Using Stable Isotopes to Assess Surface-Groundwater Interactions and Contaminant Pathways in a Drinking Water Supply Watershed System

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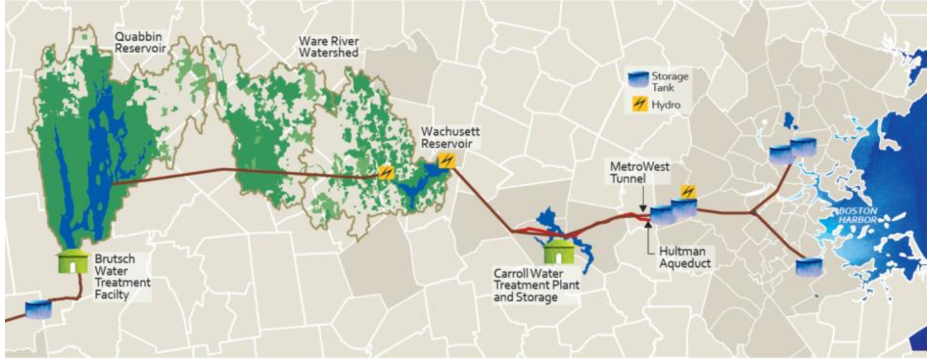
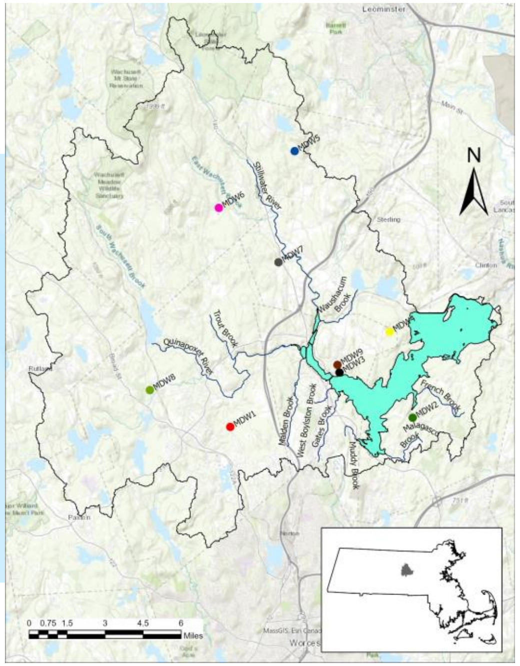
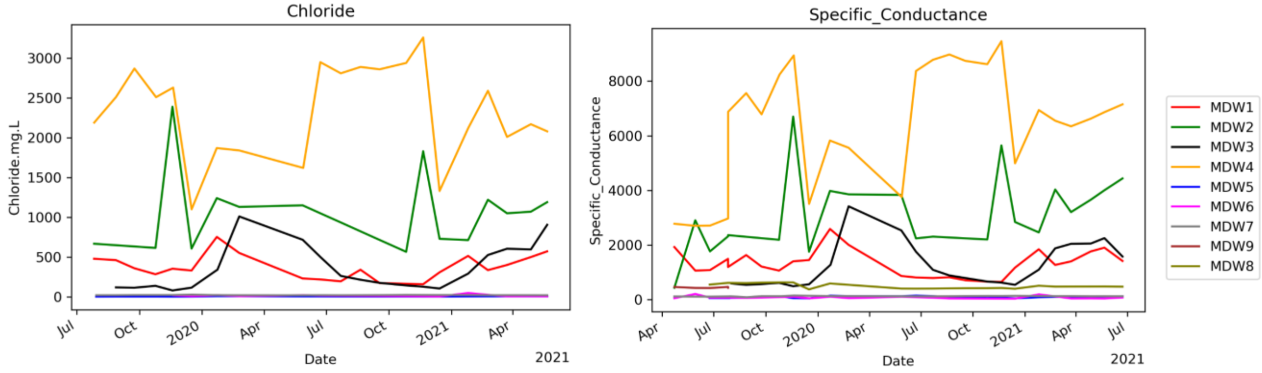
Motivation



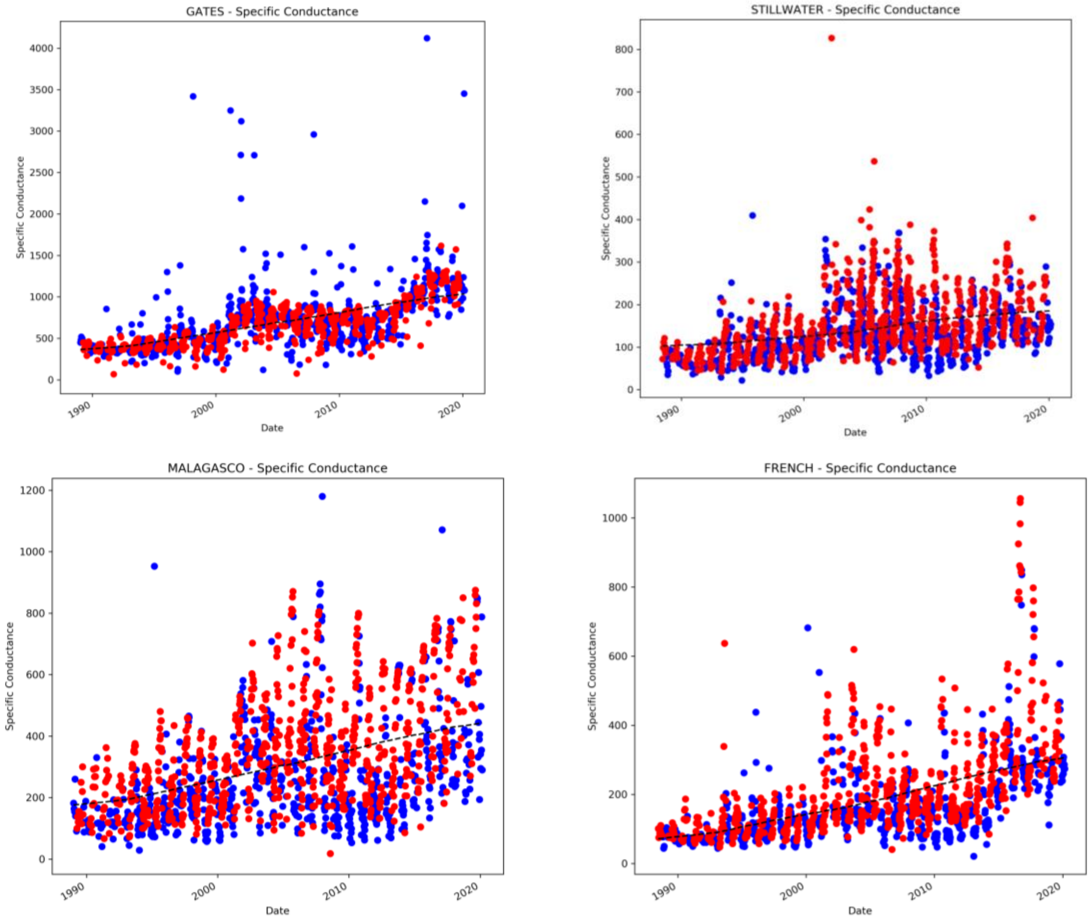
MWRA, 2019



Groundwater



Surface Water



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What purpose does this isotope analysis have?

- Recharge predominance/bias
- Kriging
- Mean transit times

- Periodic regression analysis
- Storm-based fraction contribution

Quabbin Reservoir, MA

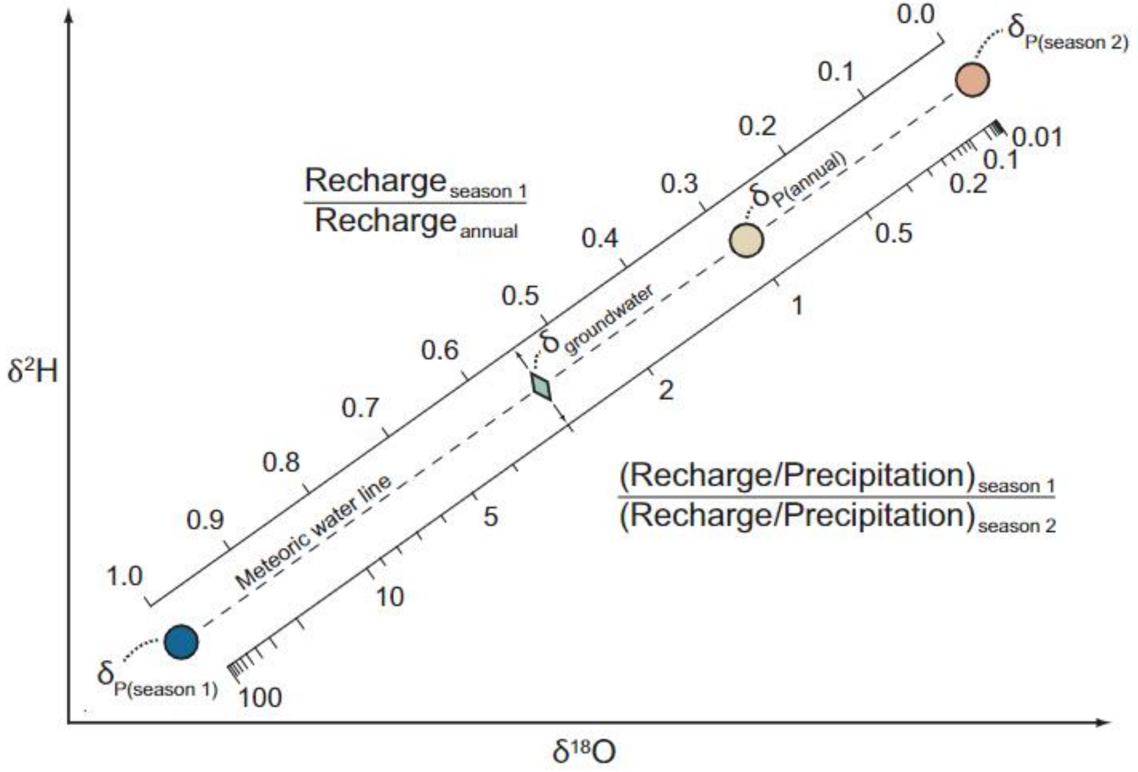
Preliminary Analysis on Groundwater Recharge Patterns

$$\frac{R_{winter}}{R_{annual}} = \frac{\delta_{groundwater} - \delta_{P(summer)}}{\delta_{P(winter)} - \delta_{P(summer)}} \qquad \frac{R_{summer}}{R_{annual}} = 1 - \frac{R_{winter}}{R_{annual}}$$

Jasechko et al., 2014
Stahl et al., 2019

Summer: April-September
Winter: October-March
Precipitation data from September 2017 to August 2018
Groundwater data from August 2019 to January 2020

Groundwater	-8.71
P Summer	-5.62
P Winter	-8.99
P Annual	-7.12
Rwinter/Rannual	0.92
Rsummer/Rannual	0.08

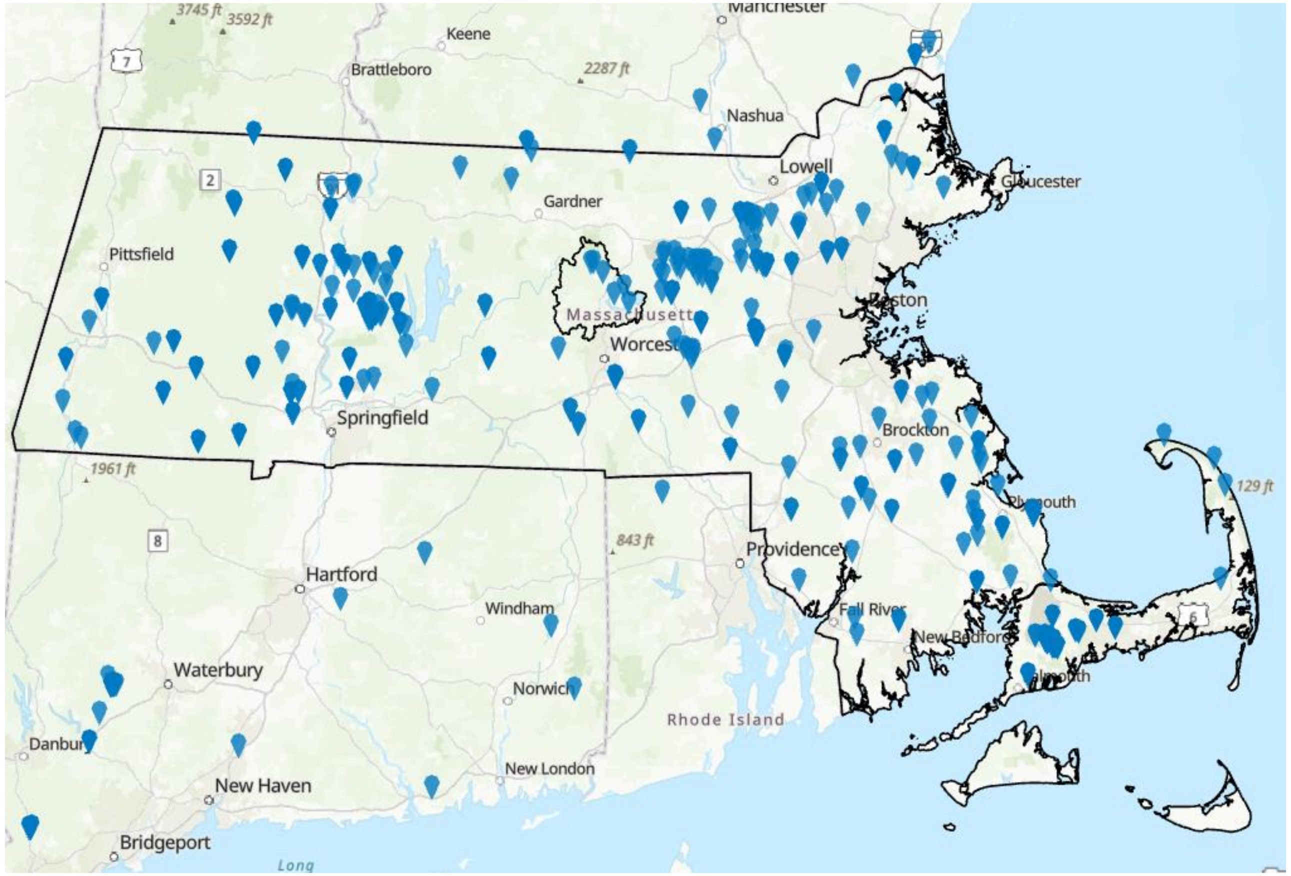


Schematic showing an isotope-based derivation of the seasonality of the groundwater recharge ratio (recharge as a proportion of precipitation: R/P)

Jasechko et al., 2014

Challenges, Data Sources, and Sample Sites

- Sources to Isotope Data:
  - GW data in the Wachusett watershed provided by DCR
  - GW, SW, and precipitation data in Massachusetts from Cole and Boutt, 2021 (including precipitation data in the Quabbin reservoir)
  - GW data in Massachusetts from Stahl et al, 2020
  - Precipitation and SW data from Waterisotopes.org (including data close to the Quabbin reservoir)
  - Precipitation data in Boston from the International Atomic Energy Agency (IAEA)

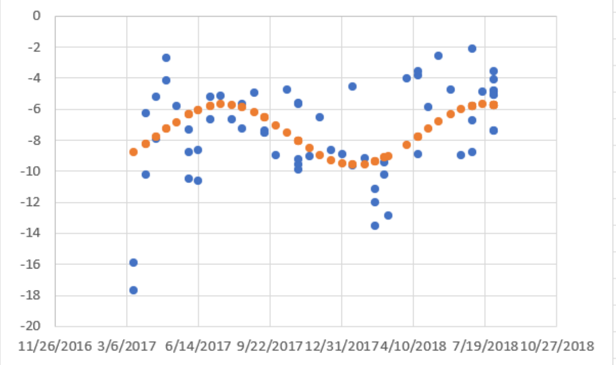


Exploratory Analysis on Prediction Curves

Sanchez-Murillo et al., 2015:

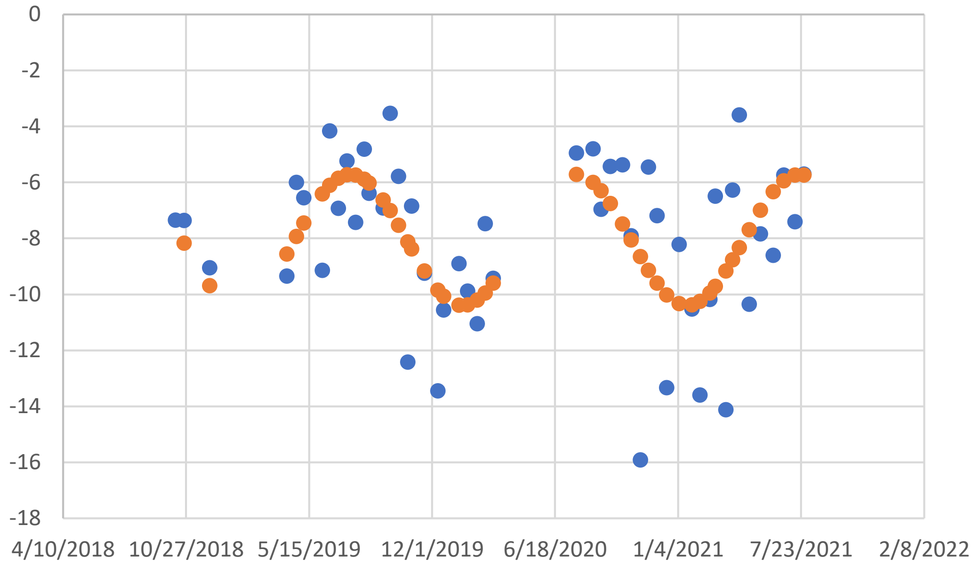
$$\delta^{18}O_p = \delta^{18}\overline{O} + A[\cos(ct - \theta)]$$

Date Collected	d18O	dD	dExcess	t	d18O_pred	SQE	18O annual mean	-7.66286	error	415.0808
3/16/2017	-15.94	-112.84	14.71				Amplitude	-1.95353		
3/16/2017	-17.68	-129.44	12.01	0	-8.77391054	79.31843	lag time	-0.96583		
4/3/2017	-6.29	-33.55	16.74	18	-8.2310538	3.76769				
4/3/2017	-10.27	-67.62	14.54	18	-8.2310538	4.157302				
4/17/2017	-7.96	-49.79	13.88	32	-7.76854081	0.036657				
4/17/2017	-5.2	-27.94	13.67	32	-7.76854081	6.597402				
5/1/2017	-4.14	-19.59	13.5	46	-7.2999197	9.985092				
5/1/2017	-2.72	-17.87	3.87	46	-7.2999197	20.97566				
5/15/2017	-5.82	-35.81	10.76	60	-6.85227608	1.065594				
6/1/2017	-8.76	-61.2	8.85	77	-6.3739868	5.693059				
6/1/2017	-10.48	-75.93	7.92	77	-6.3739868	16.85934				
6/1/2017	-7.33	-49.18	9.47	77	-6.3739868	0.913961				
6/15/2017	-8.65	-55.85	13.32	91	-6.060861	6.703641				
6/15/2017	-10.66	-74.93	10.35	91	-6.060861	21.15208				
7/1/2017	-6.68	-42.42	10.99	107	-5.81719913	0.744425				
7/1/2017	-5.21	-32.81	8.9	107	-5.81719913	0.368691				
7/15/2017	-5.16	-30.32	10.98	121	-5.71774684	0.311082				
8/1/2017	-6.66	-40.1	13.2	138	-5.74817719	0.831421				
8/15/2017	-7.27	-45.13	13.01	152	-5.89603215	1.887788				
8/15/2017	-5.72	-32.07	13.72	152	-5.89603215	0.030987				
9/1/2017	-4.98	-26.86	12.95	169	-6.21157427	1.516775				
9/15/2017	-7.42	-44.61	14.77	183	-6.56562226	0.729961				
9/15/2017	-7.51	-43.4	16.64	183	-6.56562226	0.891849				
9/15/2017	-7.52	-48.47	11.72	183	-6.56562226	0.910837				

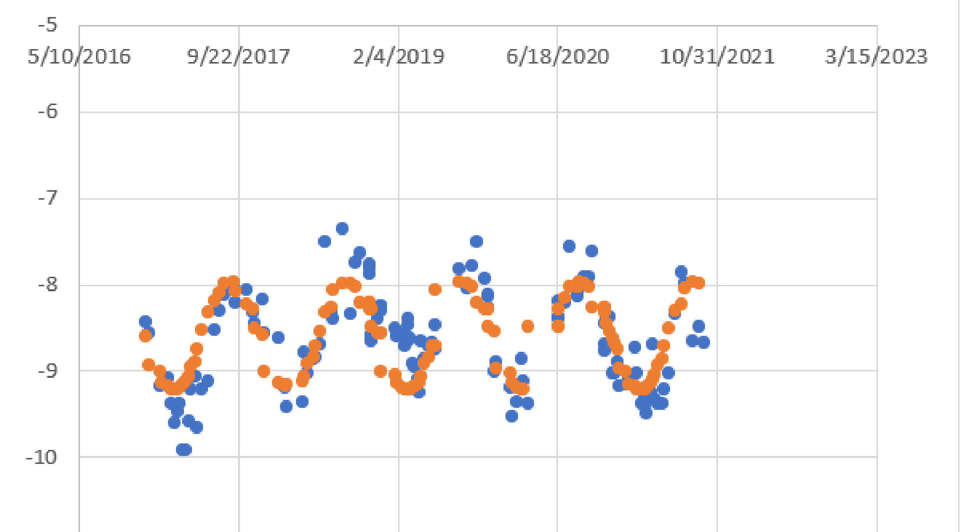


Precipitation in the Quabbin (data from Cole and Boutt, 2021)

Precipitation near the Quabbin (data from Waterisotopes.org)



SW near the Quabbin (data from Waterisotopes.org)



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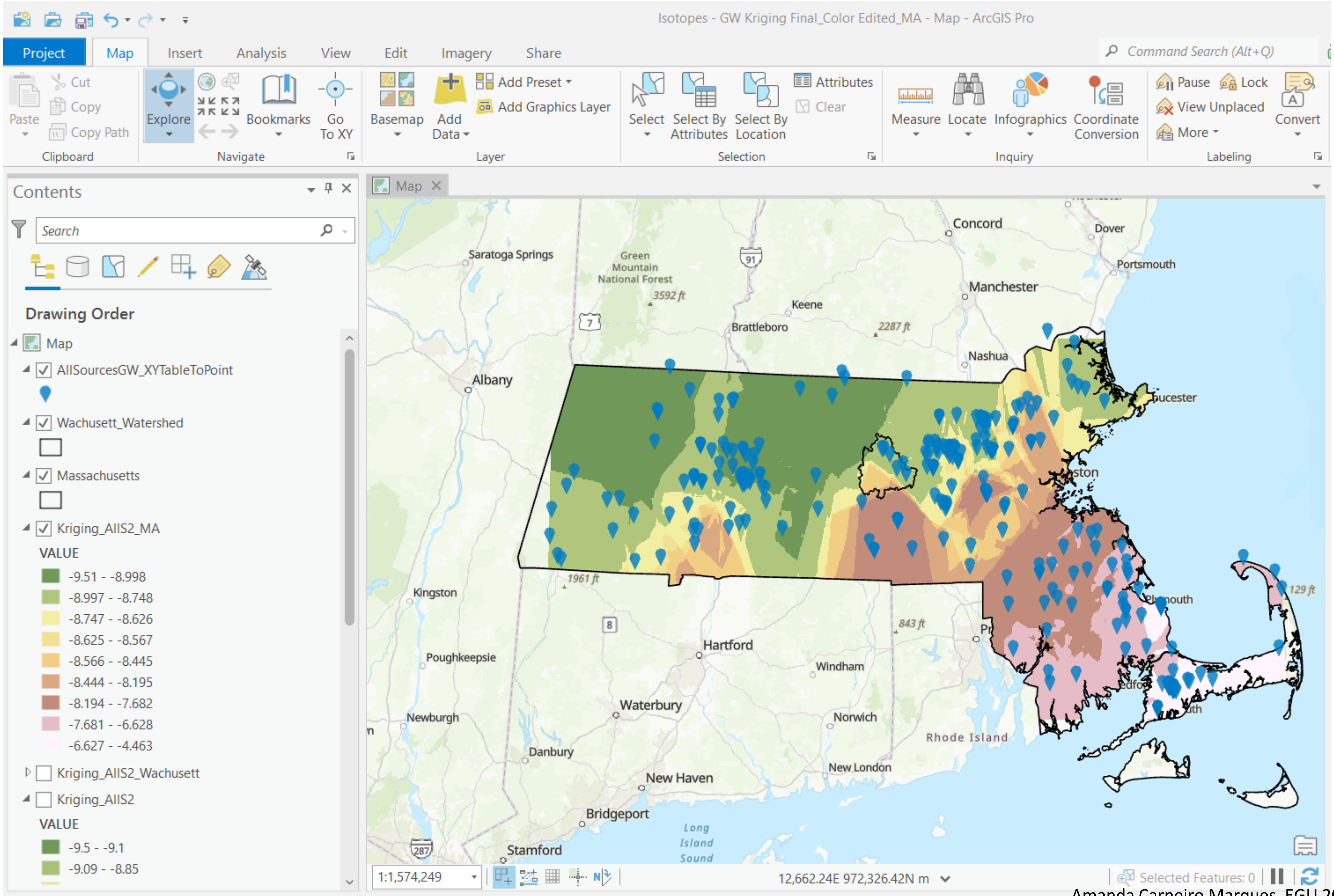
GIS



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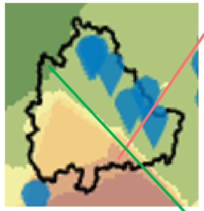
MTT and Recharge Patterns - Wachusett

Sanchez-Murillo et al., 2015:

$$D = \frac{\mathrm{SD_s}}{\mathrm{SD_p}}$$

$$\tau = c^{-1}[(D)^{-2} - 1]^{0.5}$$



	Spherical	Gaussian	
SD Precip Max	2.32	2.43	
SD Precip Min	2.15	2.29	
SD GW Max	0.66	0.66	
SD GW Min	0.33	0.33	
Damping Ratio Max	0.284483	0.271605	
Damping Ratio Min	0.153488	0.144105	
c	0.017214	rad/day	
MTT Min	196	206	days
MTT Max	374	399	days

Upper Boundary		
Groundwater	-8.71	*Average from DCR unpurged wells
P Summer	-5.85	*Geospatial interpolation
P Winter	-8.90	*Geospatial interpolation
P Annual	-7.59	*Geospatial interpolation
Rwinter/Rannual	0.94	
Rsummer/Rannual	0.06	
Lower Boundary		
Groundwater	-8.71	*Average from DCR unpurged wells
P Summer	-6.19	*Geospatial interpolation
P Winter	-9.80	*Geospatial interpolation
P Annual	-8.43	*Geospatial interpolation
Rwinter/Rannual	0.70	
Rsummer/Rannual	0.30	

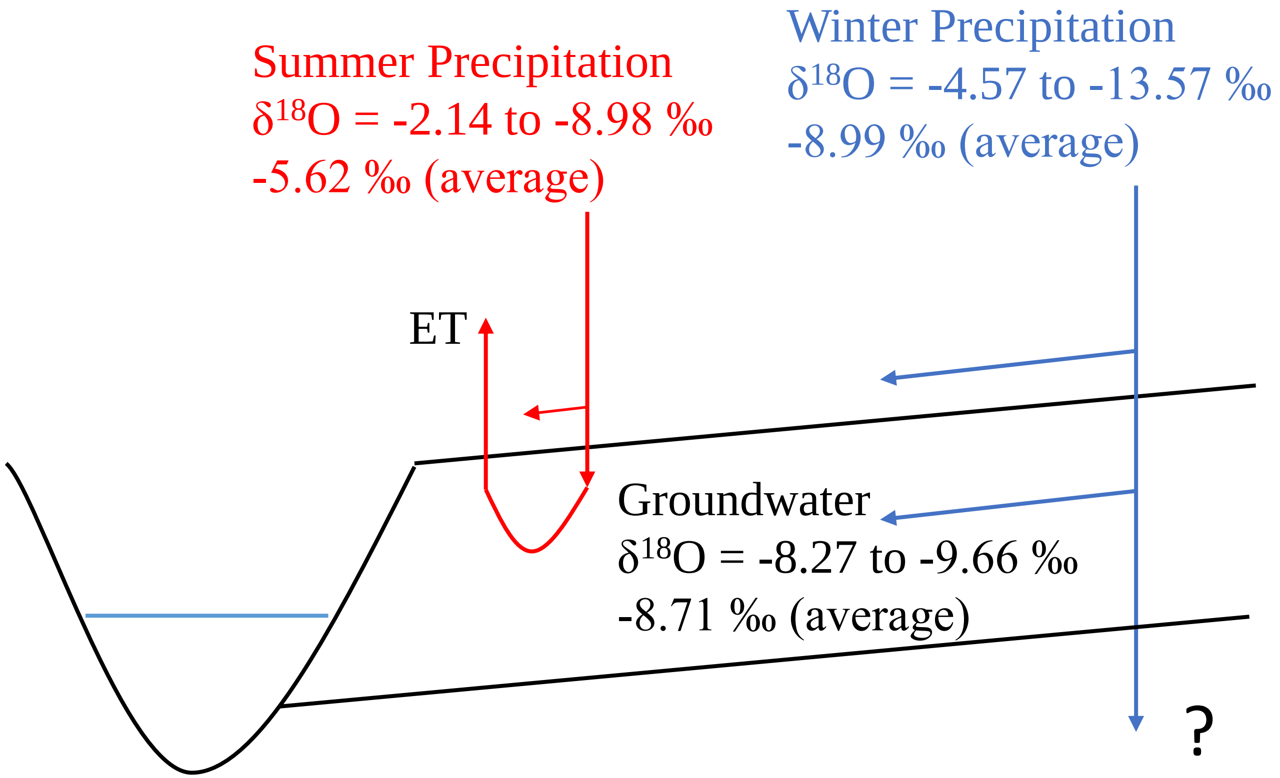
Annual	Spherical	Gaussian
Mean Precip Max	-7.86	-7.59
Mean Precip Min	-8.55	-8.43
Mean GW Max	-8.42	-8.42
Mean GW Min	-9.09	-9.09

Winter	Spherical	Gaussian
Mean Precip Max	-8.7	-8.9
Mean Precip Min	-10.3	-9.8

Summer	Spherical	Gaussian
Mean Precip Max	-5.77	-5.85
Mean Precip Min	-6.37	-6.19

Next Steps, Discussion, and Insights

- Different geospatial interpolation methods
- Geospatial interpolation used to predict mean and amplitude isotopic composition values for the study region. Considering lack of on-site data, are there any insights for the estimation of phase shift values for the prediction curves?
- Shallow vs. deep groundwater



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Thank you!

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