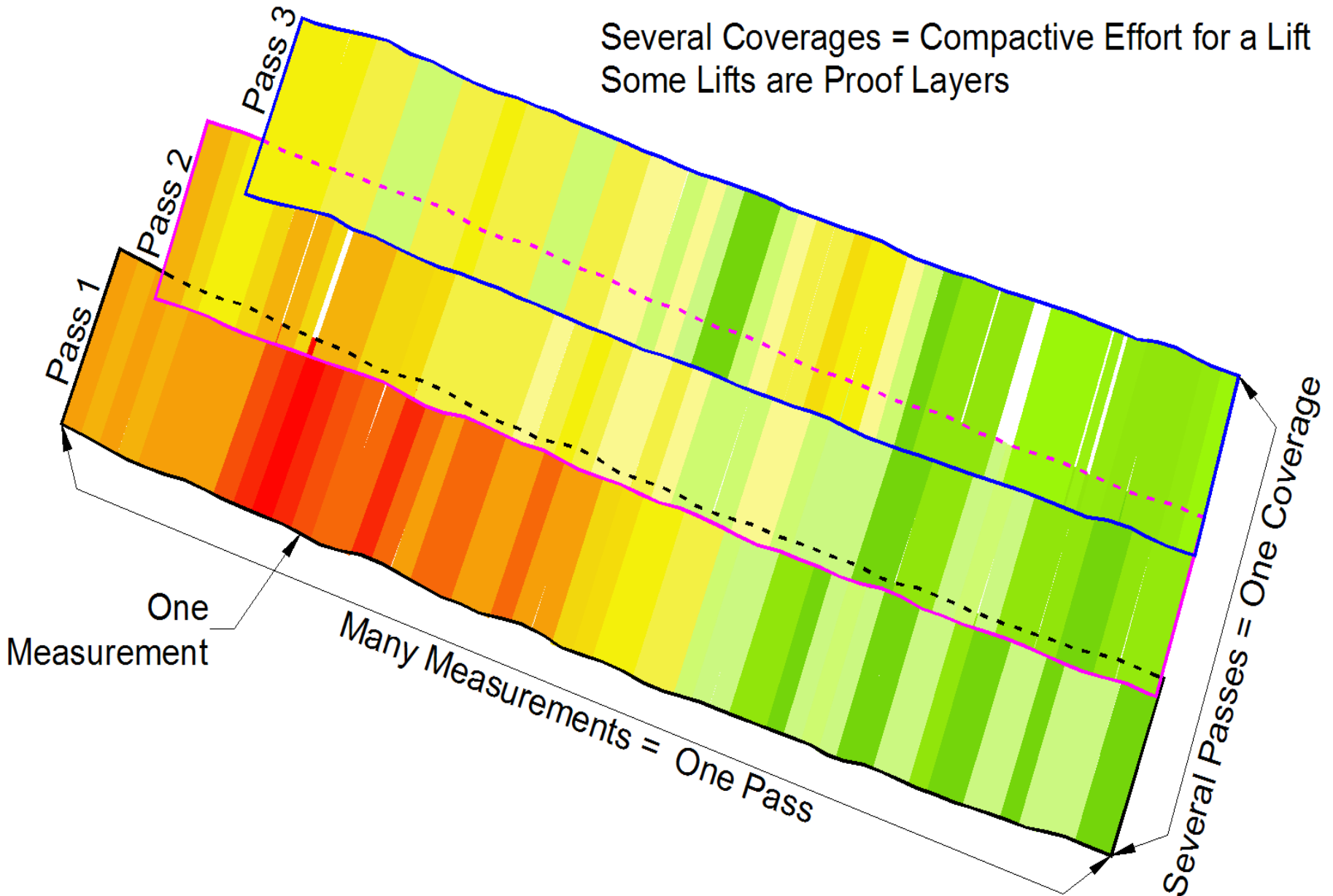
MnROAD
Office of Materials

Your Destination... Our Priority



IC Data Terminology

Several Coverages = Compactive Effort for a Lift
Some Lifts are Proof Layers



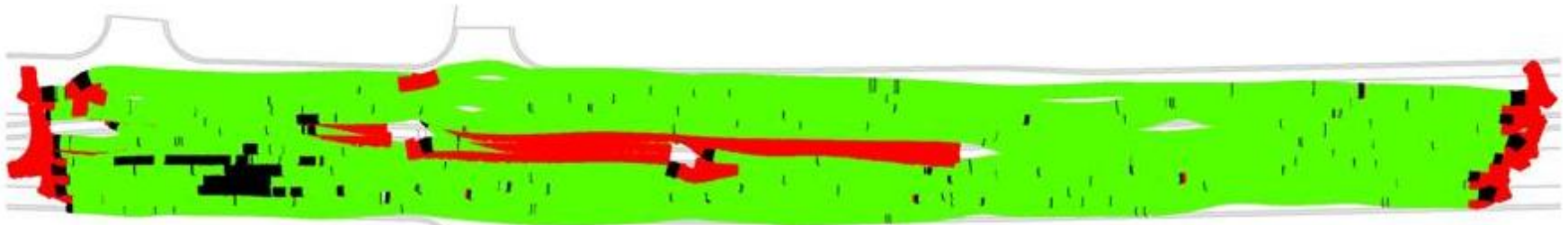
IC Data Validation

- ▶ Parameter driven validation criteria
- ▶ Criteria definable by users
 - ▶ With guidance of manufacturer
- ▶ Done during import of data to relieve pressure on GIS
 - ▶ Also allows for data queries to pull data using same validation
- ▶ Validation criteria definable by roller and project

“Attempted Compaction”

- ▶ Use validation criteria to identify areas where compaction was attempted
 - ▶ Valid data
 - ▶ Compaction/measurement was being attempted
 - ▶ Marginally valid data (with minor flaws)
 - ▶ Compaction/measurement was being attempted
 - ▶ A “minor” problem invalidated data
 - ▶ Invalid data (with major flaws)
 - ▶ Compaction/measurement was not being attempted

Viewing Data Based on Validity



ISVALIDREC

- Valid
- Invalid
- Marginally Invalid

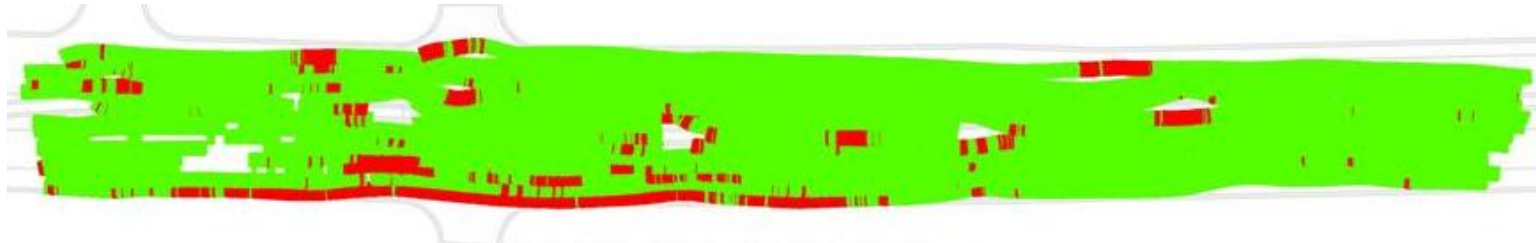


ISVALIDREC

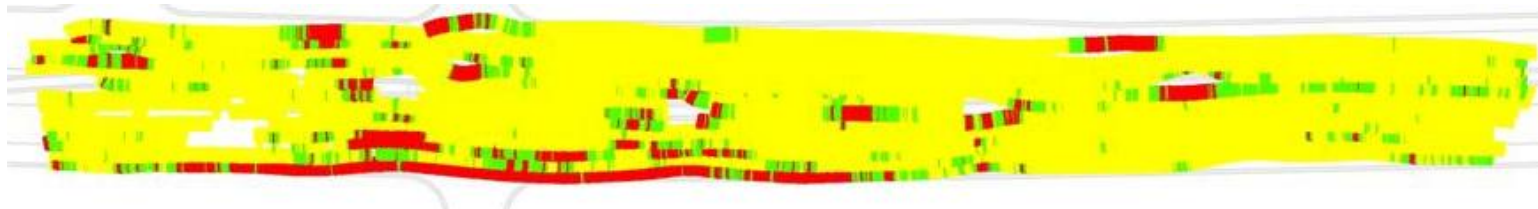
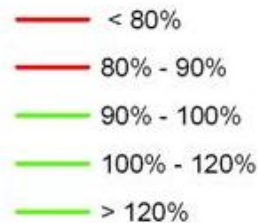
- Valid
- Invalid
- Marginally Invalid



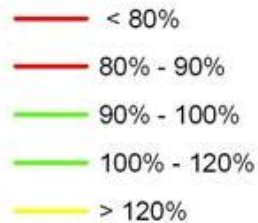
Viewing Data Based on Percent of Target Compaction



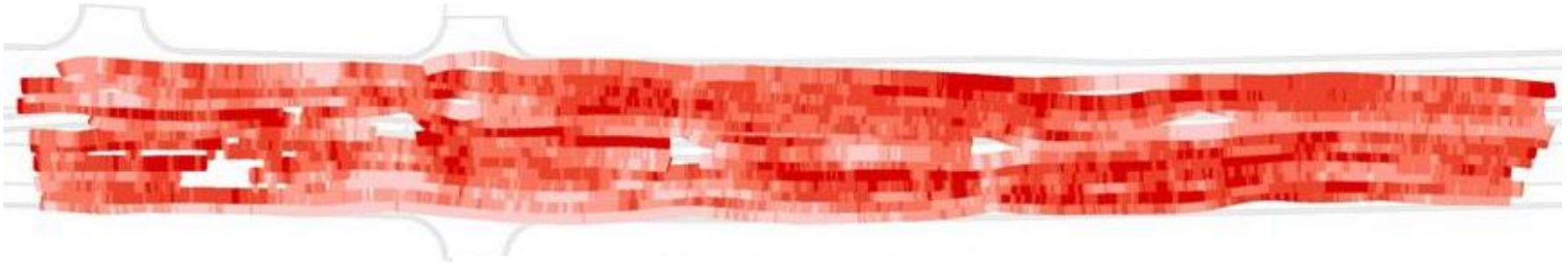
Percentage of Target Value



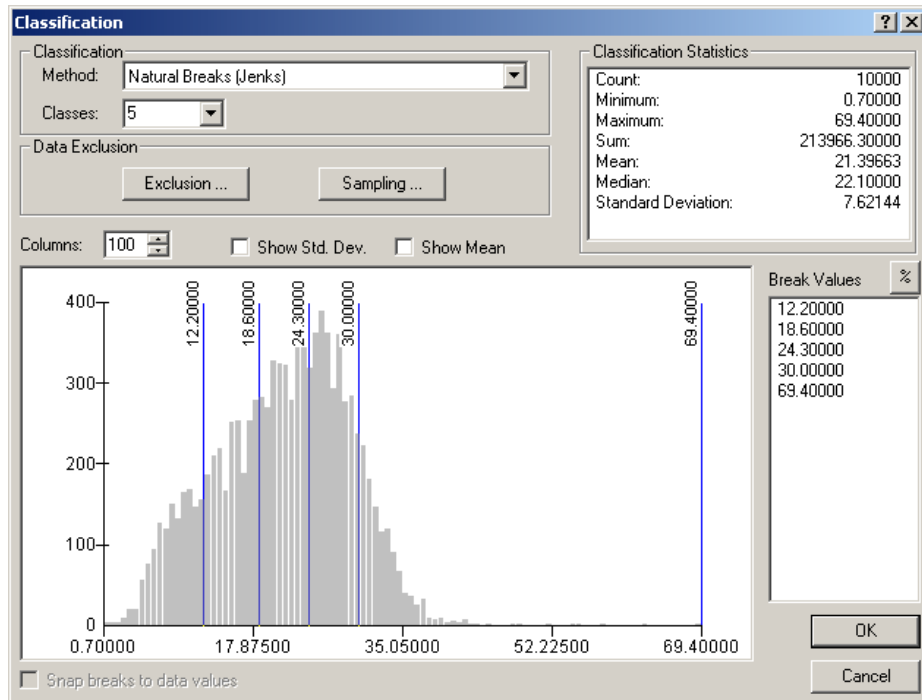
Percentage of Target Value



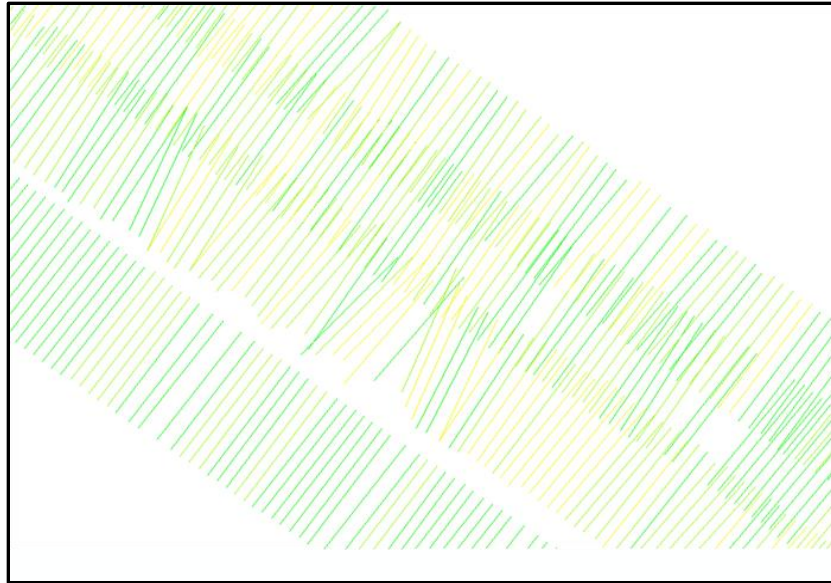
Viewing Data Based on Compaction Value



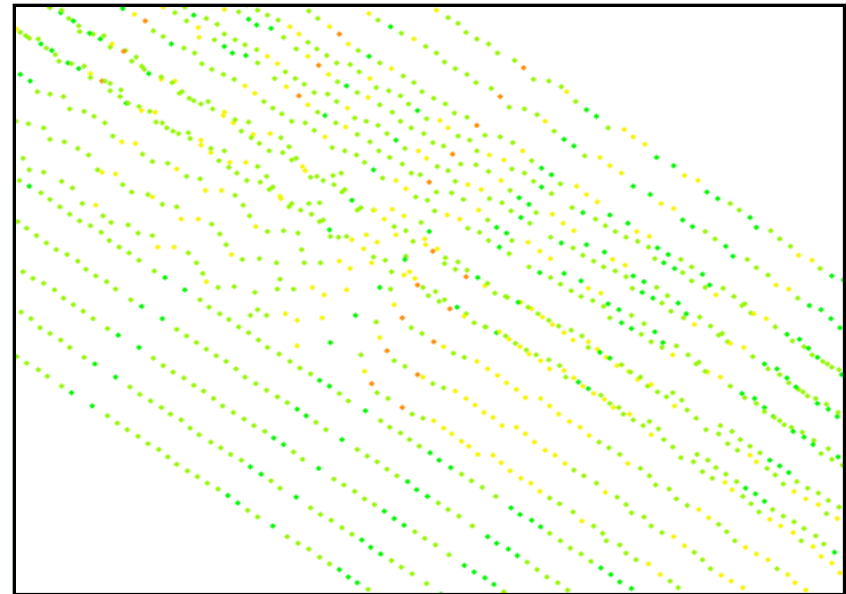
Compaction Value



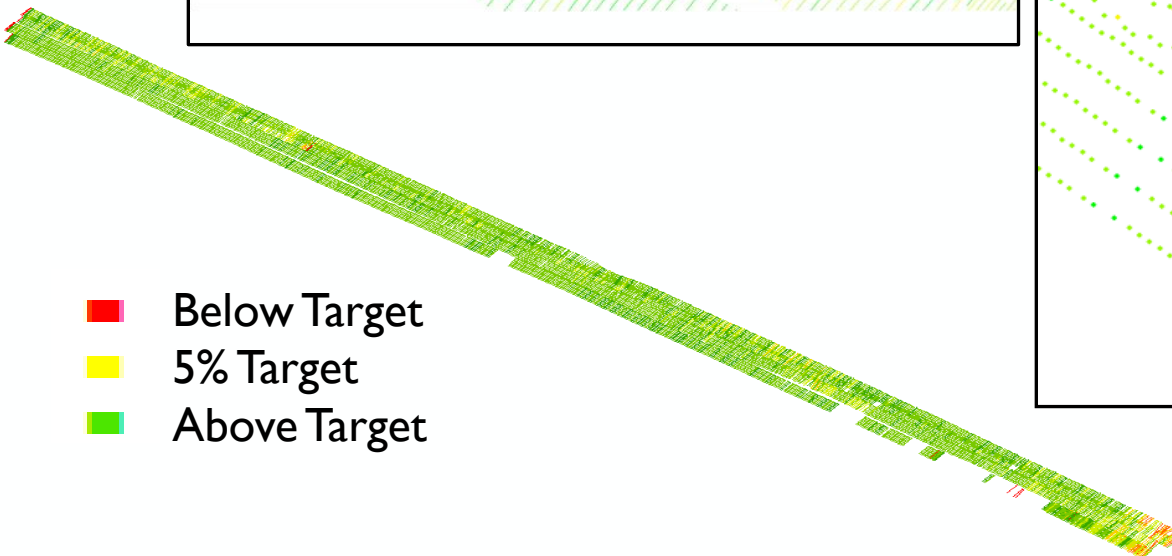
IC Data as Lines or Points



Lines of roller width displaying compaction values converted to 5 points along the drum.

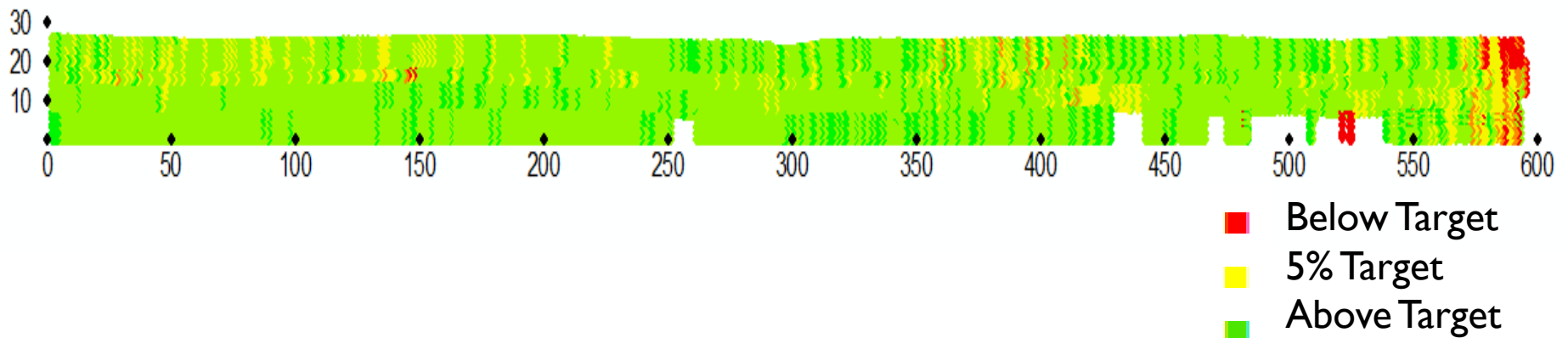


-  Below Target
-  5% Target
-  Above Target



Coordinate conversion to station offset

- ▶ Convert IC the coordinate system to station offset requires a baseline
- ▶ A point is placed every foot along the baseline, creating stations.
- ▶ A join is performed between the baseline points to the IC points.
 - ▶ This assigns each IC point a nearest station and offset distance.
- ▶ Points are then displayed using the station and offset coordinates.

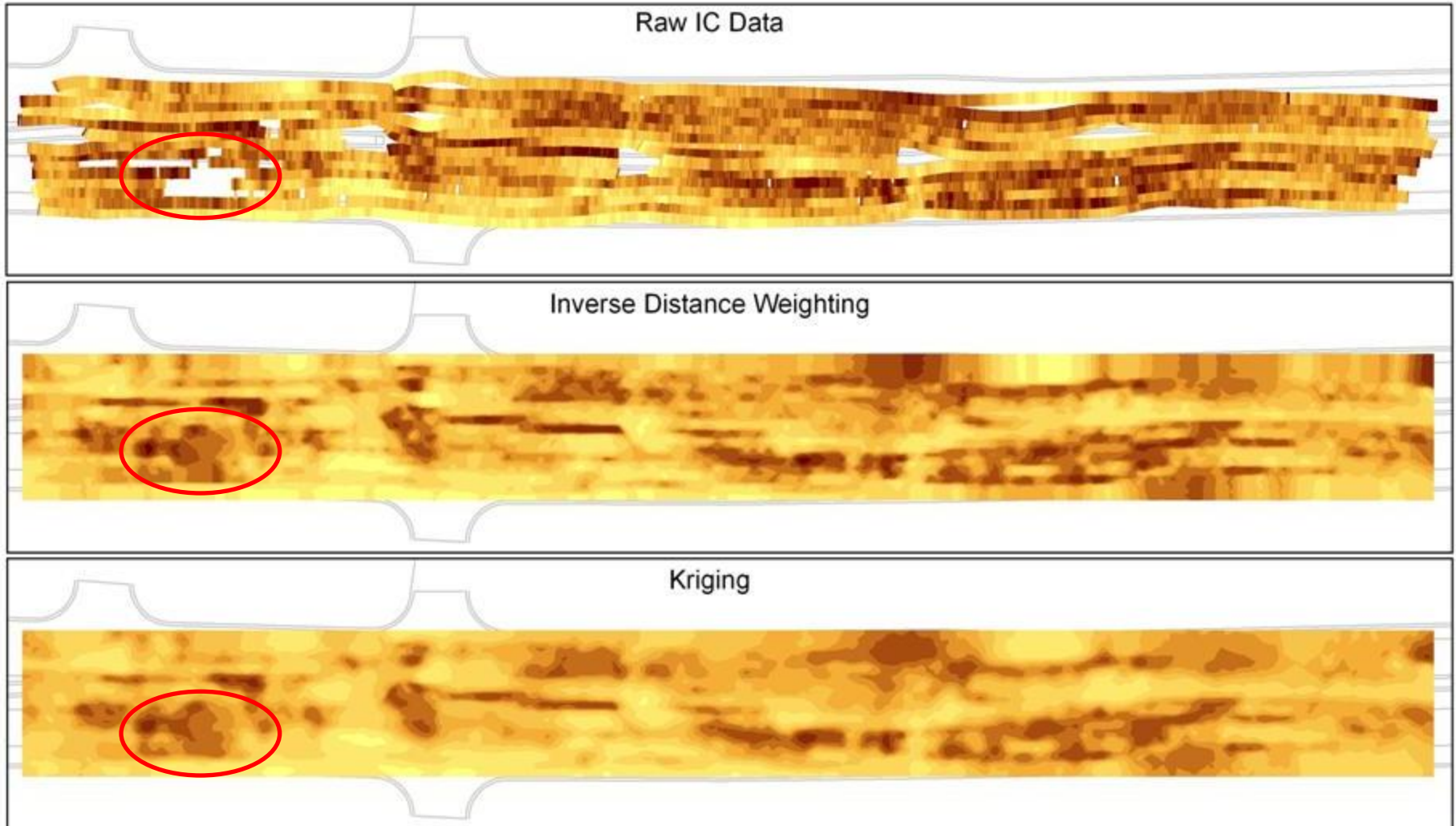


IC Data Analysis

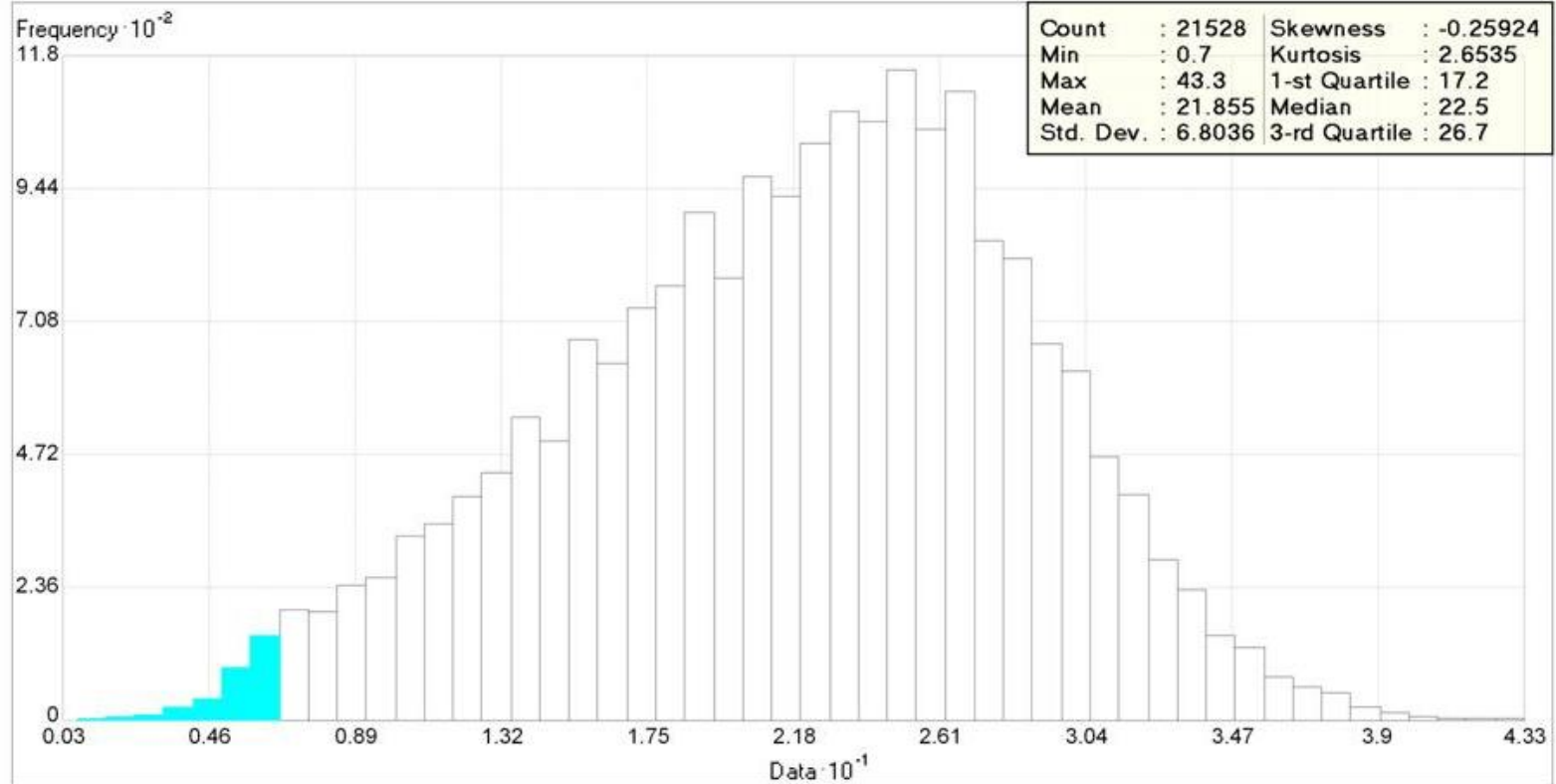
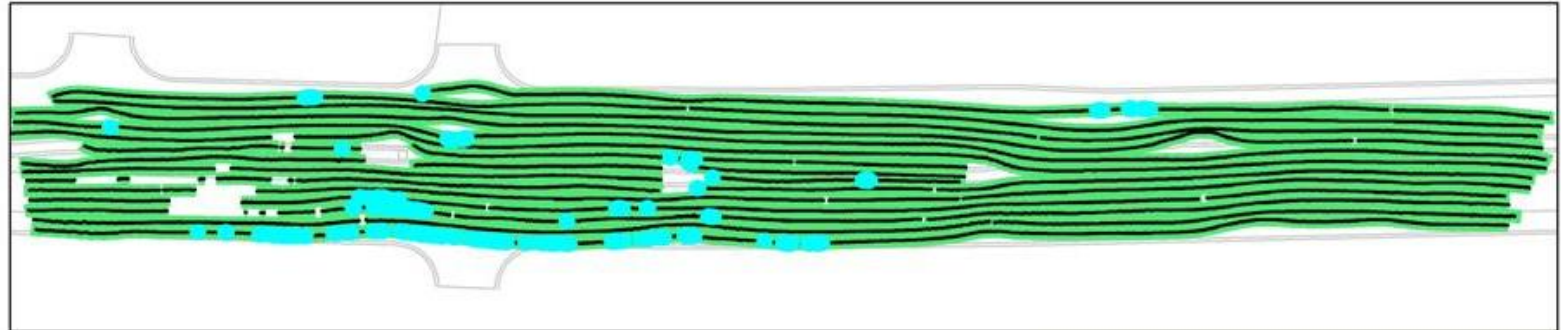
- ▶ Geostatistics
- ▶ Histogram
- ▶ 3D visualization
- ▶ 95% passing
- ▶ Compaction gradient
- ▶ Lift comparison
- ▶ Moment of improvement



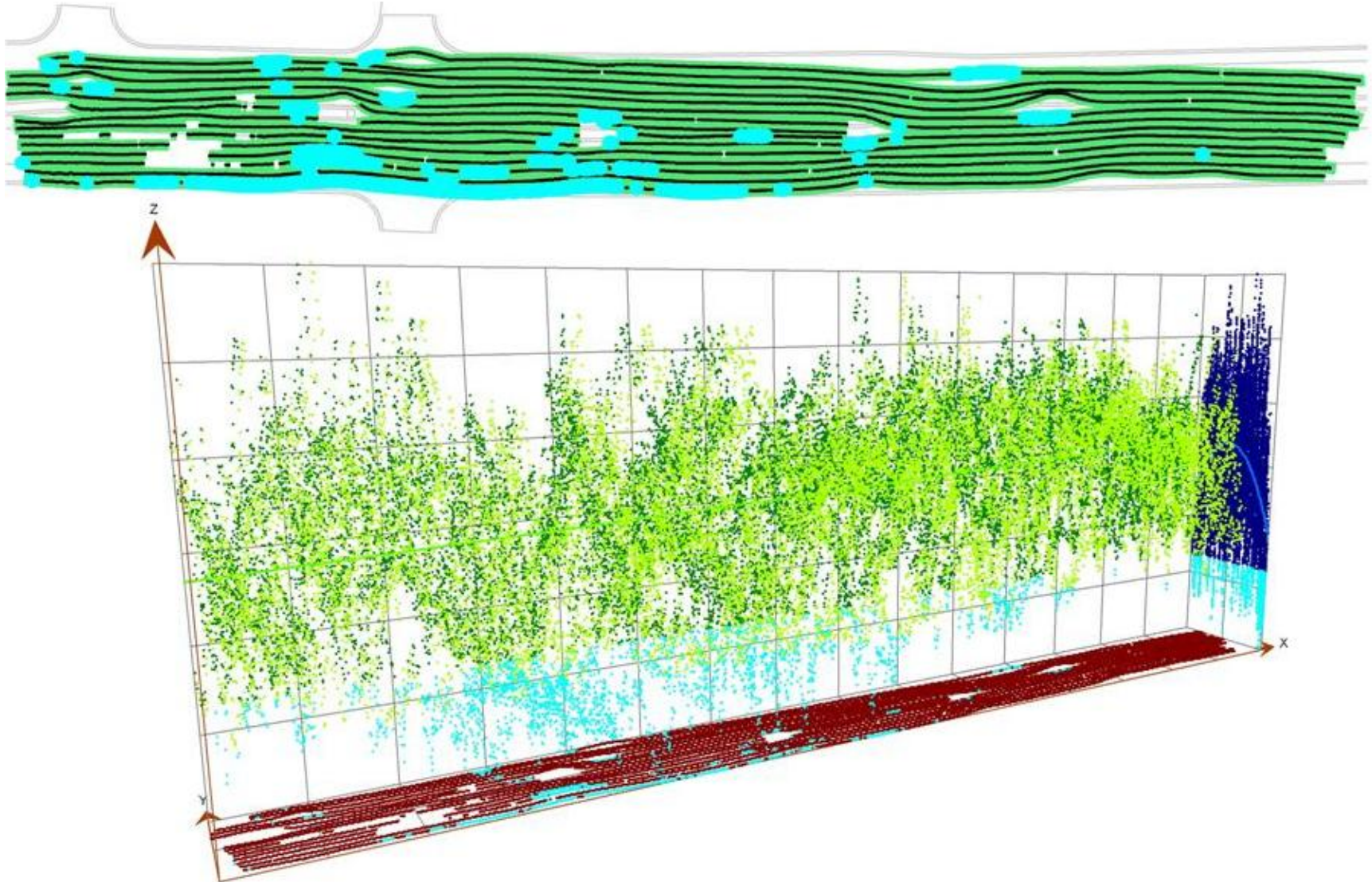
Geostatistical Analysis



Interactive Histogram



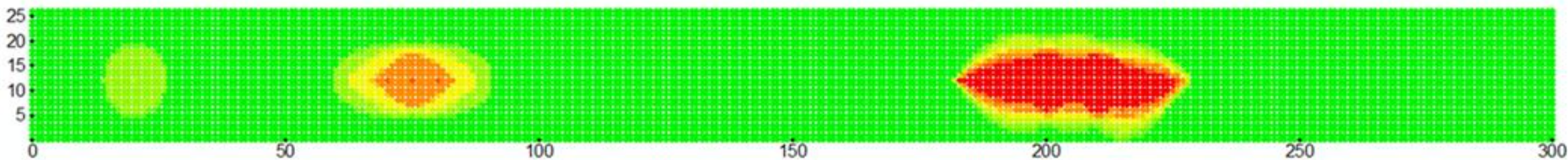
3D Graphical Representation



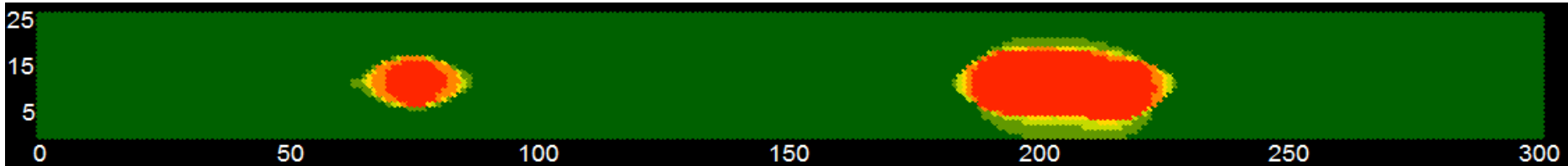
95% passing

- ▶ Compute average compaction value at each grid point at various radii
- ▶ Binary data of points that fell below the 5th percentile
- ▶ Color indicates number of times the point fell into this criteria for the various radii

Synthetic Compaction Value Data

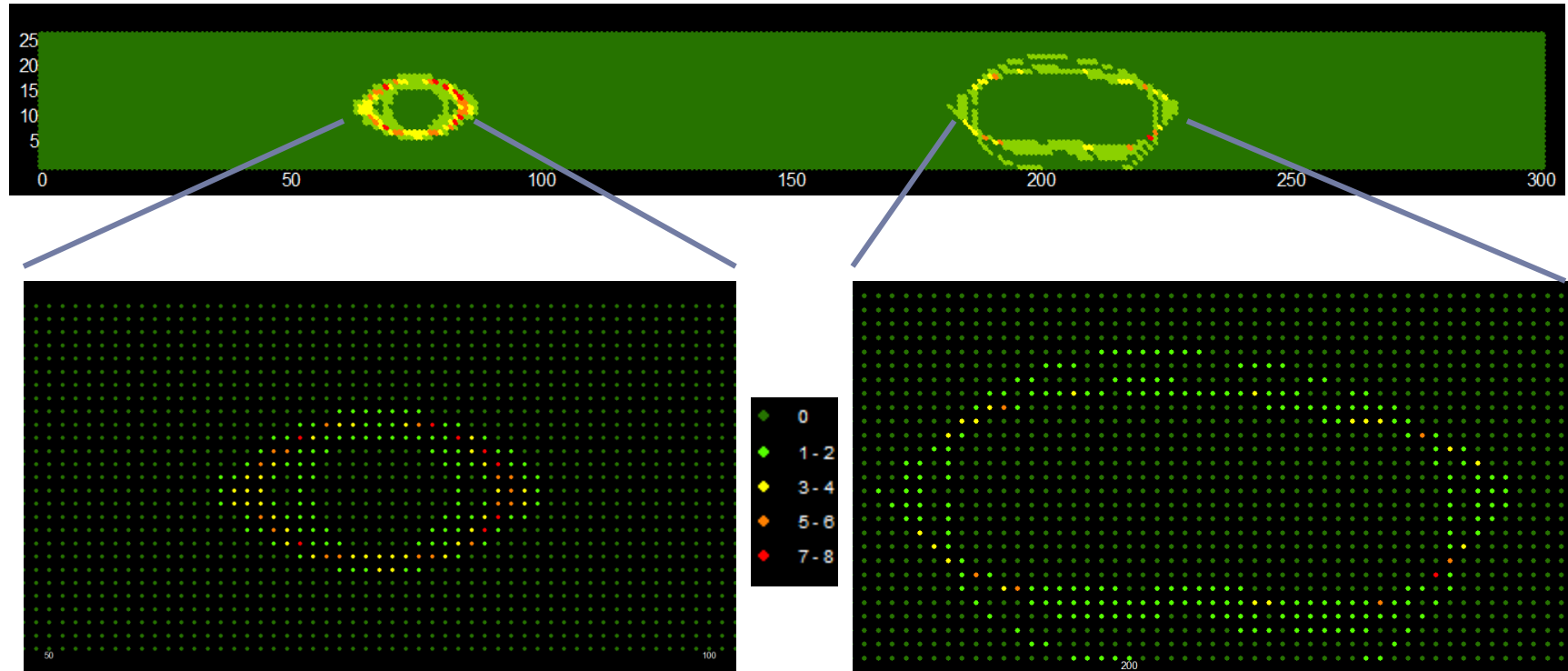


Count of times location is below 5th percentile



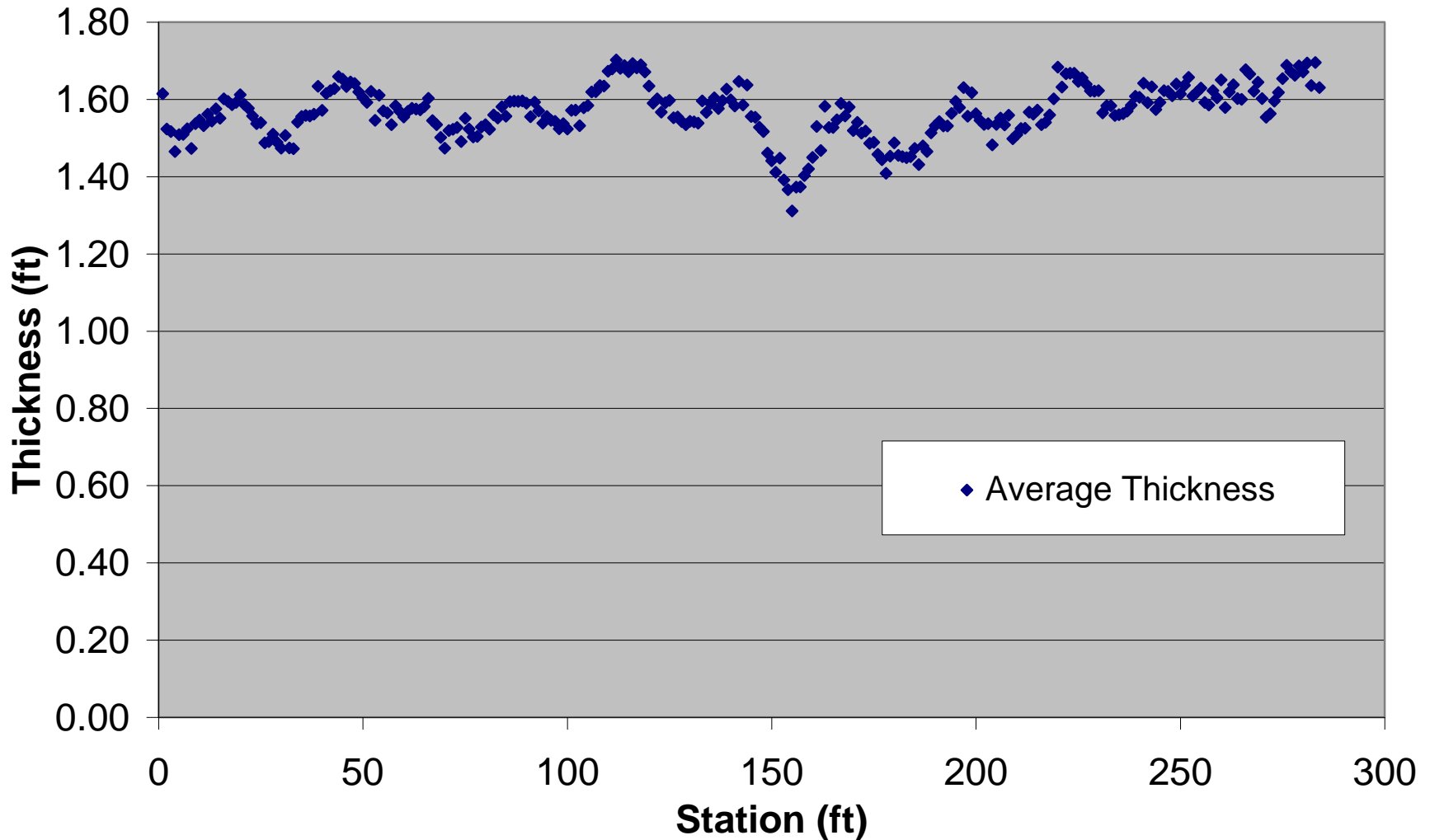
95% passing sampling location

- ▶ Color indicates number of times the point fell between the 4th and 6th percentile

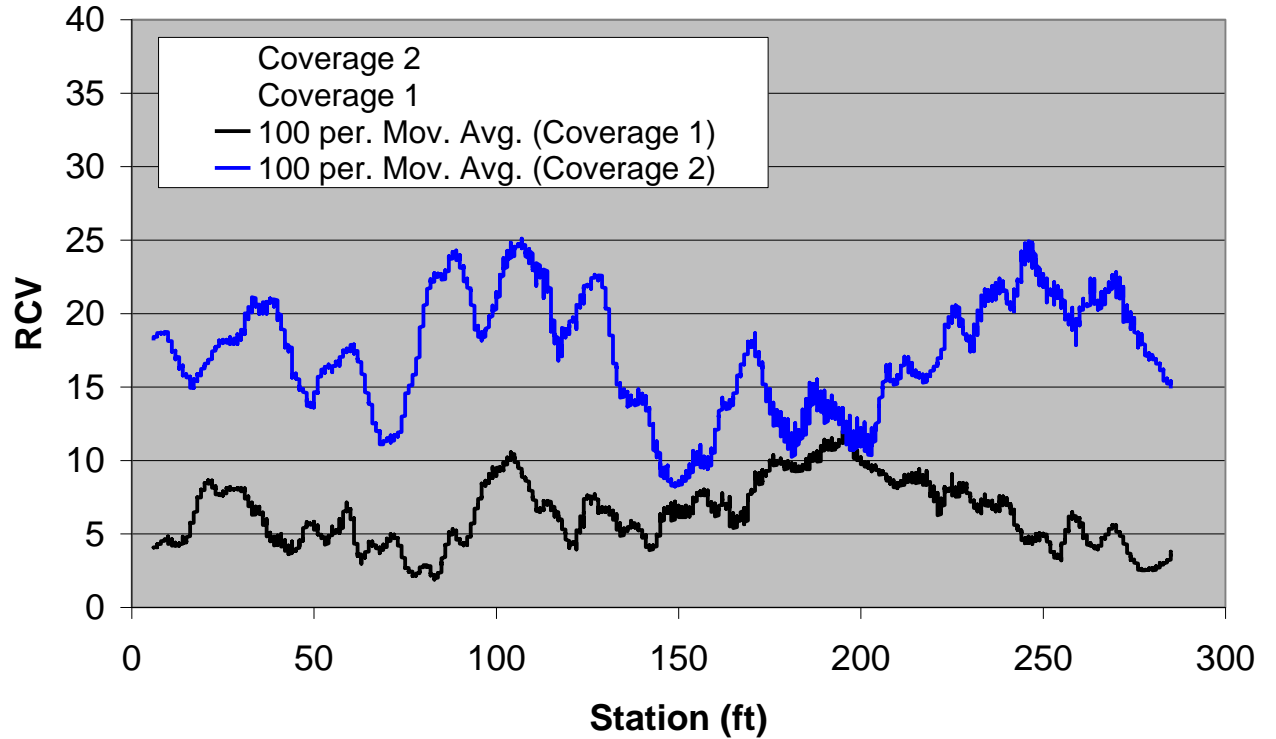
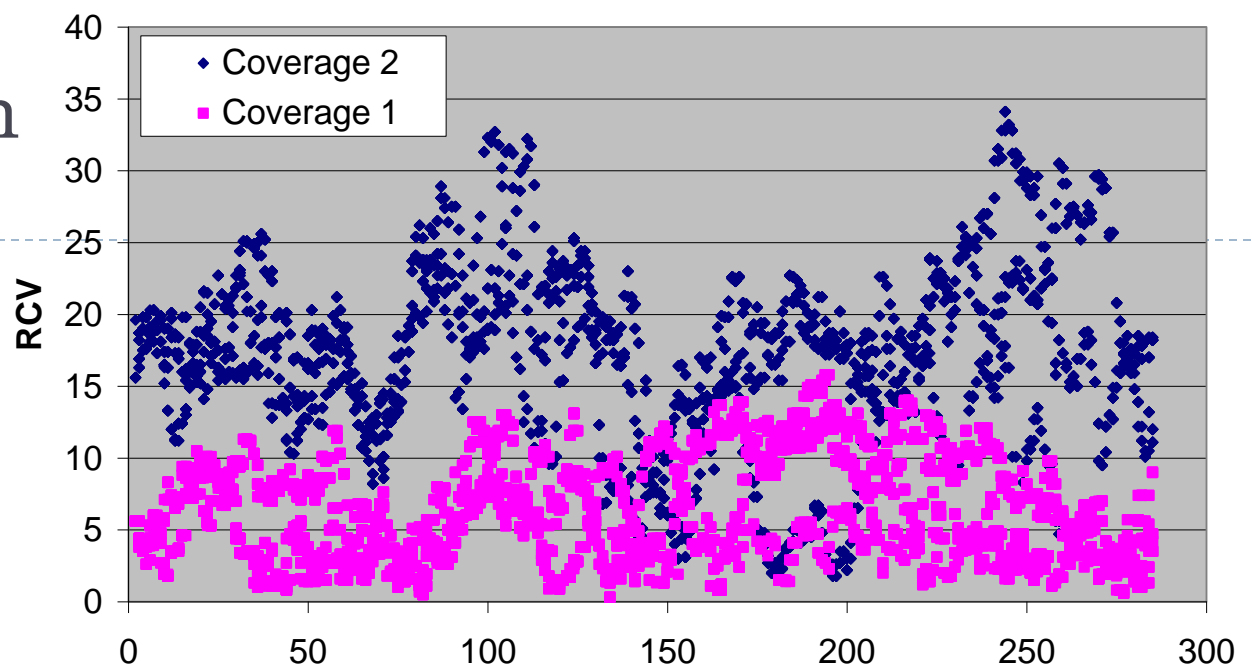


Comparing Lifts

Estimating Lift Thickness



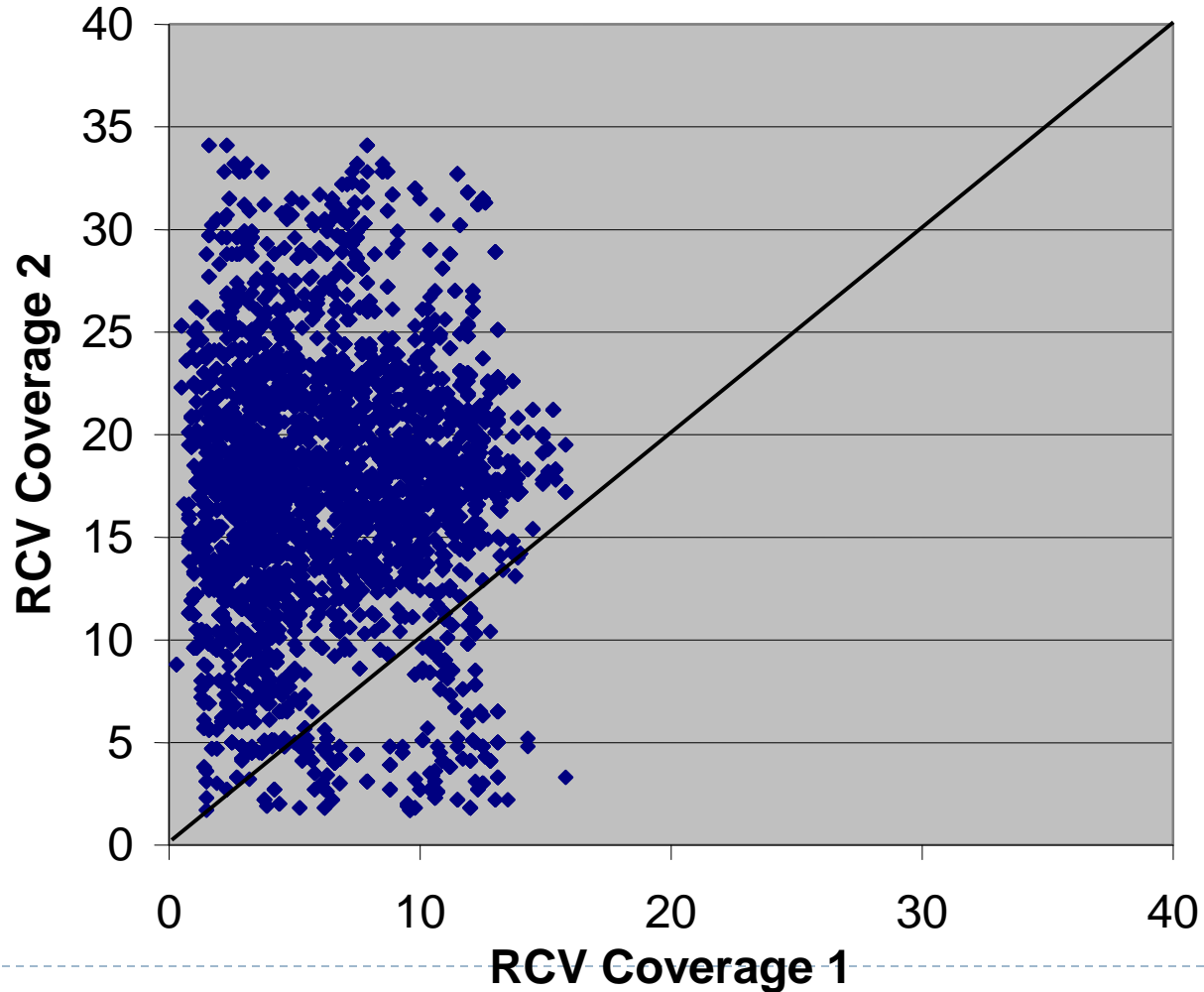
Compaction Value



Lift Comparison

Compaction Value

Moment of Improvement



Lessons Learned

- ▶ Post processing and visualization of IC data is a powerful tool for engineers and inspectors
- ▶ GIS software provides the visualization needed, but is unwieldy for field use
- ▶ FWD tests correlate reasonably well with IC measurements
- ▶ LWD and DCP tests correlate reasonably well
- ▶ LWD, DCP, and nuclear density tests do not correlate well with IC data because of the differences in test details



Conclusions

▶ Intelligent compaction

- ▶ Documents the entire lift, providing information between the individual quality assurance point tests.
- ▶ Documents the uniformity of a section of compacted roadway.
- ▶ Assists inspectors in best locating quality assurance test locations, thus making these field tests more valuable.

▶ Post processing

- ▶ Classic example of “Drowning in Data”
- ▶ Currently validate, store, and display of IC data
- ▶ Complete coverage of IC data shown tremendous potential
- ▶ More work needs to be done on analysis, specifically in field

