

Multivariate statistical analysis of hydrochemical and isotopic environmental tracer data to manage artificial groundwater recharge within a fractured carbonate aquifer

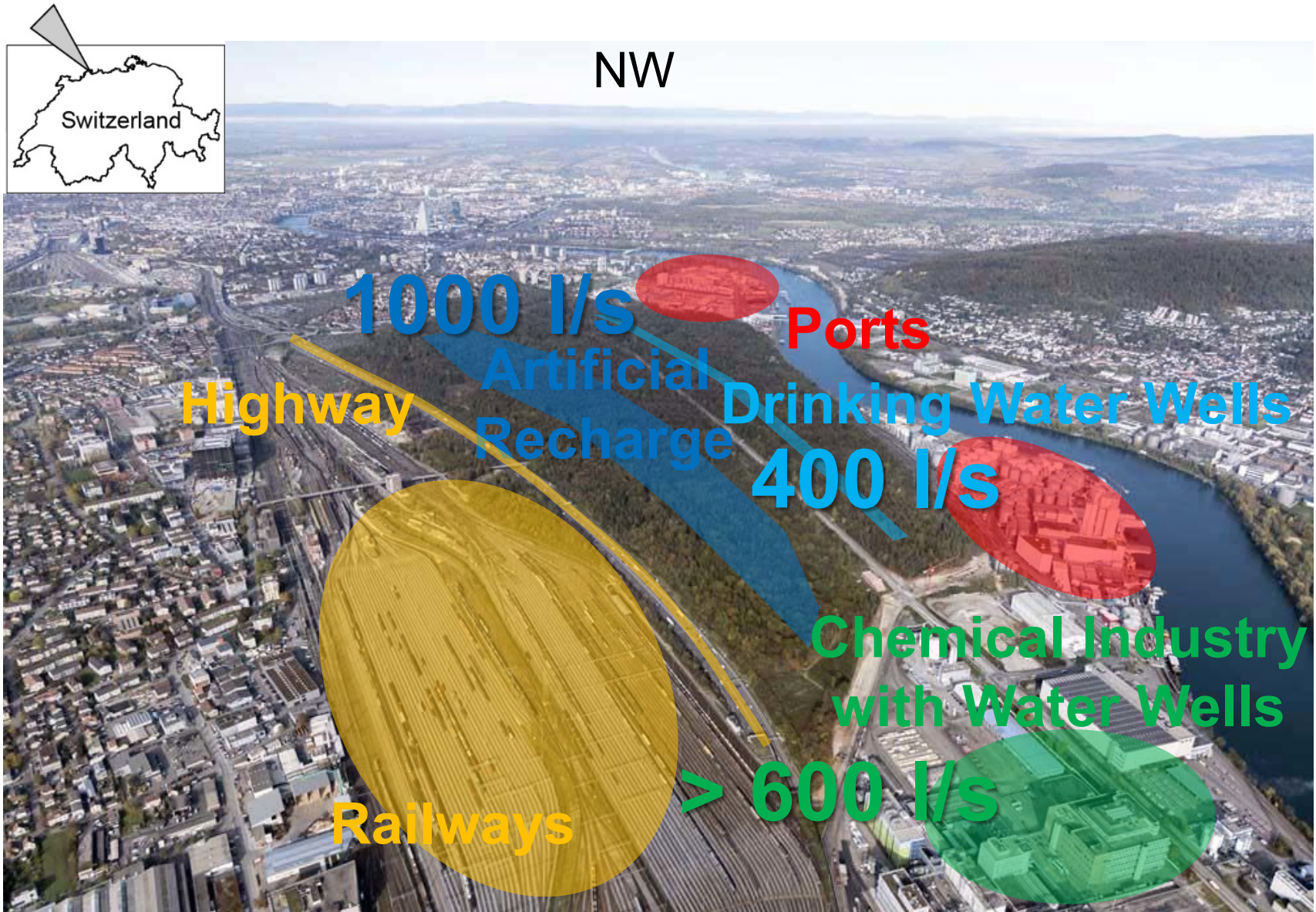
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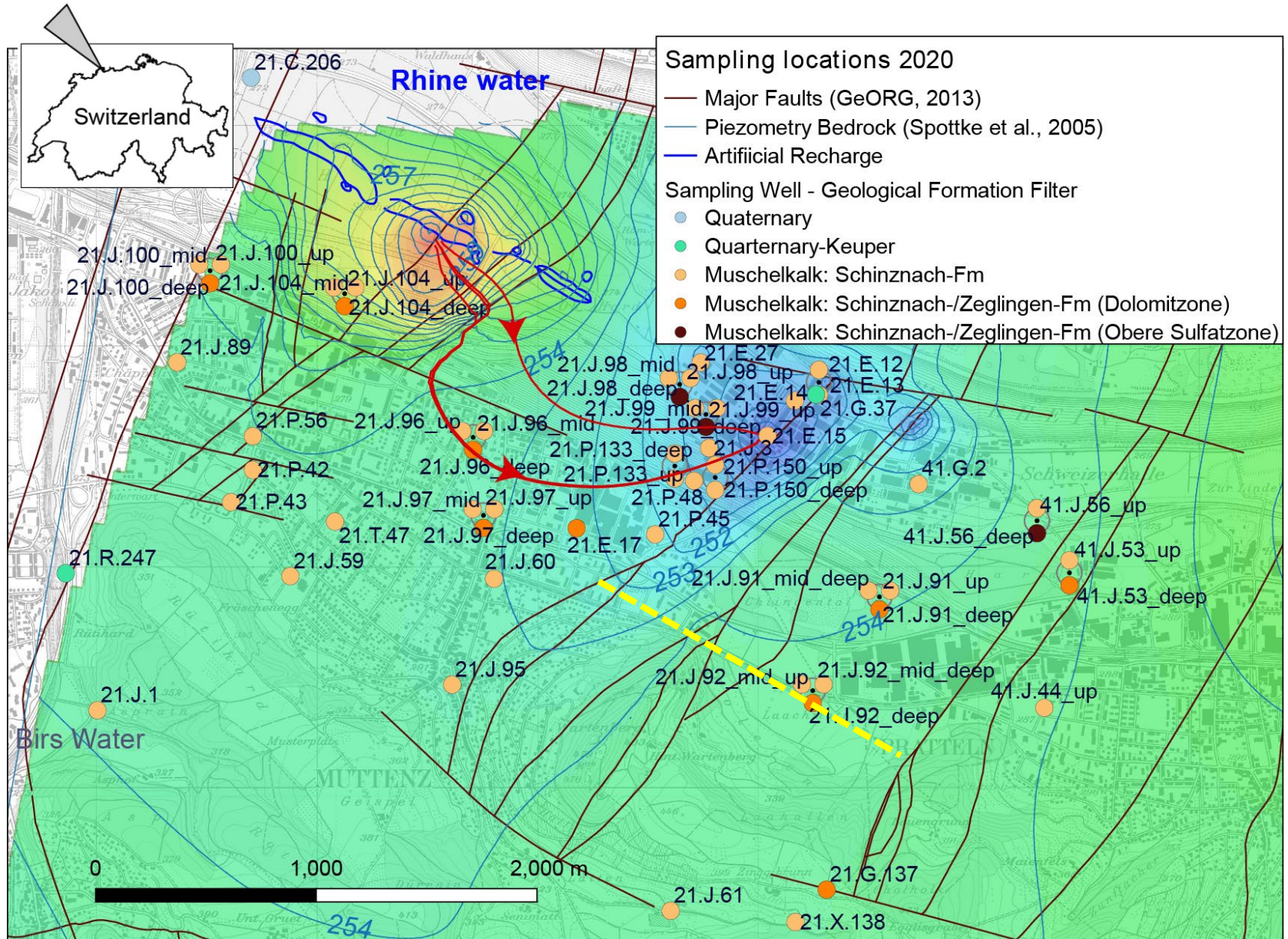
(2) Office of Environmental Protection and Energy Canton Basel-Country, Liestal, Switzerland



Introduction, Setting



Hydrogeological Setting, Sampling Wells

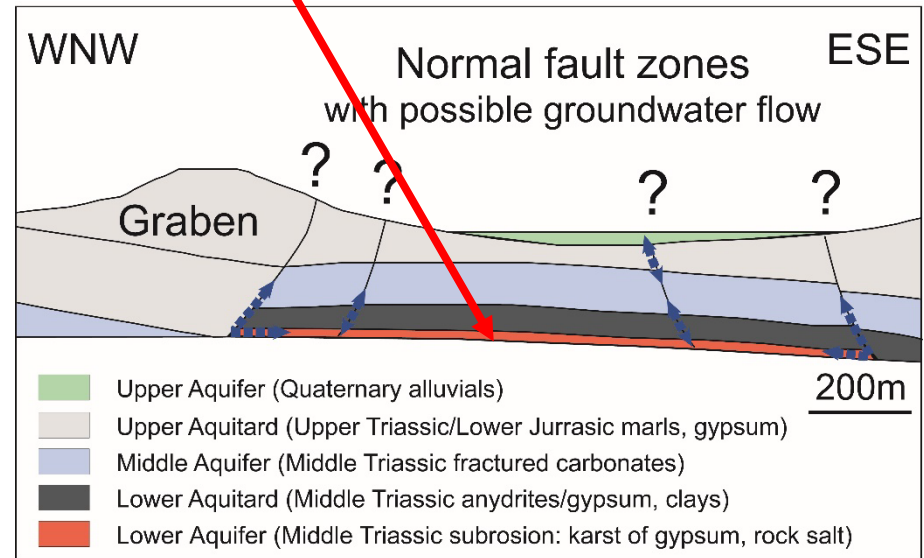


Hydrogeological Setting, Subrosion process of evaporites

System	Series	Stage	Profile	Formation	Thickness
QUATERNARY				Fluvio-glacial gravels	max. 40m
JURASSIC	Dogger	Aalénien		Opalinus-Ton	
		Lias		Arietenkalk	max. 325m
TRIASSIC	Keuper	Upper		Rhät Obere Bunte Mergel Gansinger Dolomit Schilfsandstein / Untere Bunte Mergel	
		Middle		Gipskeuper	
		Lower		Lettenkohle	
	Muschelkalk	Upper		Trigonodusdolomit Hauptmuschelkalk	80m 90m
		Middle		Dolomitzone Sulfatzone Salzlager	70m 160m
		Lower		Wellengebirge	

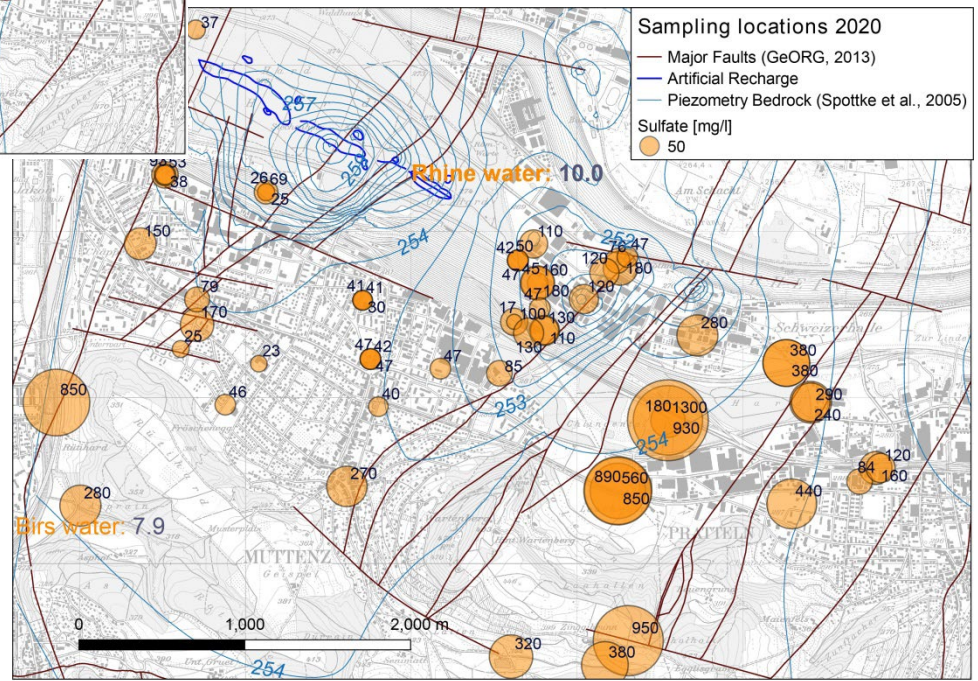
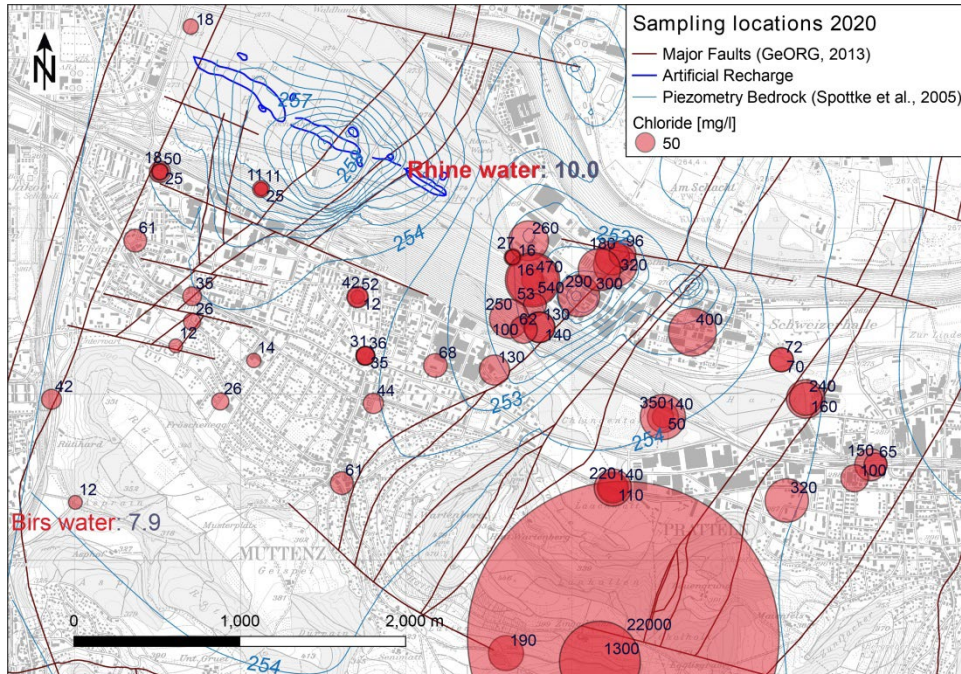
Aquifer Aquiclude

Subrosion (evaporite karst):
Source for major ions e.g. Ca, Na, Cl, SO₄

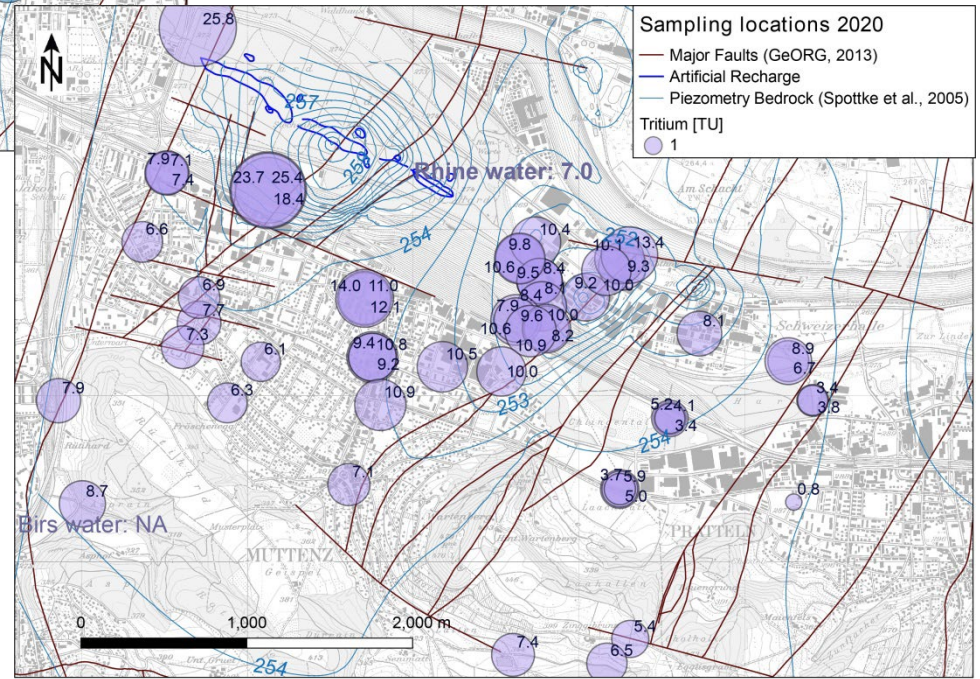
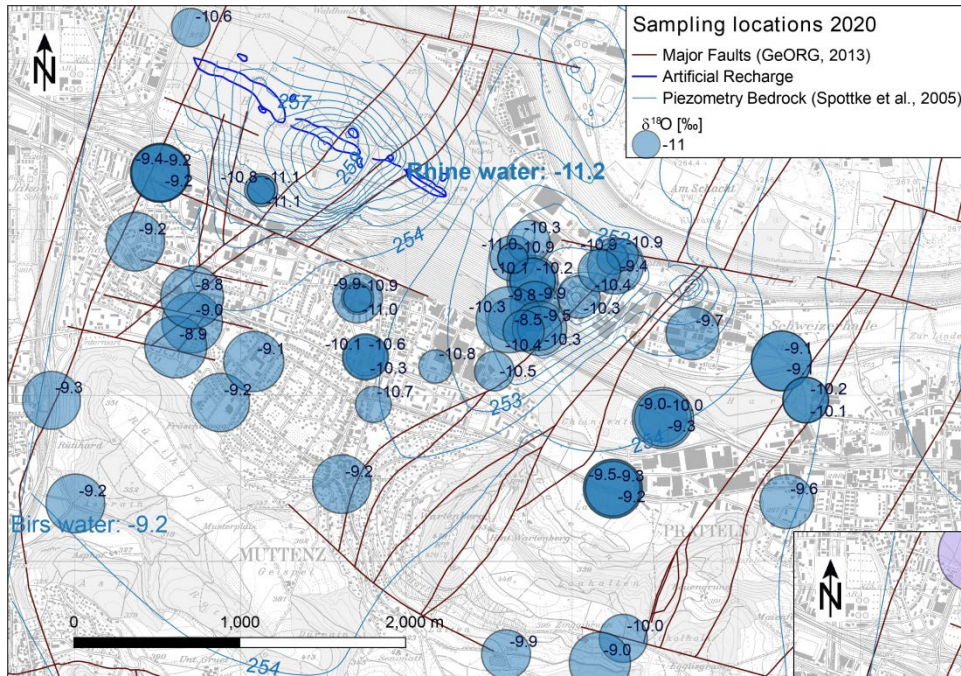


Zechner E., Konz M., Younes A., Huggenberger P., 2011: Effects of tectonic structures, salt solution mining, and density-driven groundwater hydraulics on evaporite dissolution (Switzerland), *Hydrogeology J.*, 7, 1323-1334, DOI: 10.1007/s10040-011-0759-5.

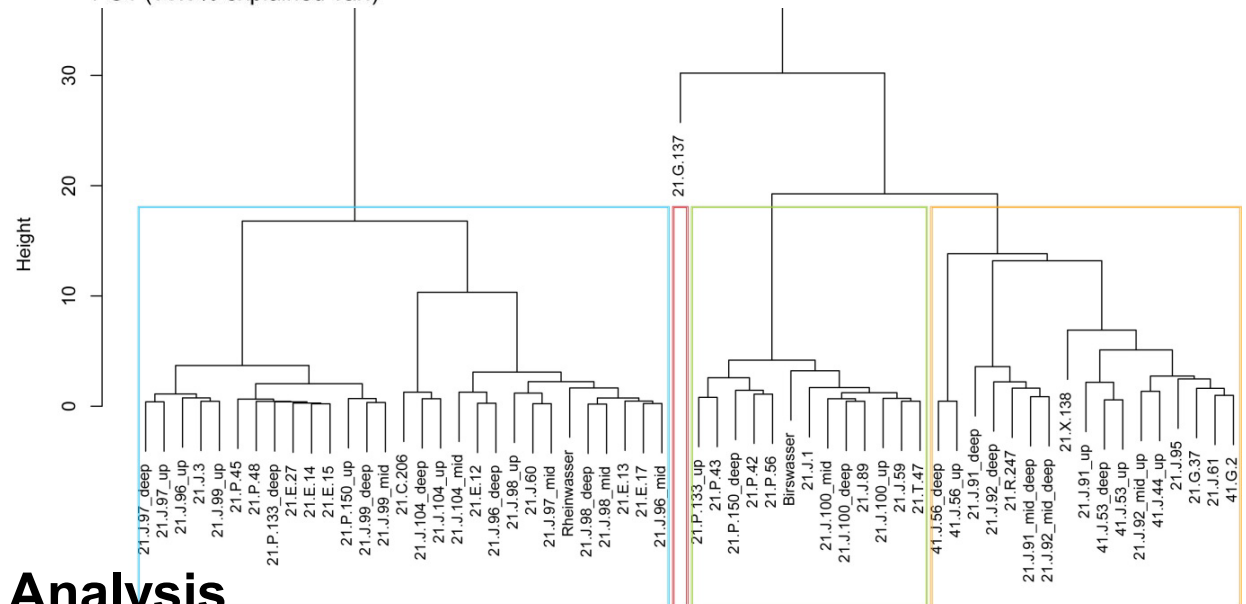
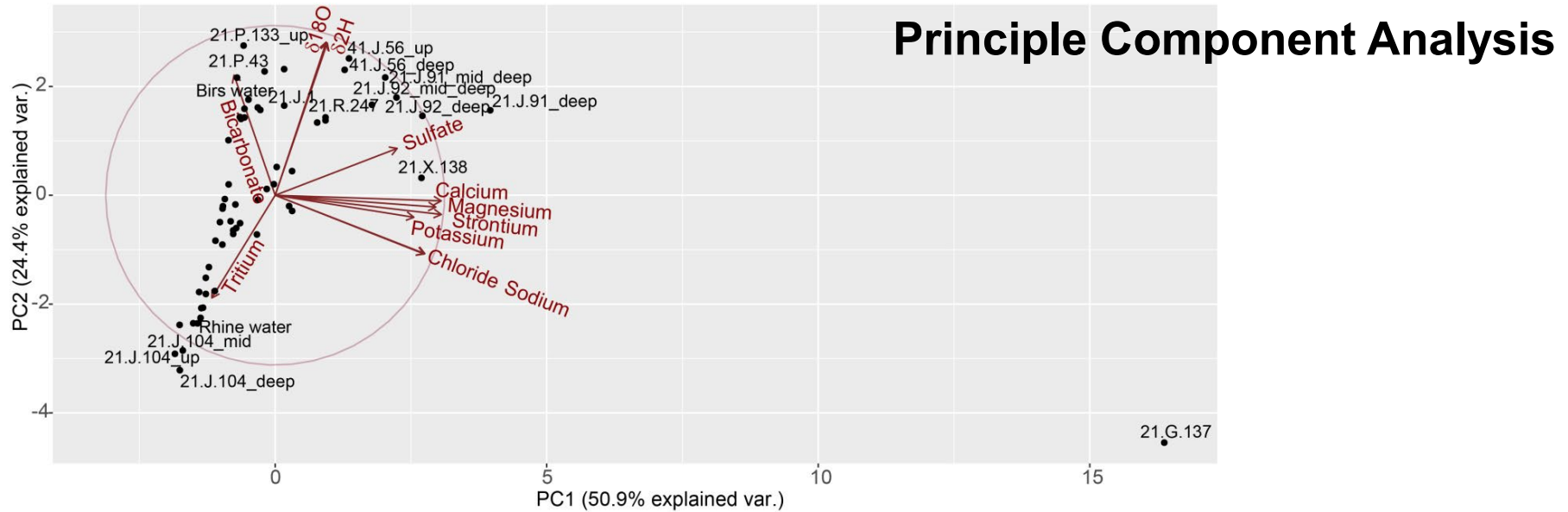
Hydrochemistry: Chloride, Sulfate



Water Isotopes: ^{18}O , (^2H), Tritium

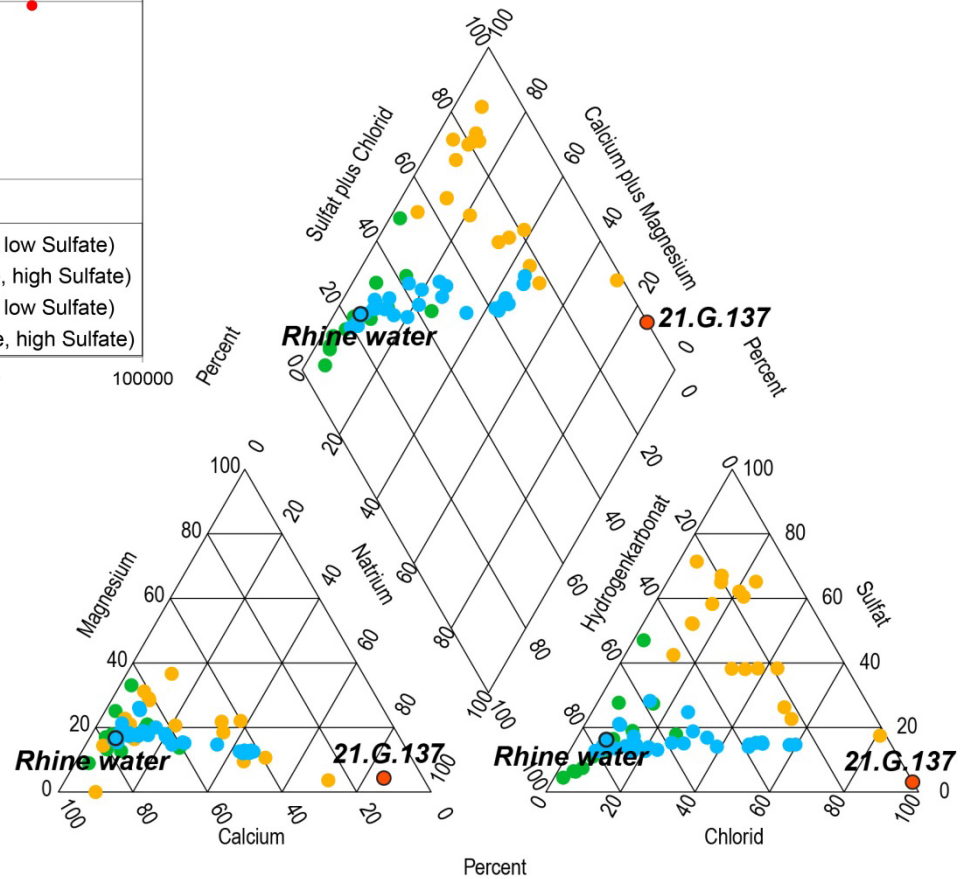
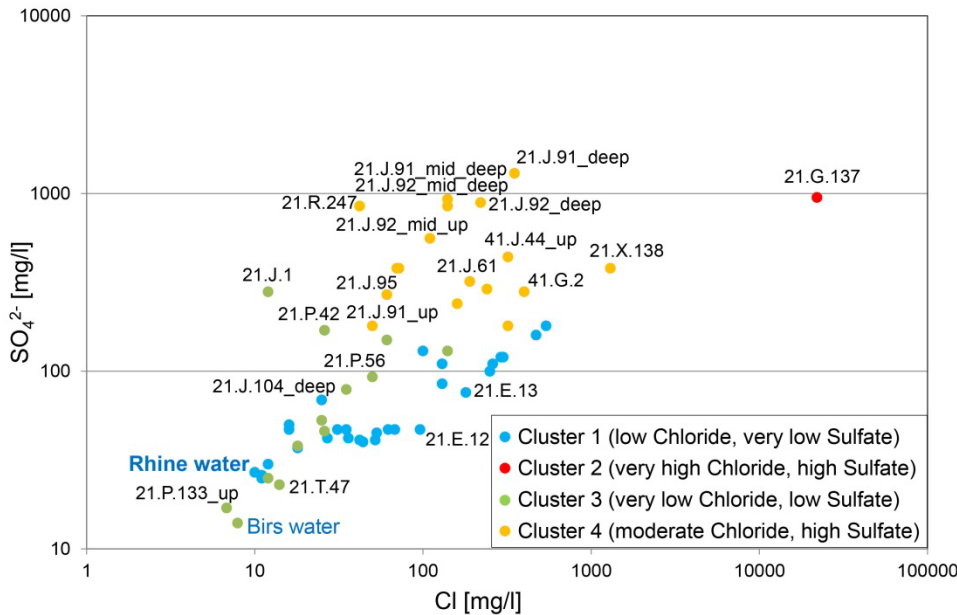


Multivariate statistical analysis: 8 Major Ions, 3 Water Isotopes



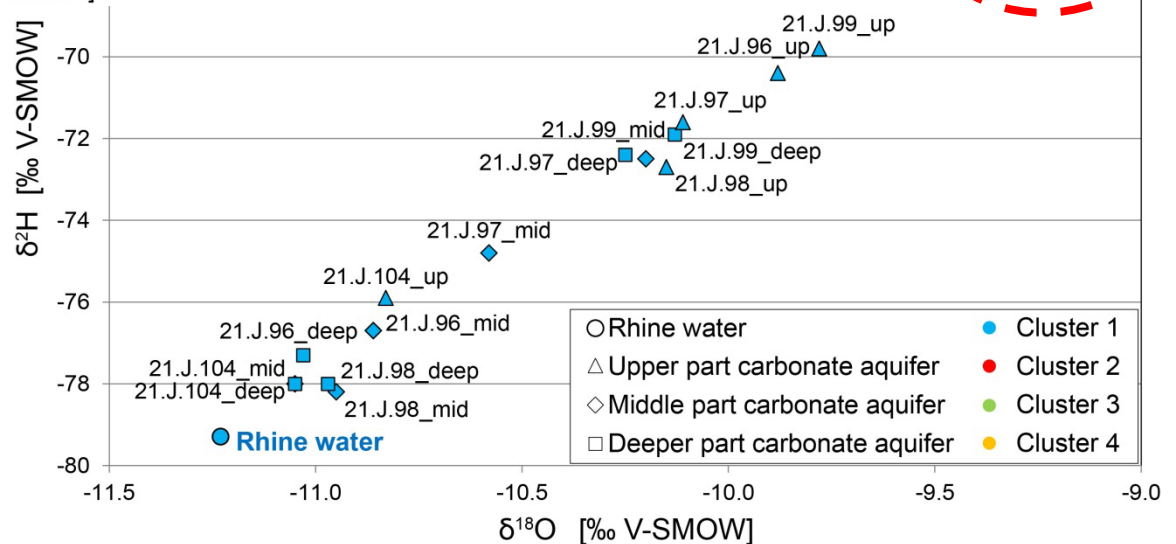
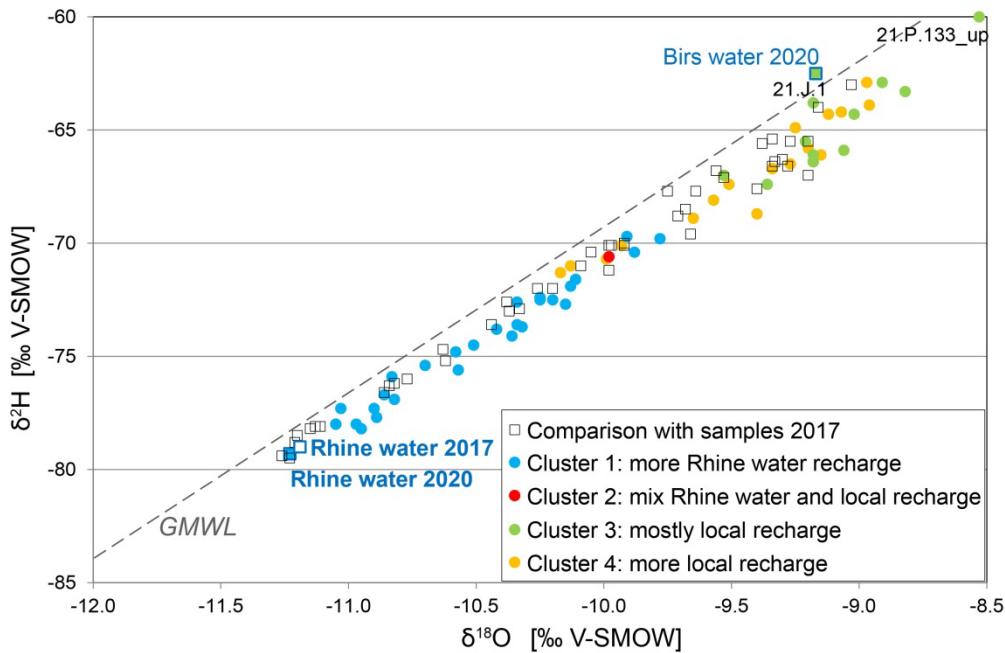
Hierarchical Cluster Analysis

Clustering: Major Ions, e.g. Sulfate vs Chloride

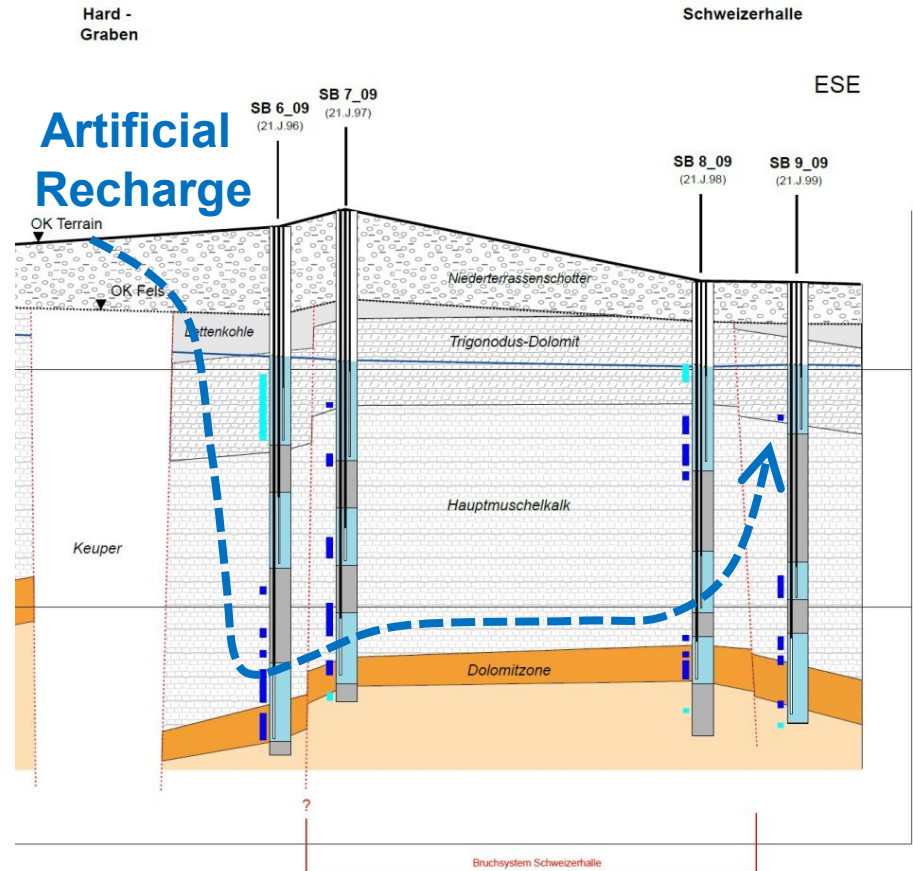
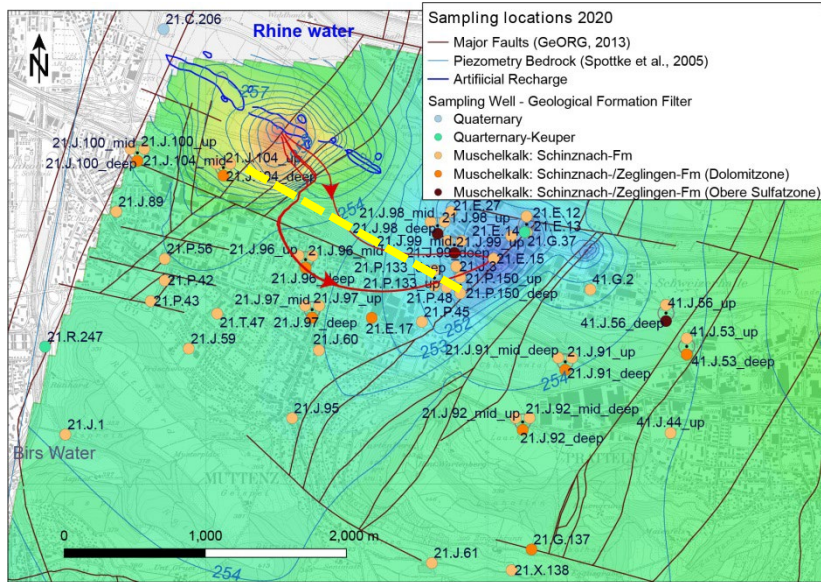


- Cluster 1: Calcium and Bicarbonate (some Chloride) types
- Cluster 2: Sodium and Chloride types
- Cluster 3: Calcium and Bicarbonate types
- Cluster 4: Calcium (some Sodium) and Sulfate/Chloride types

Clustering: Stable Isotopes ^{18}O vs ^2H

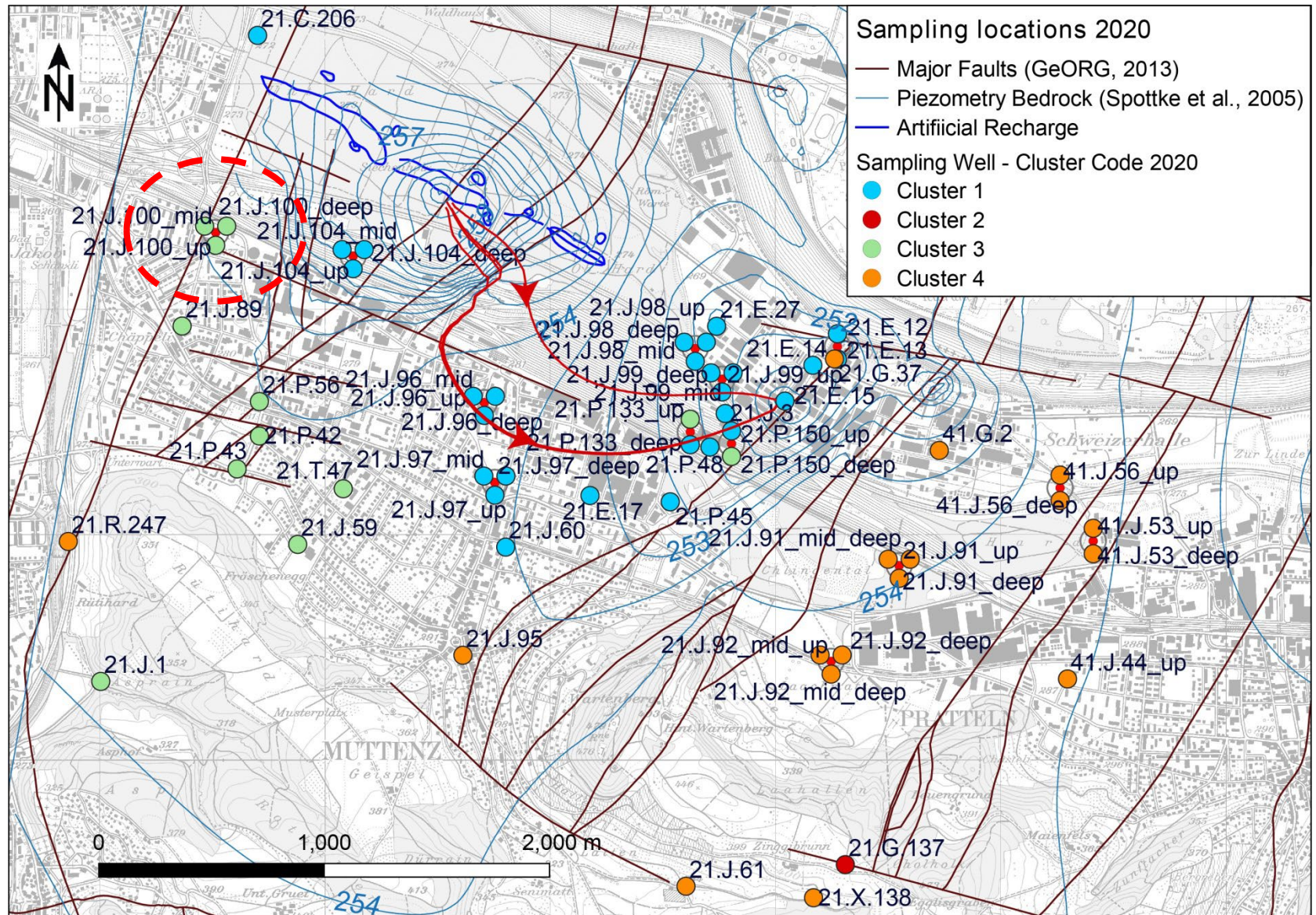


Clustering: Stable Isotopes ^{18}O vs ^2H



Meyer, M., Guldenfels, L., 2010: Errichtung von Grundwassermessstellen 2009 - 2010, Geologisch - hydrologischer Bericht, Kanton Basel-Landschaft, Amt für Umweltschutz und Energie.

Clustering: Characterization of Artificial Recharge



Conclusions

Effectiveness of Artificial Recharge for drinking water production and protection was observed with:

- Sampling groundwater wells reaching depths between 2m and 273m located in Quaternary Alluvial Aquifer and (mostly) in a Triassic Carbonate Aquifer;
- Selection of groundwater parameters which characterize the mixing process in the Aquifers:
 - Major ions due to the subrosion of Triassic Evaporites
 - Water isotopes signatures from artificial recharge with Rhine water and from recharge due to local rainfall;
- Principle component analysis and hierarchical cluster analyses with 8 Major Ions and 3 Water Isotopes;
- Cluster graphs and maps show lateral and vertical extend of artificial recharge in the Triassic Carbonate Aquifer mostly SE towards groundwater wells for industrial use, which is (mostly) in accordance with simulated advective transport from a 3D groundwater flow model (Spotke et al. 2005).