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

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Road Salt (NaCl)

- Short and long term effect on groundwater
- The contaminated base flow can impede the reproduction of the macroinvertebrates.
- Surface waters in southern Maine have been showing increasing conductivity.

Why study chloride?

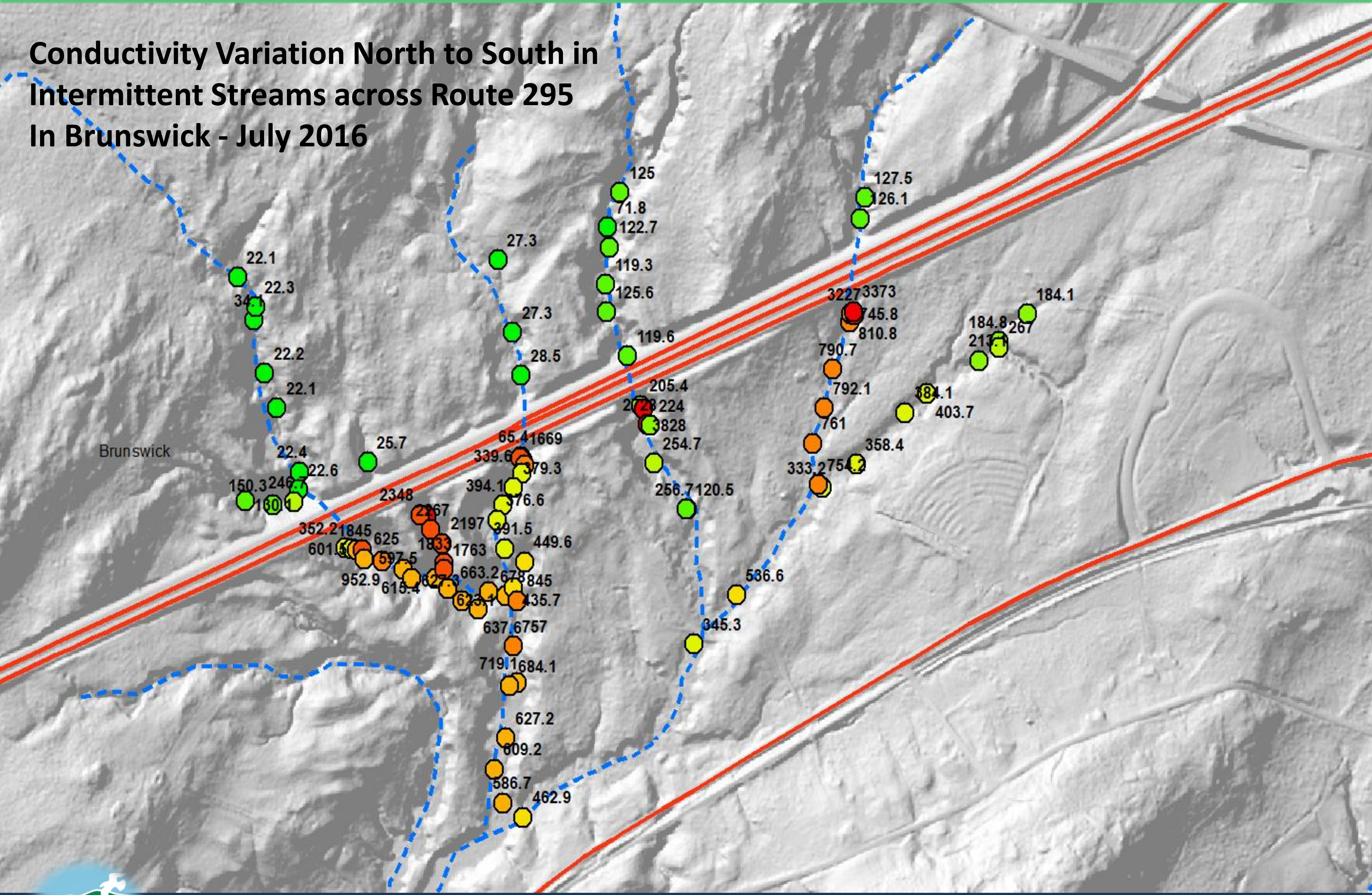
- Chloride is a common contaminant in groundwater and surface waters.
- Chloride is a conservative contaminant, so there are fewer variables to consider in contaminant migration.
- To develop and test risk models that could be applied to diverse conditions of slope, bedrock and overburden geology, and soils.

Chloride in Streams

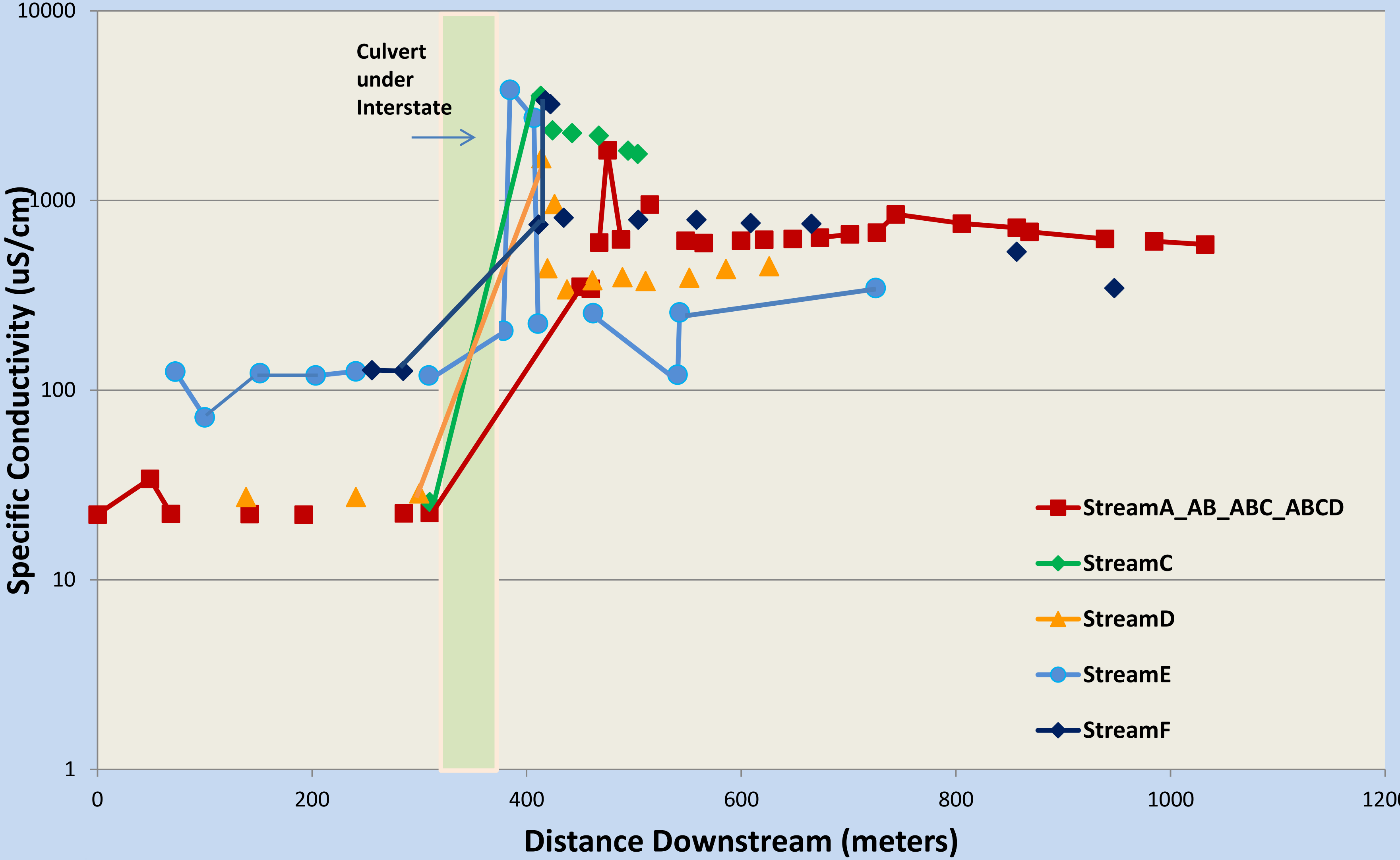
- Many intermittent streams which cross roads to which salt is applied in the wintertime have been observed to show a distinct increase in conductivity downstream of the road

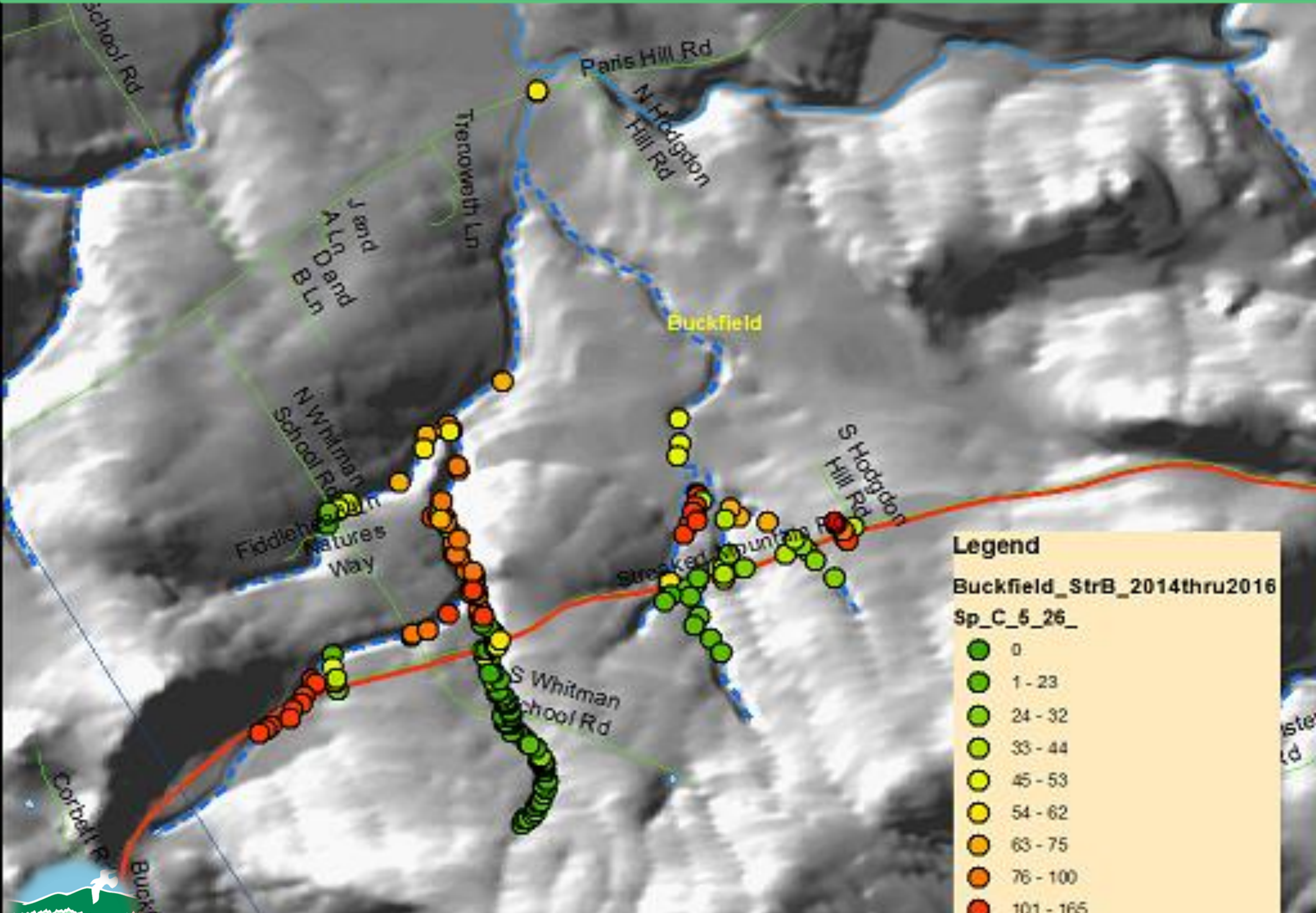
- Chloride appears to be stored in the soil and bedrock fractures and slowly released over the course of the year as base flow

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

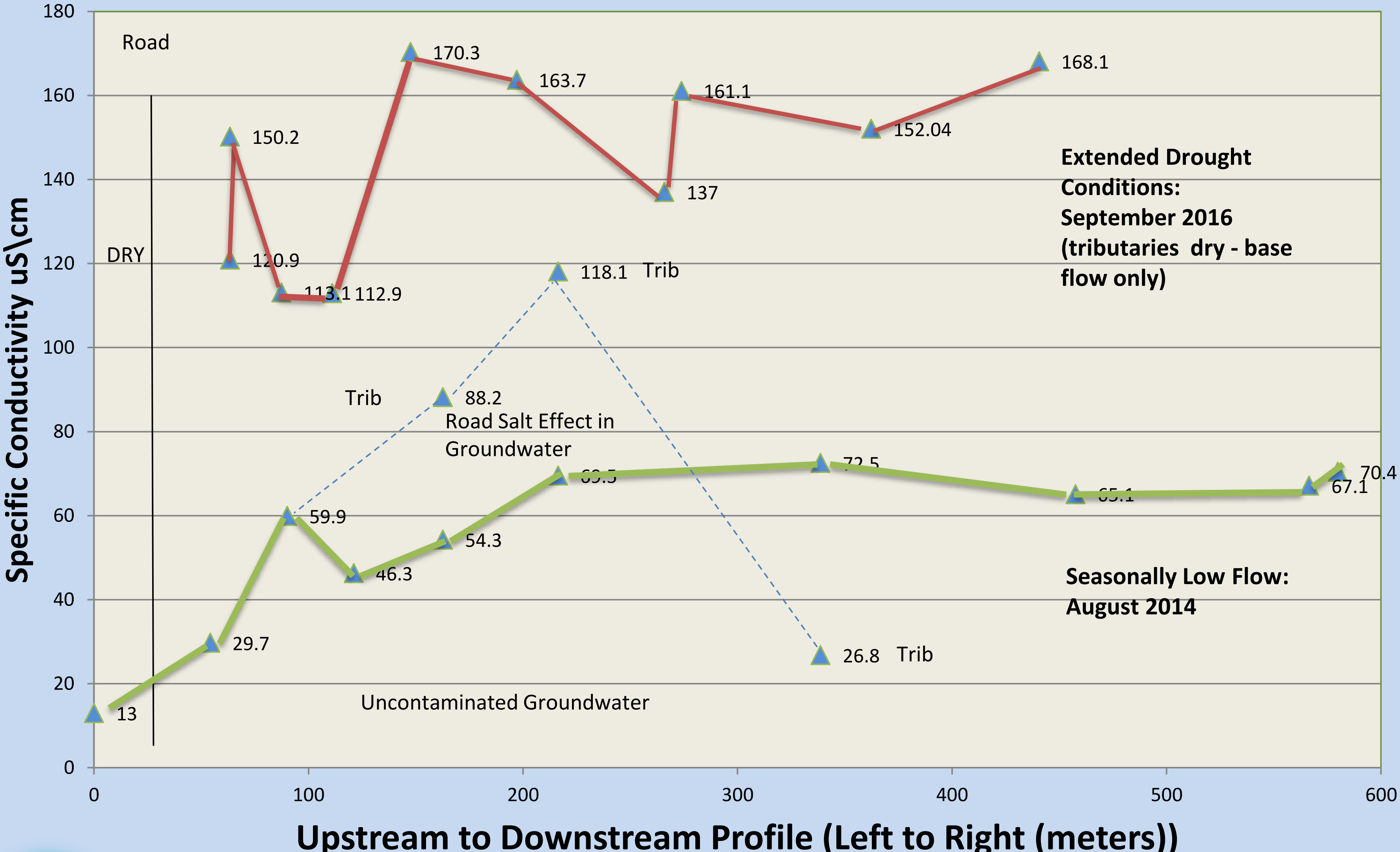


Variation in Specific Conductivity in Low Flow Streams and Confluences North to South across Interstate 295 in Brunswick - 2016




Paris Hill Rd
N Hodgdon Hill Rd
Trenoweth Ln
J and A Ln D and B Ln
Buckfield
N Whitman School Rd
Natures Way
S Hodgdon Hill Rd
S Whitman School Rd
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

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

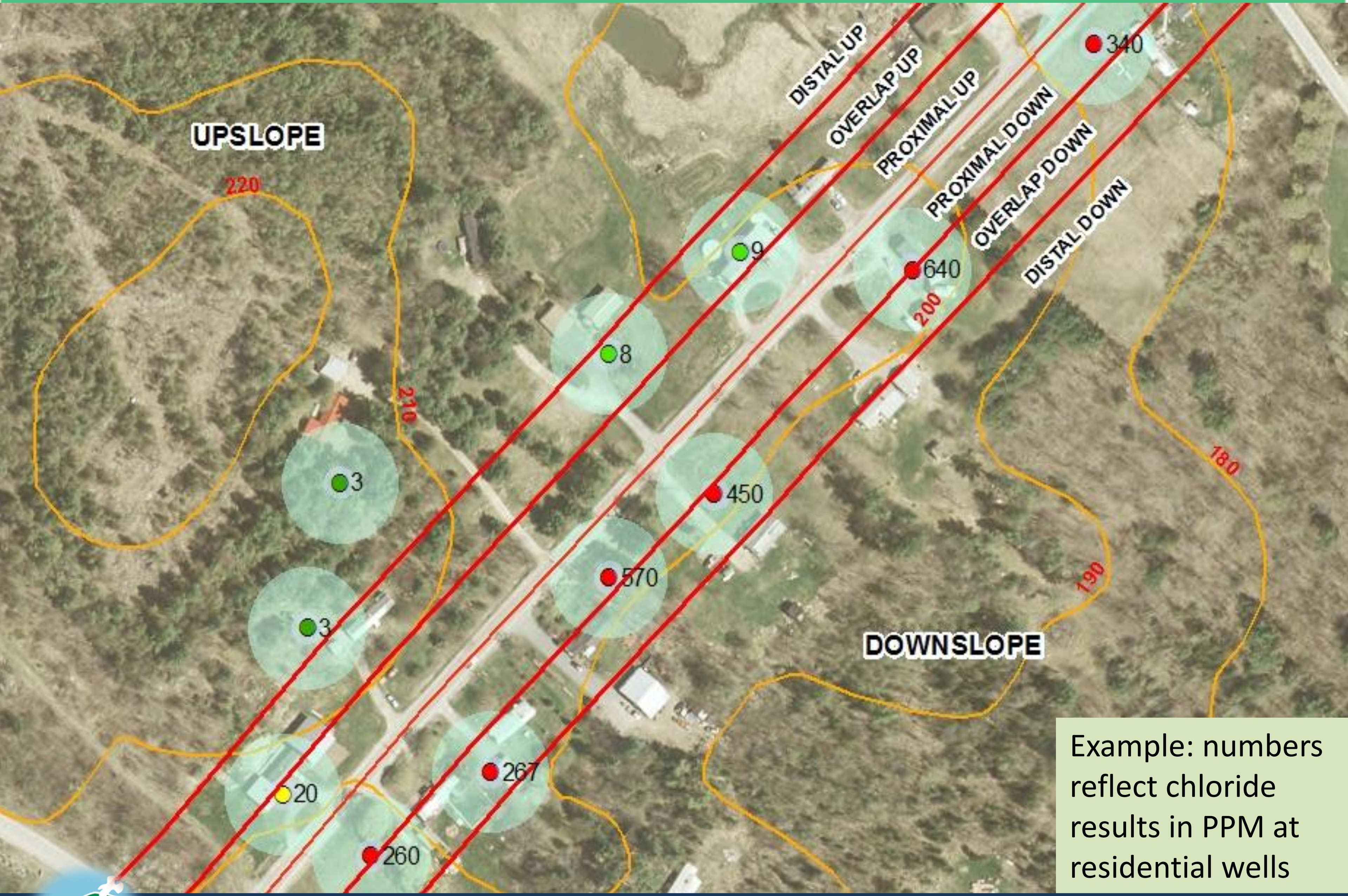


Chloride in Residential wells

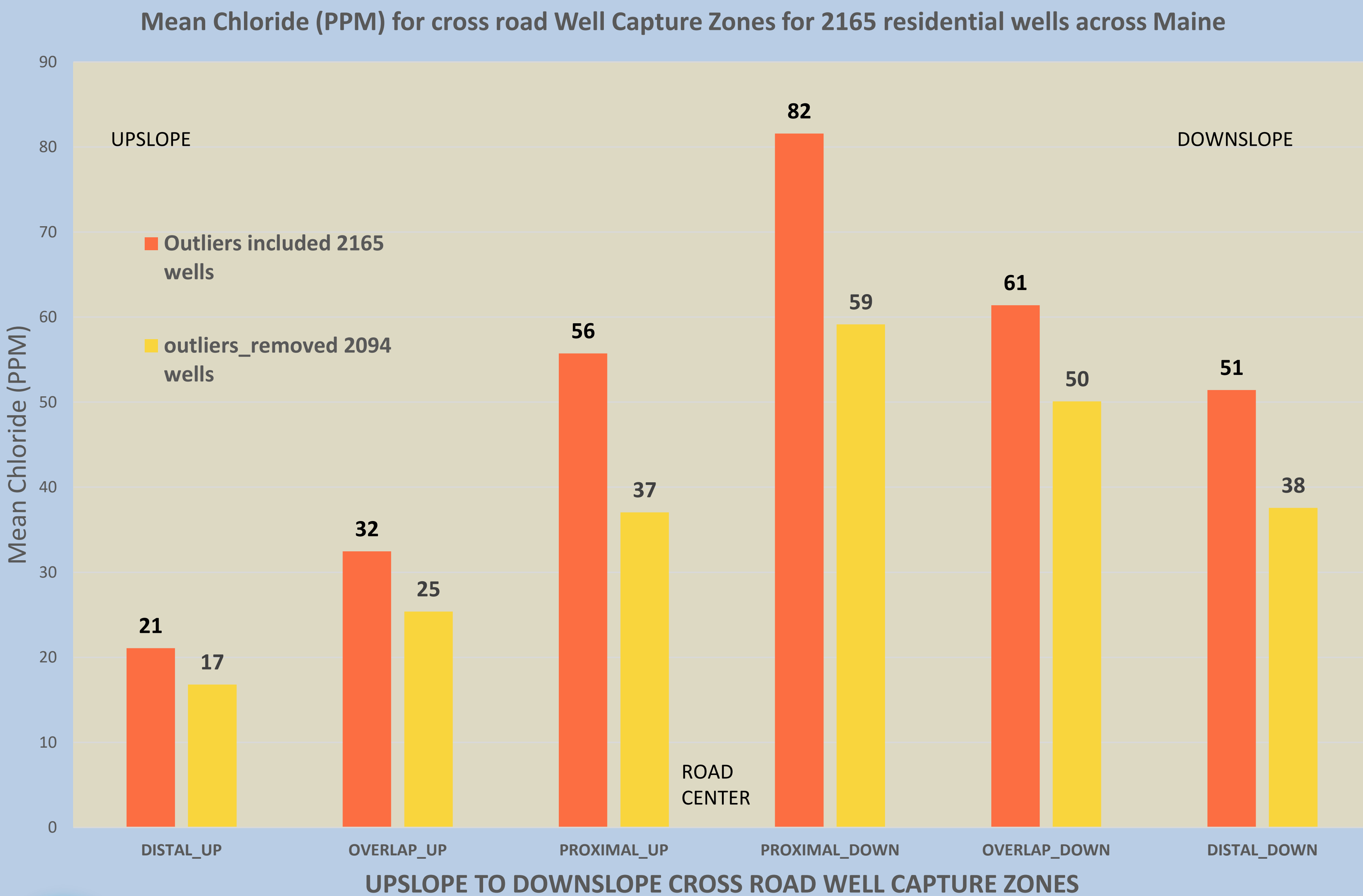
- Maine DOT sampled over 5000 wells in pre-construction surveys during 2001 – 2016.

- 3000+ wells were spatially located by Maine DEP in the field.

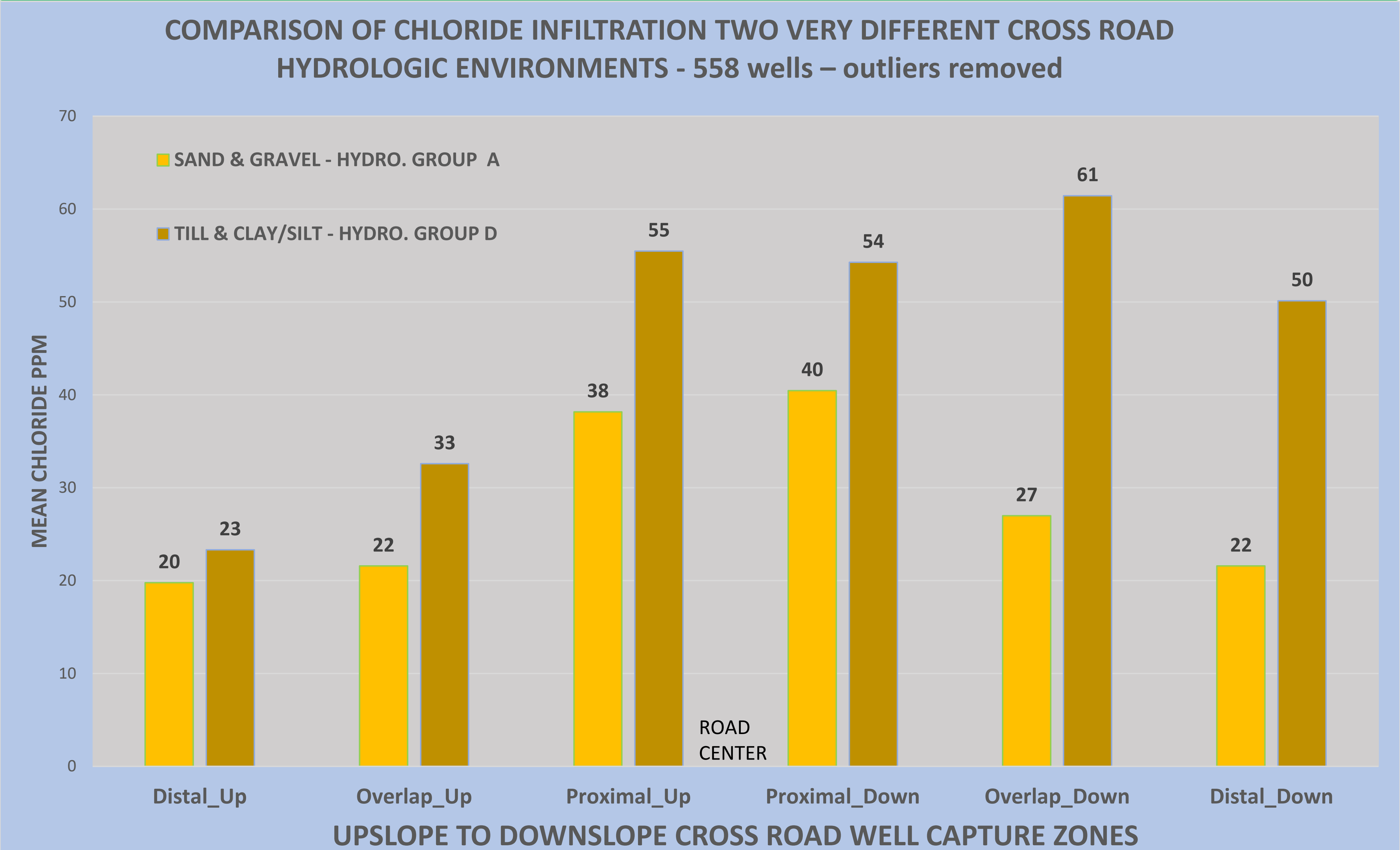
- These were selected from over 150 different municipalities in spatially diverse geographic settings.



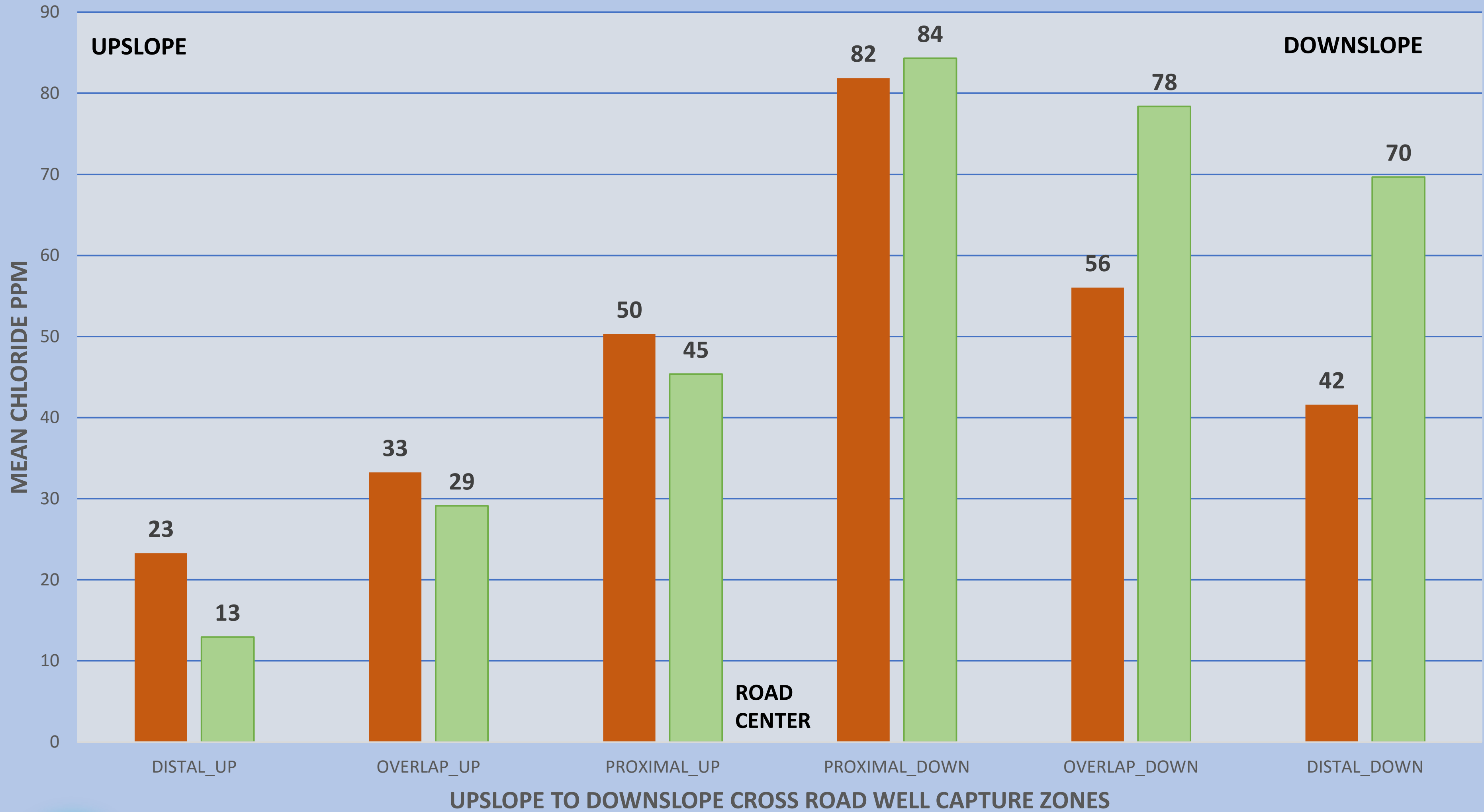
Example: numbers reflect chloride results in PPM at residential wells

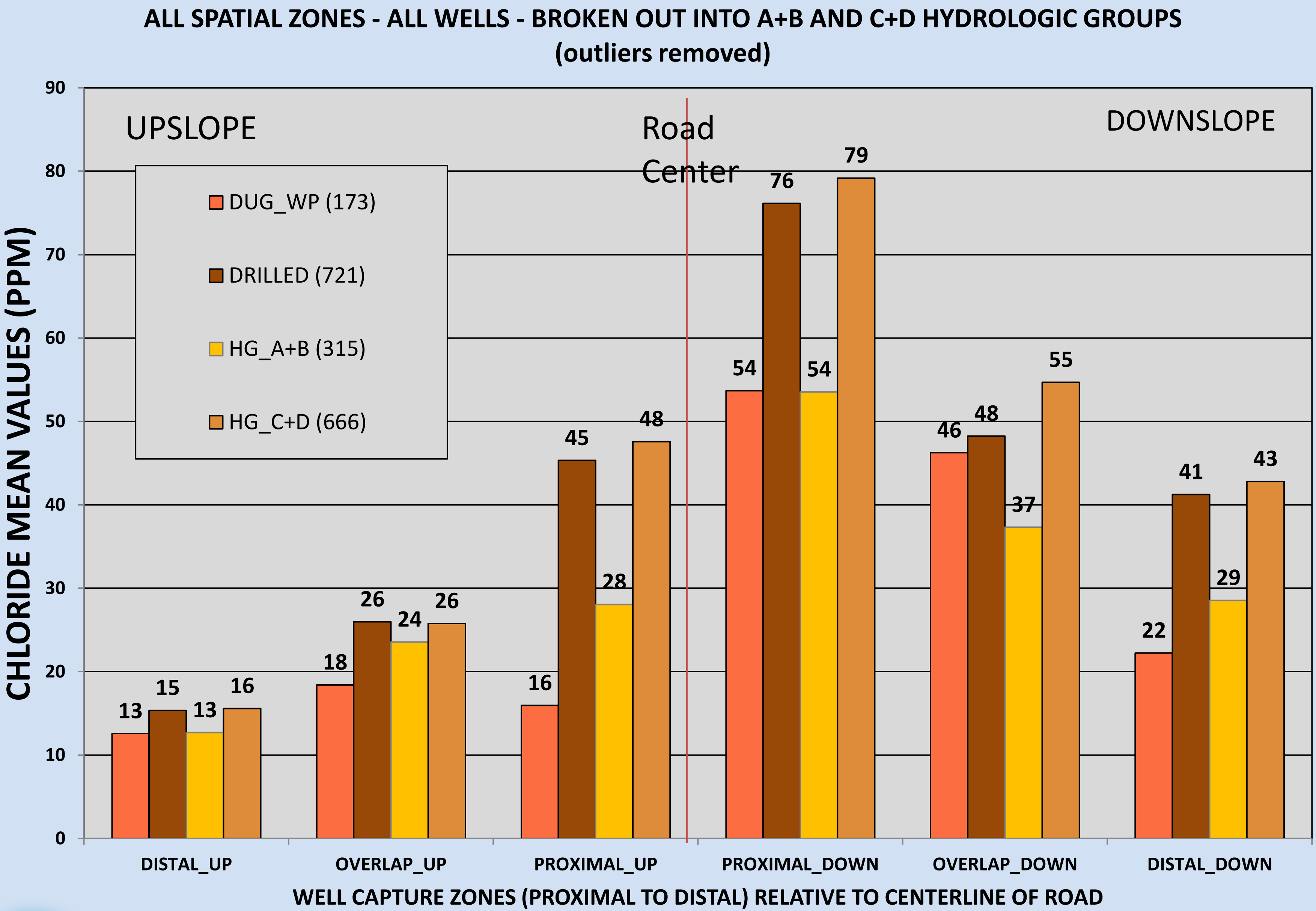


Mean Chloride (PPM) for cross road Well Capture Zones for 2165 residential wells across Maine
Mean Chloride (PPM)
0
10
20
30
40
50
60
70
80
90
UPSLOPE
DOWNSLOPE
Outliers included 2165 wells
outliers_removed 2094 wells
21
17
32
25
56
37
82
59
61
50
51
38
ROAD CENTER
DISTAL_UP
OVERLAP_UP
PROXIMAL_UP
PROXIMAL_DOWN
OVERLAP_DOWN
DISTAL_DOWN
UPSLOPE TO DOWNSLOPE CROSS ROAD WELL CAPTURE ZONES

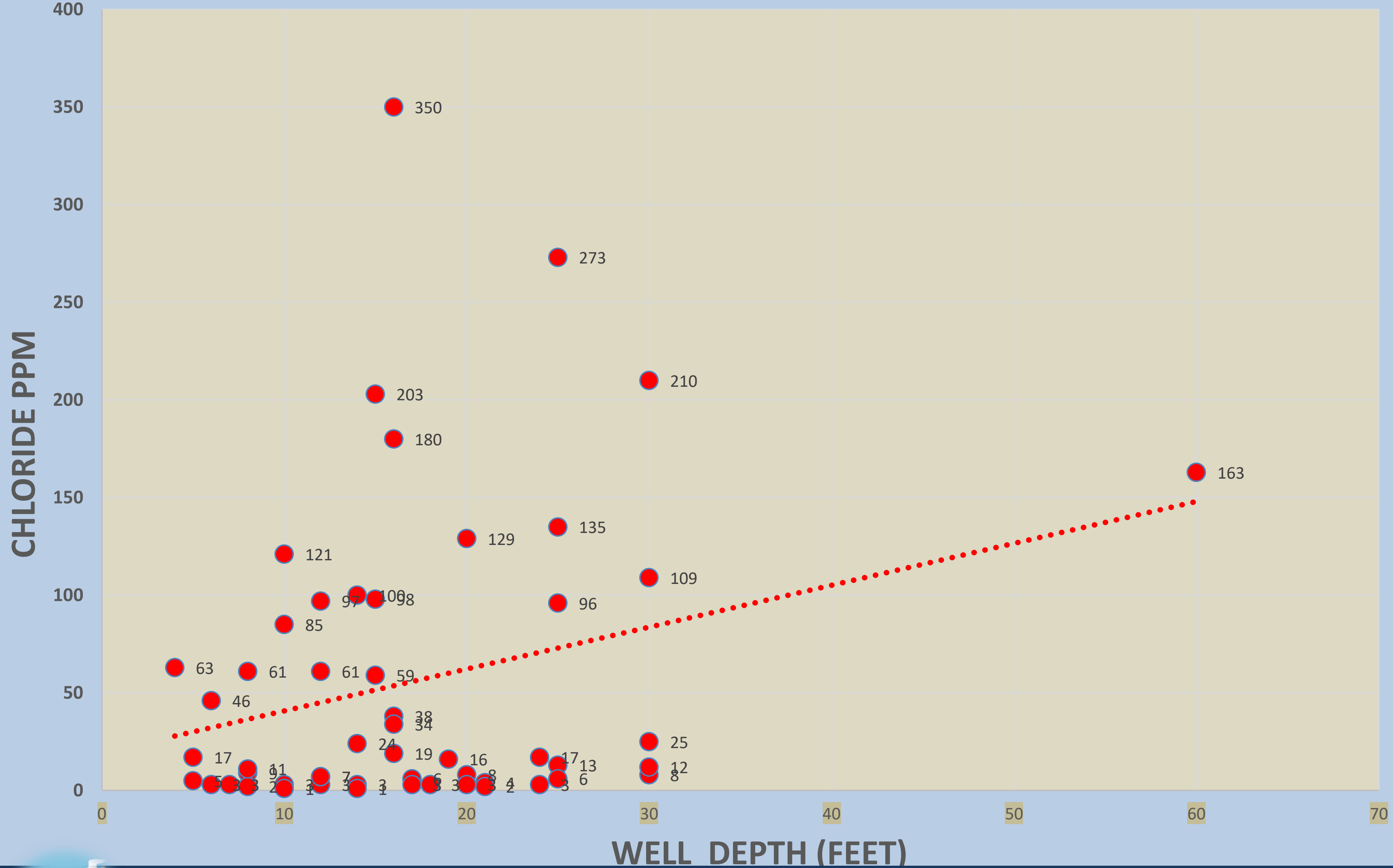

COMPARISON OF CHLORIDE INFILTRATION TWO VERY DIFFERENT CROSS ROAD HYDROLOGIC ENVIRONMENTS - 558 wells – outliers removed
SAND & GRAVEL - HYDRO. GROUP A
TILL & CLAY/SILT - HYDRO. GROUP D
MEAN CHLORIDE PPM
0
10
20
30
40
50
60
70
20
23
22
33
38
55
40
54
27
61
22
50
ROAD CENTER
Distal_Up
Overlap_Up
Proximal_Up
Proximal_Down
Overlap_Down
Distal_Down
UPSLOPE TO DOWNSLOPE CROSS ROAD WELL CAPTURE ZONES

Mean Chloride results (PPM) upslope to downslope in well capture zones periferal to roads in Maine - soils 0_80%slopes (green - 528 wells) and <10%slopes (red - 1321 wells) - (derived via SSURGO data)

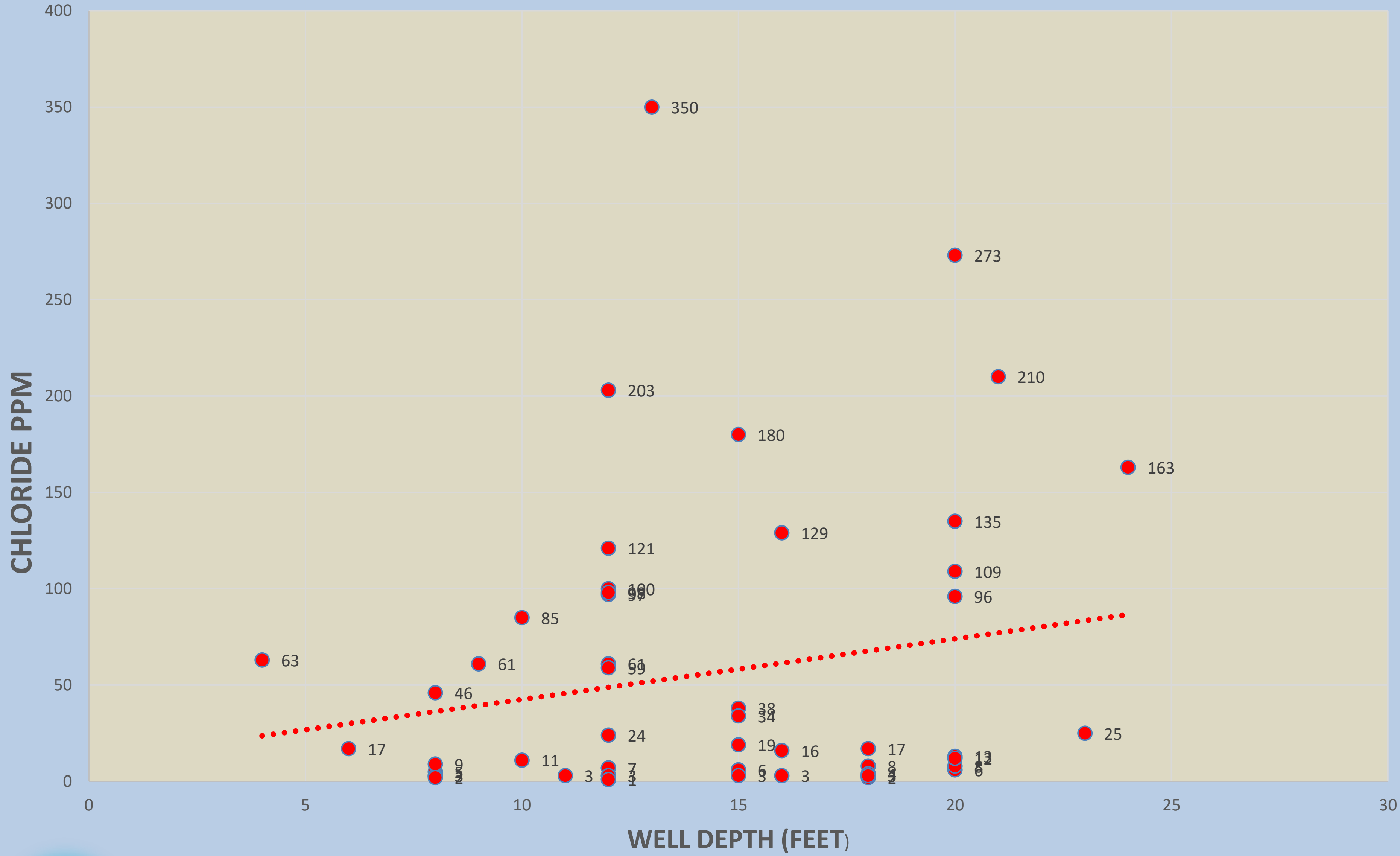



ALL SPATIAL ZONES - ALL WELLS - BROKEN OUT INTO A+B AND C+D HYDROLOGIC GROUPS
(outliers removed)
UPSLOPE
Road Center
DOWNSLOPE
DUG_WP (173)
DRILLED (721)
HG_A+B (315)
HG_C+D (666)
CHLORIDE MEAN VALUES (PPM)
0
10
20
30
40
50
60
70
80
90
13
15
13
16
18
26
24
26
16
45
28
48
54
76
54
79
46
48
37
55
22
41
29
43
DISTAL_UP
OVERLAP_UP
PROXIMAL_UP
PROXIMAL_DOWN
OVERLAP_DOWN
DISTAL_DOWN
WELL CAPTURE ZONES (PROXIMAL TO DISTAL) RELATIVE TO CENTERLINE OF ROAD

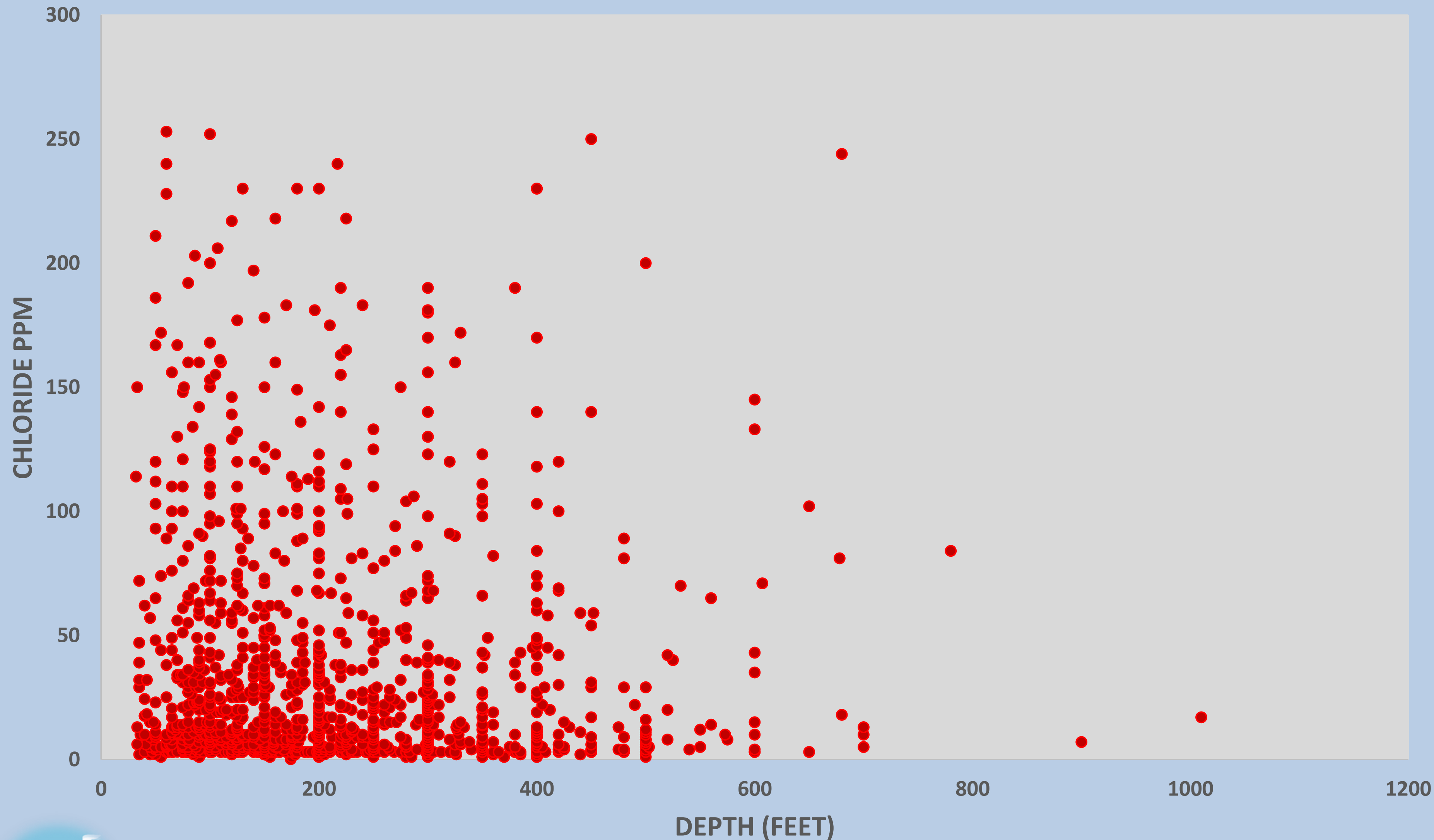
CHLORIDE with Depth: overburden wells (53): mainly TILL



CHLORIDE with Depth: overburden wells (65): mainly SAND and GRAVEL



CHLORIDE with Depth: 1337 Drilled wells: Bedrock - outliers removed

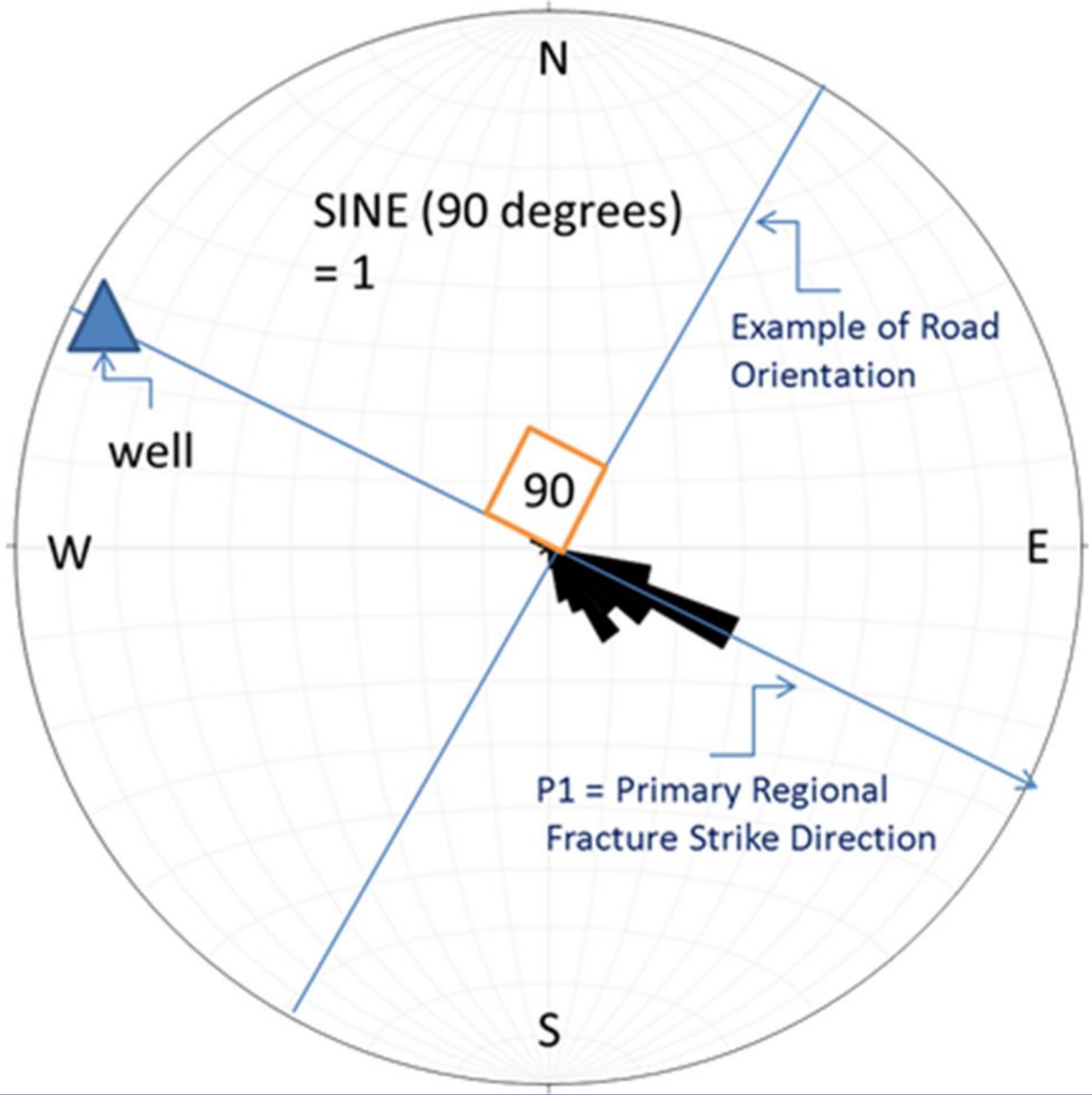


Effect of bedrock fractures

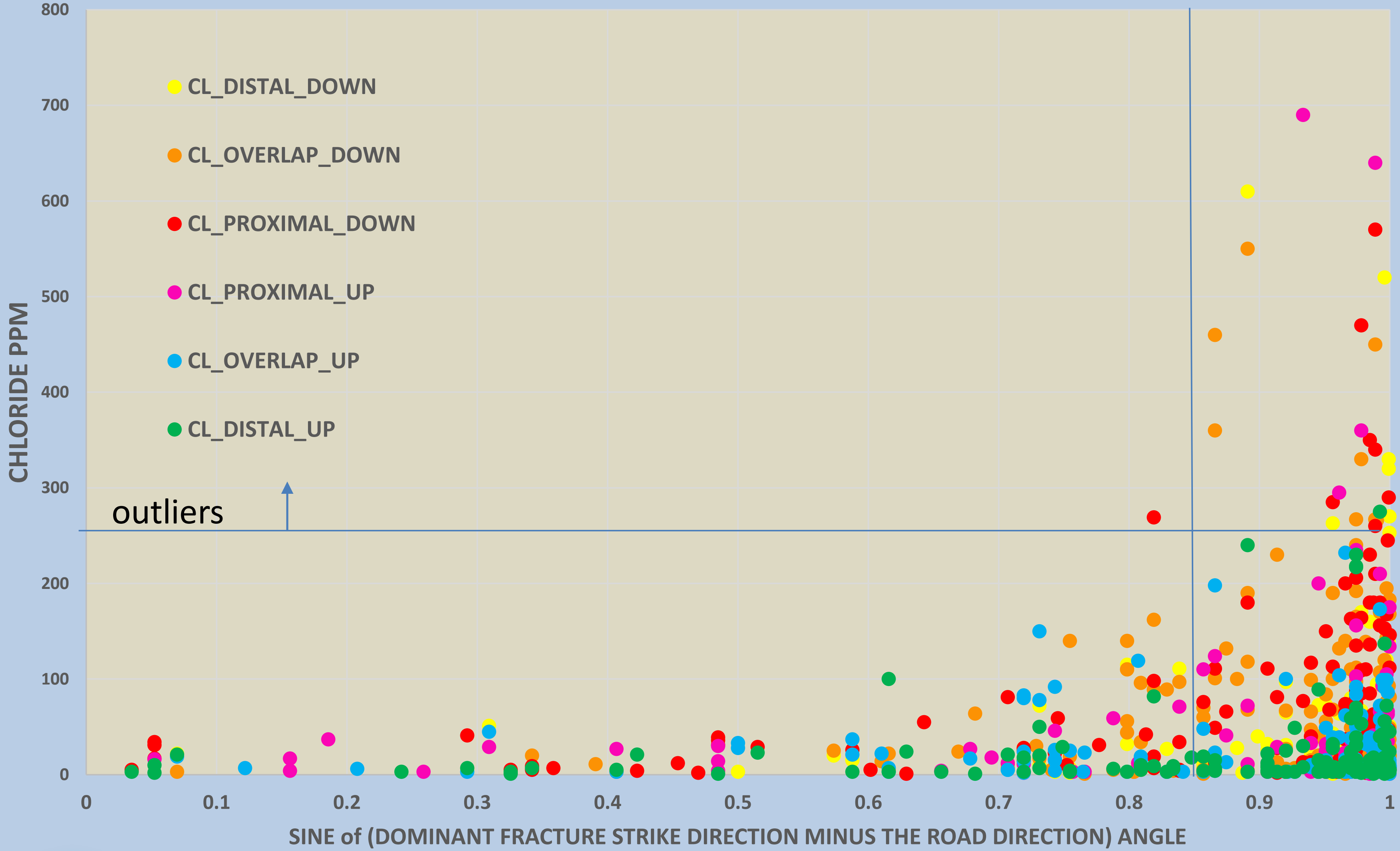
- Does bedrock fracture (joints, fracture cleavage) orientation have an effect on hydrologic movement of Chloride in the groundwater?

- 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 stereographic projection analysis (rose diagrams) to determine dominant trends

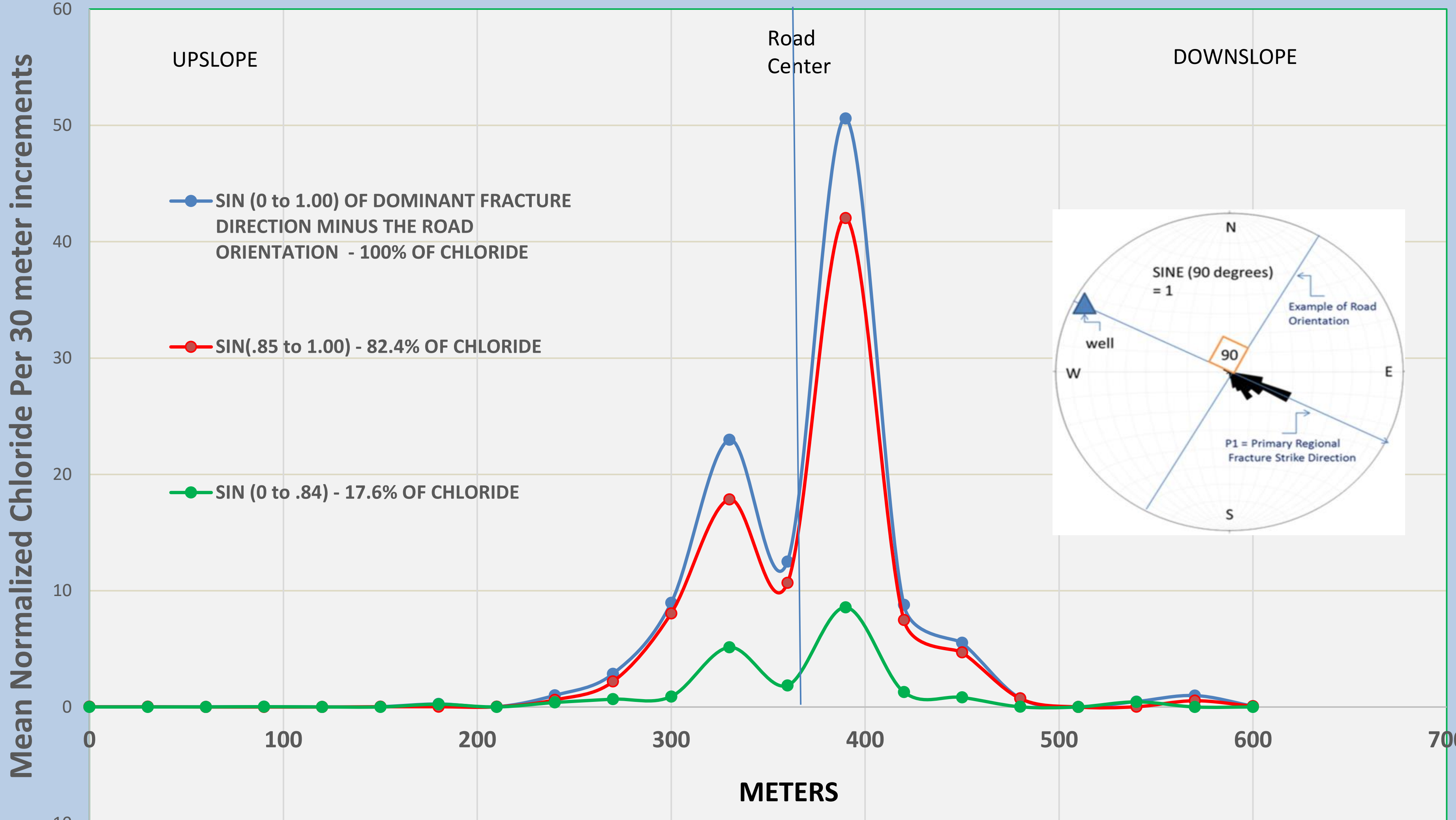
- Determine the shortest well to road direction, then measuring the direction of the road at that location


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

CHLORIDE IN PPM SHOWN BY WELL CAPTURE ZONE VS. SINE OF (DOMINANT BEDROCK FRACTURE TREND MINUS ROAD DIRECTION) AT NEAREST POINT ON ROAD - MAINE - 800 WELLS



BEDROCK FRACTURE EFFECT: Mean Normalized Chloride (from results in PPM) per 30 meter intervals upslope to downslope across roads in Maine - 773 wells - outliers removed



30 meter Increments Upslope to Downslope from roads in Maine

ALL SPATIAL ZONES - 982 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?

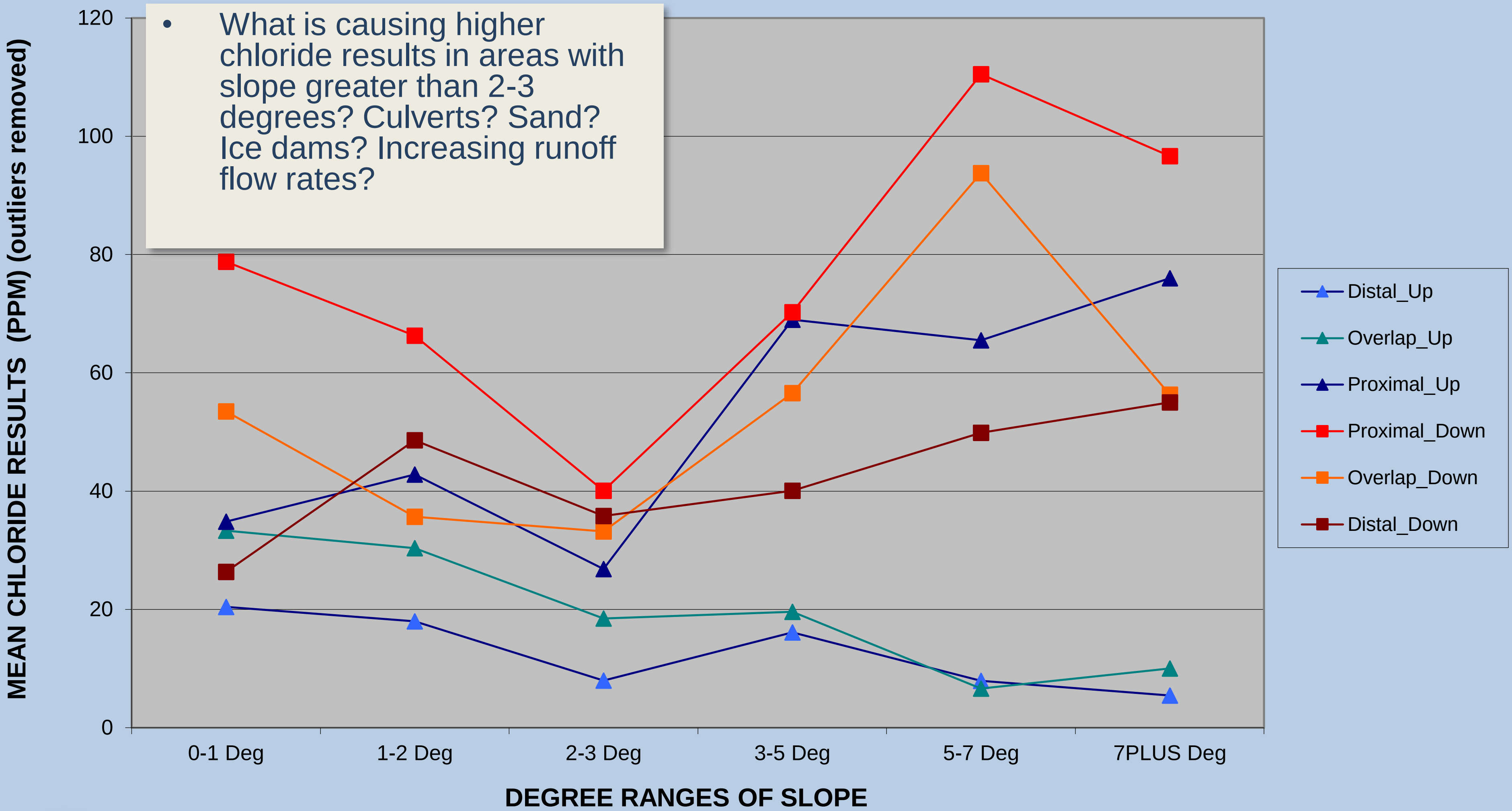


Figure 2. Salt and sand use for deicing roads by Maine Department of Transportation, 1990–2008. Data are from B. Burne, Maine Department of Transportation, written commun., 2009.

From USGS Report 2012-5205

IN CONCLUSION: AND WHAT DOES THE FUTURE HOLD?

1. Chloride becomes stored in the soils and overburden to varying degrees depending on the hydraulic conductivity of the medium.

2. Regional dominant fractures in bedrock are preferred conduits for chloride.

3. 2-3 degrees of cross road topographic slope is a demarcation above which wells downslope from the road increase dramatically in chloride content.

4. Overall chloride levels in wells tend to increase with depth in overburden wells while decreasing in bedrock with depth.

5. Generally Chloride retention is higher in tighter soils and overburden types.

6. The use of road salt is increasing.

7. Redesign of drainage systems could divert more Chloride away from the source in some cases.

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