Pathways of a conservative contaminant: Infiltration, fracture conduits, and re-emergence of chloride in wells and streams

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Why study chloride?

- Road salt is applied widely in Maine and chloride is a common contaminant in groundwater and surface waters.
- Chloride is a conservative contaminant, so there are fewer variables to consider in contaminant migration.
- There is a large data set available from Maine DOT pre-construction sampling.

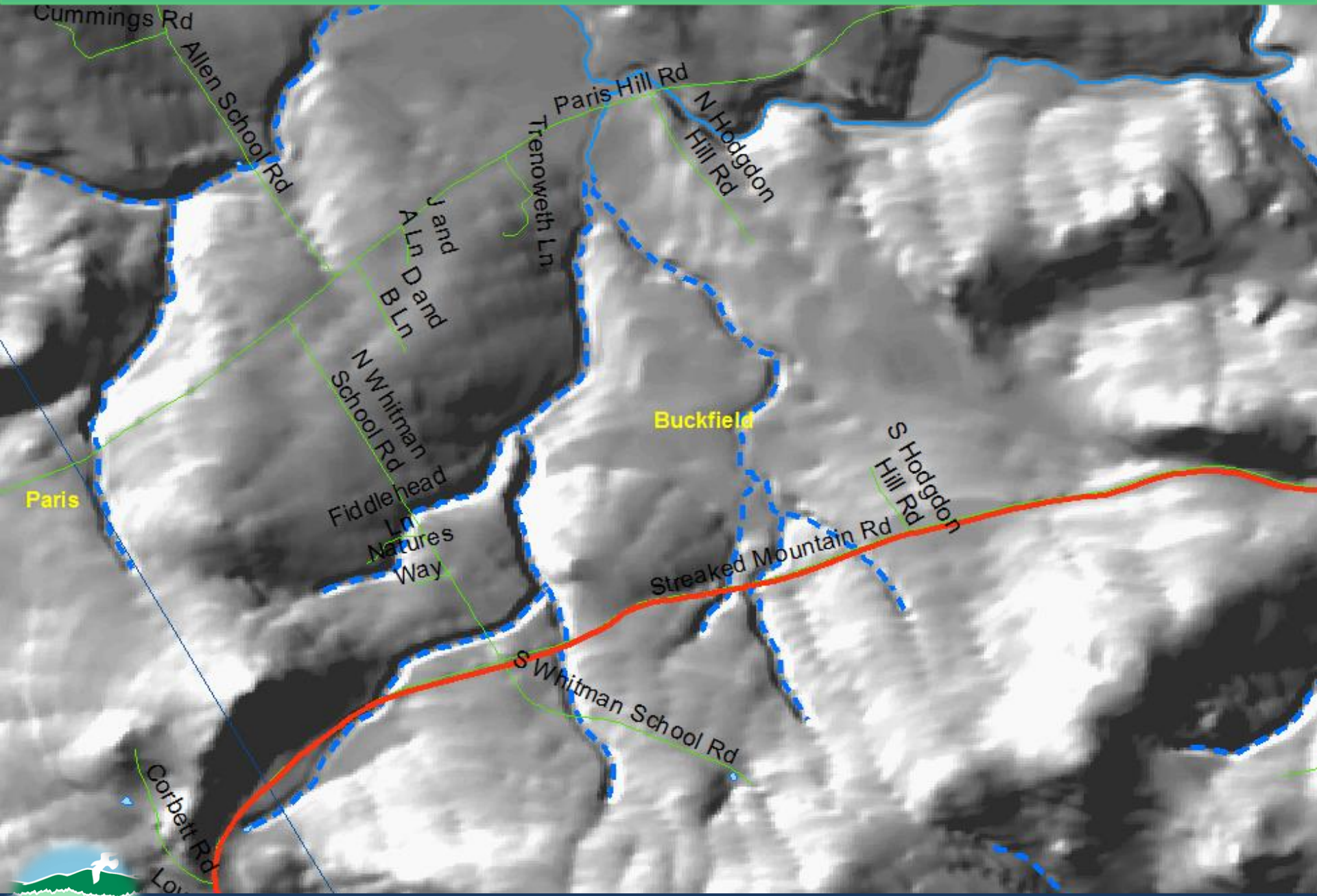
Why study chloride?

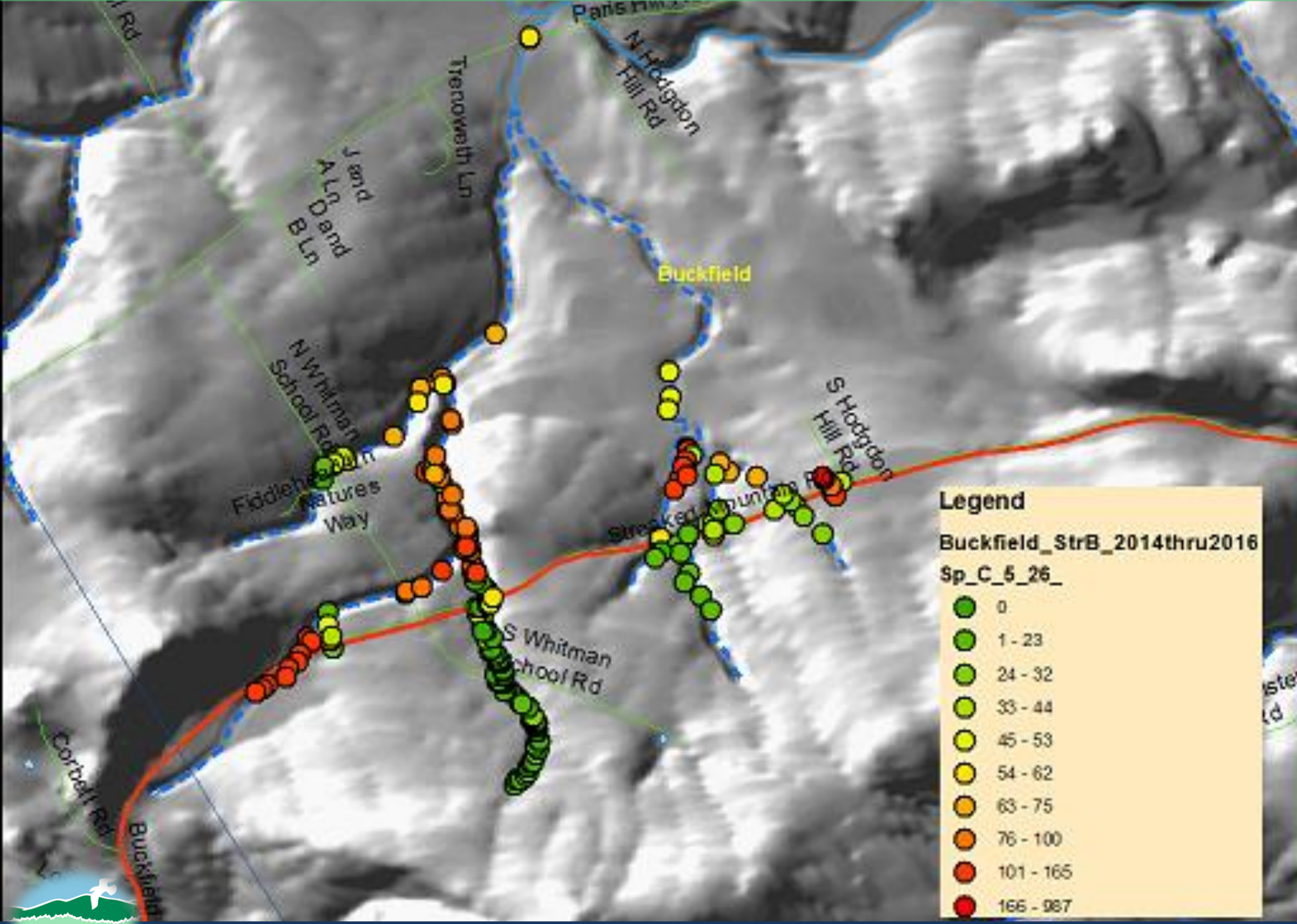
To develop and test risk models that could be applied to diverse conditions of slope, bedrock and overburden geology, and hydrologic soil groups.

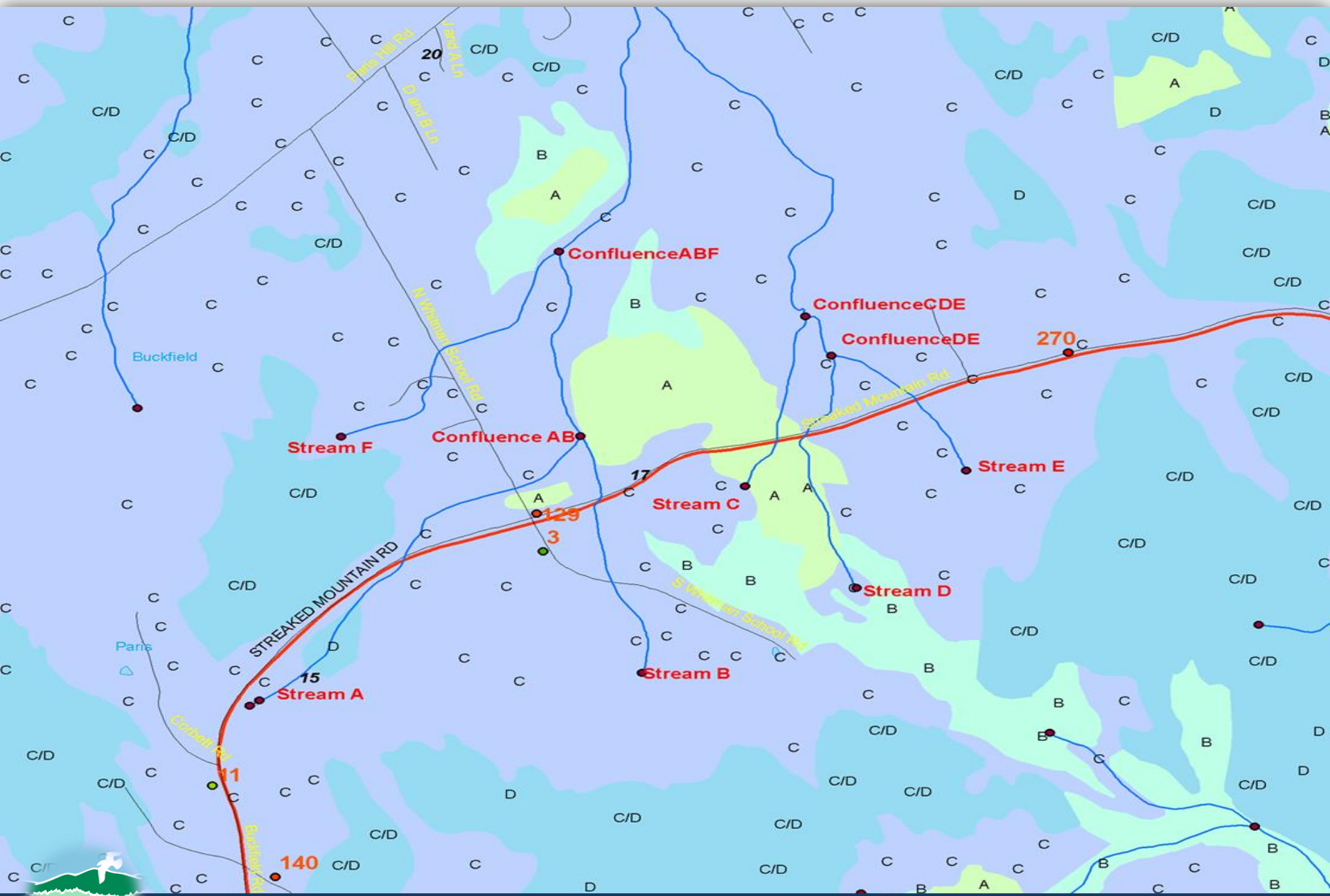
Chloride in Streams

- Many intermittent streams which cross roads to which salt is applied in the wintertime have been observed to show a distinct increase in conductivity downstream of the road

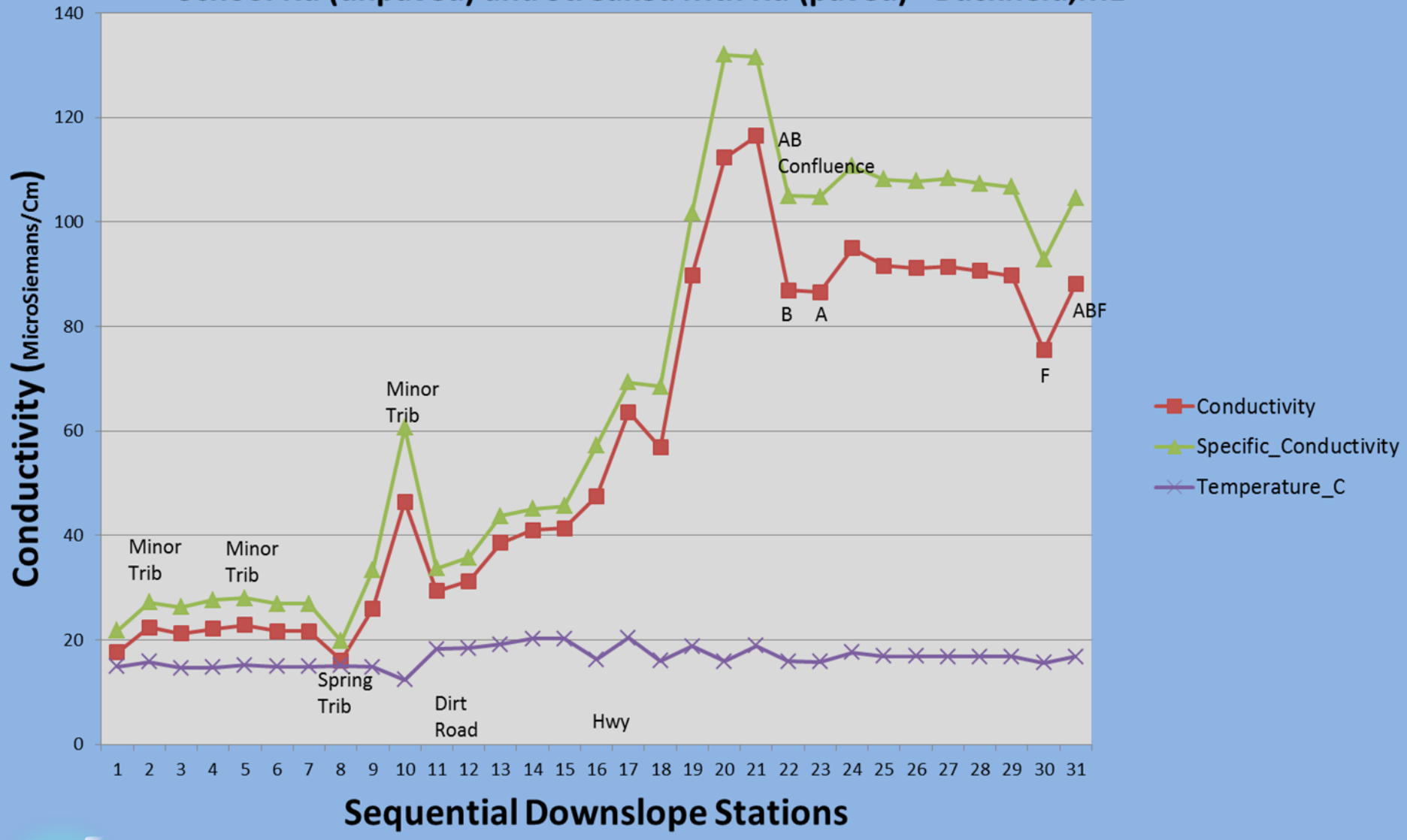
- Salt appears to be bound up in the soil and slowly released over the course of the year into groundwater and subsequently into the streams as base flow


Cummings Rd
Allen School Rd
Paris Hill Rd
N Hodgdon Hill Rd
Trenoweth Ln
J and A Ln
D and B Ln
N Whitman School Rd
Fiddlehead Ln
Natures Way
Buckfield
Paris
S Hodgdon Hill Rd
Streaked Mountain Rd
S Whitman School Rd
Corbett Rd

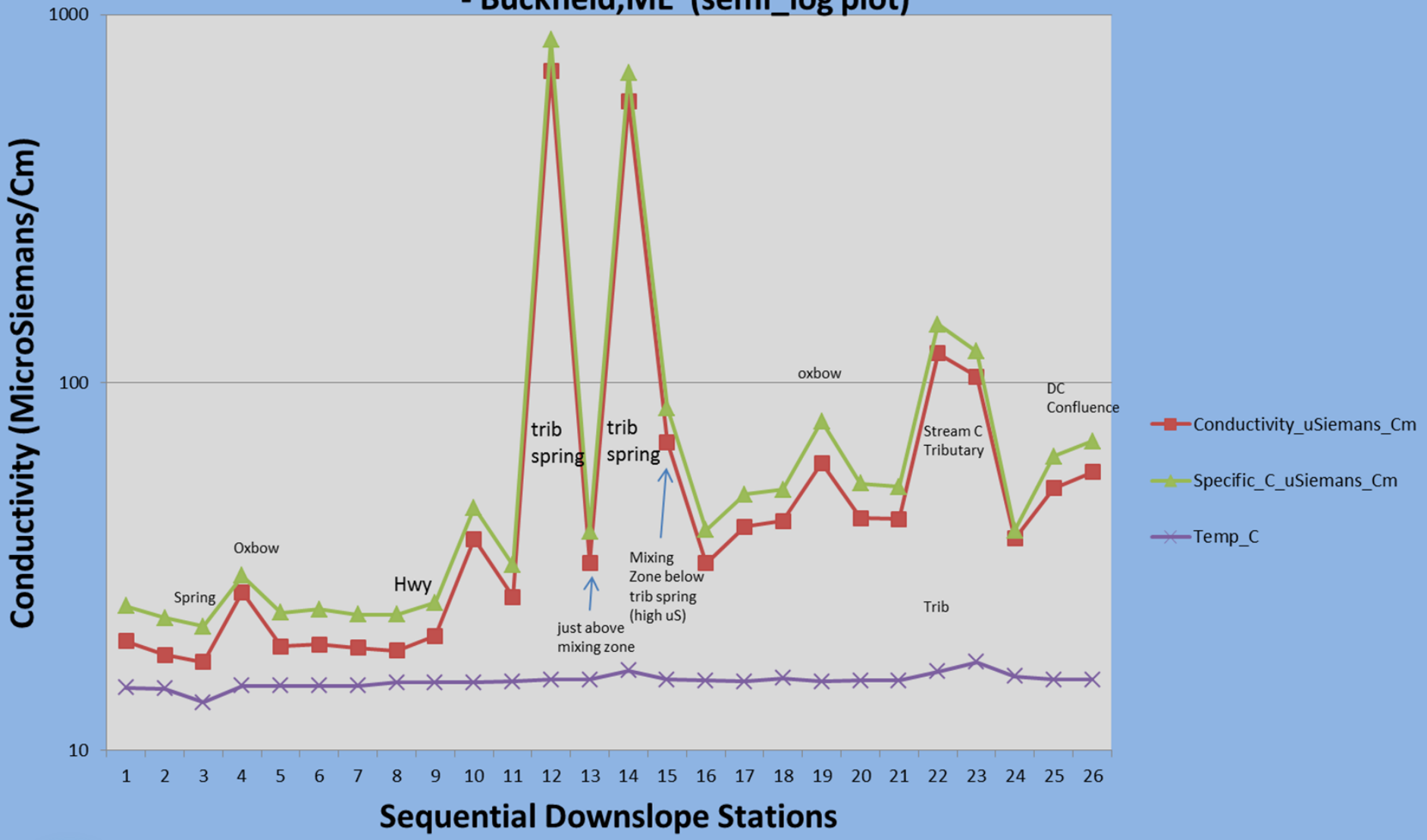

Trenoweth Ln
N Hodgdon Hill Rd
J and A Ln
D and B Ln
Buckfield
N Whitman School Rd
Fiddlehead Natures Way
S Hodgdon Hill Rd
S Whitman School Rd
Cortell Rd
Buckfield
Legend
Buckfield_StrB_2014thru2016
Sp_C_5_26_
0
1 - 23
24 - 32
33 - 44
45 - 53
54 - 62
63 - 75
76 - 100
101 - 165
166 - 987


ConfluenceABF
ConfluenceCDE
ConfluenceDE
270
Confluence AB
Stream F
Stream E
Stream C
Stream D
Stream B
Stream A
STREAKED MOUNTAIN RD
Buckfield
Paris
Parris Hill Rd
J and A Ln
D and B Ln
N Whitman School Rd
S Whitman School Rd
Streaked Mountain Rd
Conkell Rd
Buckfield Rd
20
17
129
3
15
11
140

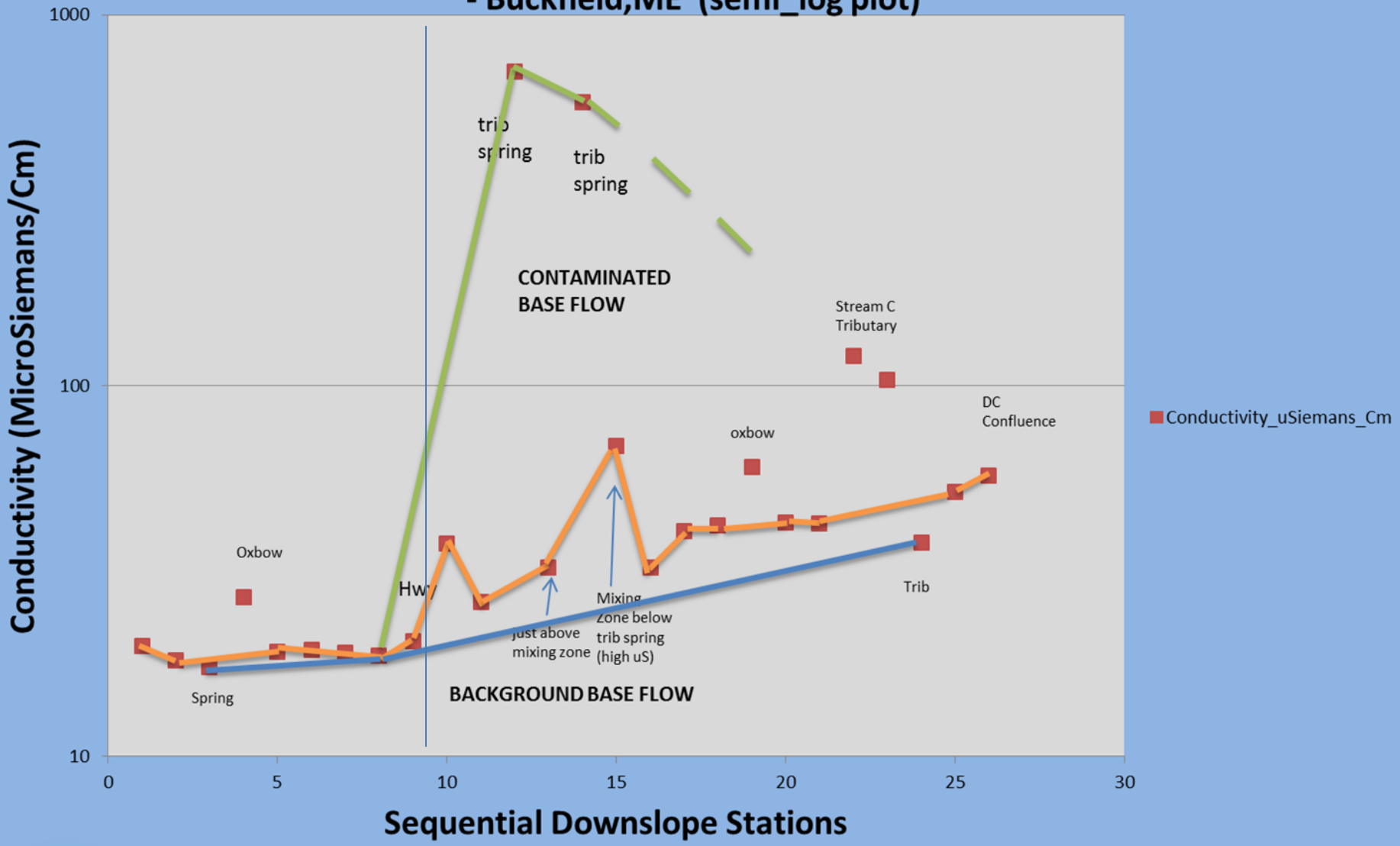
Stream (B to AB to ABF) Conductivity South to North across North Whitman School Rd (unpaved) and Streaked Mtn Rd (paved) - Buckfield,ME



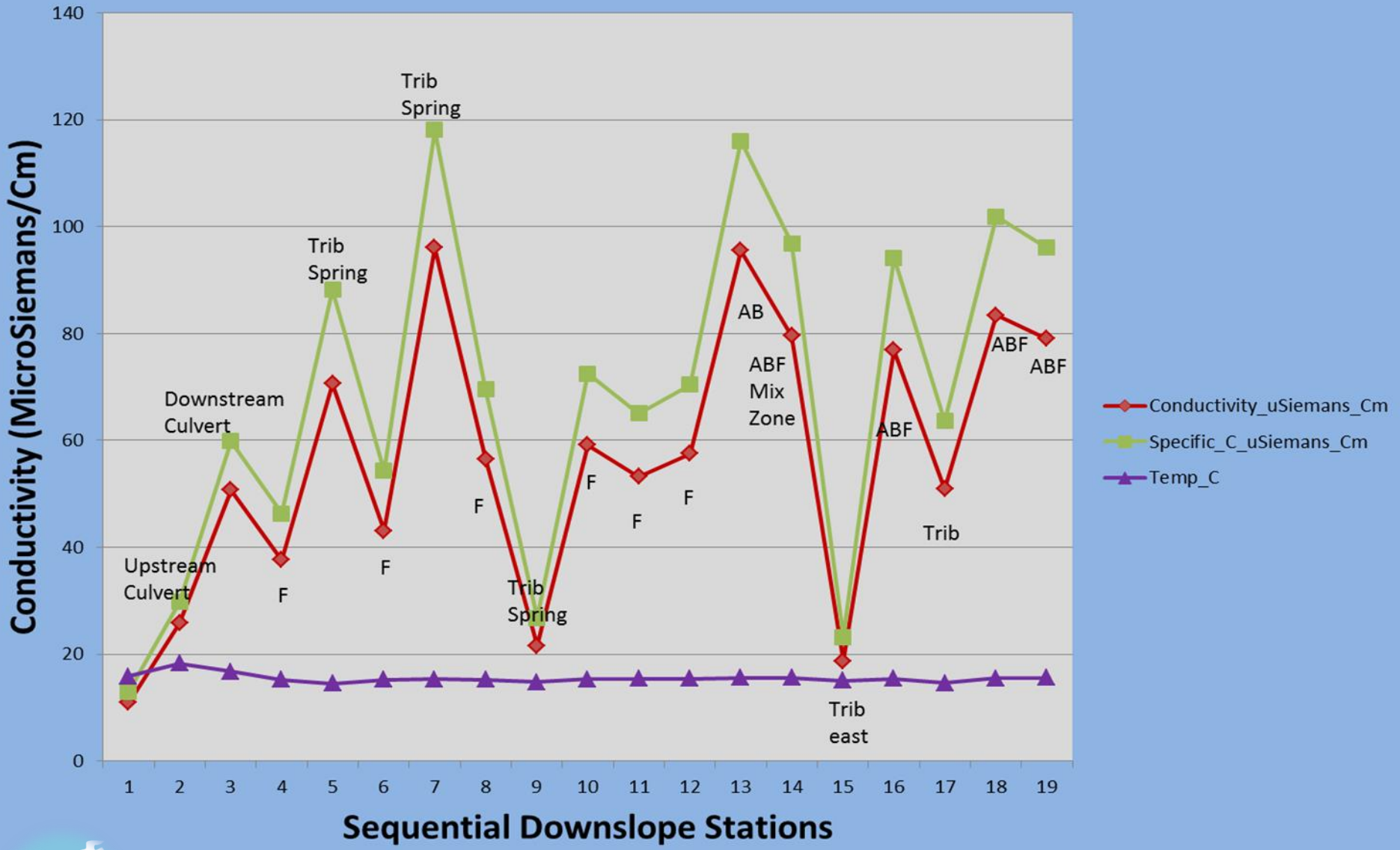
Stream (D) Conductivity South to North across Streaked Mountain Rd (Rt. 117) - Buckfield,ME (semi_log plot)



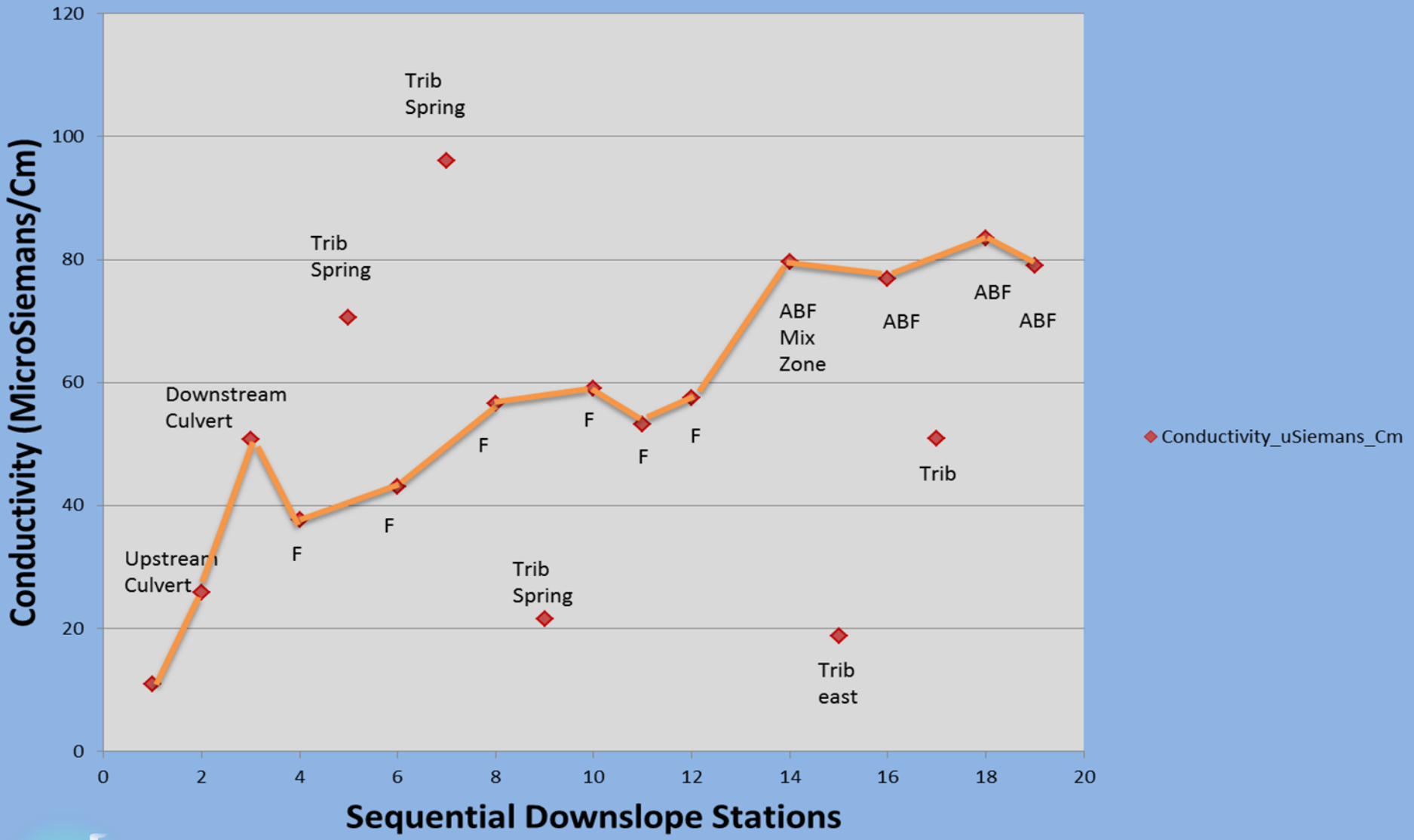
Stream (D) Conductivity South to North across Streaked Mountain Rd (Rt. 117) - Buckfield,ME (semi_log plot)



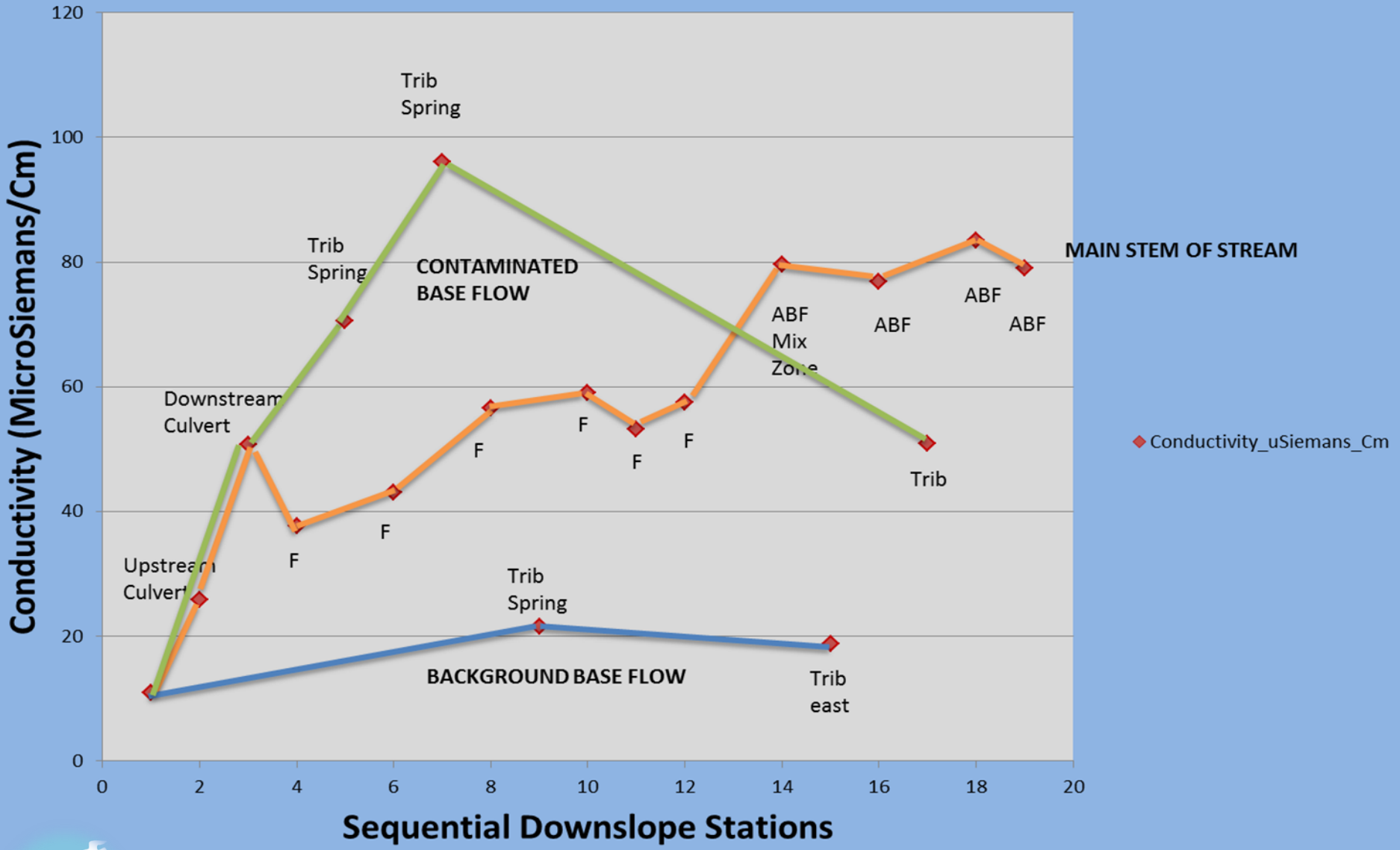
Stream (F to ABF) Conductivity Southwest to Northeast across North Whitman School Rd ((paved) - Buckfield,ME



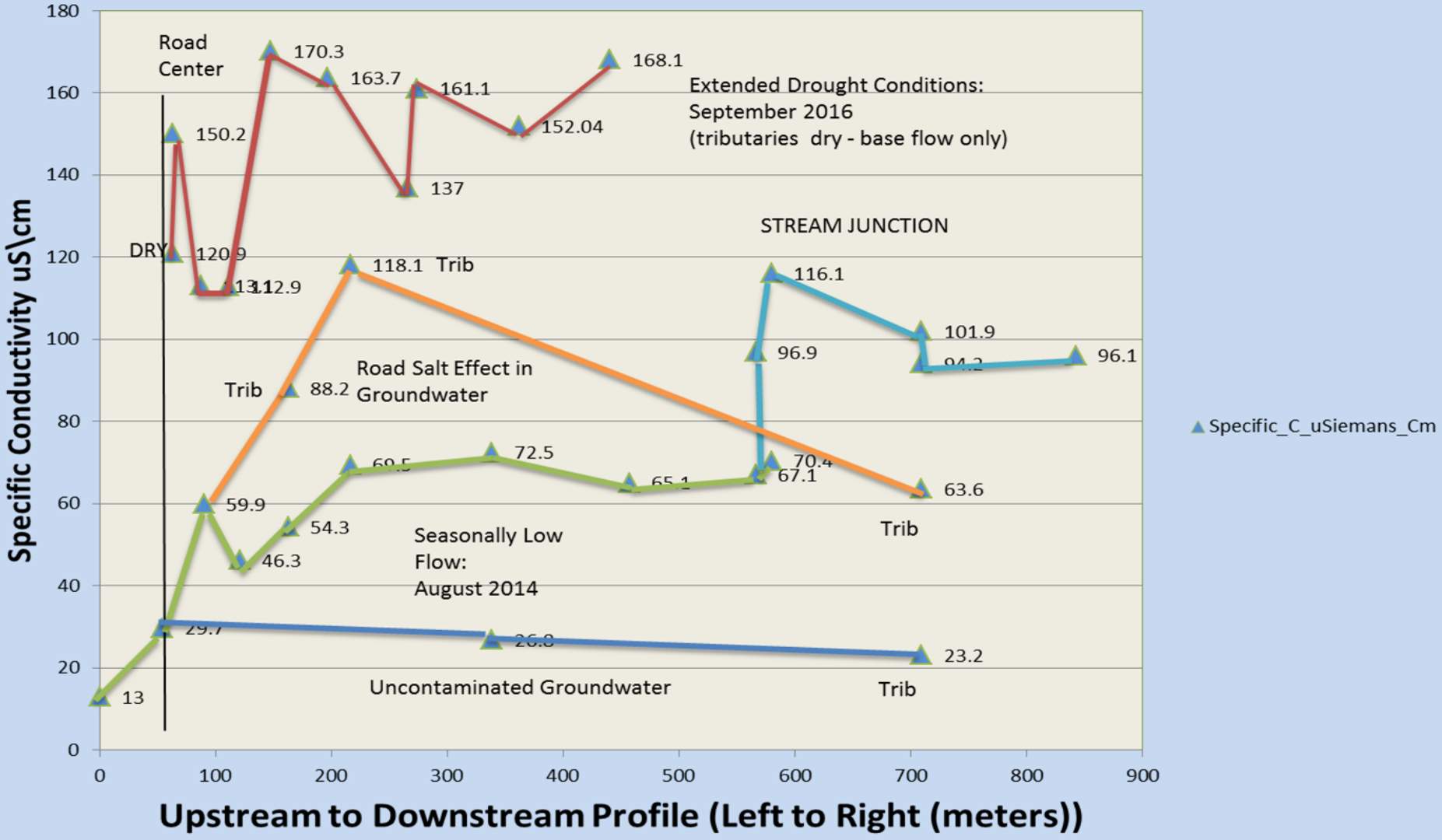
Stream (F to ABF) Conductivity Southwest to Northeast across North Whitman School Rd ((paved) - Buckfield,ME

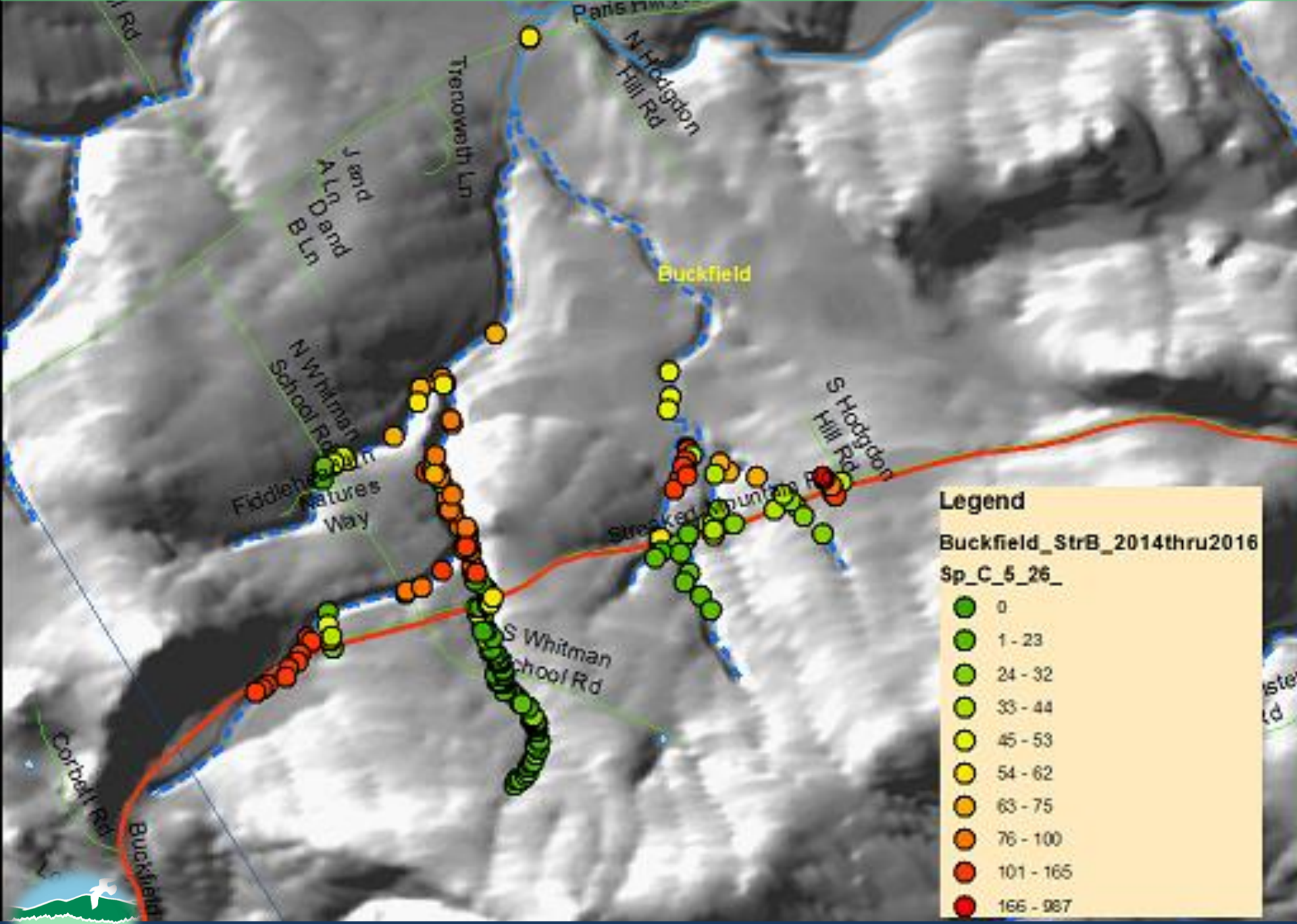


Stream (F to ABF) Conductivity Southwest to Northeast across North Whitman School Rd ((paved) - Buckfield,ME



Stream F in Buckfield on North Witham School Road - Mulltiyear results (2014- 2016)




Trenoweth Ln
N Hodgdon Hill Rd
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S Hodgdon Hill Rd
S Whitman School Rd
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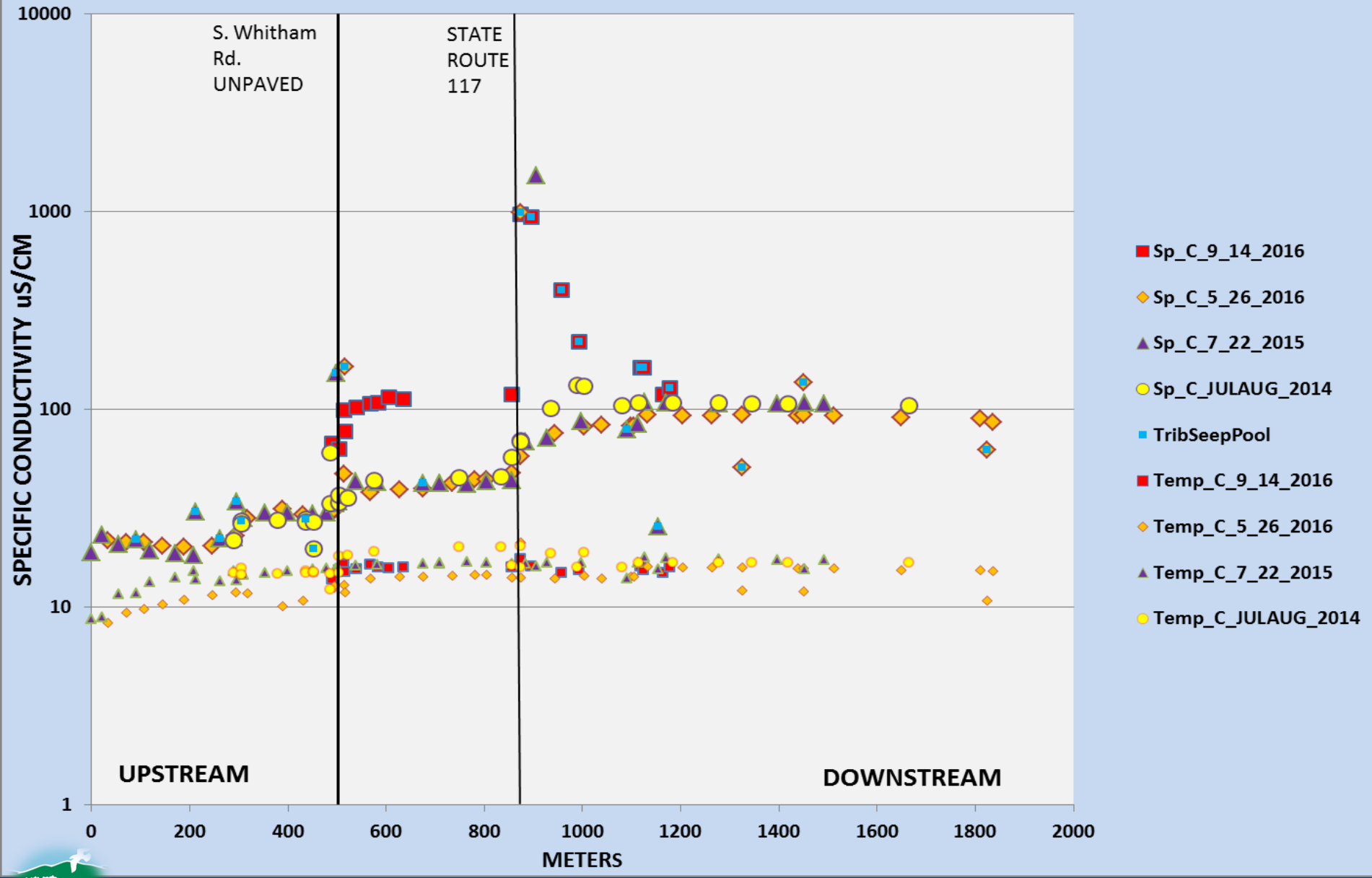
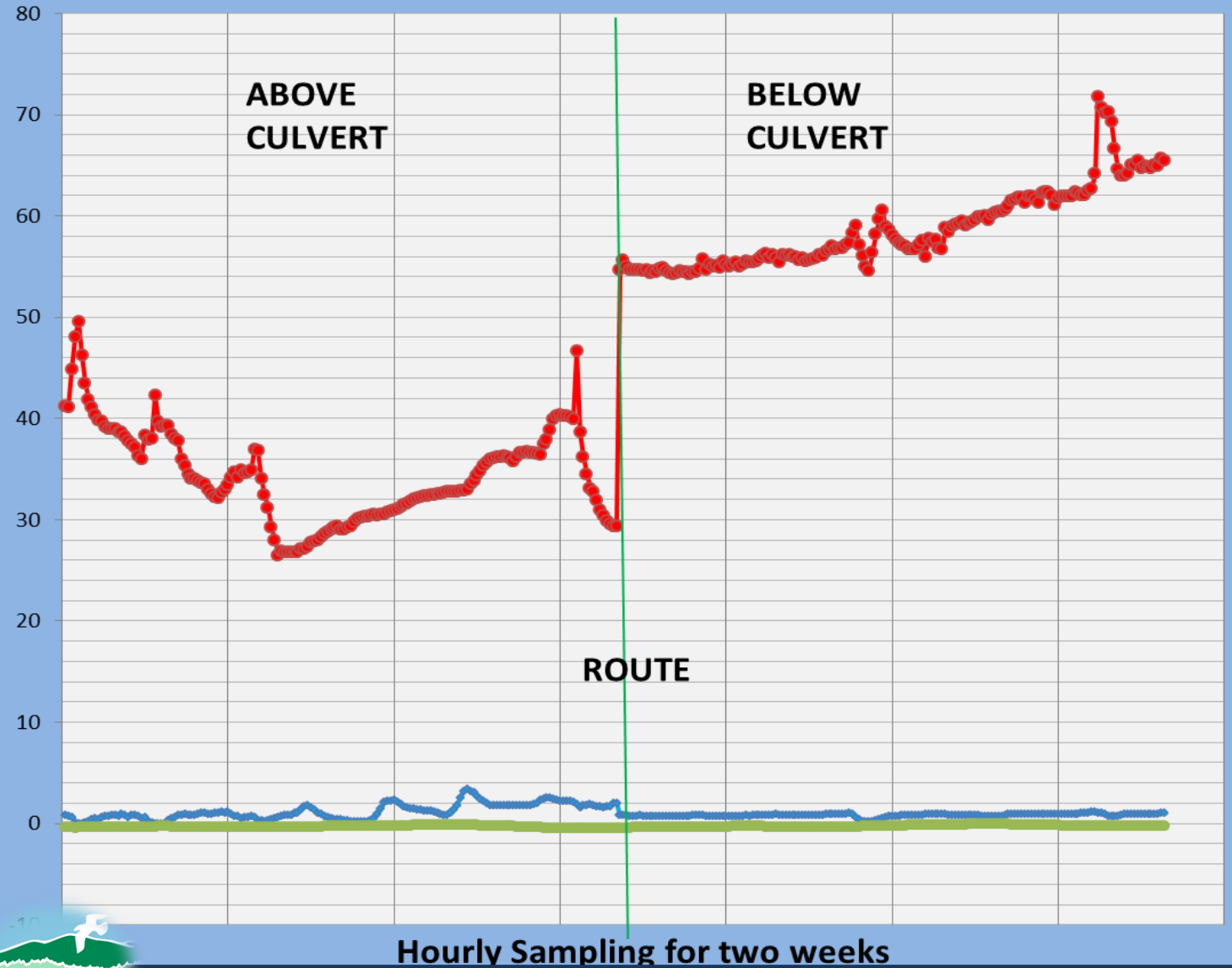
Legend
Buckfield_StrB_2014thru2016
Sp_C_5_26_
0
1 - 23
24 - 32
33 - 44
45 - 53
54 - 62
63 - 75
76 - 100
101 - 165
166 - 987

Stream (B to ABF) Specific Conductivity South to North from Streaked Mountain downstream across South Whitman School Road and State Route 117 in Buckfield

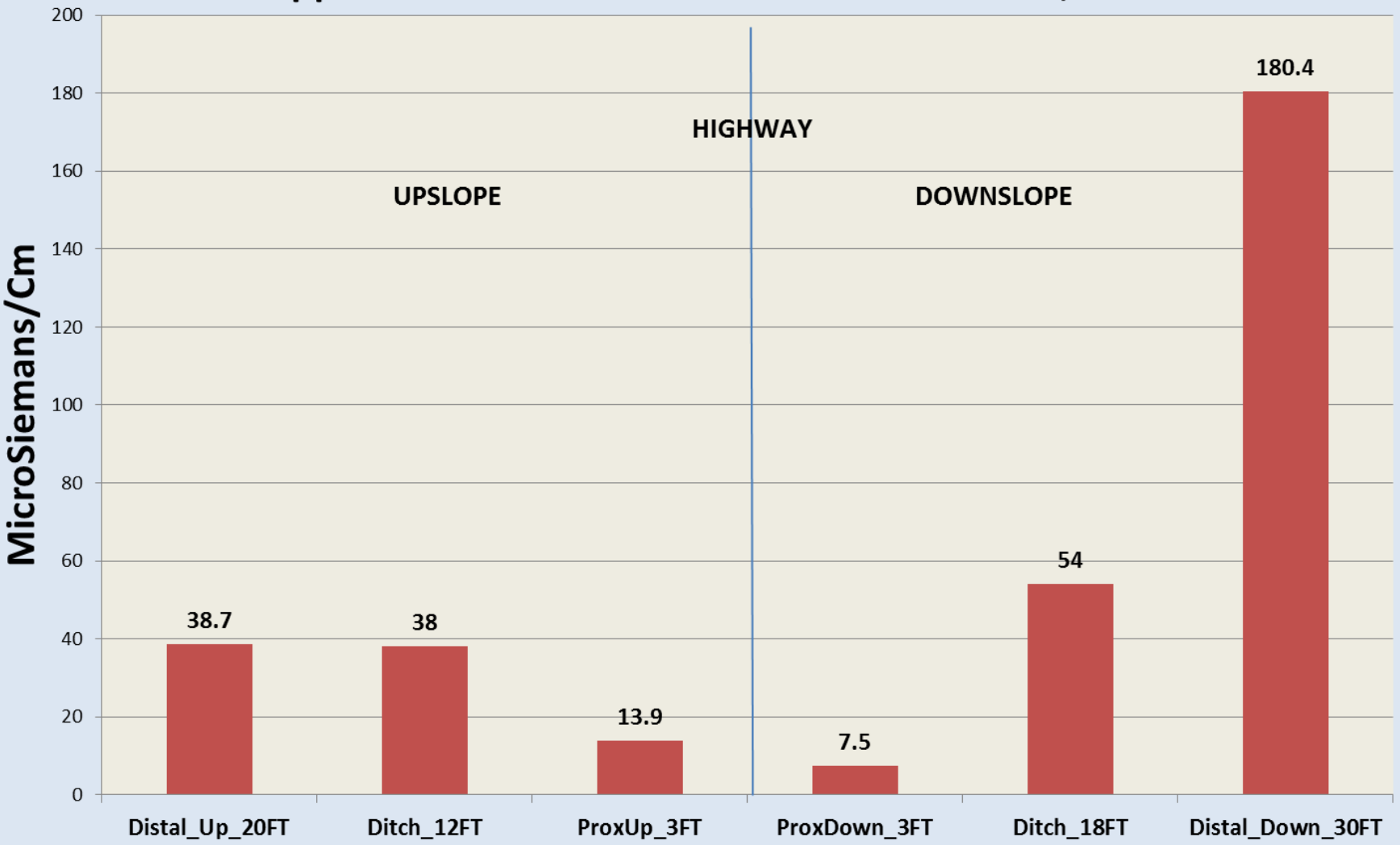


Buckfield Stream B below/above Route 117 culvert
February 16 to March 2, 2017 (hourly)



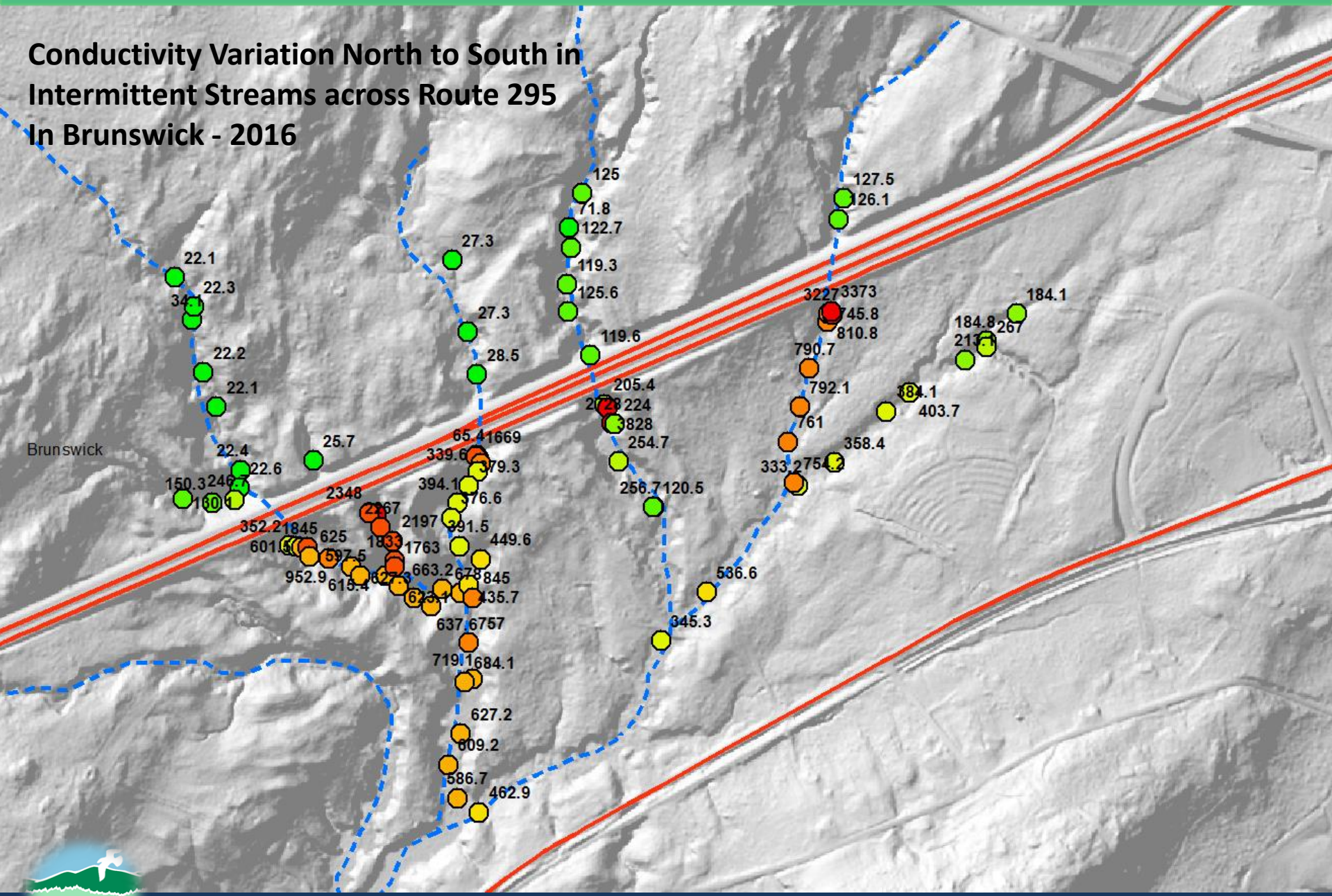
Hourly Sampling for two weeks

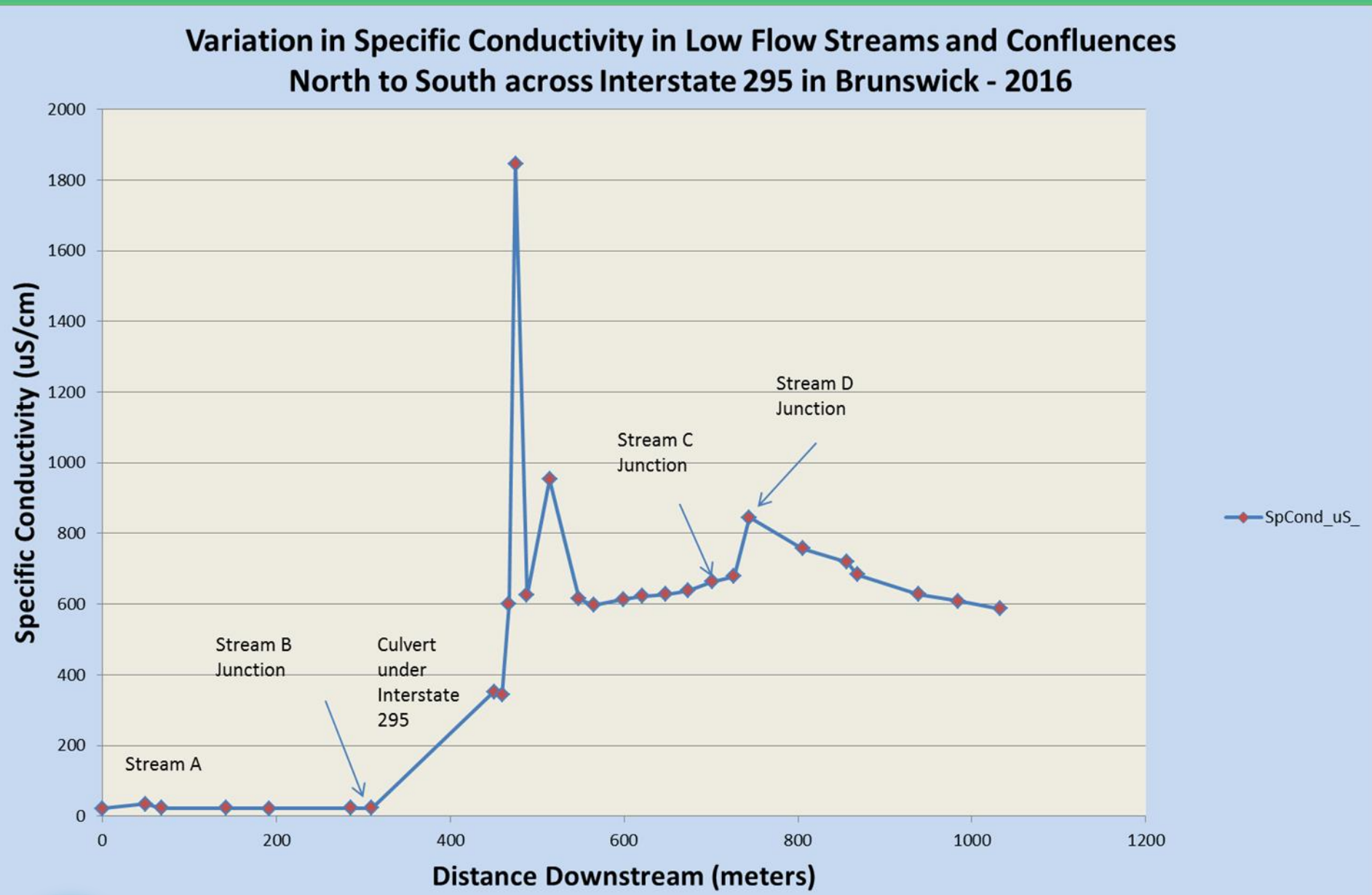
Soil Slurry Conductivity Readings Upslope and Downslope from Rt 117, approx. 500 feet East of N. Witham School Rd, Buckfield



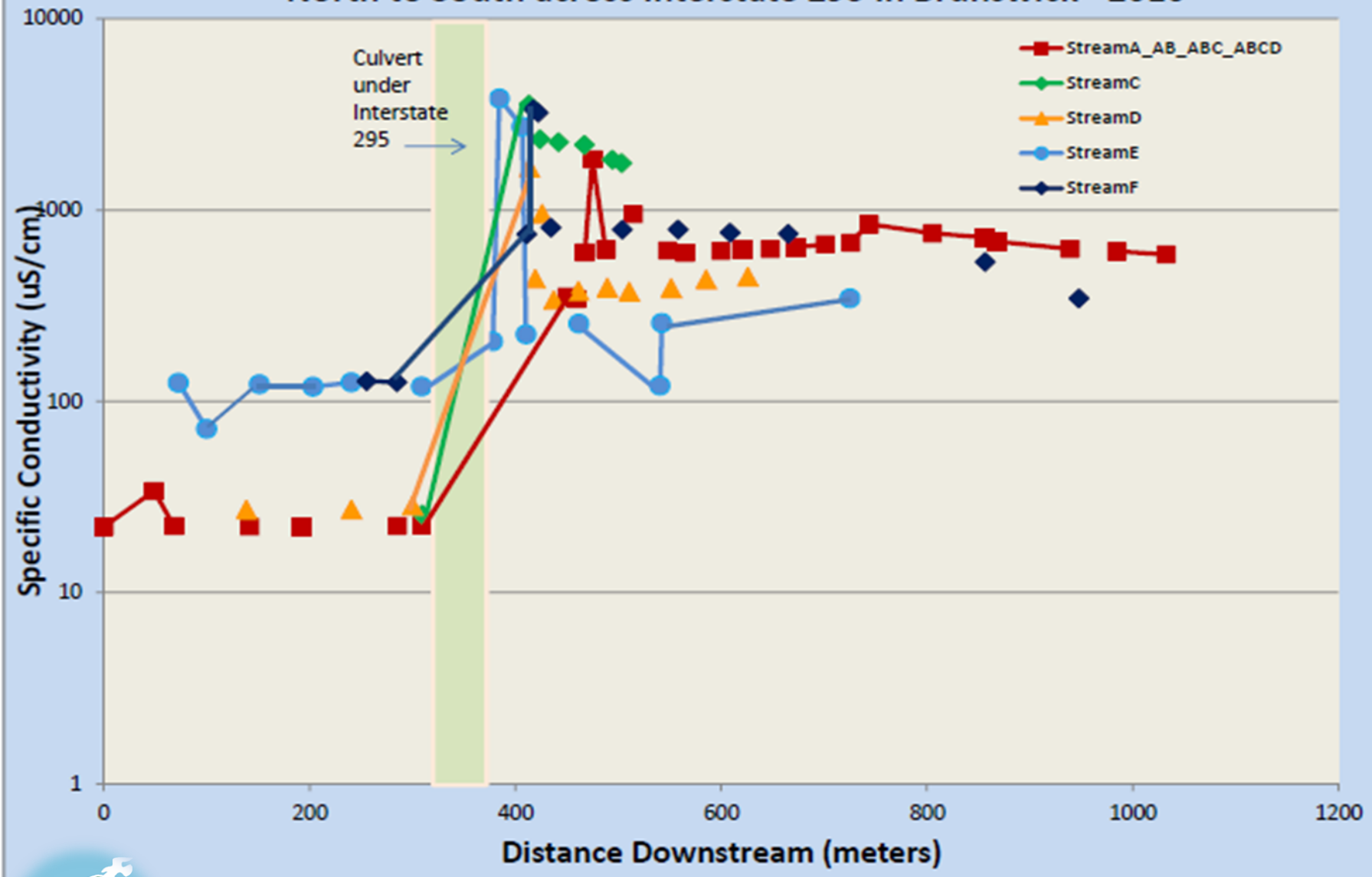
Spatial Road Salt Test Zones Upslope and Downslope from Rt 117

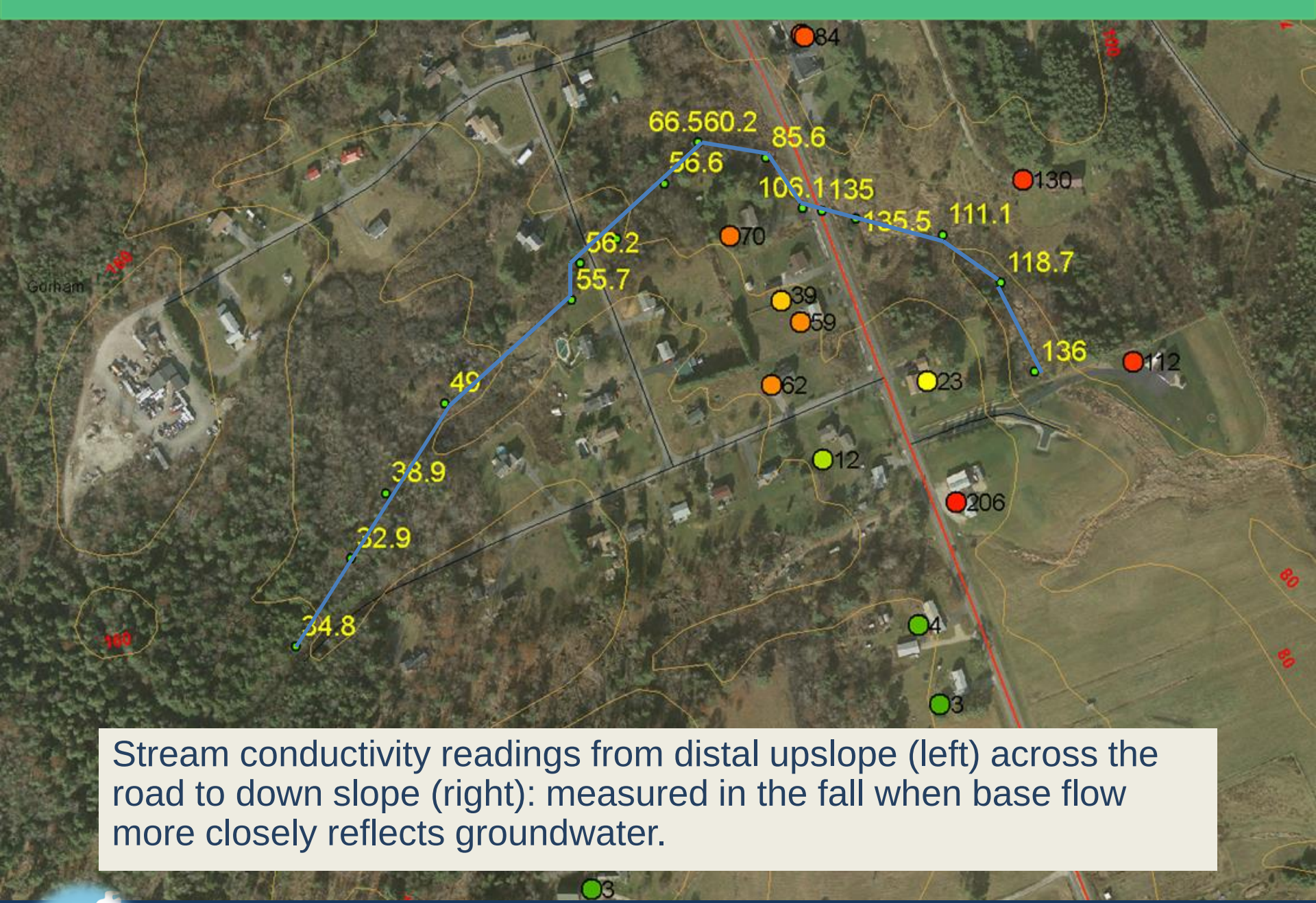
Conductivity Variation North to South in Intermittent Streams across Route 295 In Brunswick - 2016



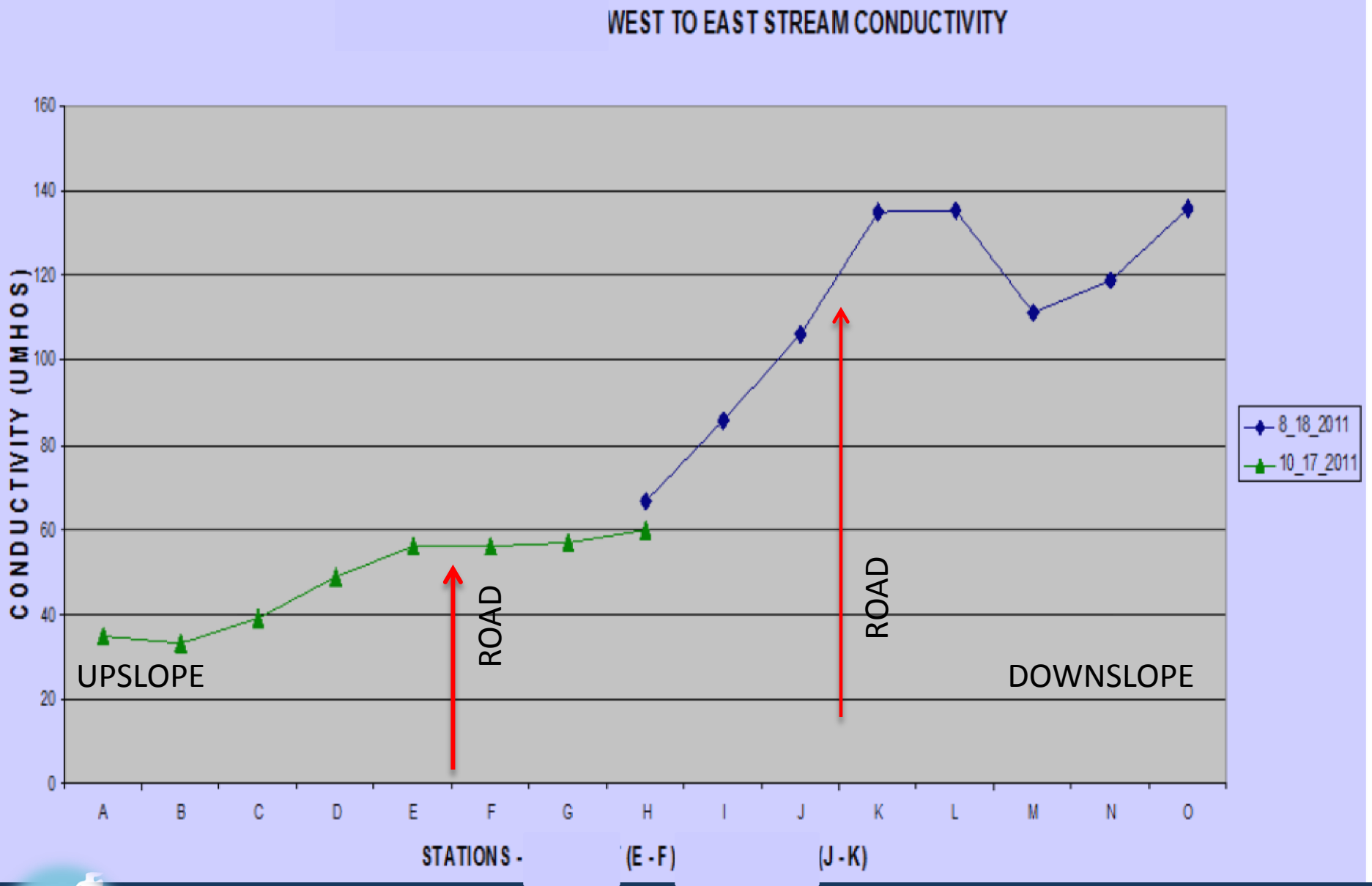

Variation in Specific Conductivity in Low Flow Streams and Confluences
North to South across Interstate 295 in Brunswick - 2016
Specific Conductivity (uS/cm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
Distance Downstream (meters)
Stream A
Stream B Junction
Culvert under Interstate 295
Stream C Junction
Stream D Junction
SpCond_uS_

Variation in Specific Conductivity in Low Flow Streams and Confluences North to South across Interstate 295 in Brunswick - 2016





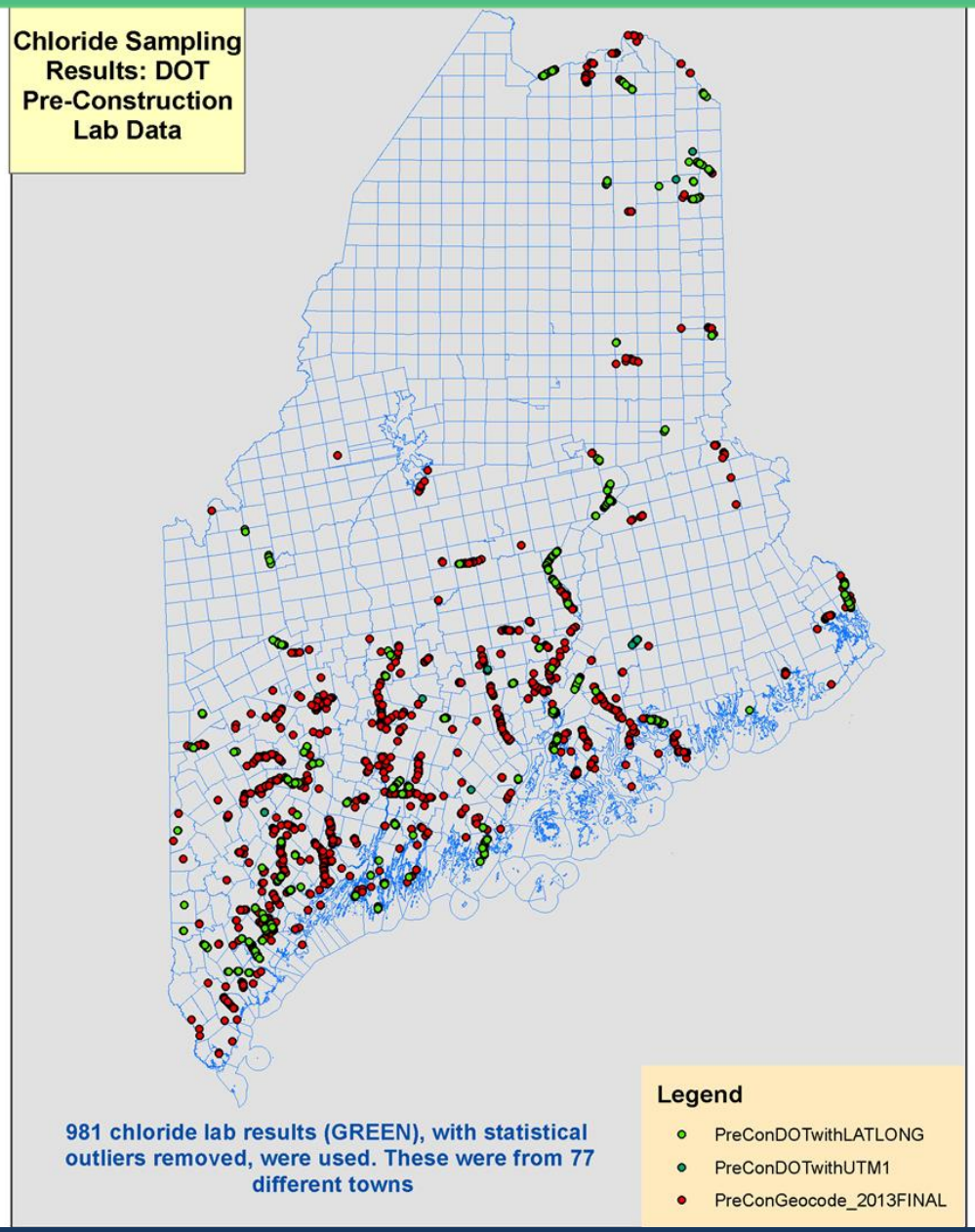
Stream conductivity readings from distal upslope (left) across the road to down slope (right): measured in the fall when base flow more closely reflects groundwater.


WEST TO EAST STREAM CONDUCTIVITY
CONDUCTIVITY (UMHOS)
160
140
120
100
80
60
40
20
0
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
STATIONS -
(E - F)
(J - K)
ROAD
ROAD
UPSLOPE
DOWNSLOPE
8_18_2011
10_17_2011

Chloride in Residential wells

- Maine DOT sampled over 5000 wells in pre-construction surveys during 2001 – 2016.
- 3000+ wells were spatially located by Maine DEP in the field.
- These were selected from over 150 different municipalities in spatially diverse geographic settings.
- Outliers (beyond the second standard deviation) were removed from chloride concentration data.

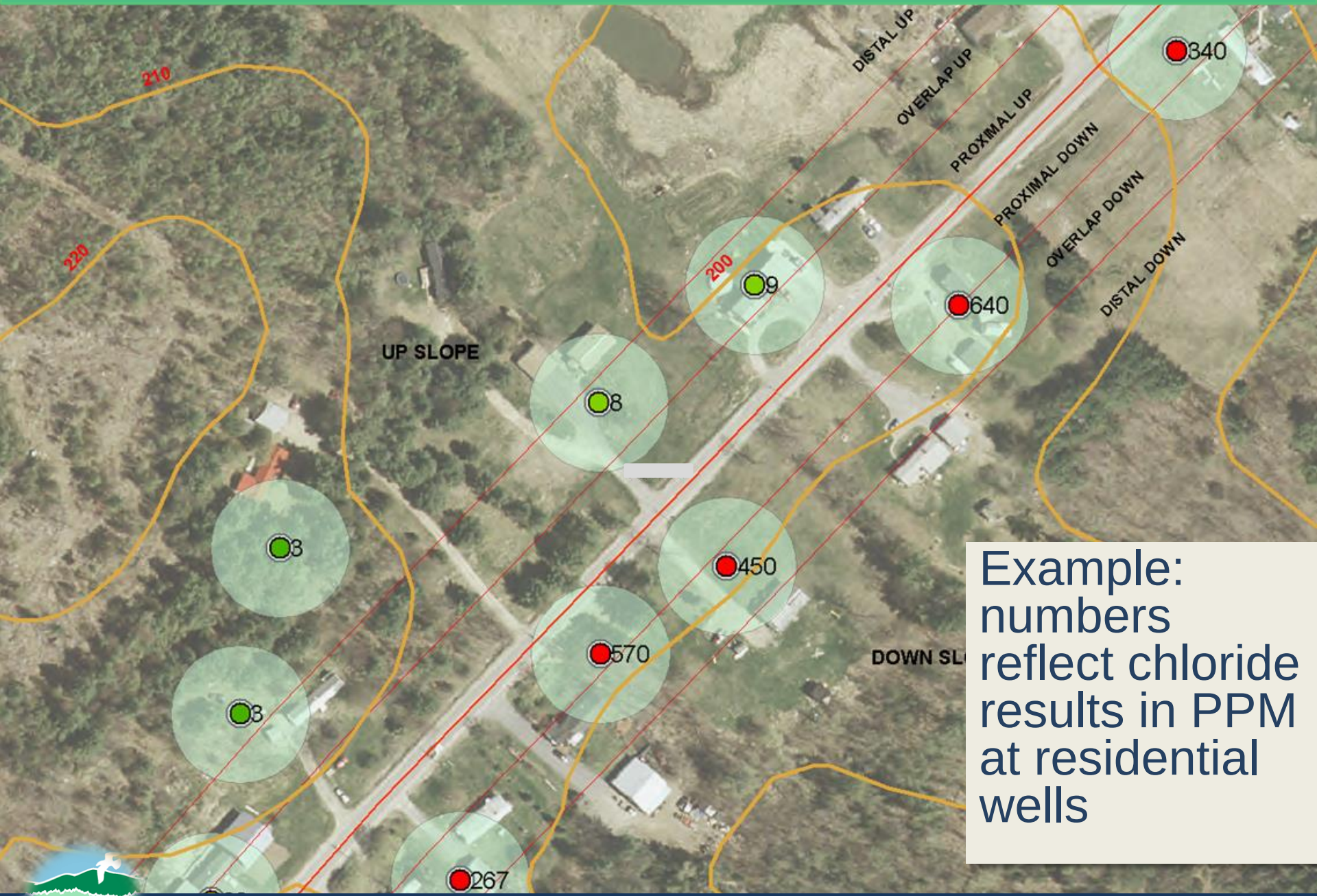
Chloride Sampling Results: DOT Pre-Construction Lab Data



981 chloride lab results (GREEN), with statistical outliers removed, were used. These were from 77 different towns

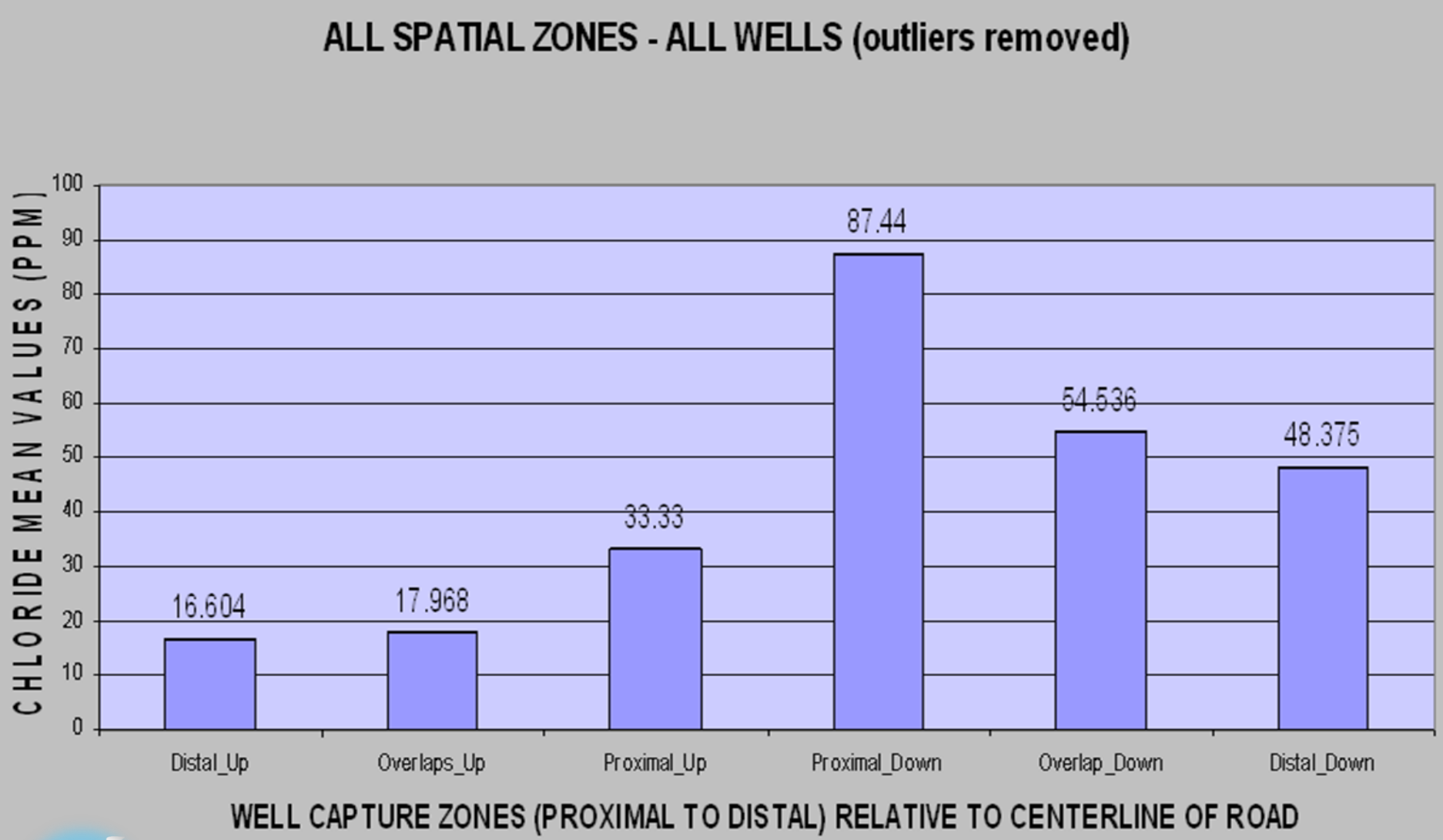
2D Spatial Parameters

- Well capture zone: 75-foot radius
- Proximal area: < 75 feet from road centerline
- Overlap zone: 75 - 150 feet from road centerline
- Distal zone: > 150 feet from road centerline

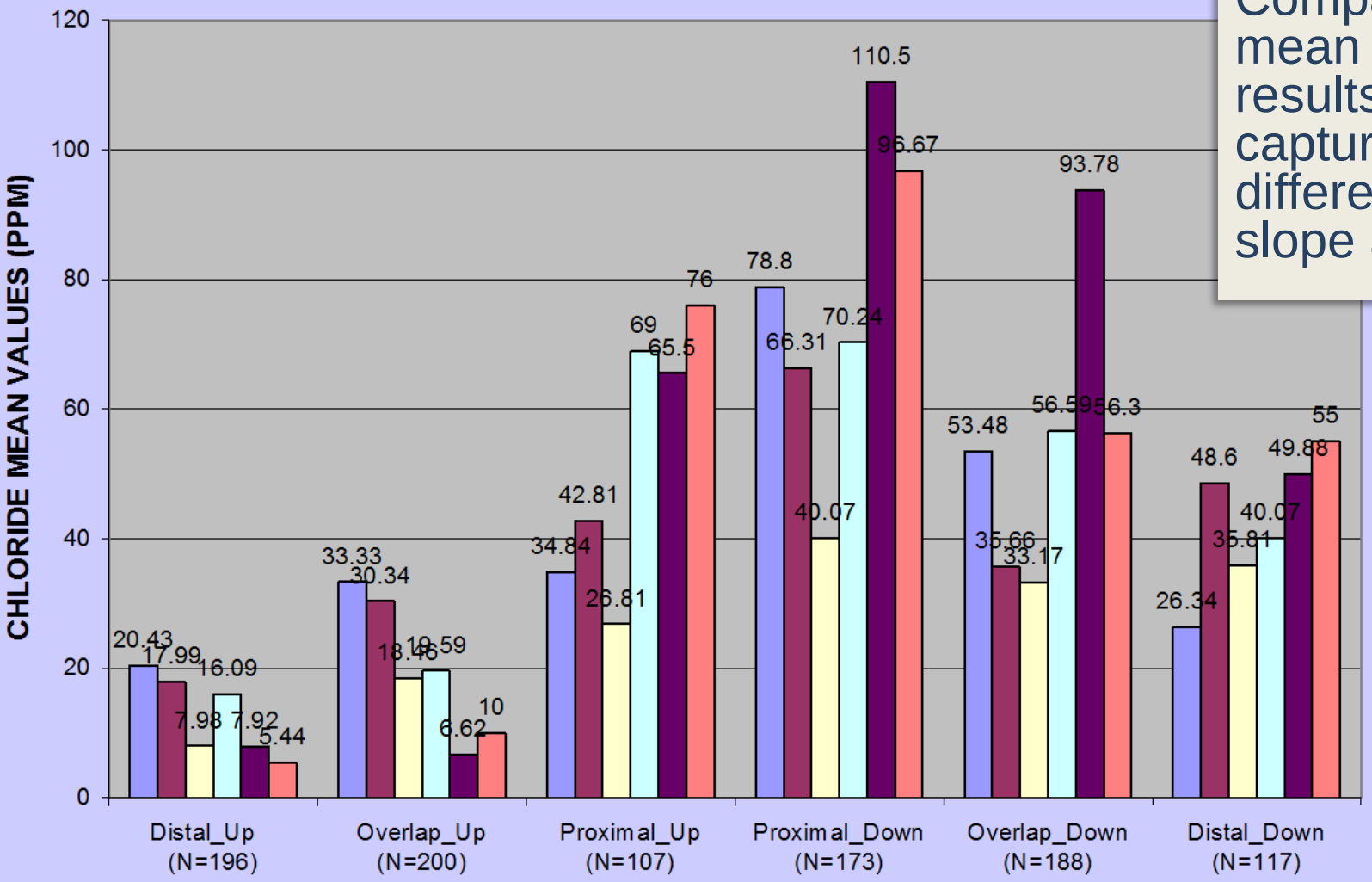


Example: numbers reflect chloride results in PPM at residential wells

Results from preliminary study (2010-2011)



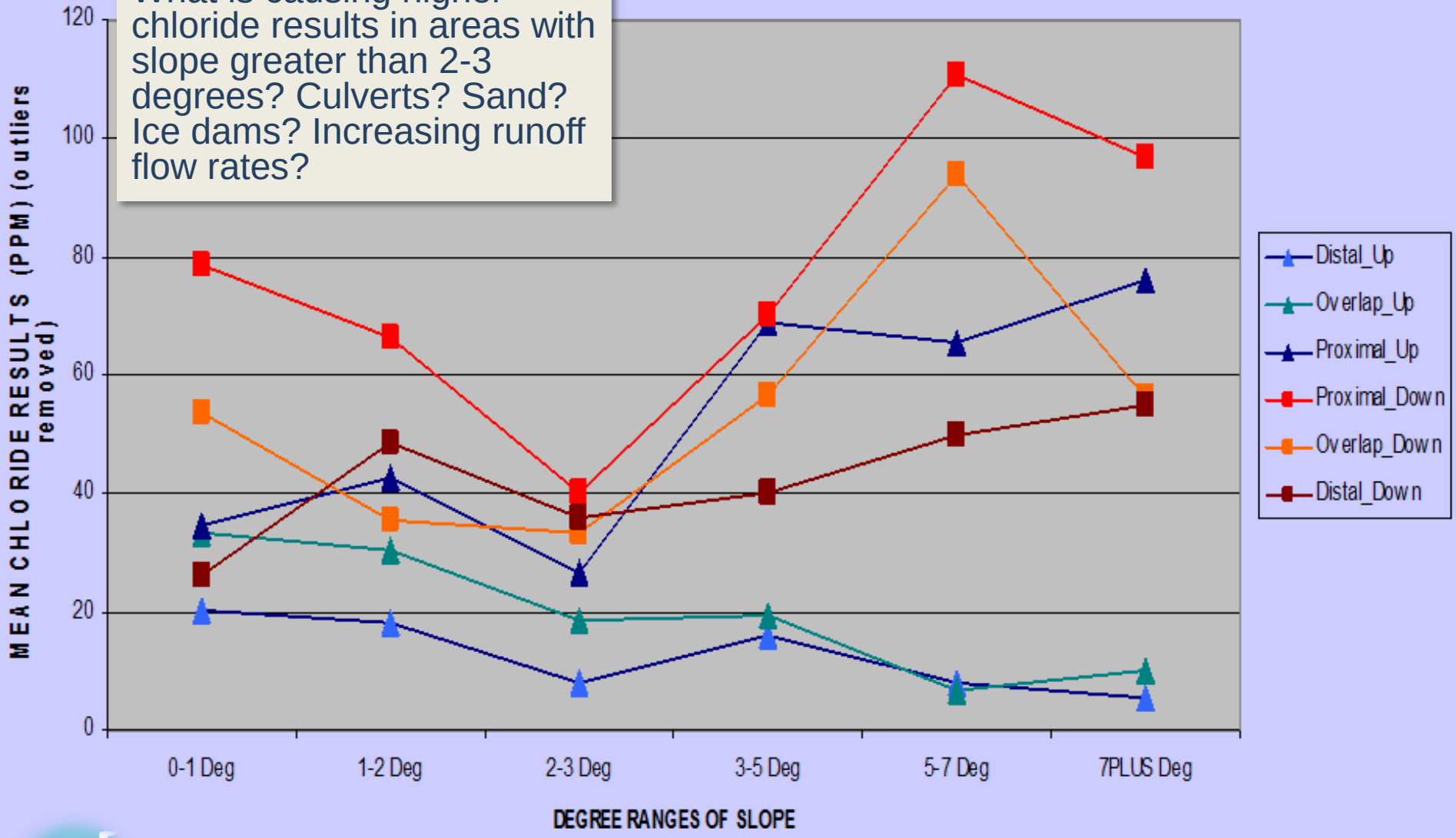
ALL SPATIAL ZONES - DIRECT SLOPE MEASURE (outliers removed)



Comparison of mean chloride results for well captures for different degree slope areas.

ALL SPATIAL ZONES - ALL WELLS - VARIATION OF CHLORIDE RESULTS BY DEGREE SLOPE

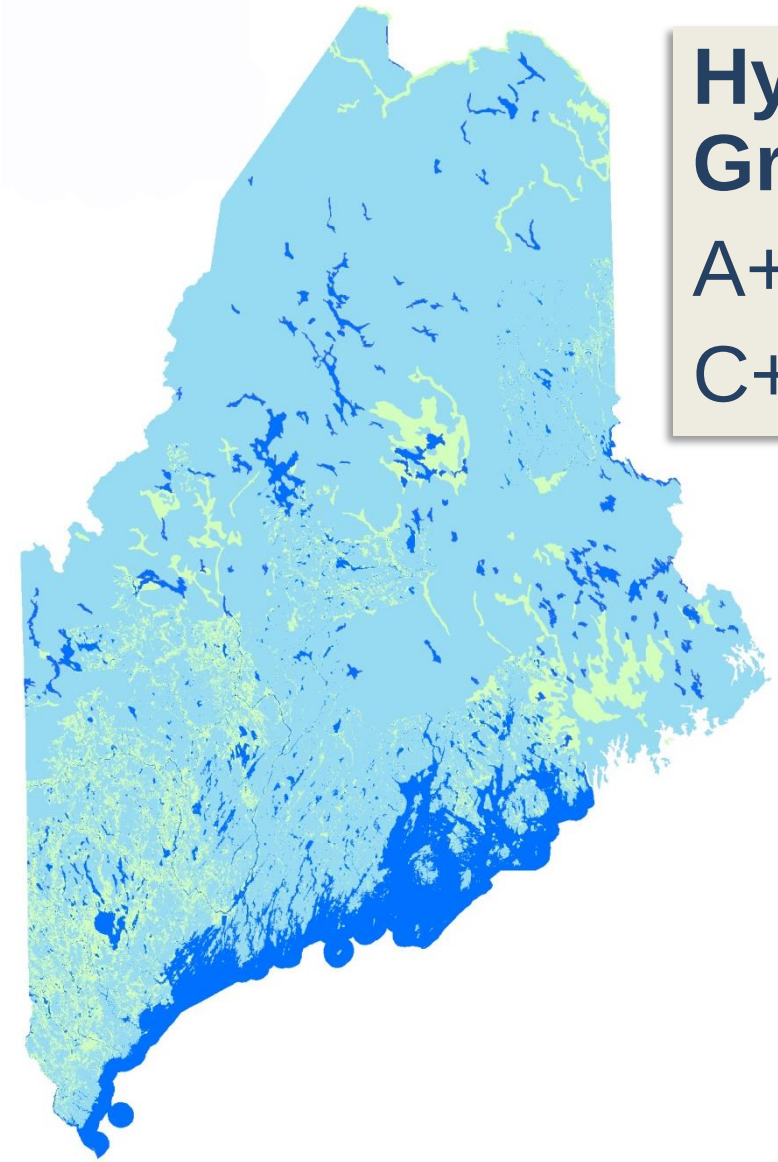
What is causing higher chloride results in areas with slope greater than 2-3 degrees? Culverts? Sand? Ice dams? Increasing runoff flow rates?




376

Hydrologic Soil Groups (HSG)

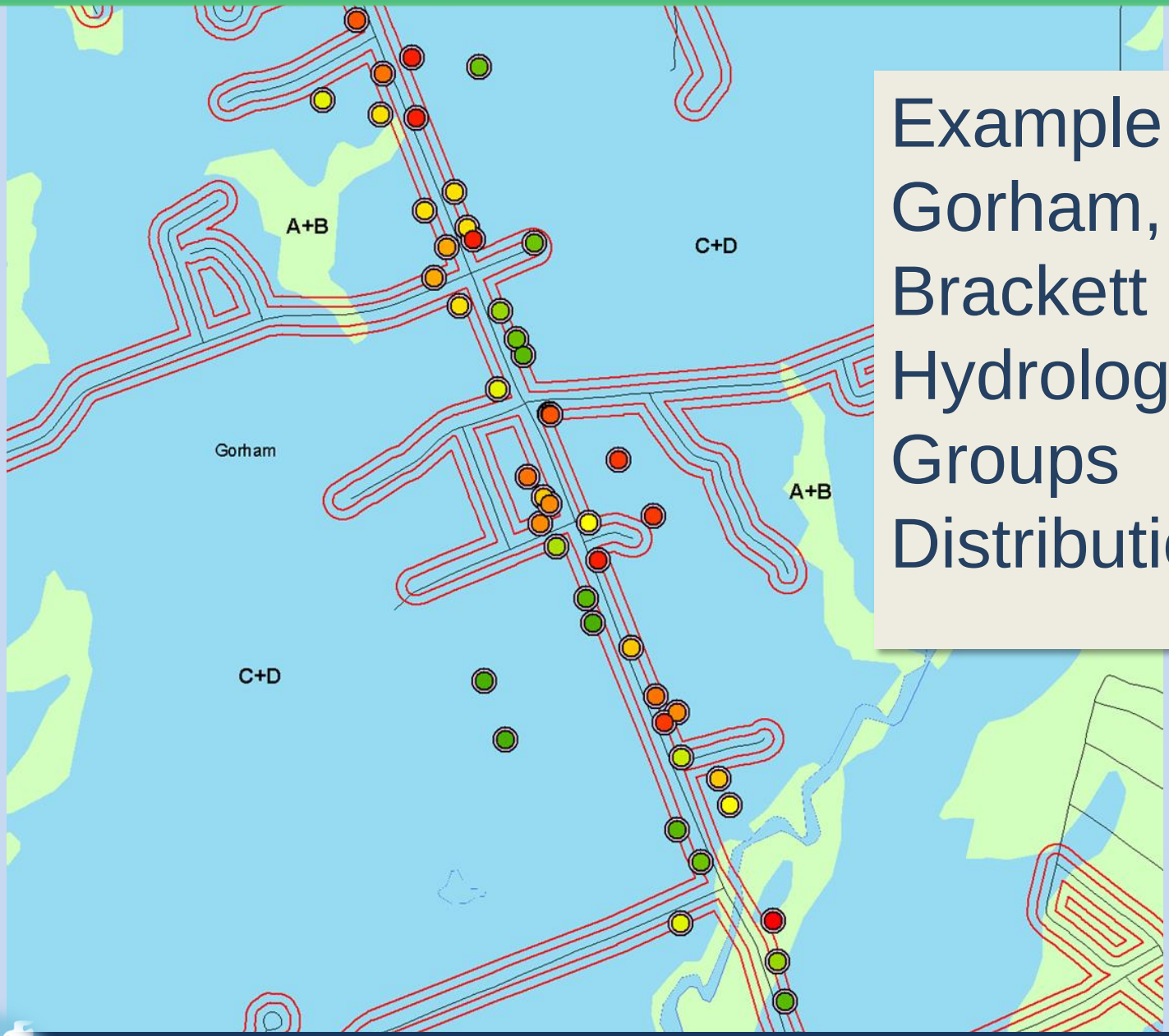
- HSG (A + B): generally more permeable
- HSG (C + D): generally less permeable
- In the statewide STATSGO layer, predominant hydrologic types (of usually three soils) were used to defined these groupings
- The less-than-statewide but more detailed SSURGO layer shows the individual A, B, C, and D hydrologic types



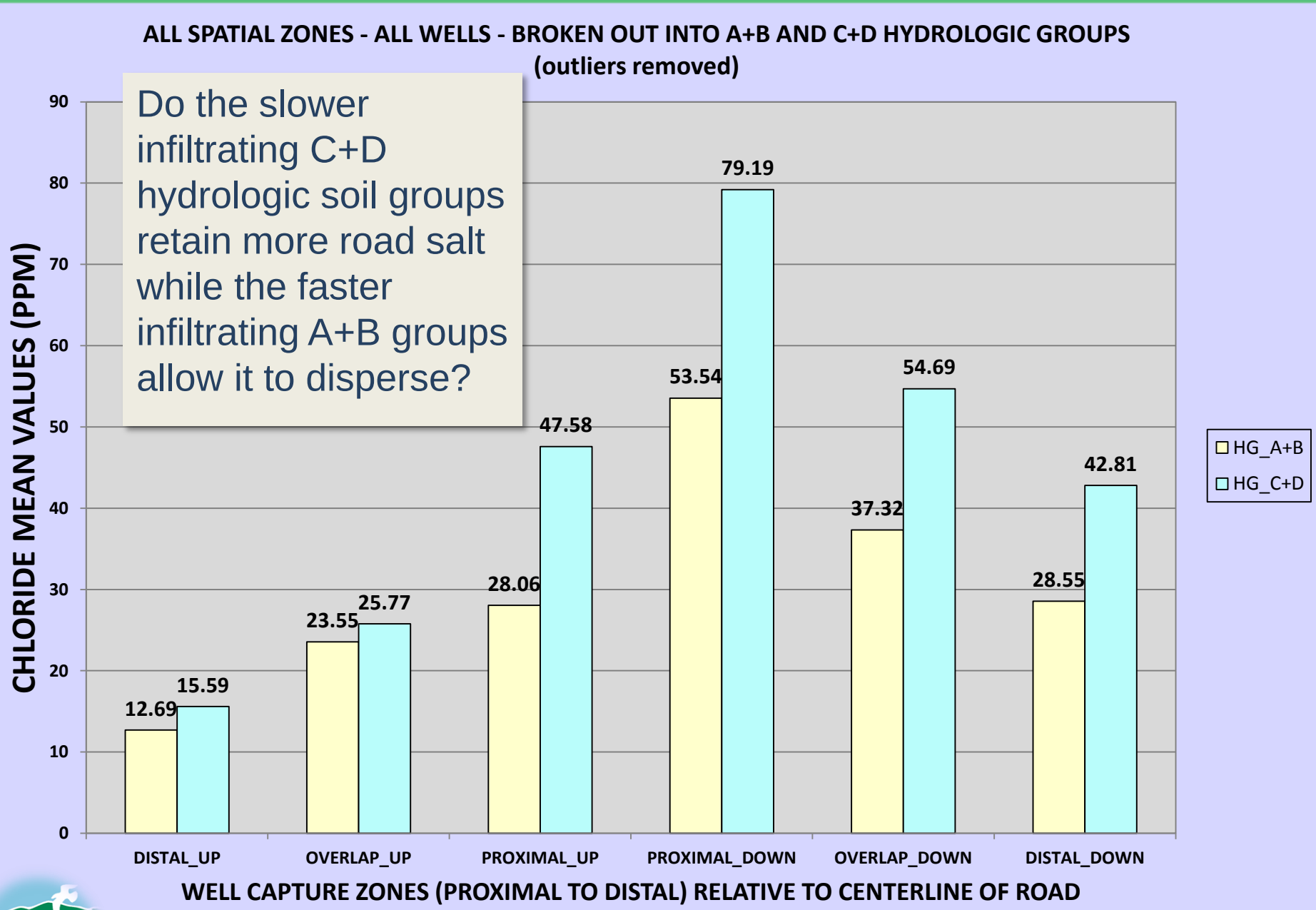
Hydrologic Soil Groupings:

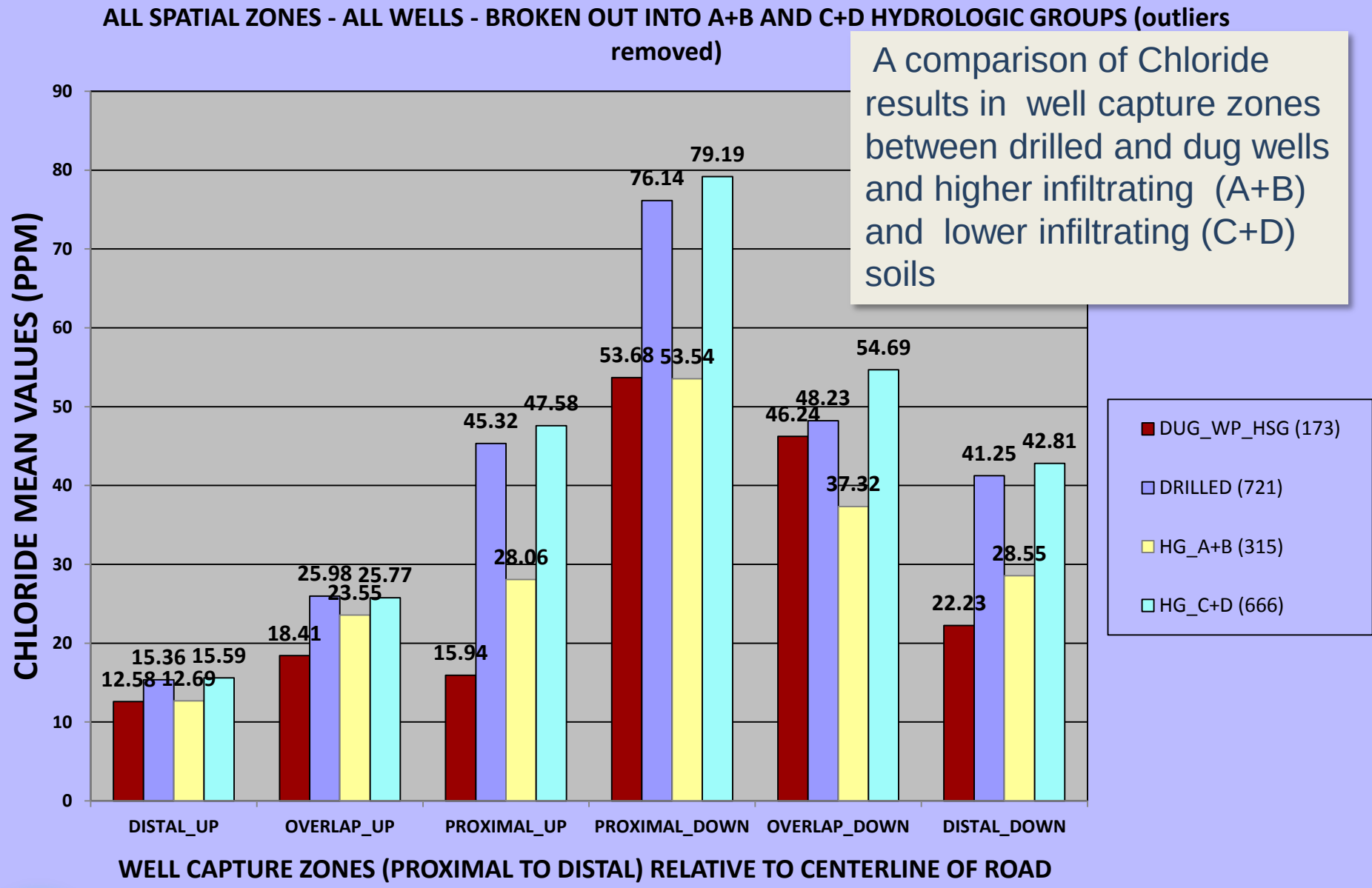
A+B: Green

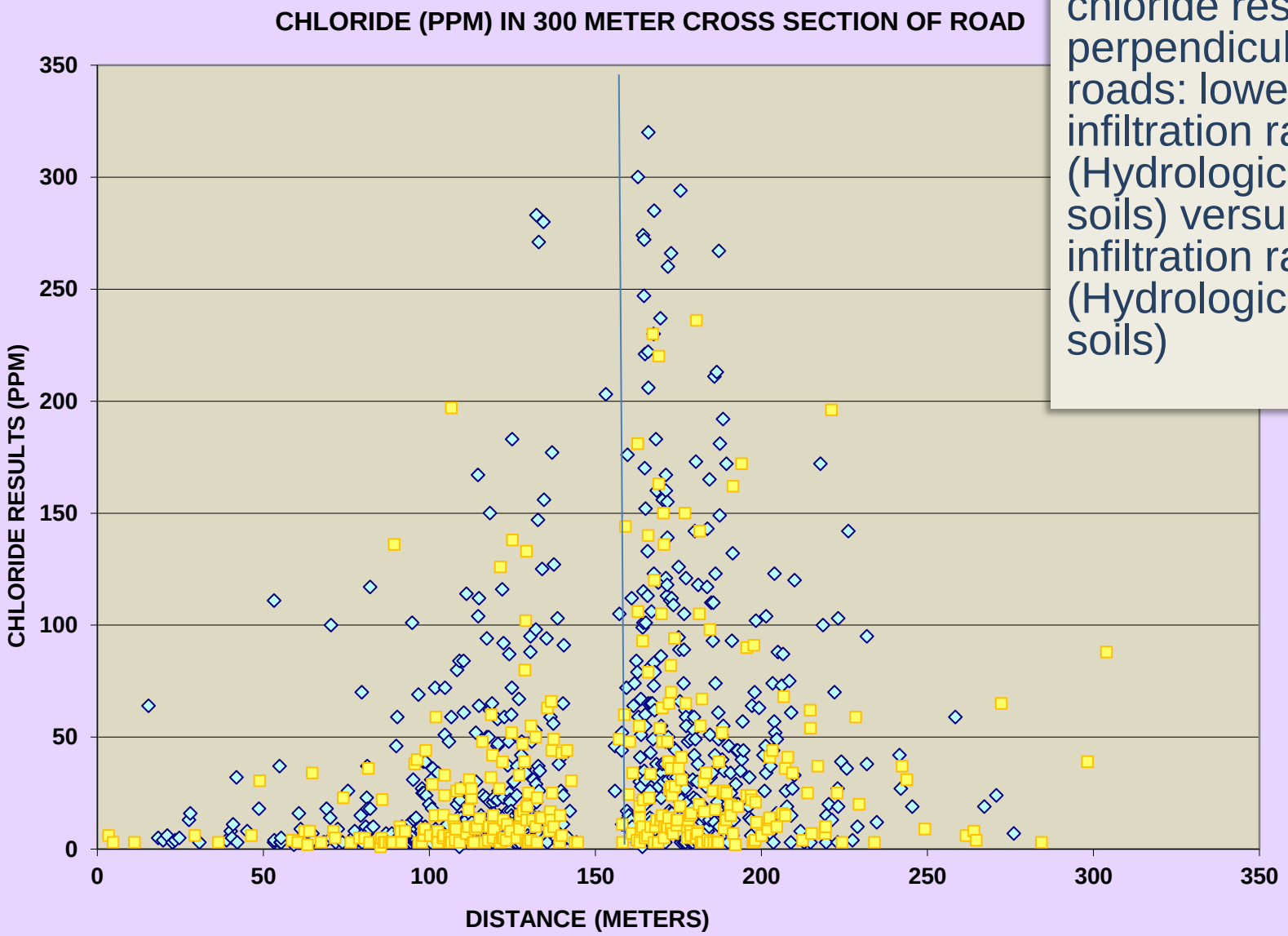
C+D: Light blue



Example from Gorham, Maine: Brackett Street: Hydrologic Soil Groups Distribution


ALL SPATIAL ZONES - ALL WELLS - BROKEN OUT INTO A+B AND C+D HYDROLOGIC GROUPS
(outliers removed)
Do the slower infiltrating C+D hydrologic soil groups retain more road salt while the faster infiltrating A+B groups allow it to disperse?
CHLORIDE MEAN VALUES (PPM)
90
80
70
60
50
40
30
20
10
0
12.69
15.59
23.55
25.77
28.06
47.58
53.54
79.19
37.32
54.69
28.55
42.81
DISTAL_UP
OVERLAP_UP
PROXIMAL_UP
PROXIMAL_DOWN
OVERLAP_DOWN
DISTAL_DOWN
WELL CAPTURE ZONES (PROXIMAL TO DISTAL) RELATIVE TO CENTERLINE OF ROAD
HG_A+B
HG_C+D

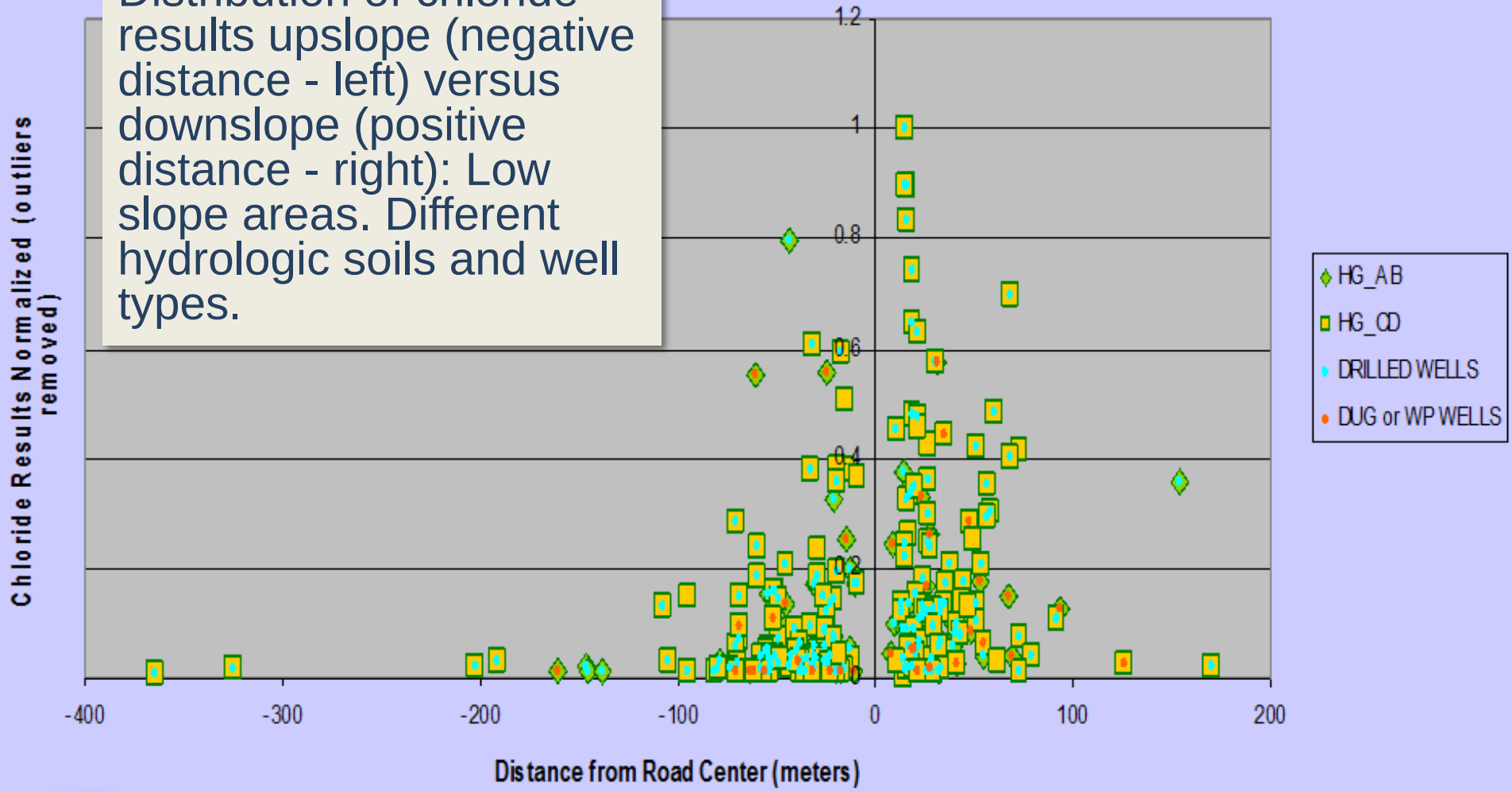

ALL SPATIAL ZONES - ALL WELLS - BROKEN OUT INTO A+B AND C+D HYDROLOGIC GROUPS (outliers removed)
A comparison of Chloride results in well capture zones between drilled and dug wells and higher infiltrating (A+B) and lower infiltrating (C+D) soils
CHLORIDE MEAN VALUES (PPM)
90
80
70
60
50
40
30
20
10
0
12.58
15.36
12.69
15.59
18.41
25.98
23.55
25.77
15.94
45.32
28.06
47.58
53.68
76.14
53.54
79.19
46.24
48.23
37.32
54.69
22.23
41.25
28.55
42.81
DISTAL_UP
OVERLAP_UP
PROXIMAL_UP
PROXIMAL_DOWN
OVERLAP_DOWN
DISTAL_DOWN
WELL CAPTURE ZONES (PROXIMAL TO DISTAL) RELATIVE TO CENTERLINE OF ROAD
DUG_WP_HSG (173)
DRILLED (721)
HG_A+B (315)
HG_C+D (666)



Distribution of chloride results perpendicular to roads: lower infiltration rates (Hydrologic C+D soils) versus higher infiltration rates (Hydrologic A+B soils)

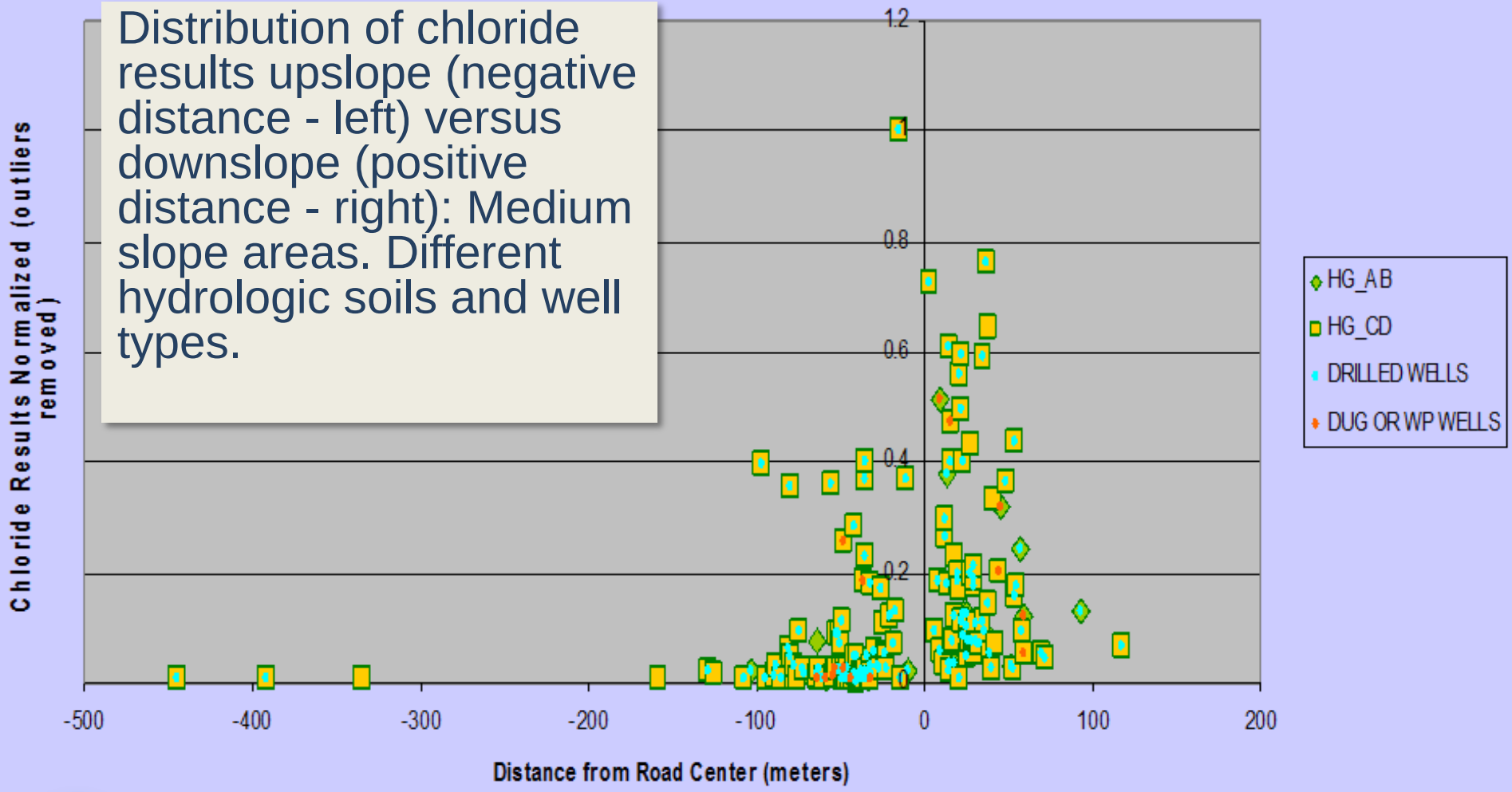
Chloride Results - Comparison of AB and CD Hydrologic Groups at 1 to 2 degree slope

Distribution of chloride results upslope (negative distance - left) versus downslope (positive distance - right): Low slope areas. Different hydrologic soils and well types.



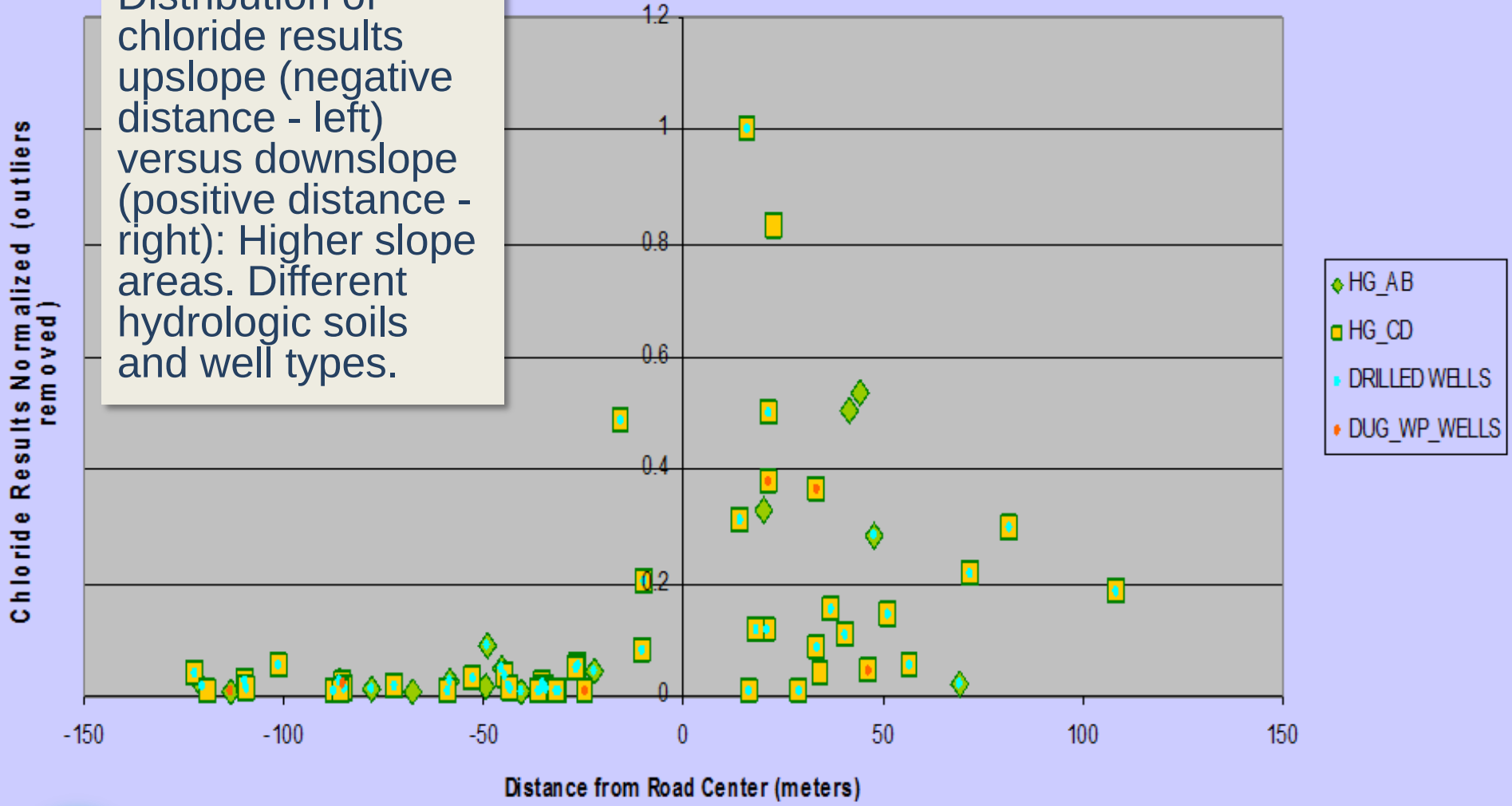
Chloride Results - Comparison of AB and CD Hydrologic Groups at 3 to 5 degree slope

Distribution of chloride results upslope (negative distance - left) versus downslope (positive distance - right): Medium slope areas. Different hydrologic soils and well types.



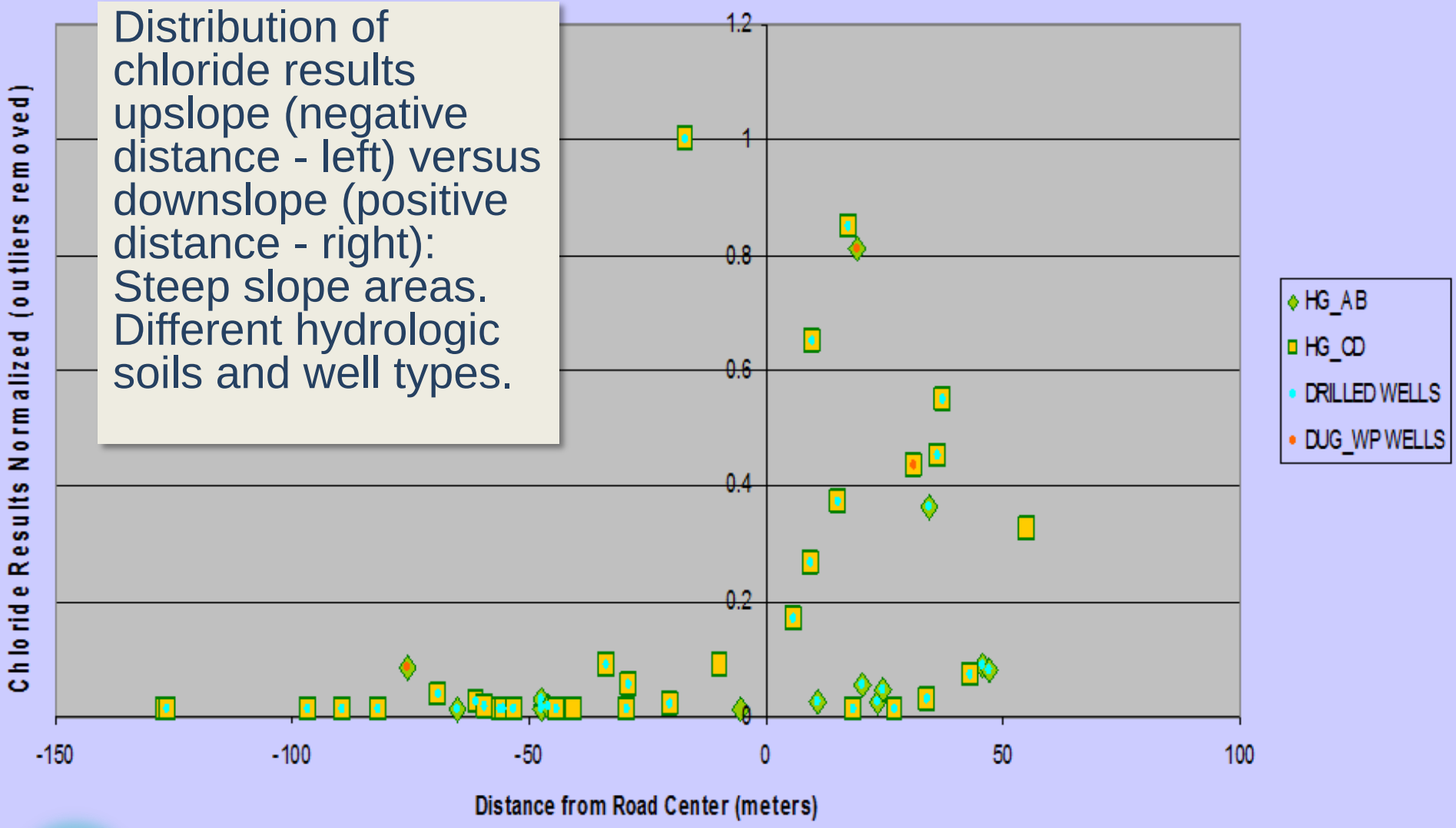
Chloride Results - Comparison of AB and CD Hydrologic Groups at 5 to 7 degree slope

Distribution of chloride results upslope (negative distance - left) versus downslope (positive distance - right): Higher slope areas. Different hydrologic soils and well types.



Chloride Results - Comparison of AB and CD Hydrologic Groups at 7PLUS degrees slope

Distribution of chloride results upslope (negative distance - left) versus downslope (positive distance - right): Steep slope areas. Different hydrologic soils and well types.



Effect of bedrock fractures

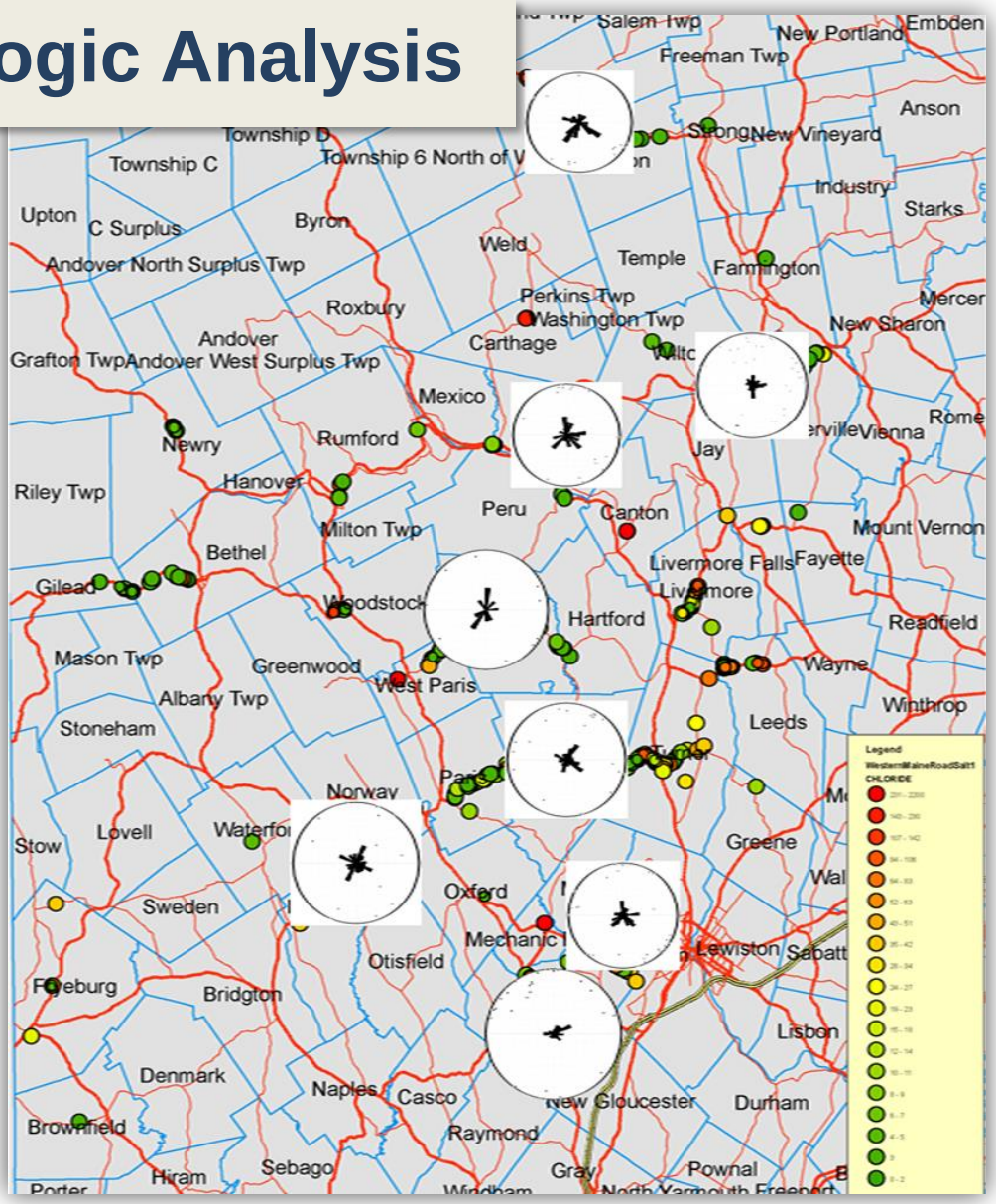
- Does bedrock fractures (joints, fracture cleavage) orientation have an effect on hydrologic movement of road salt in the groundwater?

- How to proceed:
  - Identify principal fracture directions
  - Concentrate on higher angle fracture planes (>40 degrees of dip)
  - Measure within as close a proximity to well data as possible
  - Do stereoscopic projection analysis (rose diagrams) to determine dominant trends

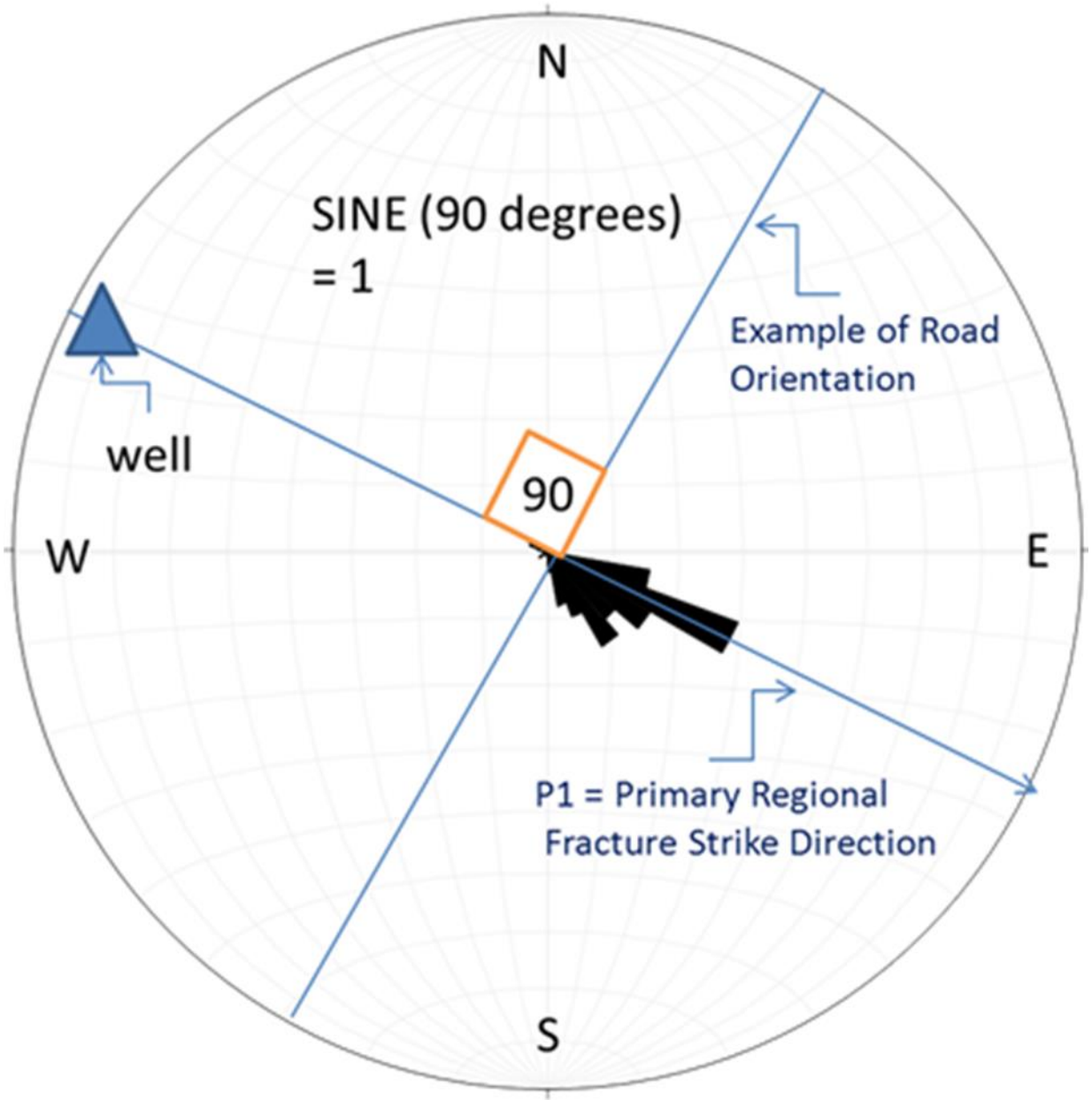
- Determine the well to road declination as well as declination of the tangential perpendicular at the road for each well

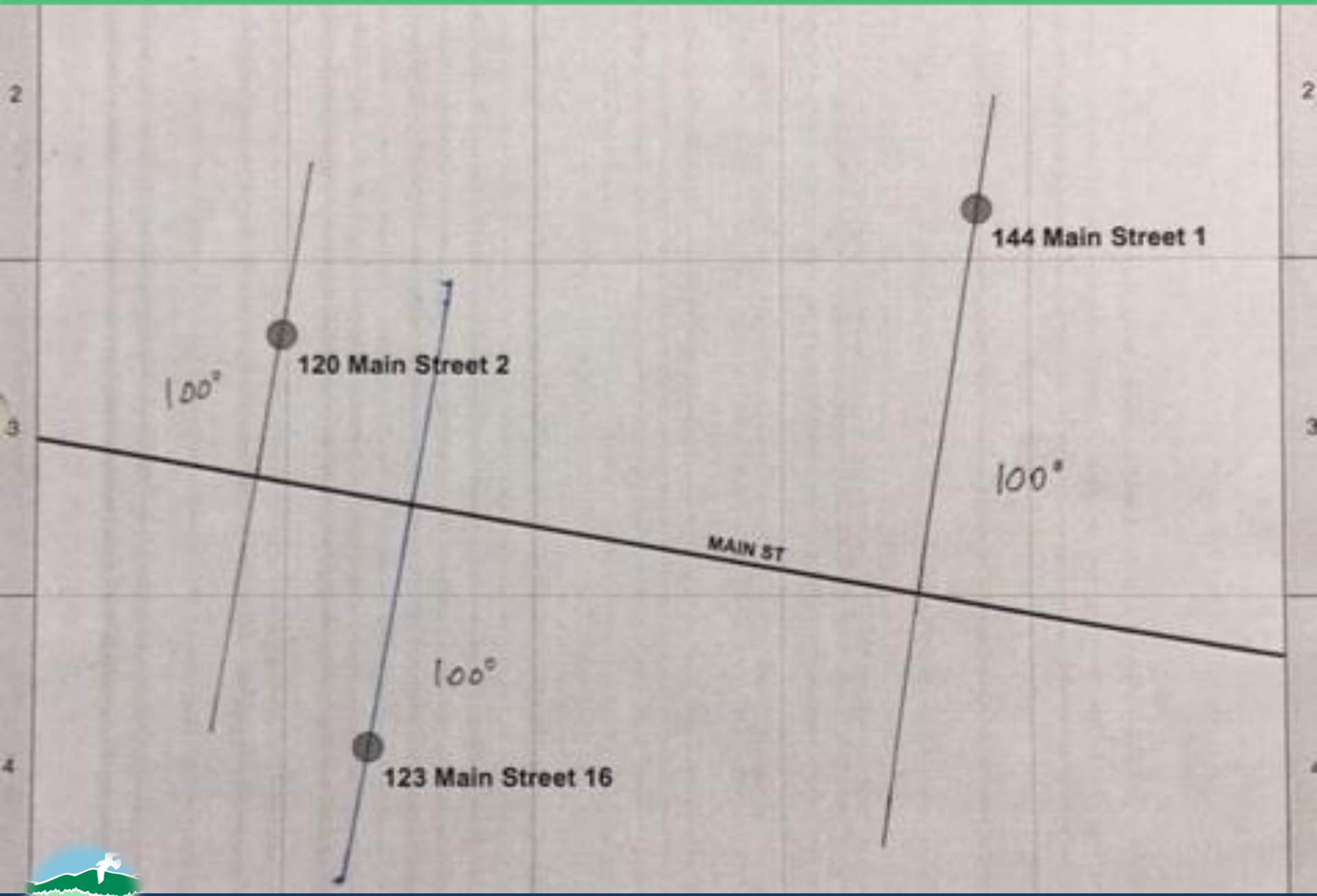
Road Salt Hydrologic Analysis

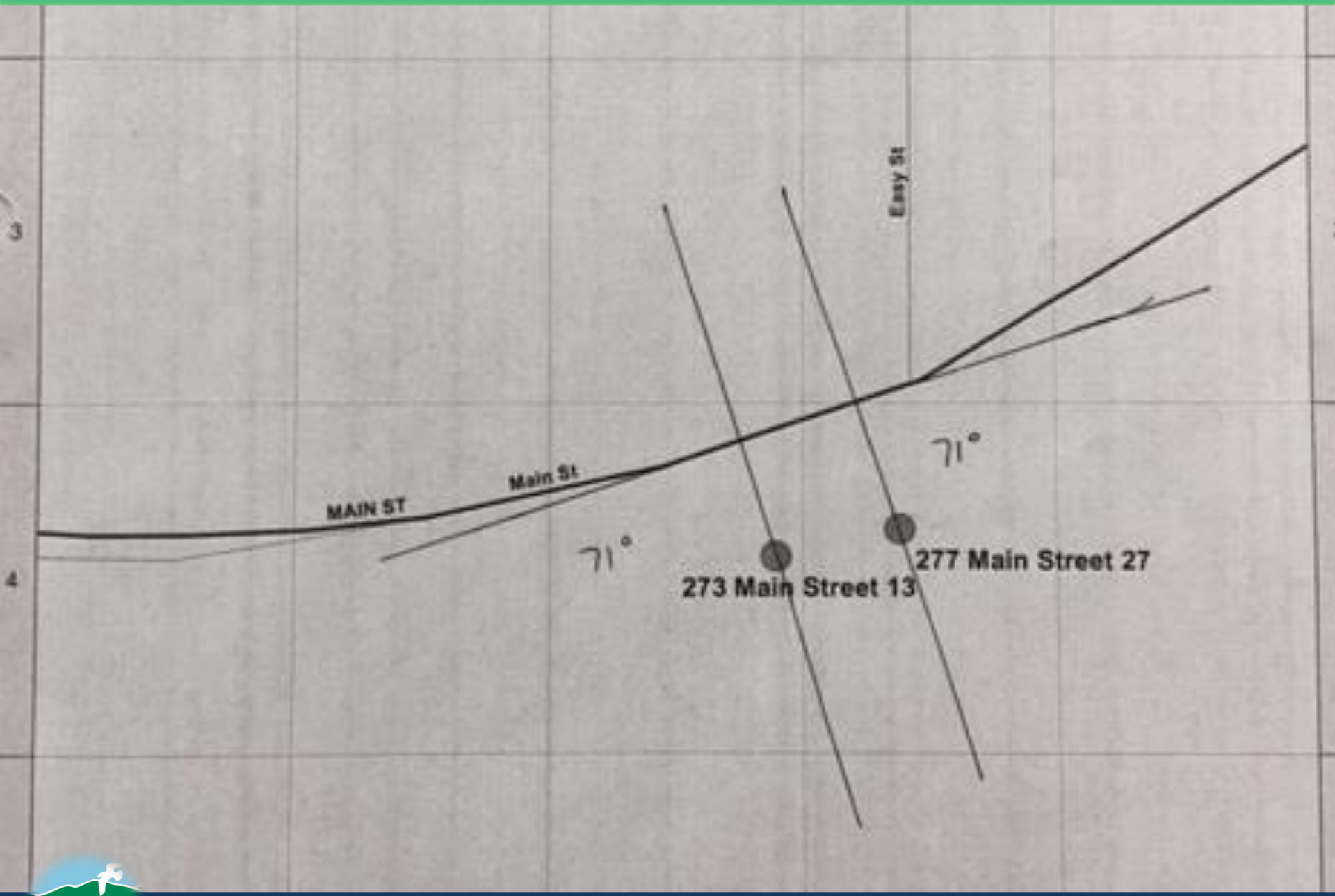
Western Maine Road Salt Analysis: Regional Fracture Orientations



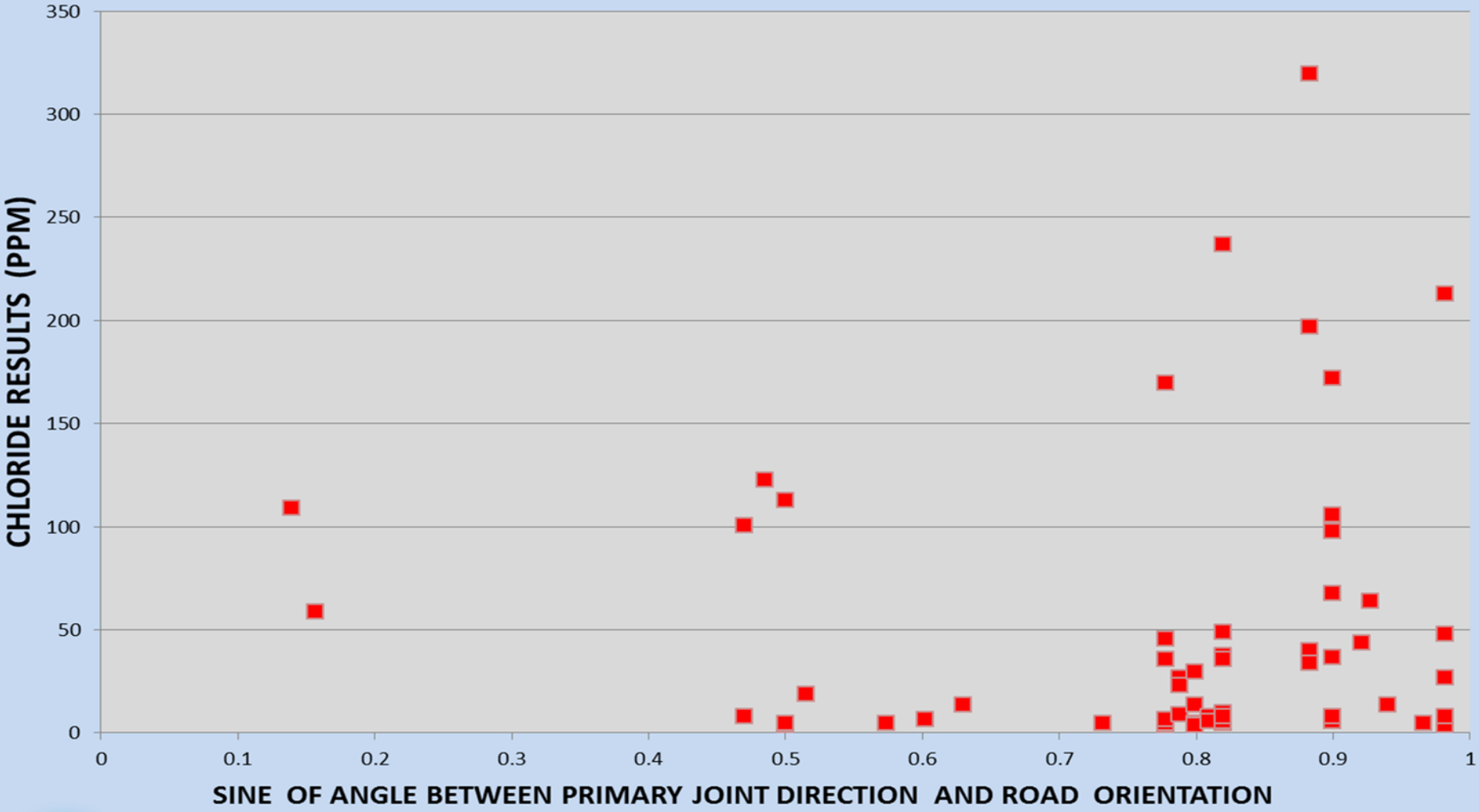
Strike Angle and Dip Slope Measurements – Brunton Compass


N
SINE (90 degrees)
= 1
Example of Road
Orientation
well
90
W
E
P1 = Primary Regional
Fracture Strike Direction
S

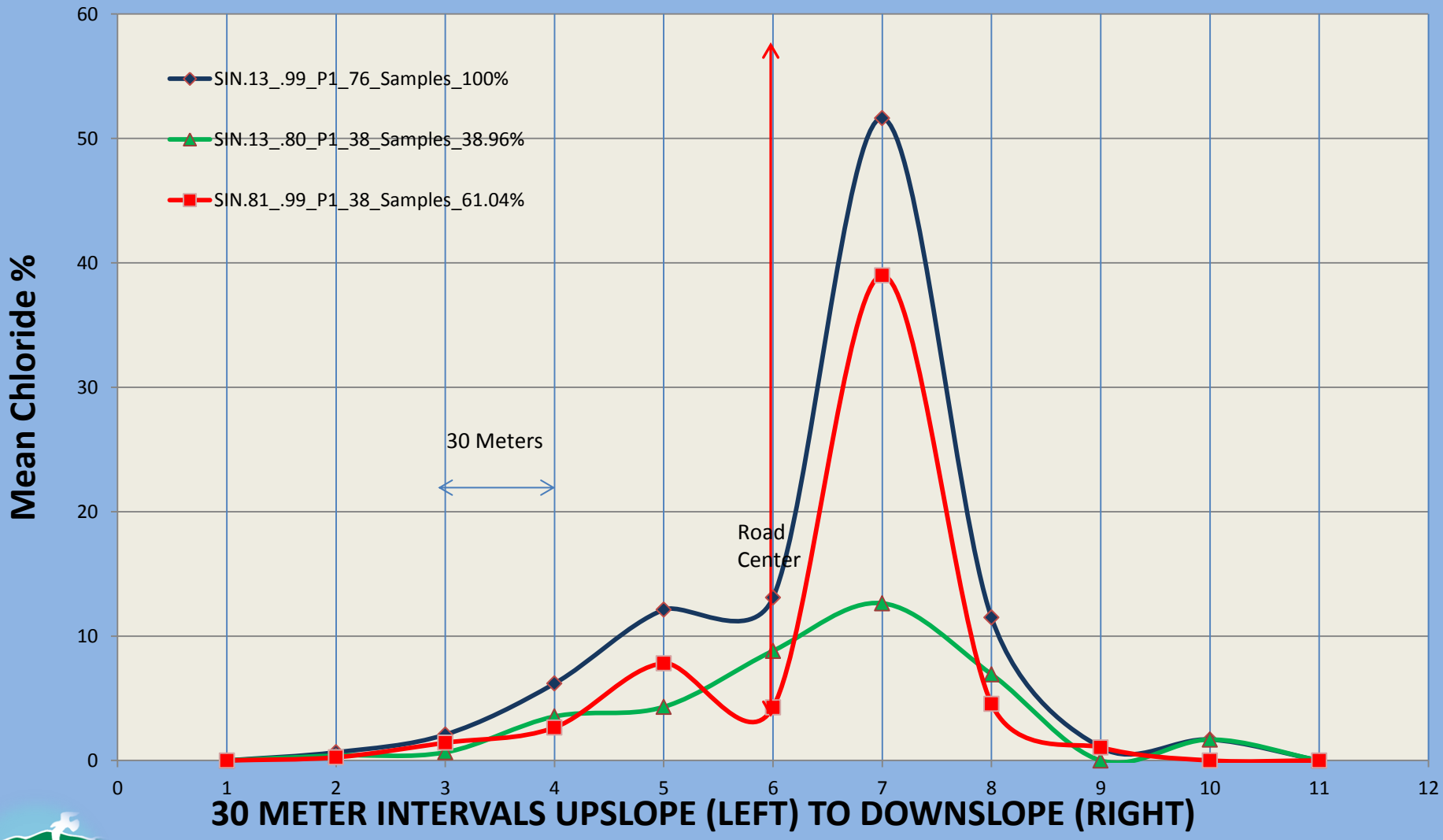

144 Main Street 1
120 Main Street 2
100'
100'
MAIN ST
100'
123 Main Street 16

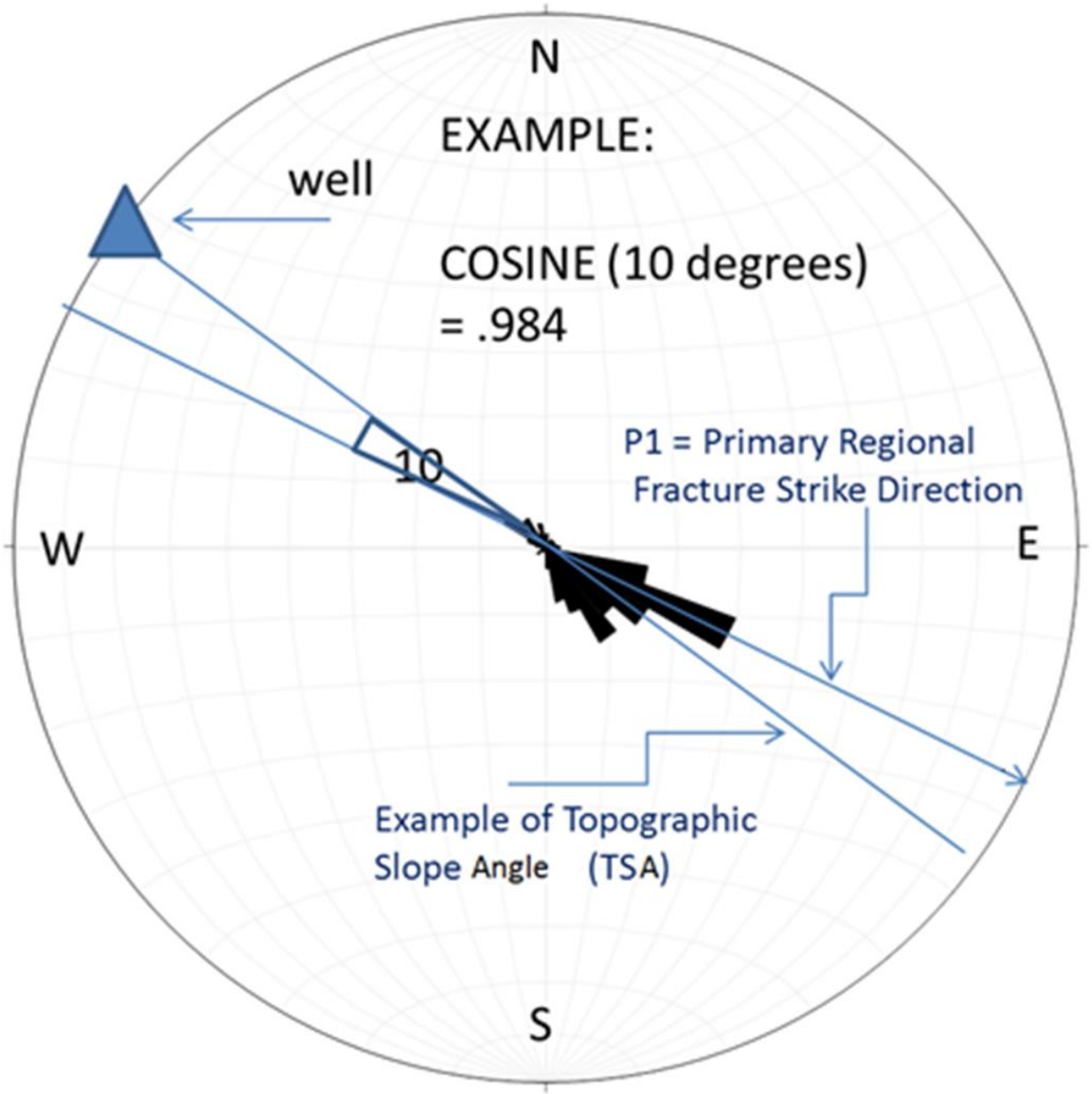

Easy St
MAIN ST
Main St
71°
71°
277 Main Street 27
273 Main Street 13

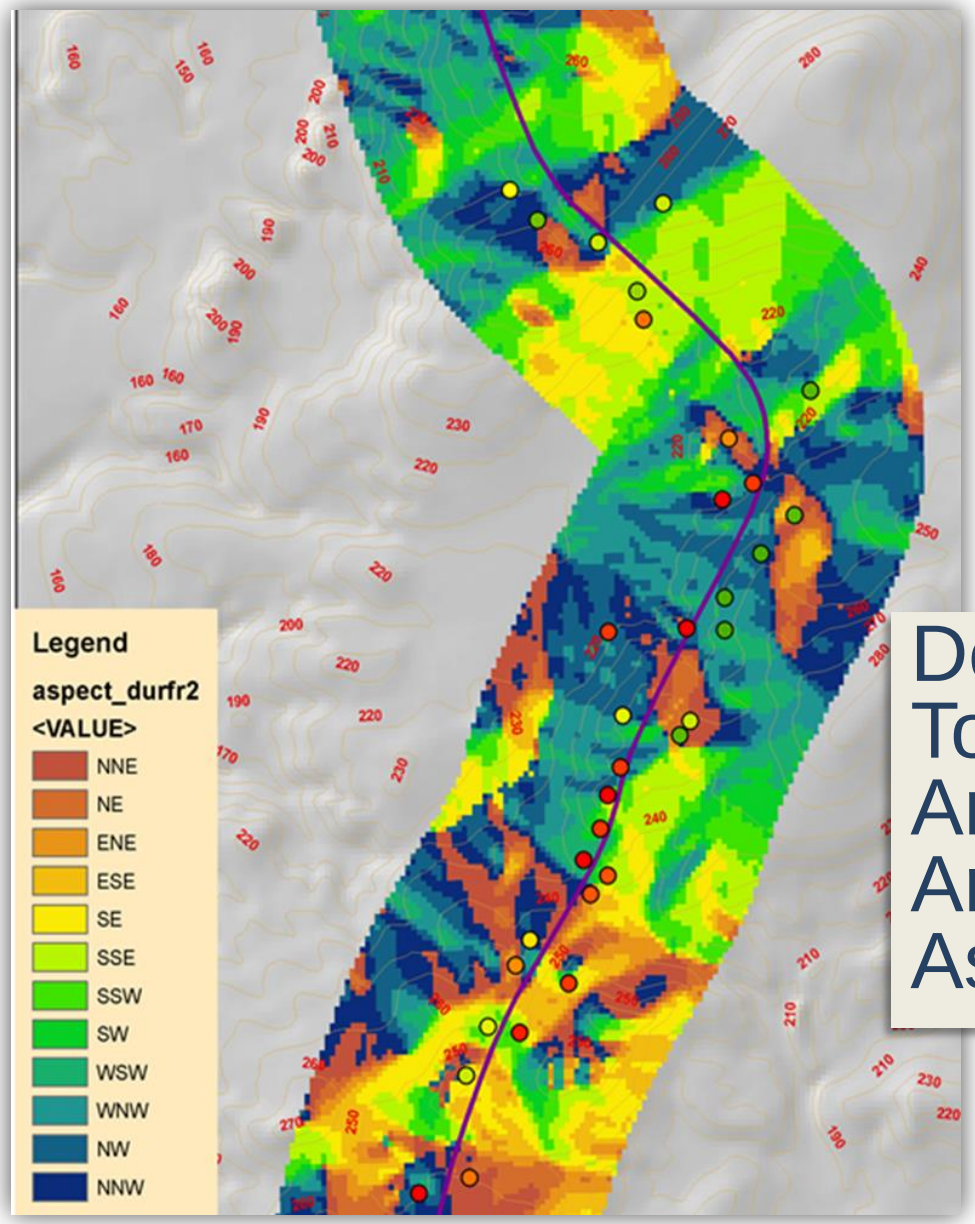
Chloride Results varying with Sine of the Joint Plane Strike angle (P1) relative to road angle in Sullivan_Hancock - Drilled Wells Only



Percentage Distribution of Normalized Chloride Data in 30 meter increments perpencular to the road (Upslope (left) and Downslope (right)) - Hancock_Sullivan (Rt. 1) - outlier (1)

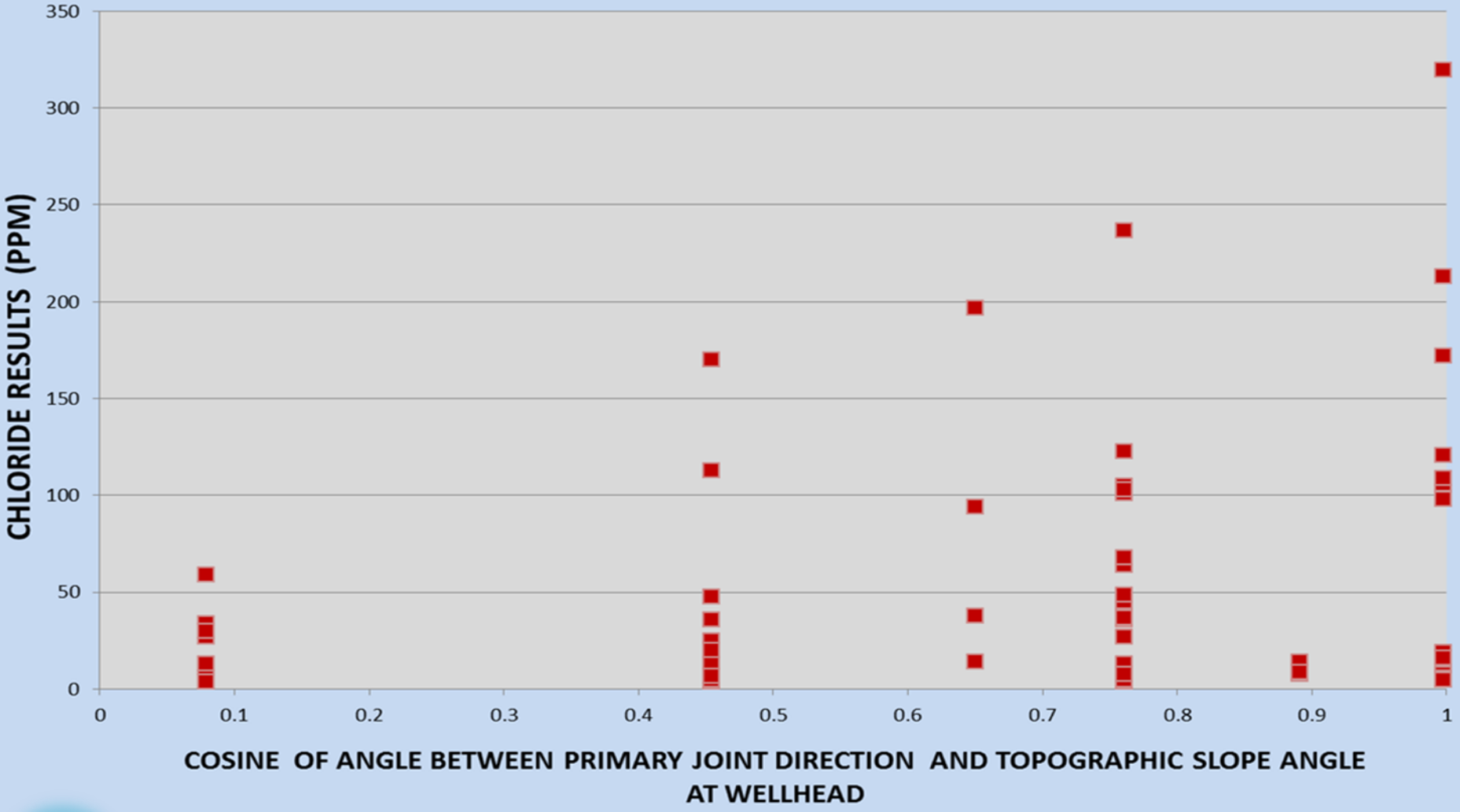


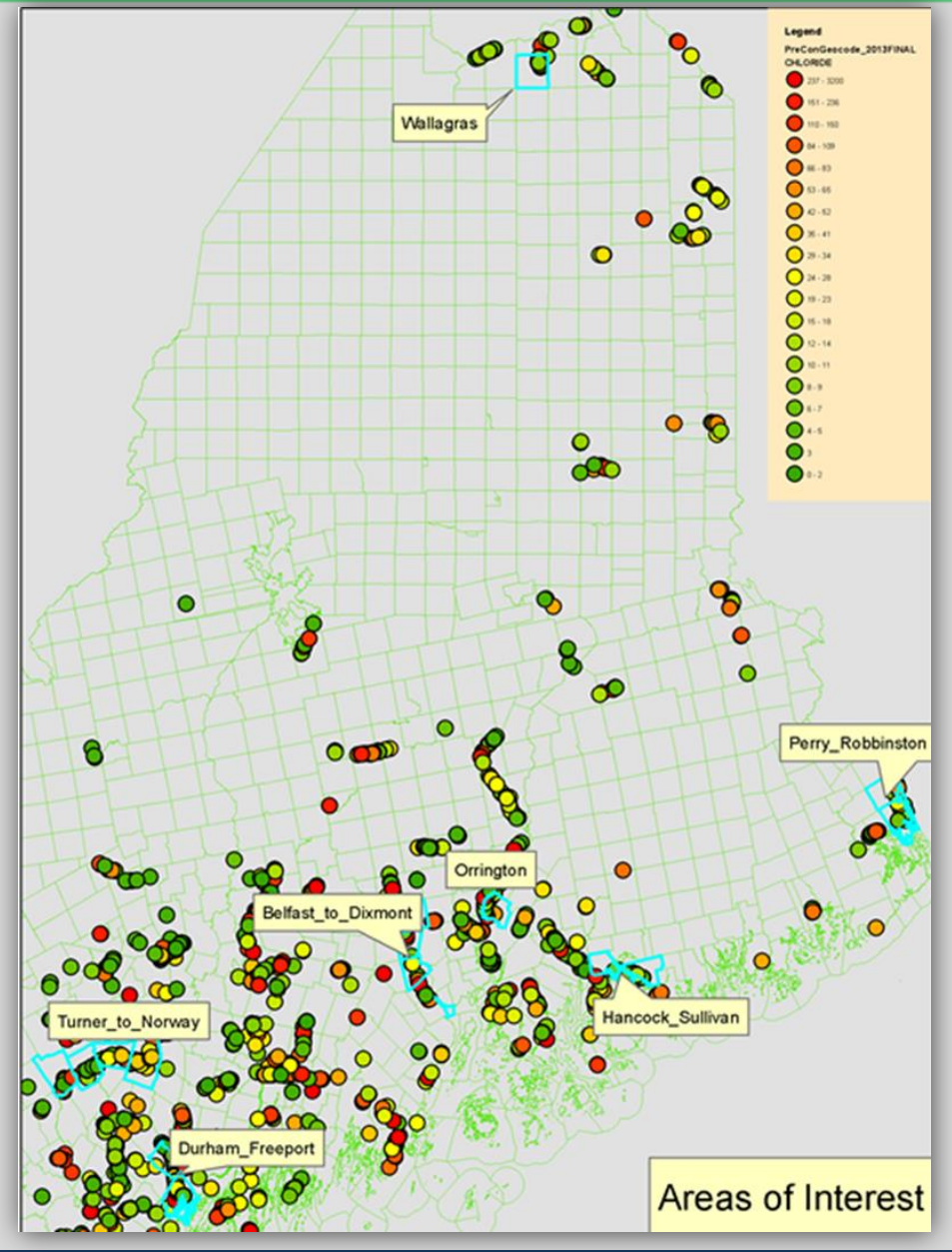

N
EXAMPLE:
well
COSINE (10 degrees)
= .984
10
P1 = Primary Regional
Fracture Strike Direction
W
E
Example of Topographic
Slope Angle (TSA)
S



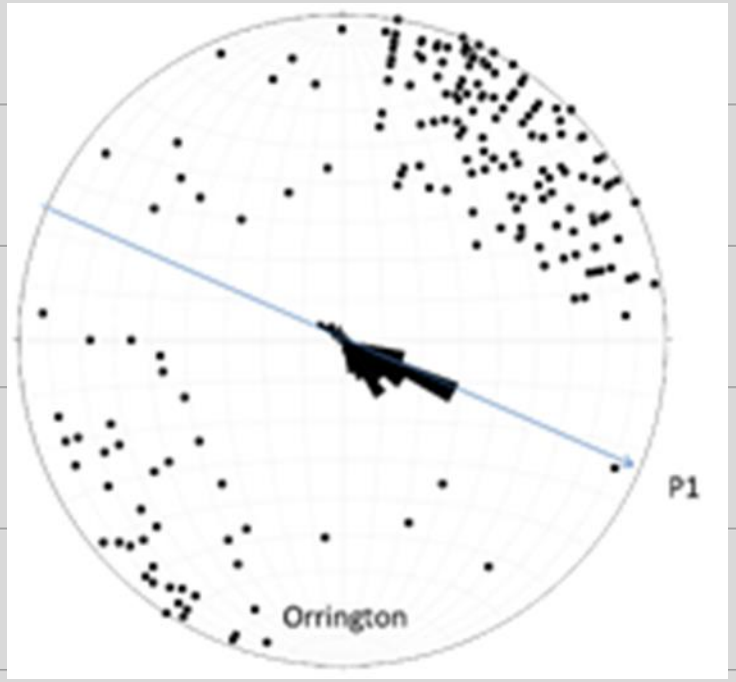
Determination of Topographic Slope Angle using ArcMap Tool: Aspect

Chloride Results varying with Cosine of the Joint Plane Strike angle (P1) relative to Topographic Slope Angle at the Wellhead (Sullivan_Hancock) outlier (1) included




Legend
PreConGeocode_2013FINAL
CHLORIDE
Wallagras
Perry_Robbinston
Orrington
Belfast_to_Dixmont
Hancock_Sullivan
Turner_to_Norway
Durham_Freeport
Areas of Interest

Orrington - River Road (P1) - all data



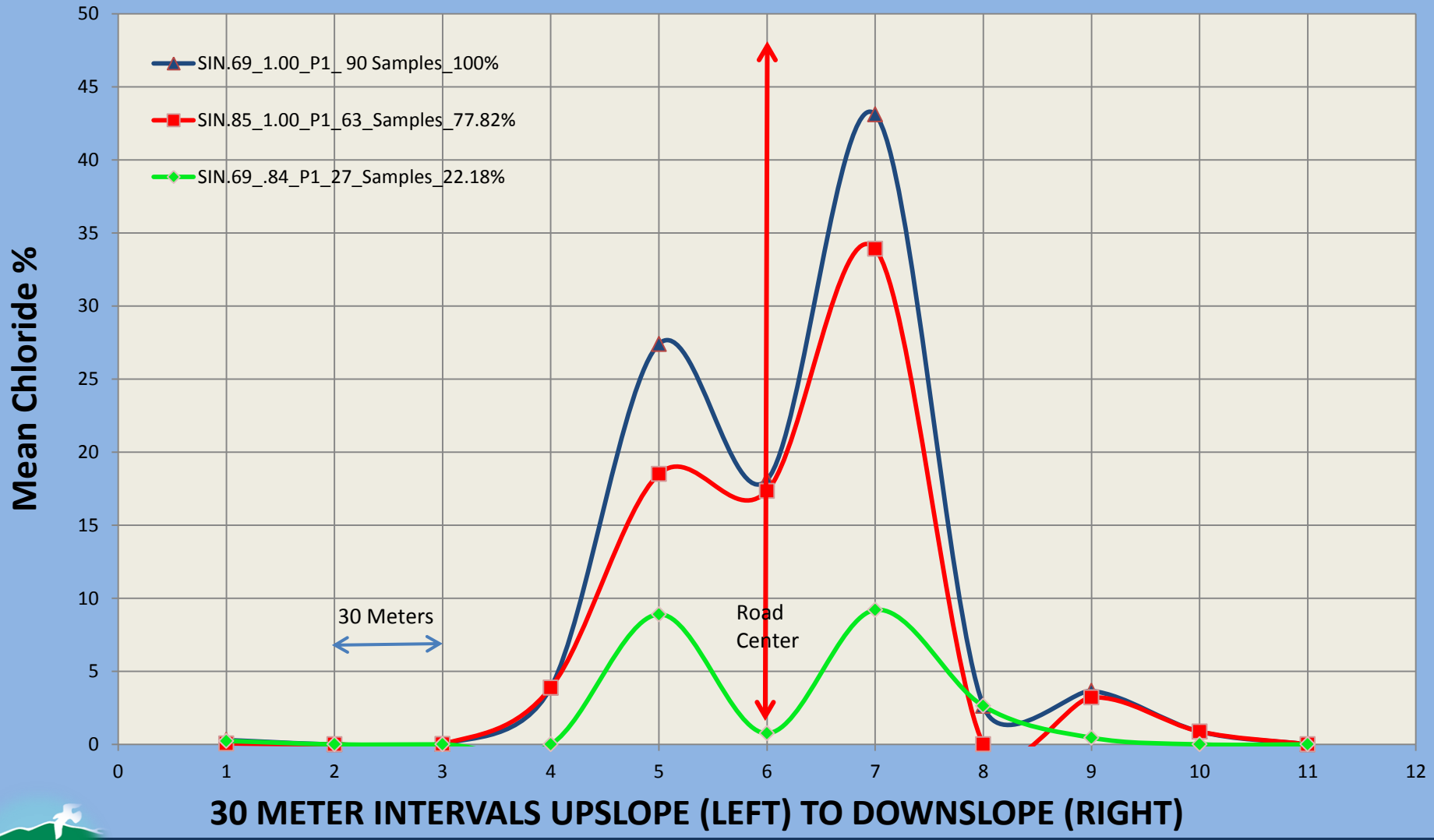
CHLORIDE RESULTS (PPM)

350
300
250
200
150
100
50
0

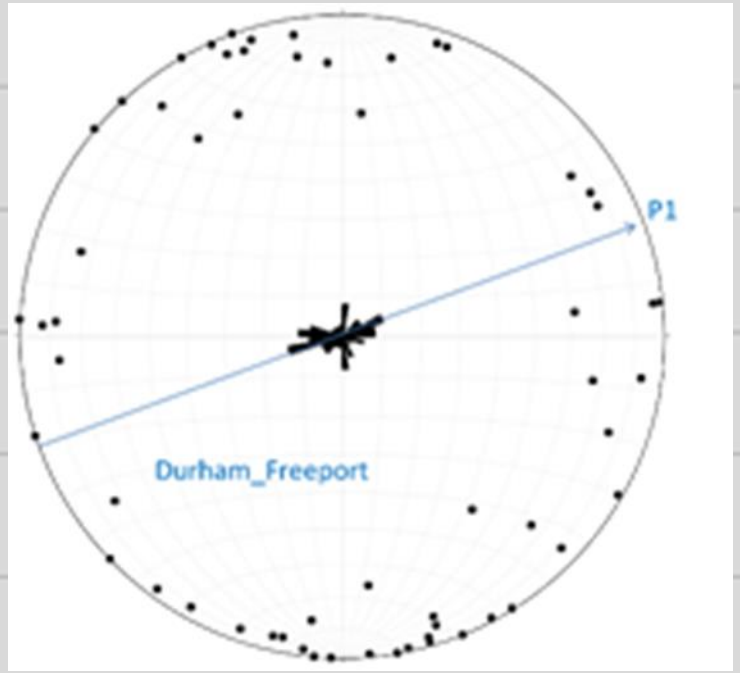
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

SINE OF ANGLE BETWEEN PRIMARY JOINT DIRECTION AND ROAD ORIENTATION

Percentage Distribution of Normalized Chloride Data in 30 meter Increments perpencular to the road and in relation to the direction of the Primary Fracture Direction (P1)- Orrington (River Road) - all data



Durham_Freeport (P1=72) – outlier removed



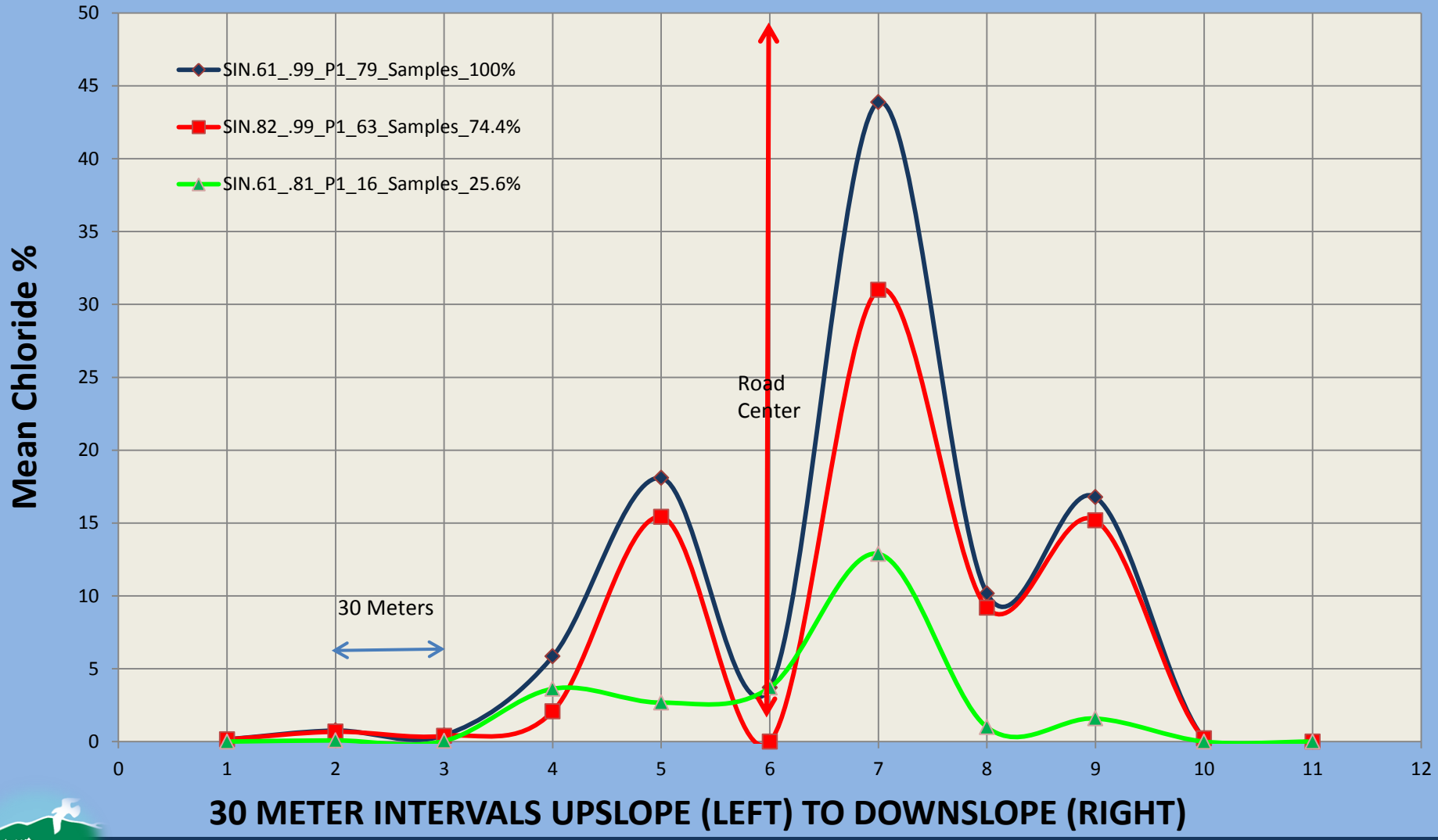
CHLORIDE RESULTS (PPM)

800
700
600
500
400
300
200
100
0

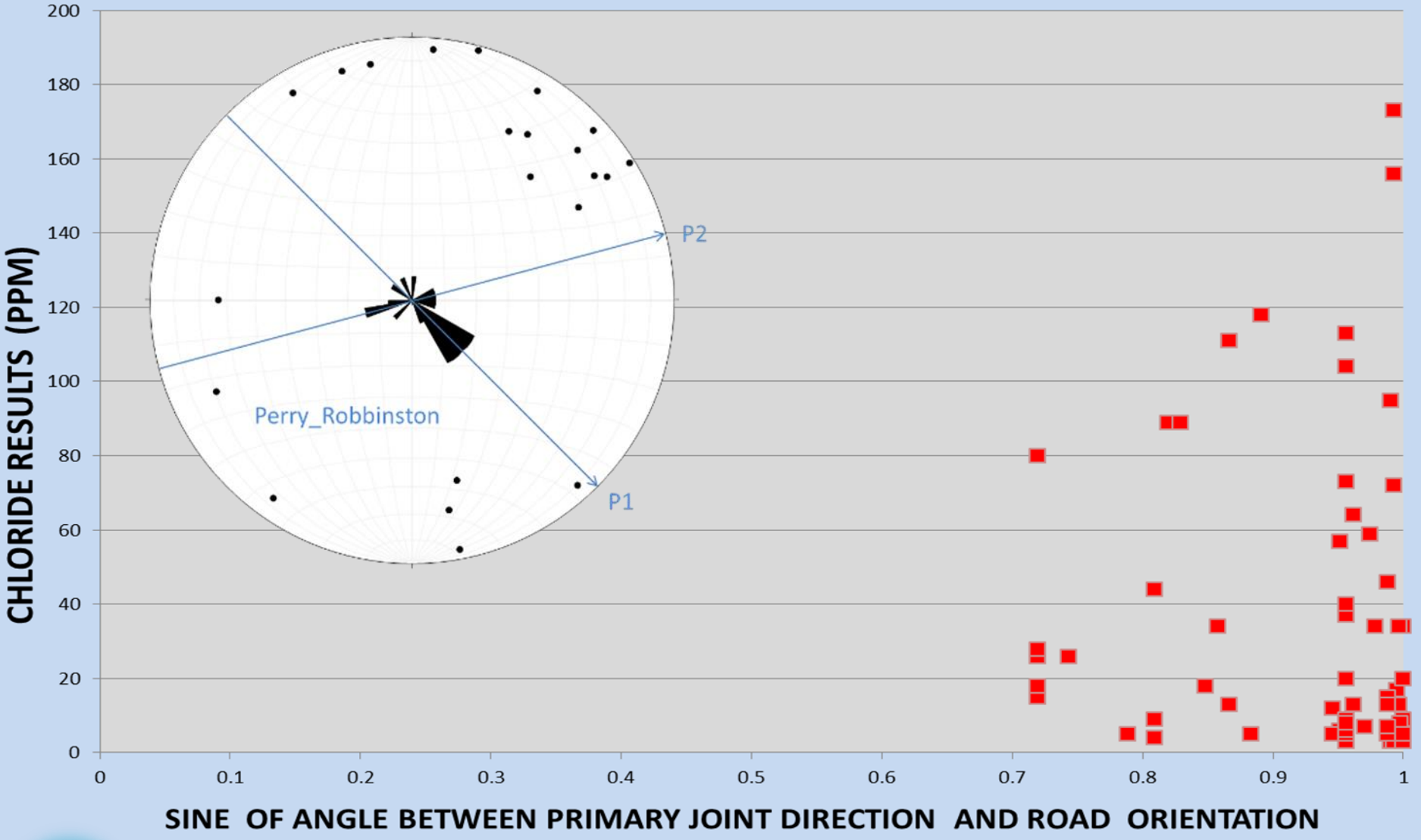
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

SINE OF ANGLE BETWEEN PRIMARY JOINT DIRECTION AND ROAD ORIENTATION

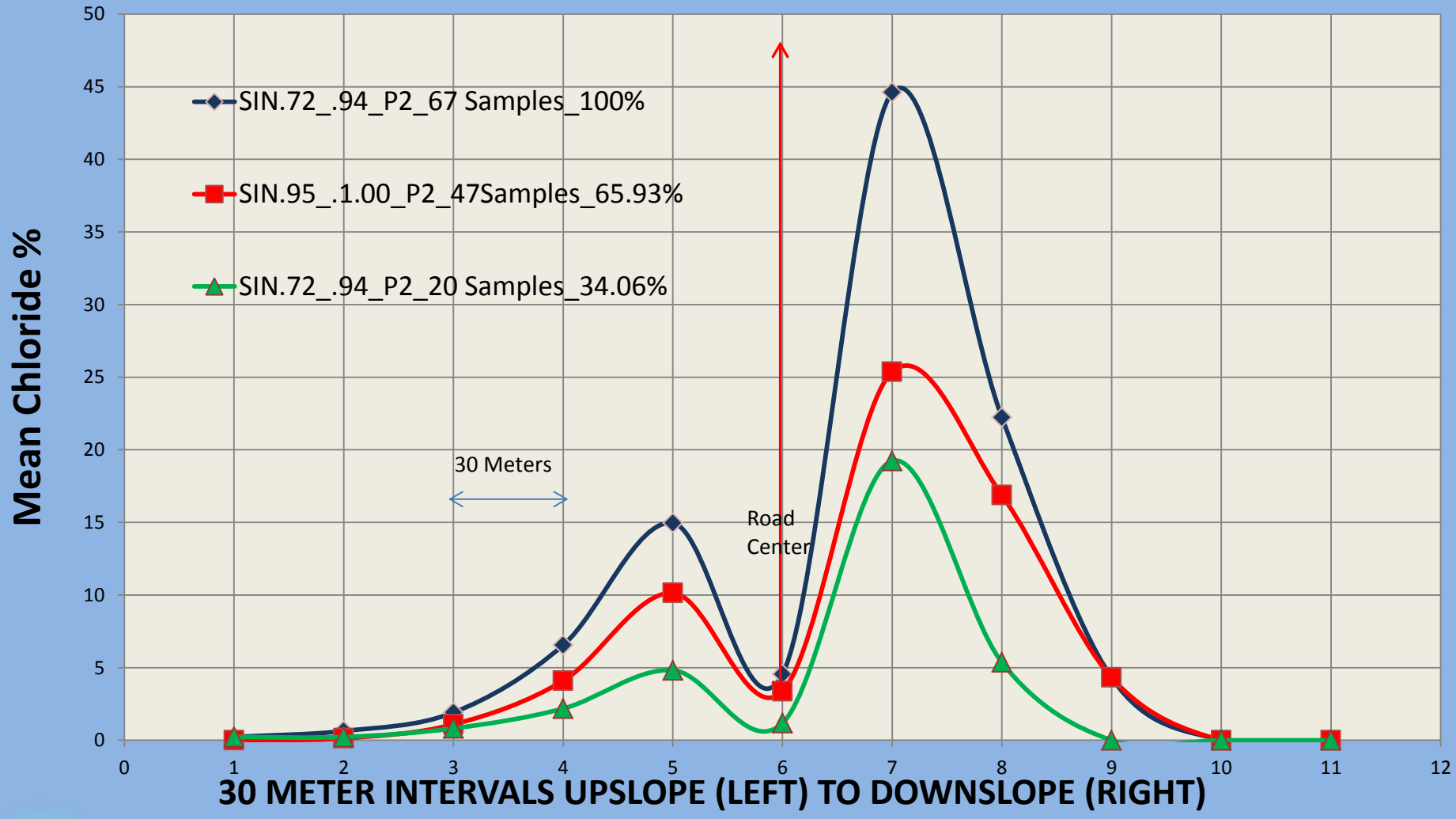
Durham_Freeport (Rte. 136) Drilled Wells Only - outlier removed



Robbinston_Perry_P2_ outliers (2) removed



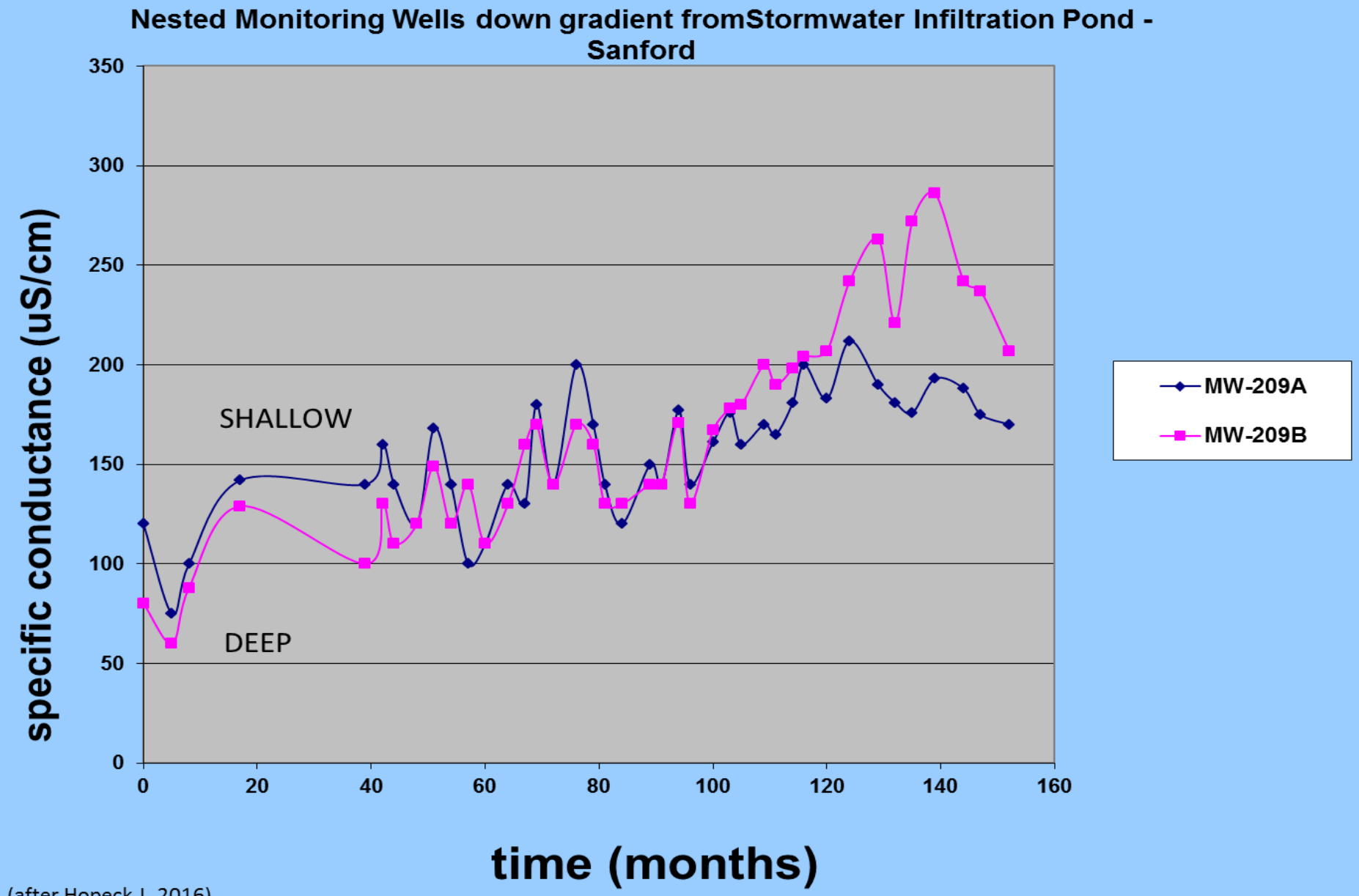
Robbinston_Perry (Rt. 1) -(P2) - outliers (2) removed



Road Salt in solution

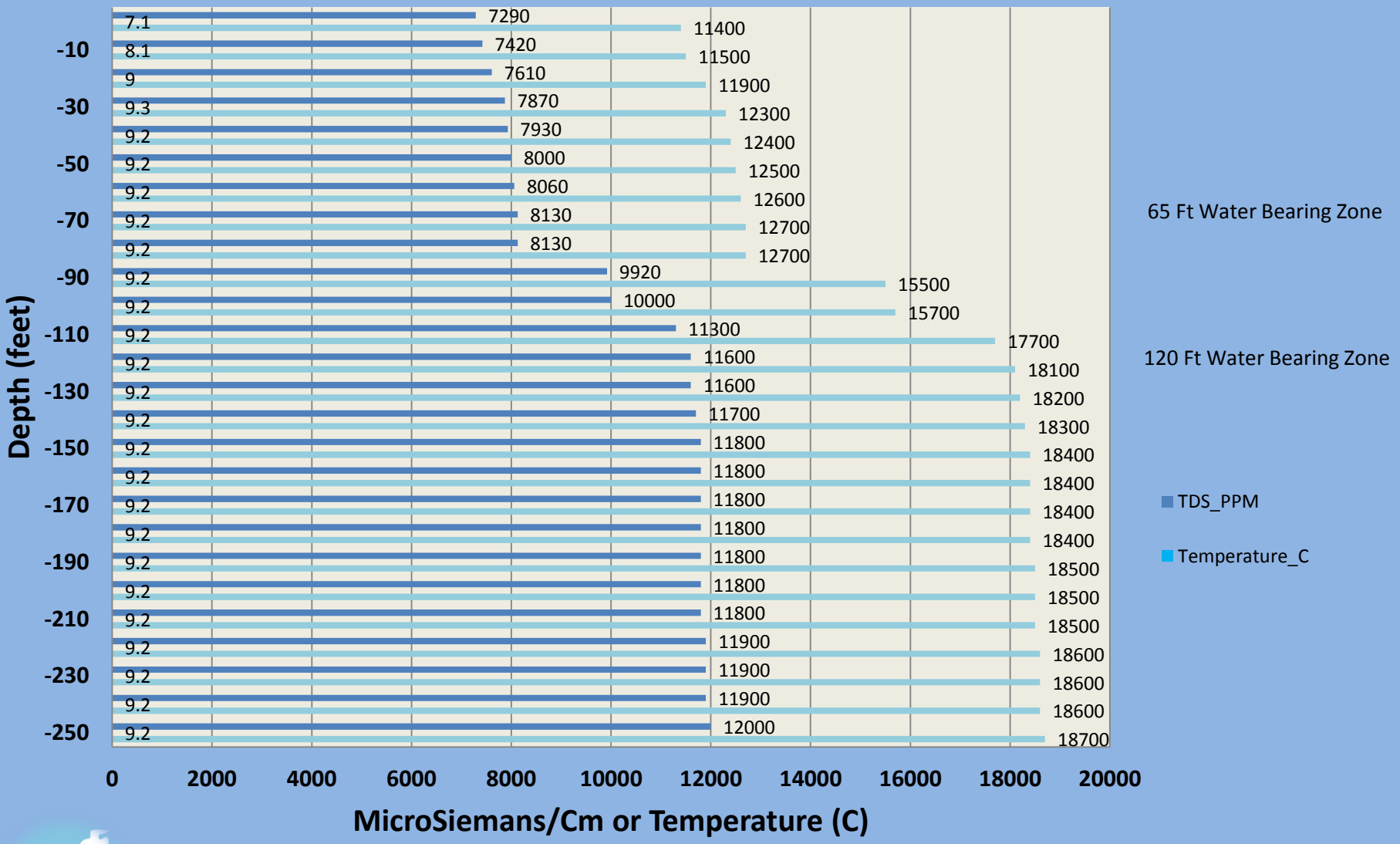
- Does the salt solution move out or down within the soils and bedrock?

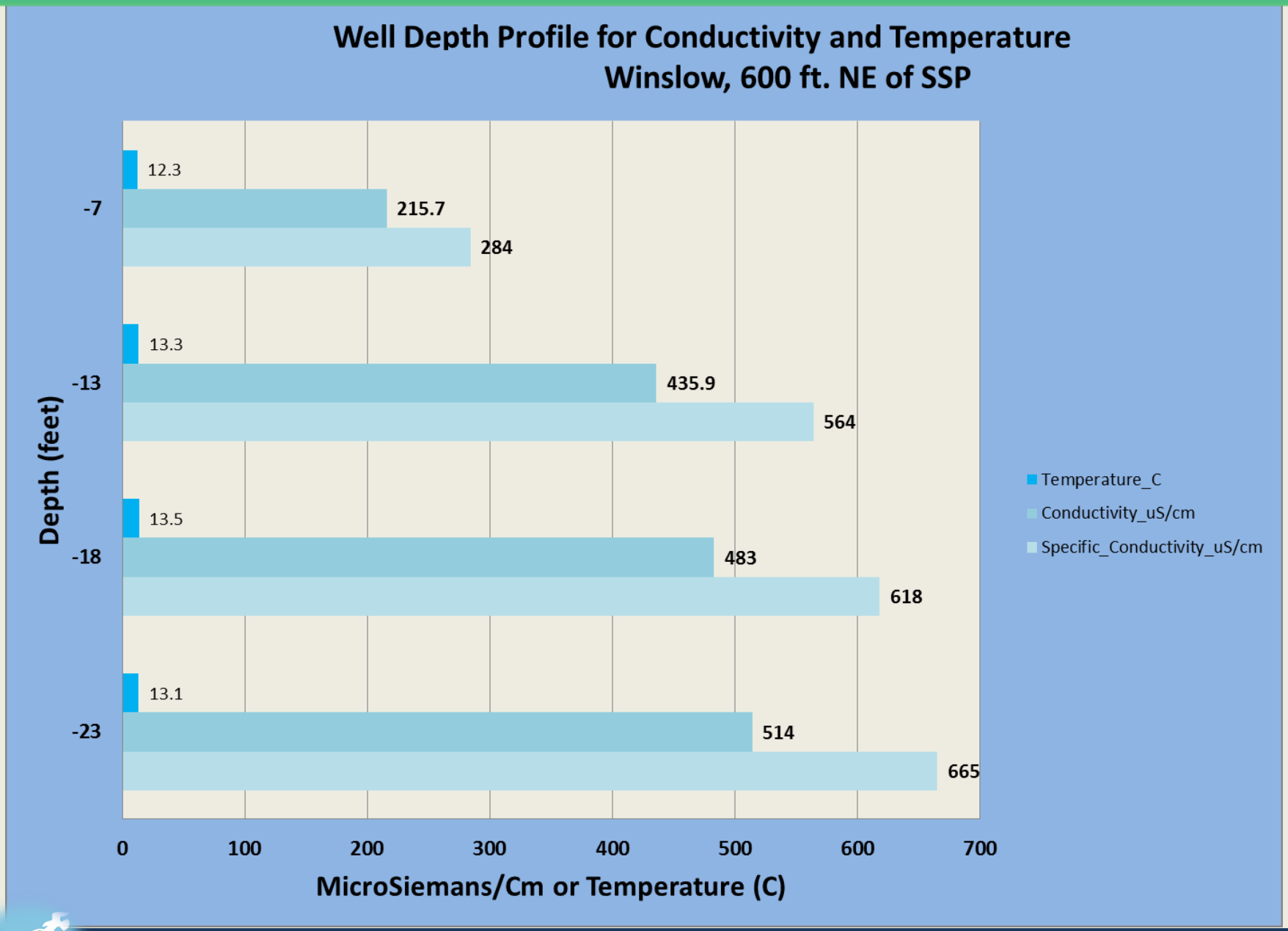
- Does it concentrate at shallow depths or deep?:



(after Hopeck,J. 2016)

Well Depth Profile for Conductivity and Temperature
Winslow, 1000 ft. NE of SSP




Well Depth Profile for Conductivity and Temperature
Winslow, 600 ft. NE of SSP
Depth (feet)
-7
-13
-18
-23
12.3
215.7
284
13.3
435.9
564
13.5
483
618
13.1
514
665
0
100
200
300
400
500
600
700
MicroSiemans/Cm or Temperature (C)
Temperature_C
Conductivity_uS/cm
Specific_Conductivity_uS/cm

Objective:

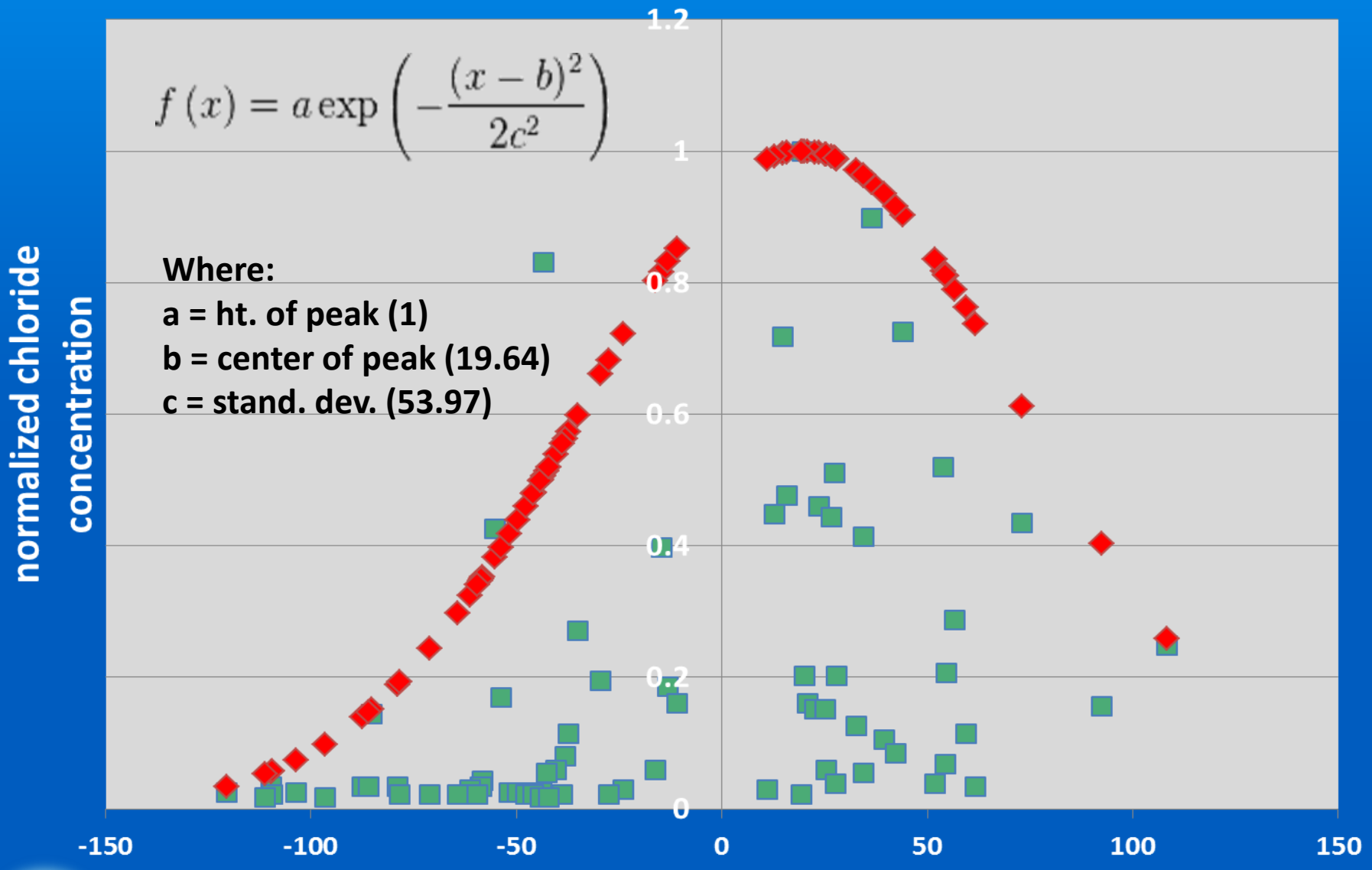
A Predictive Model for Road Salt Hydraulic Behavior in consideration of:

A. Residence time: of salt and/or salt solute

1. based on hydrologic soil type and underlying surficial geology
2. based on degree of topographic slope
3. culvert and ditch configuration: presence or absence, size

B. Regional Primary Bedrock Fracture Orientation

Hancock_Sullivan



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