

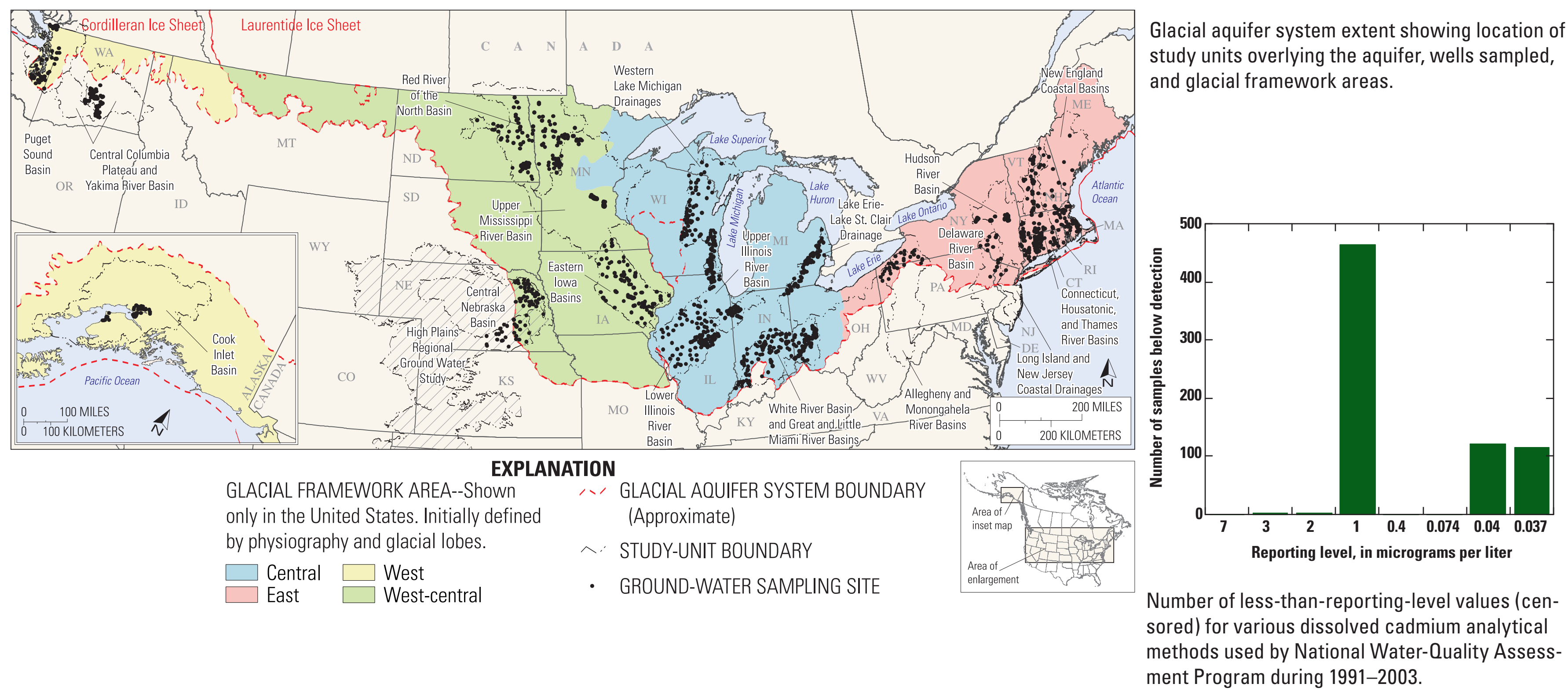
Variability in concentrations of dissolved iron, manganese, and selected trace elements in the glacial aquifer system, United States

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Introduction

The glacial aquifer system is used extensively as a source of drinking water for public and domestic supply; therefore, water quality is an issue for water managers, health officials, and private well owners. Many natural contaminants are present in the glacial aquifer system because the source of the aquifer material is from various rock types containing a wide range of possible contaminants, such as arsenic, uranium, radon, and others. The nature of the glacial materials makes these deposits potentially susceptible to anthropogenic contamination.

Many trace elements, for instance arsenic—that has recently had its maximum contaminant level lowered—pose potential health risks to people who drink ground water. The glacial aquifer system is one of the largest and most heavily used regional aquifers in the country, therefore characterizing the distribution and occurrence of dissolved trace elements, and iron and manganese in the glacial aquifer system is needed to assess the potential risks.



Methods

The National Water-Quality Assessment Program (NAWQA) of the U.S. Geological Survey (USGS) is the primary source of long-term, nationwide water-quality data from ground water. Dissolved trace element data analyzed for this study was collected at 847 ground-water sampling sites from 19 NAWQA study units across the glacial aquifer system over the period 1991–2003. In addition, dissolved iron and manganese data were available from another 753 wells. The sampled sites are concentrated within study units across the glacial aquifer system extent, but the localized study units are spatially dispersed from each other.

For the selected trace elements, the sample analytical results range from mostly unqualified concentrations (detections) to mostly, or completely, censored. For example, all samples had detectable concentrations of barium, conversely, all but two samples had no detectable concentrations of silver. For these elements, censored values—concentrations below the laboratory reporting level (LRL)—were set either at the estimated concentration, the reporting level (typically about 1.0 microgram per liter for those prior to about 1999) or, for more recent data, to the long-term method detection level. An example of the changes in reporting levels is shown in the bar chart above.

After this adjustment to the data, robust Regression on Order Statistics (ROS; Helsel, 2005) was used to compute medians, percentiles, and other summary statistics. This method does not assume any particular type of distribution for the concentrations. The software “R” was used to model these statistics (Lee and Helsel, 2005).

Results

A summary of the data is shown in the table below.

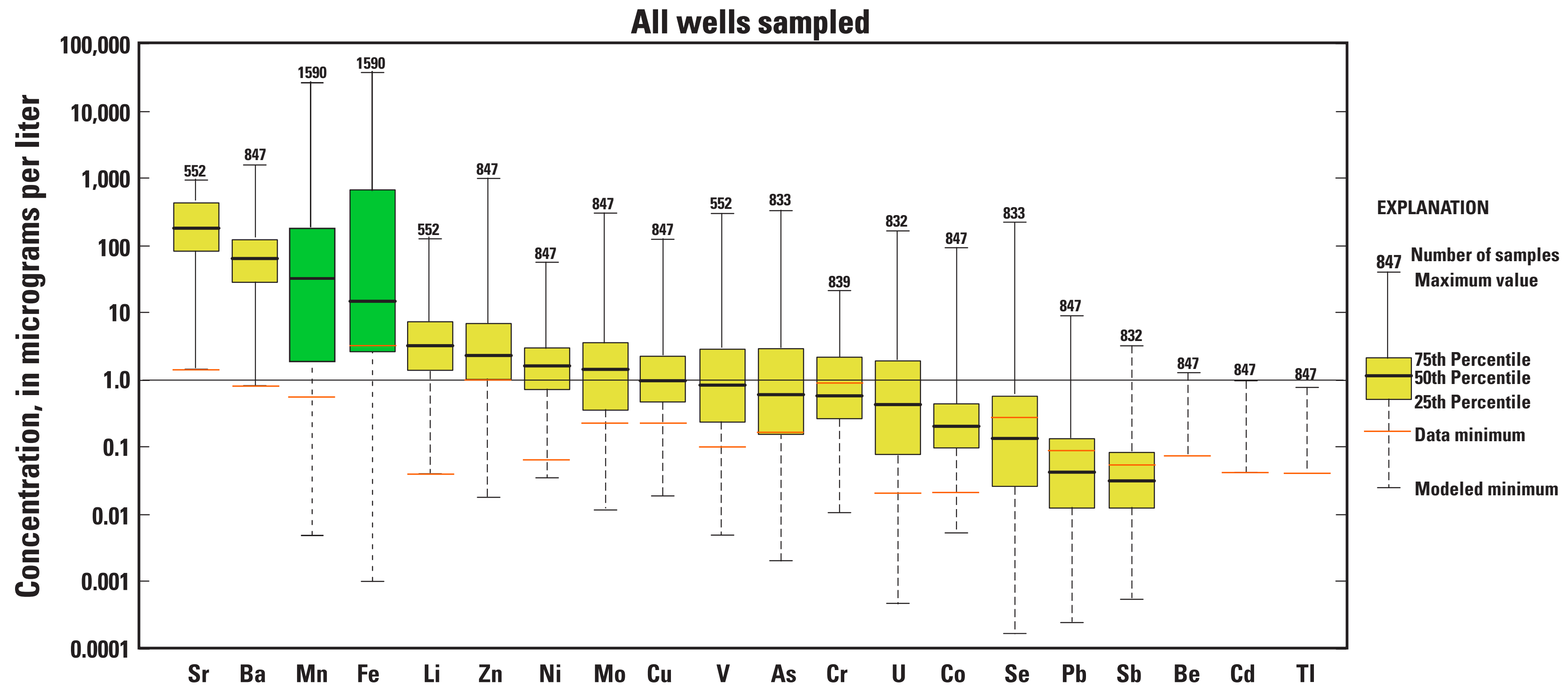
Summary of trace element, iron, and manganese concentrations in glacial aquifer wells sampled 1991–2003 in NAWQA study units. Only maximums and minimums are listed for elements that had less than 20 percent detected concentrations. Most elements had a substantial number of non-detections. For consistency, Regression on Order statistics was used to estimate the statistics for all elements in the table. [All concentrations in micrograms per liter]

Element	Number of samples	Number of censored ^a	Percent Censored	Minimum detection	Maximum detection	Mean ^b	Standard deviation ^b	Inter-quartile range	Coefficient of variation	Adjusted r ²
Antimony (Sb)	832	657	79.0	0.024	3.3	0.090	0.201	0.073	225	0.99
Arsenic (As)	833	327	39.3	0.090	340	3.95	14.7	2.84	371	0.99
Barium (Ba)	847	1	0.1	0.840	1,630	104	134	96.4	129	0.98
Beryllium (Be)	847	833	98.3	0.032	1.24	na ^c	na	na	na	na
Cadmium (Cd)	847	710	83.8	0.018	1.0	na	na	na	na	na
Chromium (Cr)	839	404	48.2	0.400	22.	1.74	2.42	1.97	139	0.92
Cobalt (Co)	847	396	46.8	0.007	95.3	0.808	4.37	0.353	541	0.96
Copper (Cu)	847	285	33.6	0.126	127	3.70	10.4	1.82	281	0.95
Iron (Fe)	1,590	504	31.7	3.00	38,100	819	2,440	676	298	0.92
Lead (Pb)	847	624	73.7	0.040	9.00	0.193	0.602	0.121	312	1.0
Lithium (Li)	552	57	10.3	0.040	126	8.24	15.5	5.93	189	0.99
Manganese (Mn)	1,590	215	13.5	0.056	28,200	224	966	189	431	0.94
Molybdenum (Mo)	847	239	28.2	0.105	304	4.12	13.4	3.23	326	0.98
Nickel (Ni)	847	155	18.3	0.035	56.4	2.63	4.37	2.28	166	0.94
Selenium (Se)	833	579	69.5	0.173	223	2.15	11.8	0.546	551	0.96
Strontium (Sr)	552	1	0.2	1.470	9,120	387	727	354	188	0.99
Thallium (Tl)	480	413	86.0	0.020	0.771	na	na	na	na	na
Uranium (U)	832	351	42.2	0.009	162	3.44	10.7	1.80	313	0.99
Vanadium (V)	552	298	53.7	0.100	294	4.45	16.6	2.57	374	1.00
Zinc (Zn)	847	174	20.5	0.536	1,000	12.4	49.4	5.90	399	0.98

a. Censored concentrations are those below detection level for the analytical method.

b. Mean, standard deviation, and interquartile range are estimated by Regression on Order Statistics (Lee and Helsel, 2005) for all elements with detection frequencies greater than 20%.

c. na, not applicable.



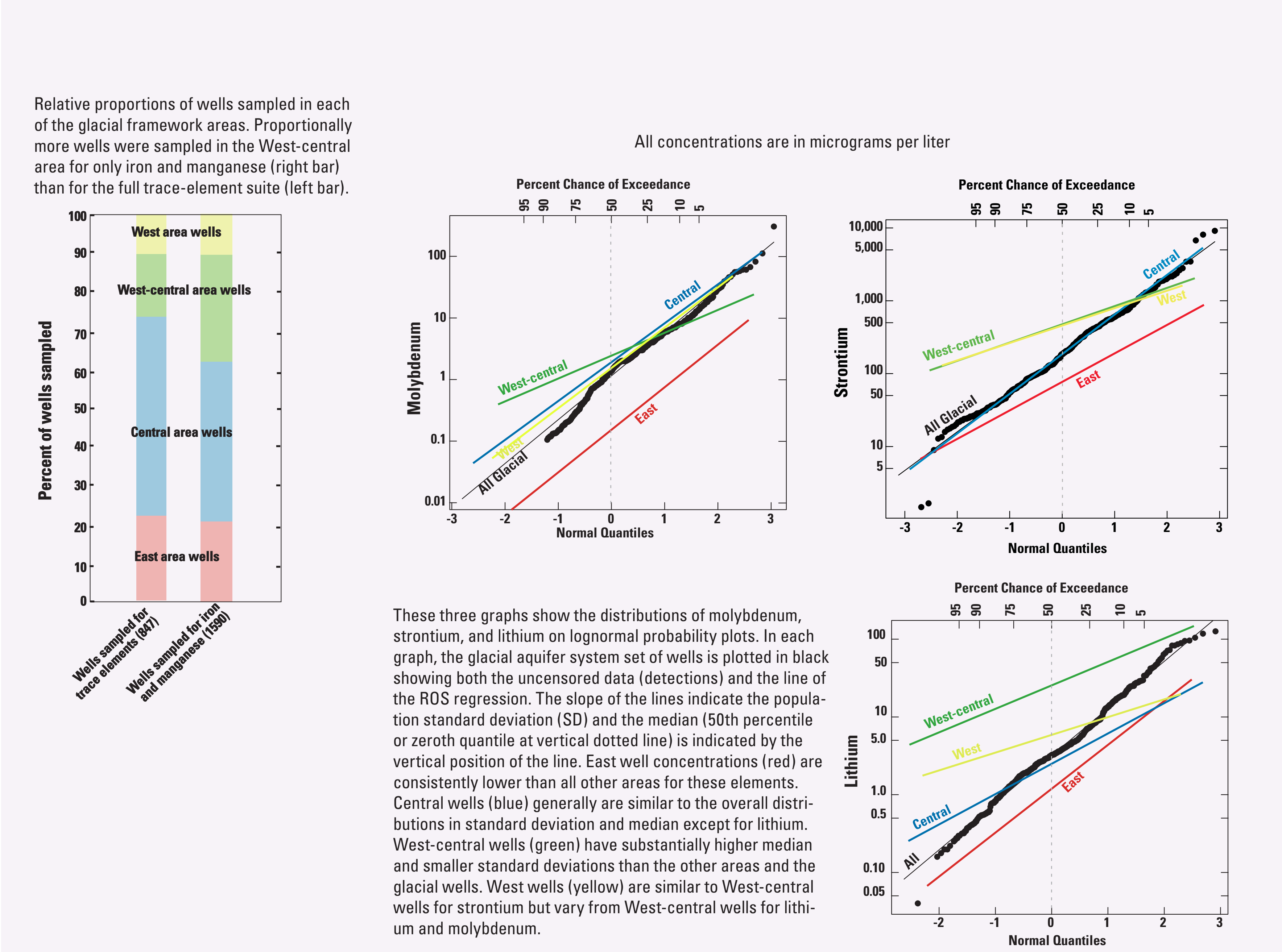
Box plots summarizing the ranges of iron, manganese, and selected trace elements, for wells sampled in the glacial aquifer system.

Regional Framework

Study of the glacial aquifer system was designed around a framework (shown in the map at upper left) that is based on two primary characteristics: (1) intrinsic susceptibility, which indicates how easily water moves through the aquifer system, and (2) vulnerability, which refers to the tendency or likelihood of contaminants to reach ground water. The regional framework for the glacial aquifer system focuses on the vulnerability from contaminants of natural sources. Land use can be overlain on this regional framework as an indication of vulnerability from anthropogenic sources. Likewise, many other indicators of natural and anthropogenic sources can be overlain on this framework for making a comparative assessment of ground-water quality.

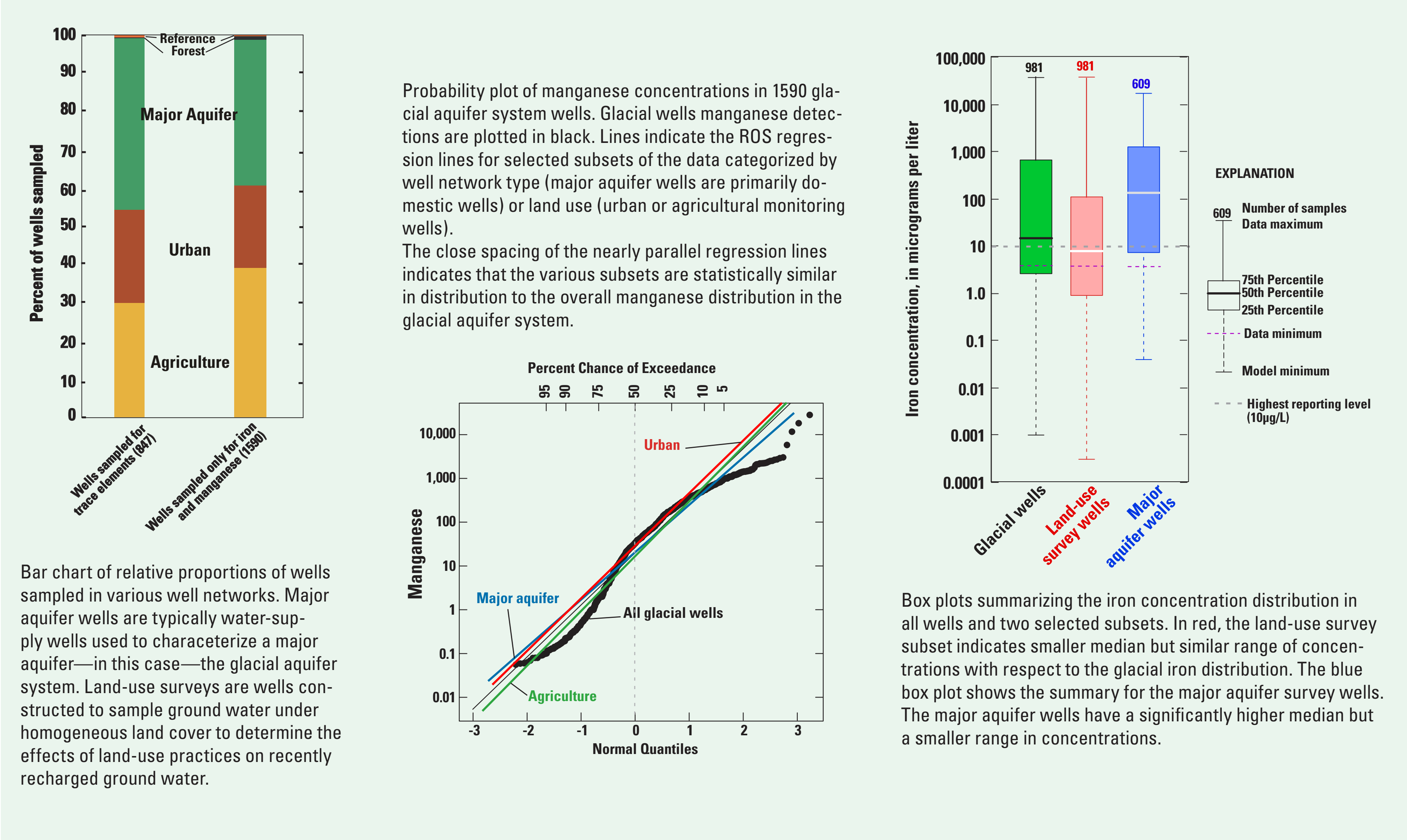
Trace elements and glacial framework areas

The framework devised by Warner and Arnold (2005) is used to organize the interpretation of water-quality data on a regional basis in the glacial aquifer system. The wells sampled for iron, manganese, and trace elements, were categorized into the four areas and summary statistics modeled for the data subsets. The proportions of wells in each area are shown below left.



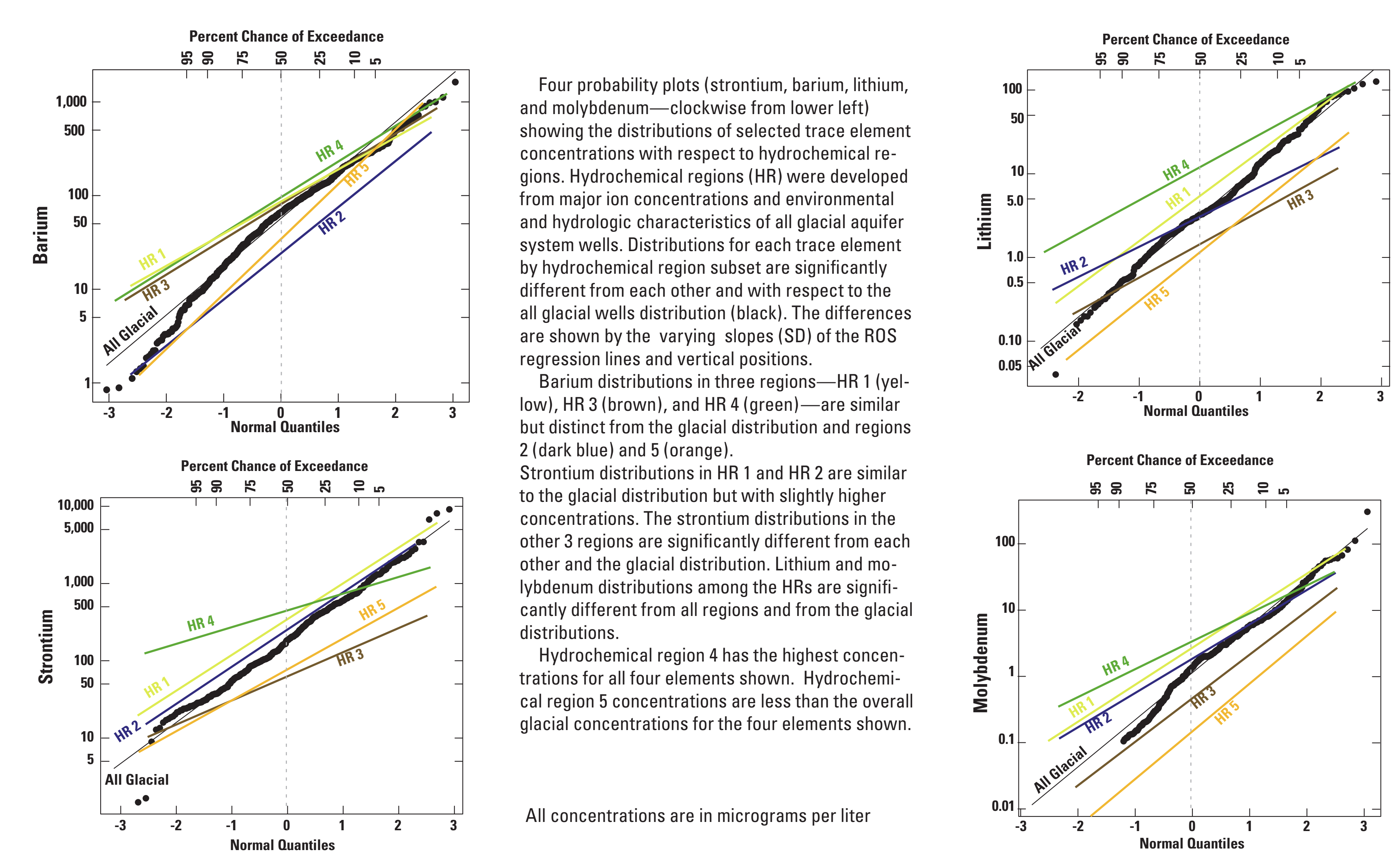
Trace elements and well type and land use

Three major factors that can substantially affect iron, manganese, and trace element concentrations in the glacial aquifer system are: land-use/land cover, well (or well-network) type and water use.



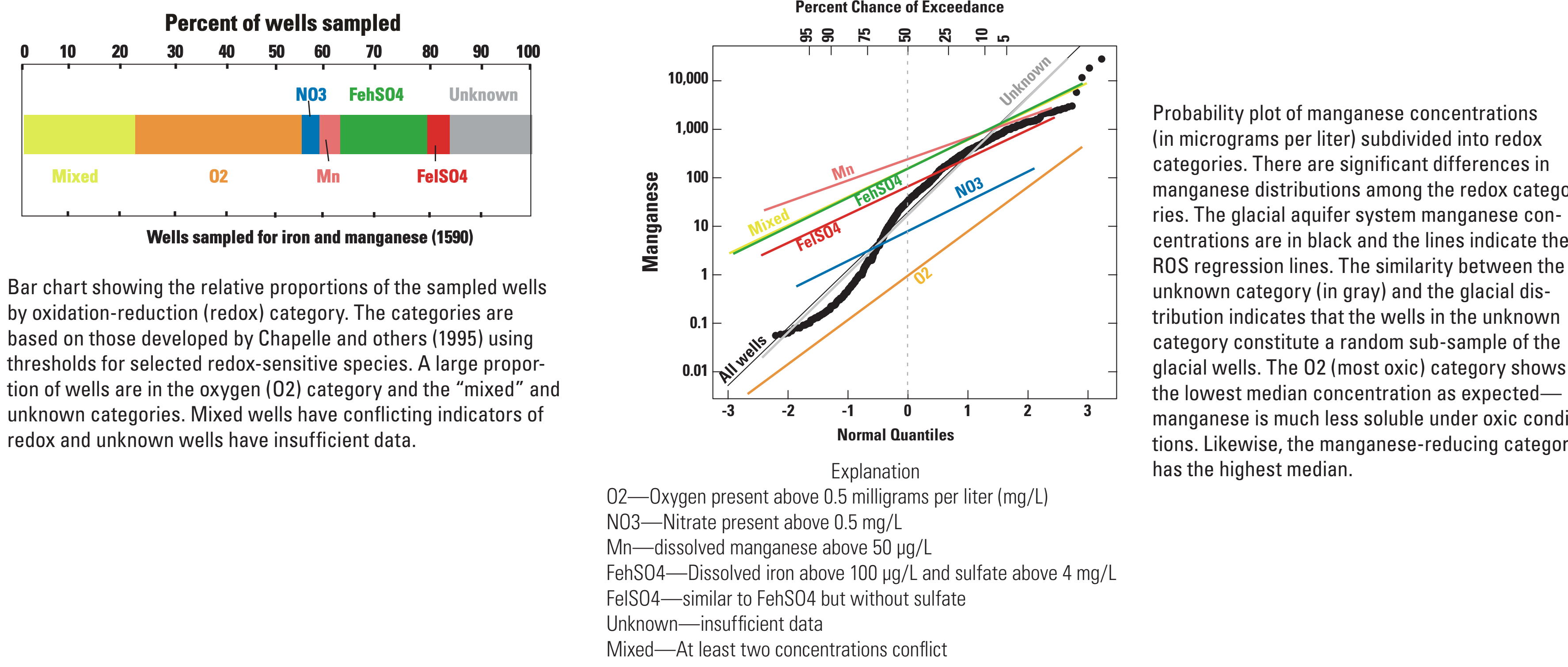
Trace elements and hydrochemical regions

Many environmental and other factors were investigated by principal components and cluster analyses to determine whether the wide range of factors can be simplified into fewer, more significant, components. Also, this procedure helps to determine the most important of these environmental and other factors that affect major ions as well as the trace elements, iron and manganese (Arnold, USGS written commun.: See “Optimizing ground-water networks” poster this session). Principal components and cluster analyses were run with and without trace element data to help characterize the variation in iron, manganese, and trace elements. Barium, strontium, lithium, molybdenum, iron and manganese were found to vary significantly among the hydrochemical regions determined using the results in a geospatial model.



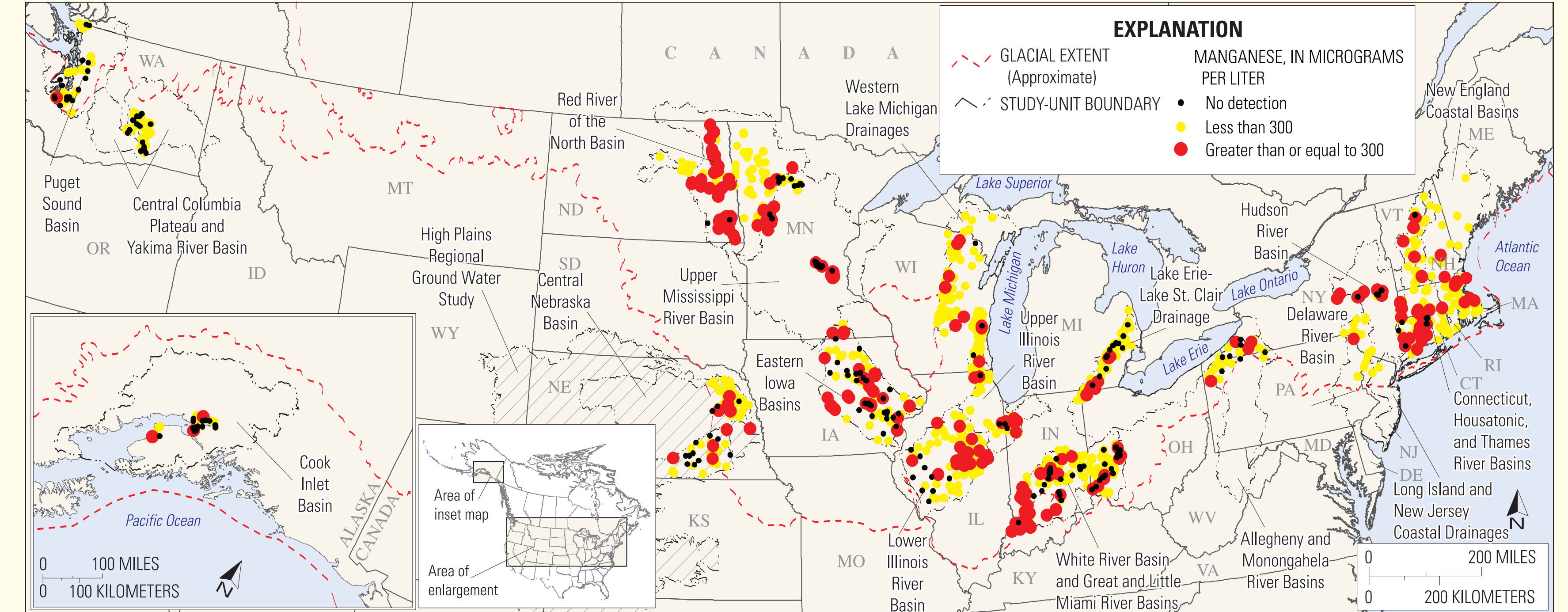
Trace elements and oxidation-reduction environment

Some trace elements are “redox-sensitive”—they may be more or less soluble in ground water depending on the electrochemical (redox) environment. Iron and manganese are strongly affected by redox plus there are many more data for these two elements. Iron and manganese therefore provide a good means of characterizing the effect of the ground-water electrochemical environment on other redox-sensitive elements.



Trace elements and human health

196 (out of 847) wells the have at least one trace element or manganese concentration that was greater than a human-health benchmark. Benchmarks, as used here, are either the relevant maximum contaminant level (MCL) or lifetime health advisory (LHA). Manganese concentrations were the most likely of any element to be above a human-health benchmark (29% of 1590). Only one well has 3 trace elements that exceed the relevant drinking-water benchmarks for arsenic, molybdenum, and uranium; however, it is a monitoring well on agricultural land in Washington State. 29 wells have 2 element concentrations above relevant drinking-water benchmarks: 15 West-Central area wells (11% of West-central area wells); 8 Central area wells (1.8% of Central area wells); 4 West area wells (4.5% of West area wells), and 2 East area wells (1% of East area wells).



Summary

Trace elements, iron, and manganese were sampled in wells to characterize the occurrence and distribution in the glacial aquifer system in the United States. Strontium and barium were the most commonly detected and at highest concentrations across the aquifer extent. The concentrations of each element sampled varied at least three orders of magnitude or more. Summary statistics were modeled because, for most elements, substantial proportions of sample concentrations were below analytical reporting levels. Concentration distributions of various subsets of the data indicated that there are significant variations among framework areas, environmental variables, and hydrochemical regions. Manganese concentrations were most likely to exceed a human-health benchmark. The West-central area generally had highest concentrations and highest proportion of wells with concentrations above a human-health benchmark.

References

Chapelle, F.H., McMahon, P.B., Dubrovsky, N.M., Fujii, R.F., Oaksford, E.T., and Vroblesky, D.A., 1995, Deducing the distribution of terminal electron-accepting processes in hydrologically diverse groundwater systems: Water Resources Research, v. 31, no. 2, pp. 359-371.
 Helsel, Dennis, 2005, Nondetects and data analysis—Statistical Methods for Censored Environmental Data, Wiley, New York, New York, 268p.
 Lee, L., Helsel, D., 2005, Statistical analysis of water-quality data containing multiple detection limits: S-language software for regression on order statistics. Computers and Geosciences, vol. 31, pp. 1241–1248.
 Warner, K.L., and Arnold, T.L. 2005, Framework for Regional Synthesis of Water-Quality Data for the Glacial Aquifer System in the United States: U.S. Geological Survey Scientific Investigations Report 2005–5223, 6 p.