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Road Deicing Salts on Groundwater in the Upper Passaic River Basin, New Jersey

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Impact of Road Deicing Salts in the Upper Passaic River Basin, New Jersey: A Geochemical Analysis of Major Ions in Groundwater

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Introduction

Rapid growth in population, road mileage density and urban development over the past 50 years in the Upper Passaic River Basin have led to increases in road salt application rates. This application of NaCl for road deicing has had a significant impact on the groundwater composition over time.
Here, we use geo-statistical methods and hydrochemical trends of groundwater samples spanning a period of 1960 —2010, to determine whether road deicing application has had a significant effect on the groundwater composition of the UPRB. Specifically, we seek to 1) determine correlations in ion to ion relationships using simple linear regression, 2) identify trends in major ionic concentrations over time, specifically Na+, Cl-, Mg2+, Ca2+, and SO42-, and 3) evaluate the hydrochemical composition of groundwater facies in decadal segments.
Results from the analyses will serve to advance our understanding of anthropogenic influences on regional groundwater quality in the UPRB. It can help not only for identifying regions that are prone to anthropogenic contamination, but also in designing better environment management techniques.

Study Area

The UPRB, also known as Water Management Area 06, is located in northern New Jersey, between latitudes 40º40" and 41º10" North and longitudes 74º15" and 74º40" West (Figure 1). It covers an area of 361.5 sq. mi. in Morris county, a region of significant population increases, from 261,620 in 1960 to 492,276 in 2010 (U.S. Census Bureau, 2015).
Approximately 3,049 miles of roads spread evenly throughout the area (Figure 2) (New Jersey Geological Survey (NJGS), 2010). Using data from NJDOT and New Jersey Bureau of GIS (NJGIS), an estimate of the amount of road salt used in 2017 in the UPRB is found to be approximately 29,389 tons (NJGIS, 2018; NJDOT, 2018).

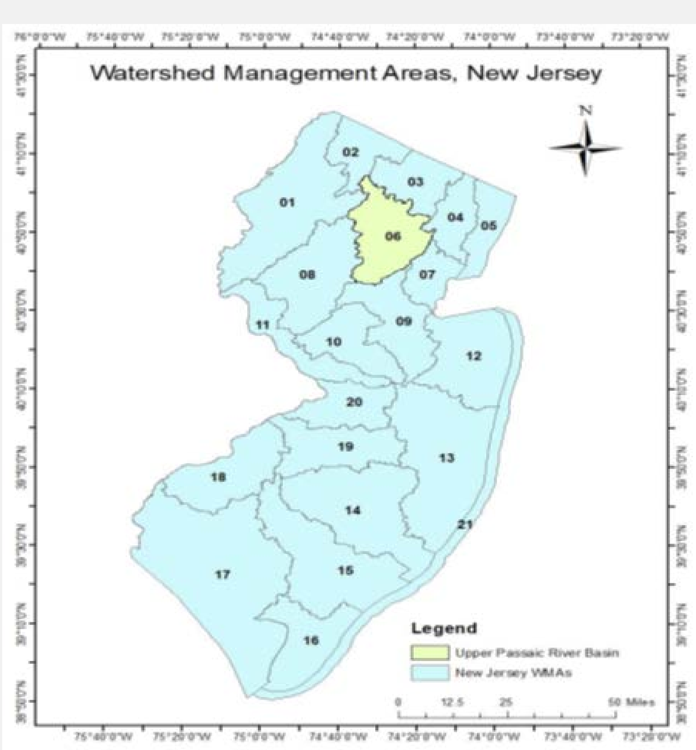

Figure 1: Location of the Upper Passaic River Basin (source: New Jersey Department of Environmental Protection, 2009)

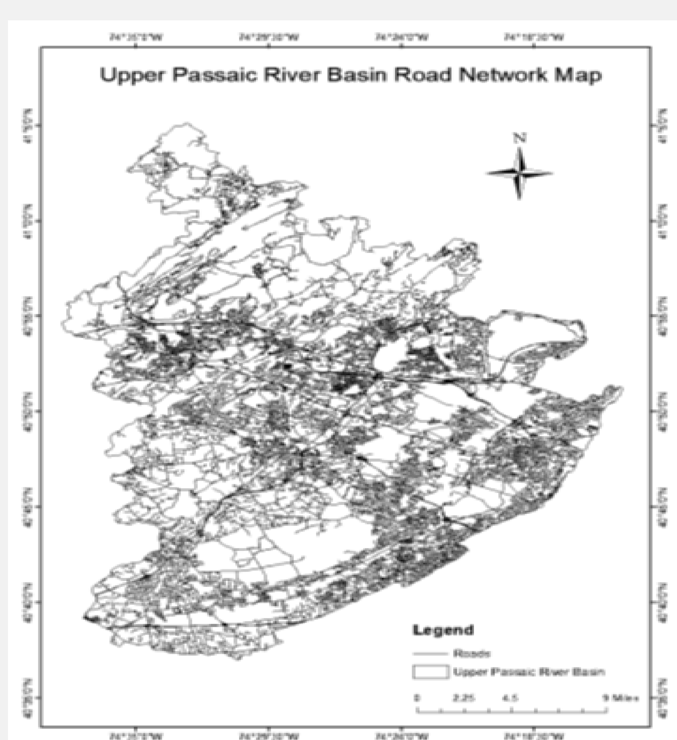

Figure 2: Spatial Distribution of Roads in the Upper Passaic River Basin (source: New Jersey Geographic Information Network, 2017)

Data and Methods

The USGS website is a repository of large amount of water chemistry data. For this study, 573 different measurements from 1960 to 2010 within the UPRB were compiled into a single database and analyzed using Microsoft Excel 2016.
Overall, four levels of analyses were performed. Linear regression approach was initially done on major ions to compare the ion partnerships of Na+ vs. Cl-, Mg2+ vs. Ca2+, Na+ vs. Ca2+, Cl- vs. Ca2+, and Cl- vs. TDS. Following this, decade average statistics were calculated for TDS, Na+, Ca2+, Mg2+, K^+, Cl-, HCO_3^-+CO_3^{2-}, and SO_4^{2-} to observe how the average concentration over the entirety of the study has varied throughout the study period. Further, ionic composition of the groundwater as a whole was evaluated using the Piper diagram. Finally, a prediction interval analysis was done to ascertain changes in major ions compositions over time.

Results

Linear Regression Analysis

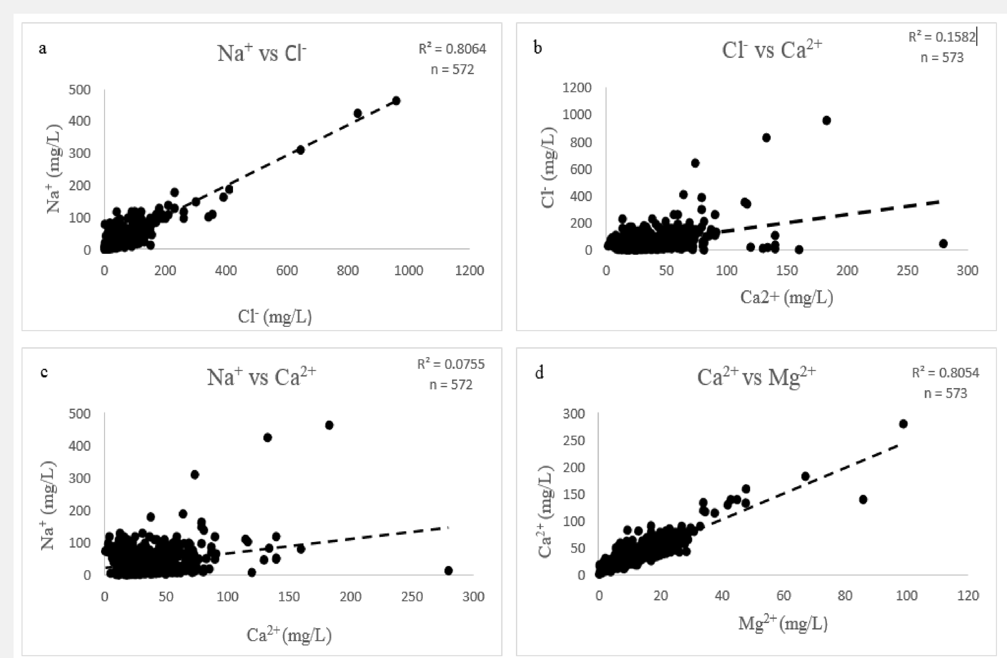

Figure 3: Regression Relationships between Major Ions in the Upper Passaic River Basin, a) Sodium and Chloride, b) Chloride and Calcium, c) Sodium and Calcium, d) Calcium and Magnesium.

Table 1: Mean, Standard Deviation, and Range for Major Ion Concentration and TDS in the UPRB (concentration in mg/L)

Ion	Collection Period	Mean	Standard Deviation	Max	Min	Data count
Na^+	1960-1969	15.77	16.57	84	3.60	35
	1980-1989	39.56	31.22	180	1.70	398
	1990-1999	37.26	34.03	190	1.83	108
	2000-2010	63.65	119.15	463	2.49	31
Mg^{2+}	1960-1969	13.27	4.87	34	6.30	35
	1980-1989	12.49	9.81	99	0.14	399
	1990-1999	11.78	7.57	28	0.24	108
	2000-2010	19.91	14.27	67	1.69	31
Ca^{2+}	1960-1969	39.69	19.27	134	18	35
	1980-1989	36.77	25.47	280	1.10	399
	1990-1999	33.57	19.51	87	1.40	108
	2000-2010	56.94	40.76	183	6.69	31
Cl^-	1960-1969	10.76	5.87	28	3.20	35
	1980-1989	60.71	49.88	300	0.80	399
	1990-1999	62.59	61.05	410	1.20	108
	2000-2010	139.62	250.18	960	2.01	31
SO_4^{2-}	1960-1969	52.86	81.34	505	17	35
	1980-1989	38.26	71.44	850	1.60	399
	1990-1999	25.67	14.93	93	2.99	108
	2000-2010	32.30	24.46	113	7.62	31
K^+	1960-1969	0.85	0.41	2	0.30	35
	1980-1989	1.98	1.88	27	0.30	398
	1990-1999	1.50	1.10	6	0.18	108
	2000-2010	1.75	1.50	6	0.33	31
HCO3+CO3	1960-1969	138.43	24.53	213	84	35
	1980-1989	142.42	52.36	257	38	65
	1990-1999	208.42	148.32	573	67	12
	2000-2010	210.11	122.48	341	66	9
TDS	1960-1969	238.92	134.29	934.05	132.38	35
	1980-1989	361.06	162.49	1507.71	66.19	397
	1990-1999	261.06	133.87	897.27	51.48	105
	2000-2010	451.33	508.13	2066.67	58.84	30

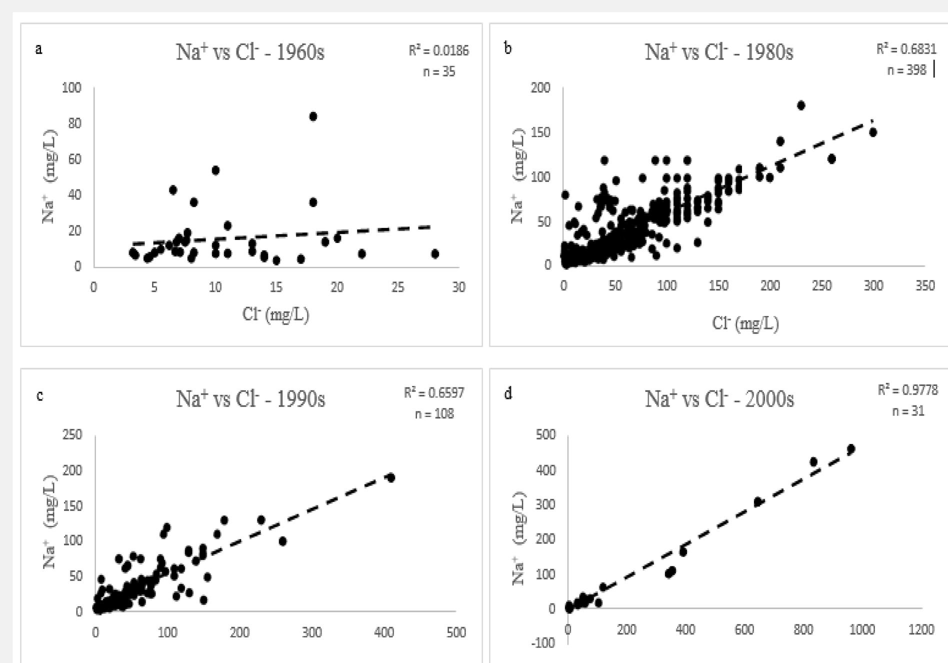

Figure 4: Relationship Between Sodium and Chloride Concentrations for Samples Collected in the 1960s, 1980s, 1990s and 2000s in the Upper Passaic River Basin

Table 2 Regression Analysis Correlations for Major Ion to Ion Relationship in the UPRB

mg/L	mg/L	yr	R^2	n
Y - Dependent	X - Independent	Sample Period	Correlation Coefficent	Sample Size
Na^+	Cl^-	1960-1969	0.02	35
		1980-1989	0.68	398
		1990-1999	0.66	108
		2000-2010	0.98	31
		Cumulative*	**0.81**	**572**
Mg^{2+}	Ca^{2+}	1960-1969	0.81	35
		1980-1989	0.81	399
		1990-1999	0.70	108
		2000-2010	0.89	31
		Cumulative*	**0.81**	**573**
Na^+	Ca^{2+}	1960-1969	0.38	35
		1980-1989	0.01	398
		1990-1999	0	108
		2000-2010	0.57	31
		Cumulative*	**0.08**	**572**
Cl^-	Ca^{2+}	1960-1969	0.14	35
		1980-1989	0.22	399
		1990-1999	0.4	108
		2000-2010	0.75	31
		Cumulative*	**0.16**	**573**
Cl^-	TDS	1960-1969	0.17	35
		1980-1989	0.36	397
		1990-1999	0.78	105
		2000-2010	0.97	30
		Cumulative*	**0.62**	**567**

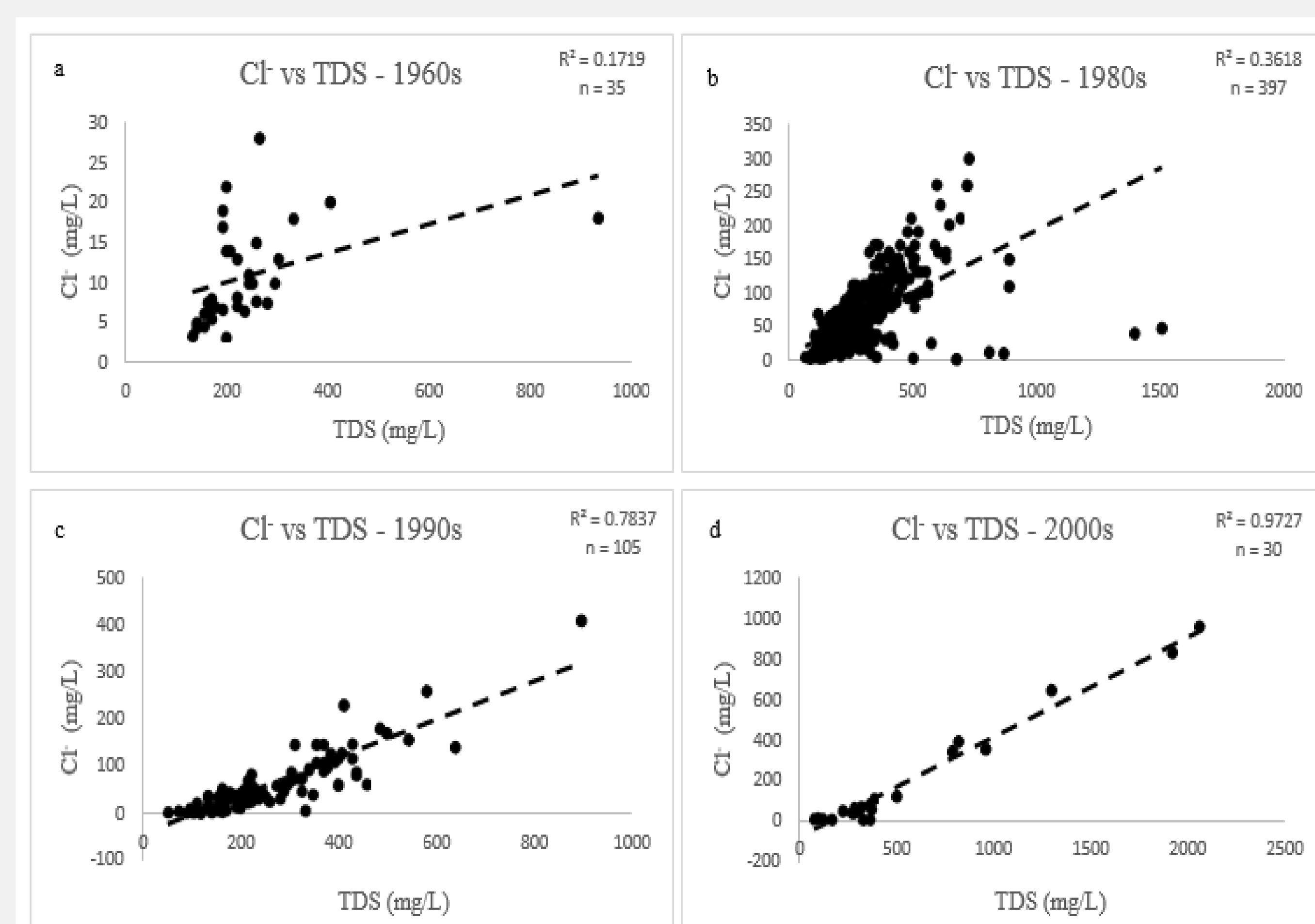

Figure 5: Relationship between Chloride and Total Dissolved Solids Concentrations for Samples Collected in the 1960s, 1980s, 1990s and 2000s in the Upper Passaic River Basin.

Conclusion

Application of NaCl for road deicing has had a significant impact on the groundwater composition over time. Chloride concentration shows increasingly significant contribution to TDS over time and has increased at a rate that would insinuate anthropogenic influence.
High levels of Na^+ and Cl- appear to be directly related to deicing salt application, while the other ions are following the natural evolution process in the system.
The groundwater in the UPRB has evolved over time to consist of a mixture of mixture of Ca(HCO3)2 and NaCl species likely attributable to both deicing salts and the geologic variation in the bedrock of the UPRB.

Results

Decade-averaged Concentration Patterns of Major Ions

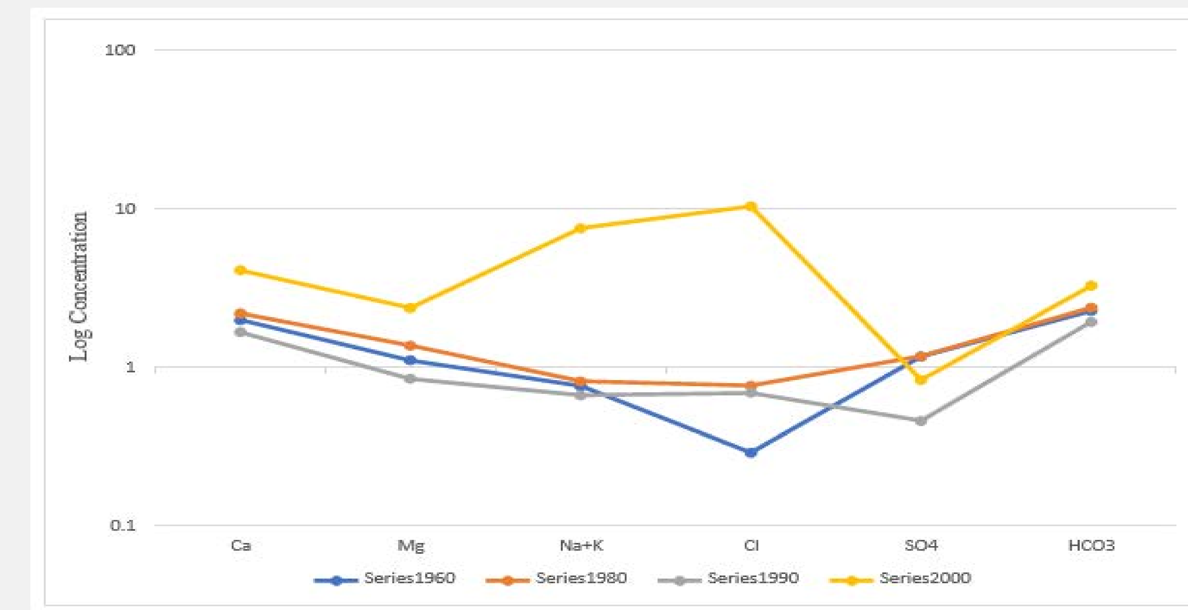

Figure 6: A Schoellar Diagram Depicting Log Concentrations of Major Ions for the 1960s, 1980s, 1990s and 2000s in the Upper Passaic River Basin.

Groundwater Species

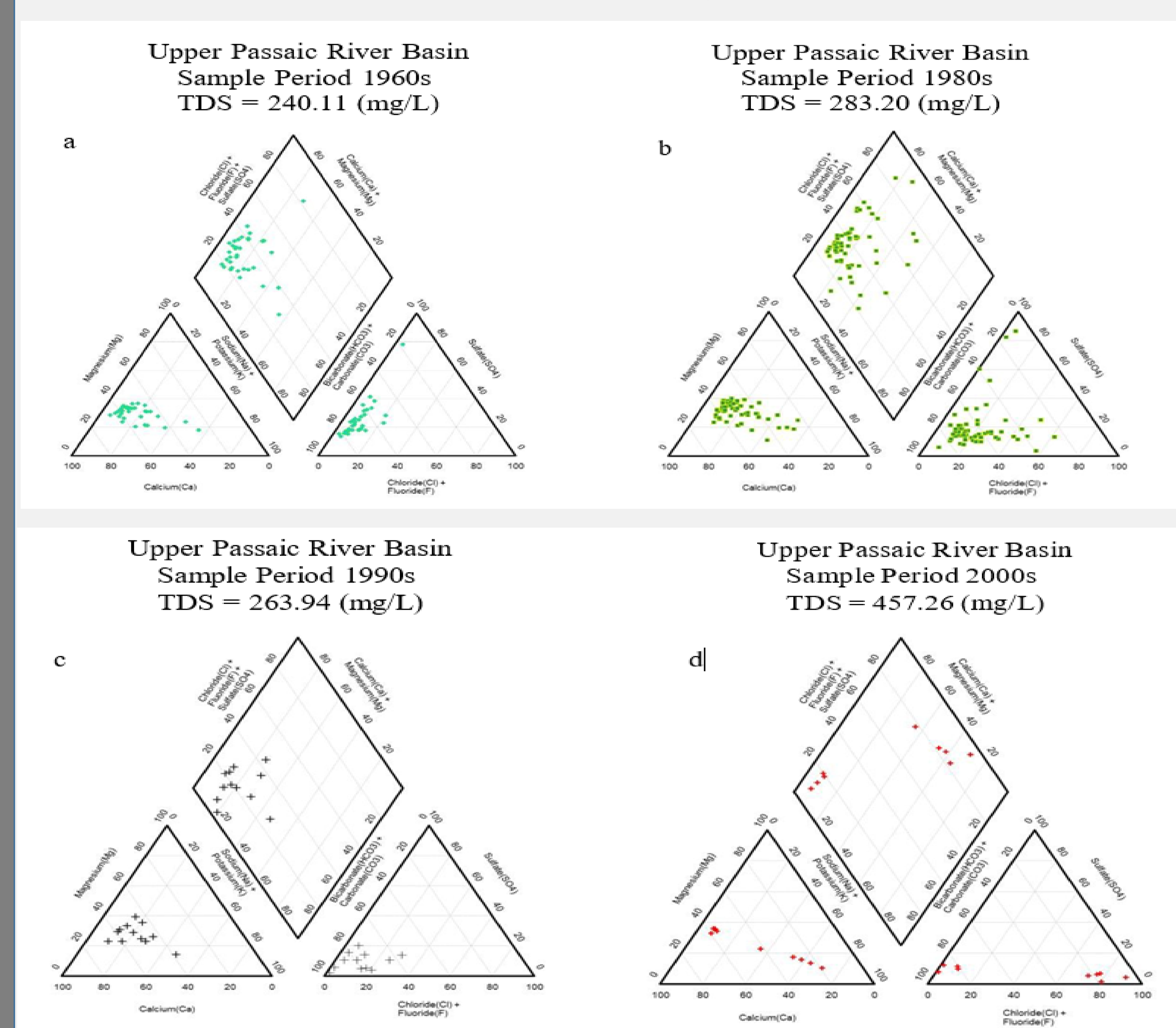

Figure 7: Piper Diagrams showing Groundwater Facies in the Upper Passaic River Basin.

Prediction Interval Analysis

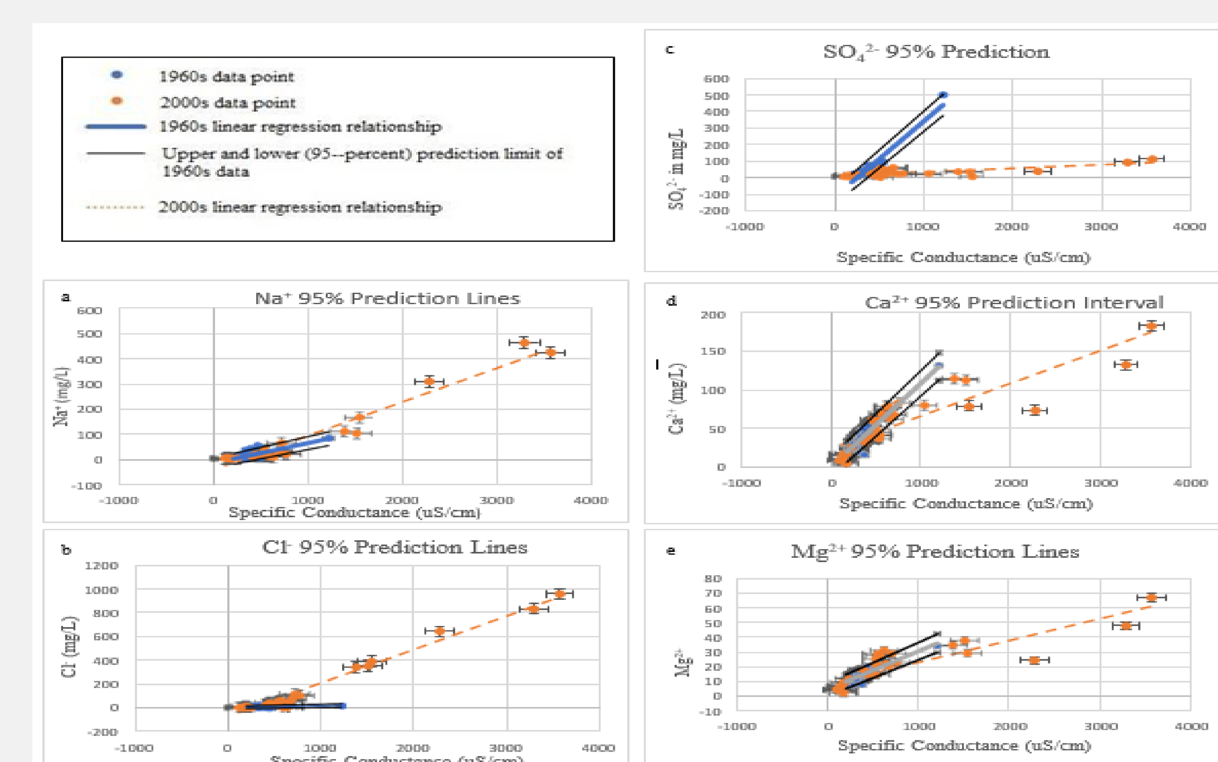

Figure 8: Relationships between Major Ions and Specific Conductance for 1960s and 2000s data, a) Sodium, b) Chloride, c) Sulphate, d) Calcium, e) Magnesium.

Table 3: Calculated Mean of Major Ion Concentration for the UPRB (concentrations in mg/L)

Constituent	1960s	2000s	Difference	Percent Increase
Sodium (Na)	15.77	63.65	47.88	303.60%
Magnesium(Mg)	13.28	19.09	5.81	43.71%
Calcium (Ca)	39.57	53.98	14.41	36.42%
Chloride (Cl)	10.26	134.87	124.61	1214.90%
Sulfate (SO4)	50.69	30.98	-19.70	-38.87%