# The Elmvale Groundwater Observatory:

## A Facility Developed to Sample Pristine Artesian Groundwater for Trace Elements

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THE GROUNDWATER PROJECT

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The Groundwater Project
Guelph, Ontario, Canada

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THE GROUNDWATER PROJECT

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*Board:* John Cherry, Shafick Adams, Richard Jackson, Ineke Kalwij, Renée Martin-Nagle, Everton de Oliveira, Marco Petitta, and Eileen Poeter.
*Cover Image:* William Shotyk, 2007.

# Dedication

This work is dedicated by William Shotyk to his father, Michael, with appreciation and thanks for the farm. Its pristine groundwater, the rich soil, the plants, and the animals have provided the inspiration for science as well as a living laboratory for research.

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# The Groundwater Project Foreword

The UN-Water Summit on Groundwater, held from 7 to 8 December, 2022, at the UNESCO headquarters in Paris, France, concluded with a call for governments and other stakeholders to scale up their efforts to better manage groundwater. The intent of the call to action was to inform relevant discussions at the UN 2023 Water Conference held from 22 to 24 March, 2023, at the UN headquarters in New York City. One of the required actions is *strengthening human and institutional capacity*, for which groundwater education is fundamental.

The 2024 World Water Day theme is *Water for Peace*, which focuses on the critical role water plays in the stability and prosperity of the world. The UN-Water website↗ states that *more than three billion people worldwide depend on water that crosses national borders*. There are 592 transboundary aquifers, yet most do not have an intergovernmental cooperation agreement in place for sharing and managing the aquifer. Moreover, while groundwater plays a key role in global stability and prosperity, it also makes up 99 percent of all liquid freshwater—accordingly, groundwater is at the heart of the freshwater crisis. *Groundwater is an invaluable resource*.

The Groundwater Project (GW-Project), a registered Canadian charity founded in 2018, is committed to advancement of groundwater education as a means to accelerate action related to our essential groundwater resources. We are committed to *making groundwater understandable* and, thus, enable *building the human capacity for sustainable development and management of groundwater.* To that end, the GW-Project creates and publishes high-quality books about *all-things-groundwater*, for all who want to learn about groundwater. Our books are unique. They synthesize knowledge, are rigorously peer reviewed and translated into many languages, and are free of charge. An important tenet of GW-Project books is a strong emphasis on visualization: Clear illustrations stimulate spatial and critical thinking. The GW-Project started publishing books in August 2020; by the end of 2023, we had published 44 original books and 58 translations. The books can be downloaded at gw-project.org↗.

The GW-Project embodies a new type of global educational endeavor made possible by the contributions of a dedicated international group of volunteer professionals from a broad range of disciplines. Academics, practitioners, and retirees contribute by writing and/or reviewing books aimed at diverse levels of readers including children, teenagers, undergraduate and graduate students, professionals in groundwater fields, and the general public. More than 1,000 dedicated volunteers from 70 countries and six continents are involved—and participation is growing. Revised editions of the books are published from time to time. Readers are invited to propose revisions.

We thank our sponsors for their ongoing financial support. Please consider donating to the GW-Project so we can continue to publish books free of charge.

**The GW-Project Board of Directors, January 2024**

# Foreword

This book presents an exceptional story about unexpected scientific discoveries that resulted from fortuitous circumstances and the dogged curiosity of one person who searched for answers over three decades. The story has three parts, one is about the recognition of the presence of pristine fresh groundwater in a shallow confined aquifer in a rural agricultural area in southern Canada. The second is about how this aquifer water was used to discover that standard methods are incapable of determining the true dissolved concentrations of common trace metallic elements such as lead in groundwater, and the third is about how to correctly determine the concentrations of these elements using monitoring wells installed for this specific purpose. Groundwater can legitimately be deemed pristine if it shows no evidence of human chemical influences (e.g. no anthropogenic constituents) when subjected to an exhaustive search for their presence. Although there is a common perception that groundwater—unlike surface water and rainwater—is generally pristine, after a comprehensive search it was found that the occurrence of pristine fresh groundwater is rare. This book provides two plausible explanations for how the groundwater in this shallow confined aquifer has remained pristine, but does not select between the two. This is an example of a common scientific situation, which is that scientific investigations identify puzzles that raise questions in need of answers and answers to those questions often pose a new puzzle. The study has important implications. For example, the concentrations of lead in groundwater that have been reported in the literature for decades, and accepted at face value, are nearly all erroneous and have gone unquestioned.

Over the three decades of this study, which continues as this book is published, the leader of the research team with its many participants is Dr. Williams Shotyk, a soil scientist and geochemist who holds the Bocock Chair for Agriculture and the Environment at the University of Alberta, Canada.

John Cherry, The Groundwater Project Leader

Guelph, Ontario, Canada, February 2024

# Preface

More than thirty years ago, when I created my laboratory at the University of Berne, I analyzed some groundwater samples from the old artesian flow on our farm in Ontario just out of curiosity. I soon learned that the water was very *clean* in regard to chloride, nitrate, and phosphate, and it became our in-house standard reference material to help monitor the accuracy and precision of the water-quality measurements we were making at that time.

Later, at the University of Heidelberg, I was given the opportunity to create a metal-free ultraclean laboratory for studying trace elements in the environment. When we had completed our research on polar snow and ice using that facility, Michael Krachler and James Zheng kindly analyzed trace elements in some groundwater samples from the farm—again, simply because I was curious. I learned that this groundwater was also very clean in regard to trace elements.

Then the real work began. To determine exactly how clean the water was, we had to design and install dedicated groundwater sampling wells with help from Michael Powell—who understood the Quaternary geology of the area and its importance—and Tommy Noernberg, who can build anything. The next step was to identify the most suitable plastic bottles for sample collection, evaluate appropriate cleaning procedures, and build clean-air cabinets to protect sample water from ambient air.

Once these efforts had been made, it became clear that the concentrations of Pb in the groundwater were well below the levels found in ancient Arctic ice. This finding came as a great surprise, but of course a happy one.

The data obtained at the University of Heidelberg have since been confirmed and replicated by Beatriz Bicalho, Chad Cuss, Iain Grant-Weaver, and Muhammad Javed with measurements made in our metal-free ultraclean SWAMP (Soil, Water, Air, Manures, and Plants) laboratory for the study of trace elements in at the University of Alberta. We are now confident in our ability to collect groundwater samples while maintaining their fidelity and integrity for the determination of trace elements. This book guides the reader through the process of characterizing groundwater geochemistry and best practices when sampling groundwater for trace elements. The main objective is to help the reader understand that groundwater sampling procedures may, to a great extent, influence the measured concentrations of trace elements as well as our interpretation of their significance.

I am happy to share our experience with others, and I thank Professor John Cherry for the opportunity to do so. Summarizing my notes and data for the past 30 years has presented some challenges, but I am sure that the results presented here are a reasonably accurate representation of reality. While I have received a lot of help throughout this journey, any errors contained herein are solely my own responsibility.

William Shotyk

Edmonton, Alberta

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For providing information about local artesian flows and/or access to their properties for water sampling over the years, the following citizens are gratefully acknowledged: Renzo Belluz, John Kidd, Darrell Leonard, Dan McLean, Anne and John Nahuis, Greg Parnell, and Bonnie and Jake Pigeon. Special thanks for the technical expertise of Canadian Well Drilling (Peter Fleming with EGO-1 and 2 and Jamie Archer with EGO-3) and Rick Buckley, ProCore Drilling (EGO-3) for installing the wells and for helpful insights into the hydrogeology of the area. The collection of 60 m of sediment at EGO-3 represents a donation to the Elmvale Foundation by Canadian Well Drilling, and this generosity is gratefully acknowledged.

Finally, thanks to Stephen and Neil Ogden for their outstanding craftsmanship on the cabins they built to house the wells and related infrastructure. Funding for the EGO was provided by the laboratory of the senior author when he was at the University of Heidelberg in Germany. Since its creation in 2007, the Elmvale Foundation↗ has provided modest financial support to help maintain the facility.

We are grateful to Amanda Sills and the formatting team of the Groundwater Project for their oversight and copyediting of this book. We thank Eileen Poeter (Colorado School of Mines) for reviewing, editing, and producing this book.

Sources are cited for images and other content of the figures provided in this book. Where no source is cited, the content is original to this work.

# 1 Introduction and Background

Human activities have increased the mobilization of many trace elements on a global scale (Fyfe, 1981; Goldberg, 1975; Lantzy & Mackenzie, 1979). Since industrialization, the impacts on the geochemical cycles of the chalcophile trace elements[1] have been especially dramatic. These elements (including As, Bi, Cd, Cu, Hg, Ni, Pb, Sb, Se, Te, Tl, and Zn)[2] occur as sulfide minerals and are highly enriched in the ore deposits formed from them (Goldschmidt, 1937, 1954). Because of their *soft acid* (Pearson, 1968a, 1968b) or *Class B* metal ion character (Nieboer & Richardson, 1980), these elements form thermodynamically stable bonds with sulfur-containing functional groups such as the thiol group found in many enzymes, which helps explain why they are so toxic to most living organisms (Manahan, 2005).

The most important industrial sources of these elements in the environment are smelting and refining of base metal ores, coal combustion, cement production, and incineration (Nriagu, 1979; Nriagu & Pacyna, 1988; Pacyna & Pacyna, 2001; Rauch & Pacyna, 2009). During these high-temperature combustion processes, sub-micron metal-rich aerosols are generated (Davison et al., 1974; Natusch et al., 1974) with atmospheric residence times as long as a week (Fennelly, 1976; Whitby et al., 1974; Willeke & Whitby, 1975), rendering them amenable to long-range atmospheric transport. Mercury (Hg) and Se also form gaseous species (Pavageau et al., 2002), and these have much longer atmospheric lifetimes.

In recent decades, metals required for advanced materials and technologies, such as the platinum group elements and the rare earth elements, have also been receiving attention (Chen & Graedel, 2012; Klee & Graedel, 2004; Sen & Peucker-Ehrenbrink, 2012). Trace elements released to the environment in the form of nanoparticles have generated additional concerns (Behra & Krug, 2008; Bundschuh et al., 2018; Hochella et al., 2019; Maurer-Jones et al., 2013; Westerhoff et al., 2018).

Among the chalcophile elements, Pb is something of a special case because of the long history of its use (at least five thousand years), its low melting point (328 °C), and—for much of the twentieth century—its use in gasoline additives (Nriagu, 1978; Shotyk & LeRoux, 2005). In fact, the geochemical cycle of Pb has been more affected by human activities than any other element (Hutchinson & Meema, 1987). This, combined with its toxicity, has generated

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[1] The term chalcophile (derived from the Greek for sulphur-loving) was originally introduced by Goldschmidt in 1923, as explained by Barnes (2018), to describe the group of elements that are concentrated in sulfide minerals of meteorites. Traditionally this group is defined as the elements Ag, As, Bi, Cd, Cu, Hg, In, Pb, S, Sb, Se, Te, Tl, and Zn. Goldschmidt classified the other elements in meteorites into two groups: those associated with Fe alloys as siderophile (iron loving) and those concentrated in silicate minerals as lithophile (rock loving). Subsequently, in 1930, Goldschmidt applied his classification to the whole Earth and modified it to include two new groups of elements: atmophile, those concentrated in the atmosphere; and biophile, those concentrated by organic processes (White, 2018).

[2] Arsenic (As), bismuth (Bi), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tellurium (Te), thallium (Tl), and zinc (Zn).

extensive concern about its mobilization, transformations, and fate in the environment (Nriagu, 1978). Lead contamination found in ancient layers of glacial ice from Greenland, dating from the Roman Period and representing Pb emissions from smelting and refining in the Mediterranean basin, is an excellent example of long-range atmospheric transport of trace elements (Murozumi et al., 1969). With the gradual phaseout and eventual elimination of leaded gasoline, combined with improvements in air pollution control technologies, anthropogenic emissions of Pb to the atmosphere in Europe and North America have been in strong decline for decades (Boyle et al., 2014; McConnell et al., 2018; Shotyk et al., 1998, 2005, 2016). However, there is ongoing concern about eventual leakage of legacy industrial Pb into the hydrosphere (Erel & Patterson, 1992, 1994; Erel et al., 1990, 1991; Graham & Vinogradoff, 2006; Klaminder et al., 2006; Outridge, 2000; Vinogradoff et al., 2005). The escape of some anthropogenic Pb from soils into surface water is inevitable, but most of the Pb tends to be in particulate forms (i.e associated with particles > 0.45 μm). Watersheds have natural processes of particle removal (e.g., aggregation and sedimentation) and element sequestration (adsorption and complexation), which are capable of reducing Pb concentrations in the dissolved fraction (i.e. all forms of Pb capable of passing through a 0.45 μm membrane filter) to extremely low concentrations—that is, at or below 10 ng/L (Shotyk & Krachler, 2010; Shotyk et al., 2017).

In contrast to surface water, much less information is available regarding Pb in groundwater, partly because of the considerable analytical challenges associated with the reliable determination of this metal at the ng/L level (Creasey & Flegal, 1999; Hodge et al., 1998; Stetzenbach et al., 1994). To understand the impacts of human activities on Pb and other trace elements in groundwater, the natural abundance of these elements must be established.

The purpose of this book is to present a summary of the approaches developed to enable the reliable determination of Pb and other trace elements in pristine groundwater. A second objective is to establish reference values for trace element concentrations against which data from other studies may be compared.

To illustrate the importance of the methods recommended here, we summarize experience and data obtained since 2004 while investigating the abundance of trace elements in the artesian groundwater near the village of Elmvale in Springwater Township, Simcoe County, Ontario (Figure 1) at the Elmvale Groundwater Observatory (EGO) site. Our hope is that the procedures described here will be helpful to other investigators as we all seek to improve the quality of our analytical data for trace elements in groundwater. The ultimate outcome of this work is to highlight the importance of sample collection, storage, processing, and analyses in the quest to identify and understand the movement of elements within and between the Earth's reservoirs while minimizing the risk of sample contamination. This type of diligence is the only way to ensure the level of analytical accuracy required for the proper determination of groundwater evolution. It is also essential for any comparison of data across research fields—that is, to be sure true concentrations are being evaluated, not just varying degrees of contamination during sampling, sample handling, preparation, or analysis.

Our original scientific question had been to determine whether any anthropogenic Pb from atmospheric deposition had reached the groundwater at the study site. To answer this, we had to overcome a series of technical challenges to establish the true concentration of Pb in groundwater. Our solutions to the problems of sampling and analysis are described in this book. Based on these efforts, we know that the abundance of Pb in the EGO groundwater is below the levels found in ancient Arctic ice. Having failed to detect any evidence of anthropogenic Pb, a new question arises: Why is this water so clean? Is the groundwater so pure because it is ancient glacial water, or are there processes taking place in the recharge area that filter out Pb and other trace elements? These new questions are beyond the scope of this book. However, the sampling and analysis methods we describe will allow us to undertake the next research effort needed to answer them.

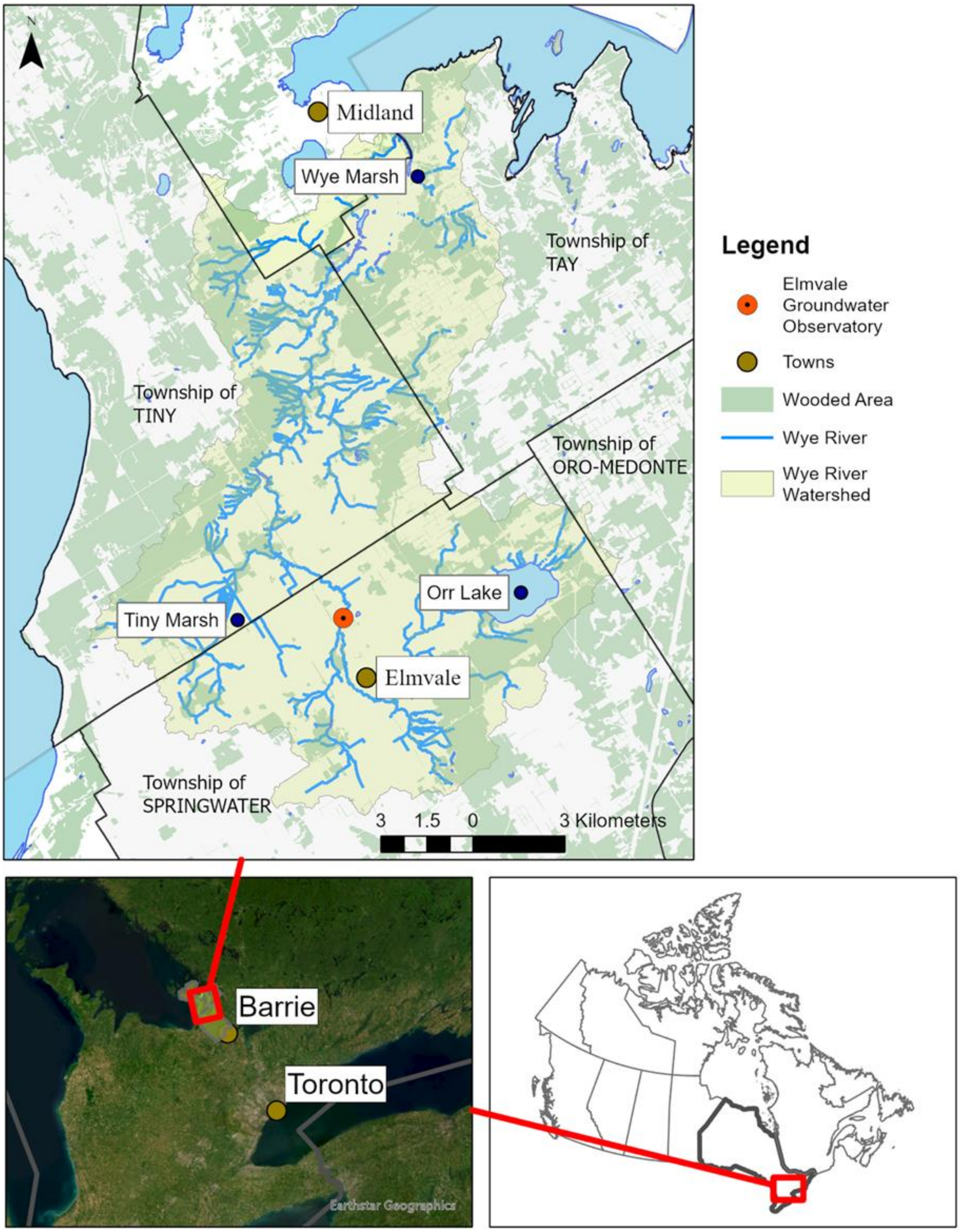

**Figure 1** - Location of the Elmvale Groundwater Observatory.

# 2 Artesian Flows in Springwater Township: Timeline from Scientific Curiosity to Analytical Obsession

## 2.1 1990 to 2009: Early Work on Existing Artesian Flows

The senior author became interested in the artesian flows of the area while he was in the eighth grade when his parents purchased a small farm property near Elmvale, Ontario, Canada, in 1972. Known locally as the "old Johnson farm," the farmhouse had a shallow (12.8 m) flowing (10 L/min) artesian well. Water testing began with water from this flow in the early 1990s, when the senior author established his first laboratory at the University of Berne (1989 to 2000).

Using ion chromatography, levels of nitrate and phosphate were determined to be below the limit of detection (LOD). Chloride concentrations were < 1 mg/L, which over the years has been confirmed many times by other laboratories (Table 1). Sulfate concentrations were on the order of 17 mg/L. Water from this artesian flow was periodically brought to Switzerland, where it was used as the in-house reference water to monitor retention times for anions and cations—which are also determined using ion chromatography—at the University of Berne laboratory (Shotyk, 1993a, 1993b; Steinmann & Shotyk, 1995).

**Table 1 -** Summary of chloride concentration measurements taken at the farmhouse and Elmvale Groundwater Observatory.

| Year of collection | Location | Chloride concentration (mg/L) | Laboratory (analyst) |
|---|---|---|---|
| 1992 | Farmhouse | 0.70 | University of Berne<br>(W. Shotyk) |
| 2009 | EGO-1[1] | 0.80 | University of Heidelberg<br>(S. Rheinberger) |
| 2009 | EGO-2 | 0.96 | University of Heidelberg<br>(S. Rheinberger) |
| 2013 | EGO-3 | 1.20 | University of Ottawa<br>(I. D. Clark) |
| 2015 | EGO-3 (bottle 3) | 0.92 ± 0.4 (n=6) | University of Alberta<br>(NRAL[2] Laboratory) |
| 2015 | EGO-3 (bottle 4) | 0.91 ± 0.06 (n=6) | University of Alberta<br>(NRAL Laboratory) |
| 2019 | EGO-1 | 0.70 | Ontario Geological Survey<br>(E. Priebe) |
| 2019 | EGO-3 | 0.90 | Ontario Geological Survey<br>(E. Priebe) |

[1] EGO: Elmvale Groundwater Observatory. 1, 2, and 3 are specific locations that were sampled on the site.
[2] NRAL: Natural Resources Analytical Laboratory

The senior author later joined the University of Heidelberg (2000 to 2011) as Professor and Director of the Institute of Environmental Geochemistry. This position brought with it an opportunity to design and construct a metal-free, ultraclean laboratory for the study of trace elements in the environment. At that time, the main task of this lab was to reconstruct the historical record of atmospheric deposition of trace elements in Arctic snow and ice.

After the work on an ice core from Devon Island, Nunavut, Canada, was completed (Krachler et al., 2005b, 2008a, 2008b; Shotyk et al., 2005; Zheng et al., 2007), we turned our attention to the release of anthropogenic Pb from soils to surface water (Shotyk & Krachler, 2010) and groundwater (Shotyk & Krachler, 2009; Shotyk et al., 2005, 2010). Given the limited amount of information on trace elements in groundwater, we compared our early findings with data for bottled water. These preliminary studies quickly showed that all bottled water in PET (polyethylene terephthalate) plastic was contaminated with Sb (Krachler & Shotyk, 2009; Shotyk & Krachler, 2007a; Shotyk et al., 2006) and bottled water in glass was contaminated with Pb (Shotyk & Krachler, 2007b) because of leaching from the containers.

The groundwater component of these studies began, as could be expected, from the artesian flow on the same family farm property where water testing had begun many years earlier (Figure 2). A map is provided in Box 1 ↴ to show the location of the property. Studies of trace elements in groundwater soon expanded to include the other artesian flows in the area. Information concerning methods, materials, tritium activity, organic contaminants, and pesticides are provided in Box 2 ↴, Box 3 ↴, Box 4↴, Box 5 ↴, and Box 6 ↴, respectively.

Except for one natural spring found in a small swamp in the area, all the water sampled at this time were from wells constructed of galvanized steel pipes. Some of the artesian flows had brass valves, including the original one at the farmhouse (Figure 2). A time series (Box 7 ↴) undertaken in July 2005 documented the contamination of groundwater from brass valves. The longer the water was allowed to flow, the lower the concentrations of many trace elements. Chalcophile elements such as Ag, Cd, Cu, Pb, and Zn were most affected, but Co, Cr, Fe, and V[3] were also impacted. Lithophile elements such as Ba, Rb, and Sr[4] were unaffected; this is true also of elements commonly enriched in groundwater such as As, Mo, and U.[4] Thus, early measurements of some trace elements (e.g., Rb, Sr, As, Mo, U) obtained using water flowing from these old steel pipes are valid.

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[3] Cobalt (Co), chromium (Cr), iron (Fe), and vanadium (V).

[4] Barium (Ba), rubidium (Rb), strontium (Sr), molybdenum (Mo), uranium (U).

1972 - Purchase of farm property by Shotyk family with artesian flow, with original brass valve

1990 - First measurements of anions and cations, in water from artesian flow, farmhouse (University of Berne)

2004 - First measurements of trace metals in water from artesian flow, farmhouse, and several other artesian flows in the area (University of Heidelberg). Eight sets of measurements were made between 2004 and 2011

2007, May - Installation of stainless steel valve, artesian flow, farmhouse

2009, May Installation of EGO-1 (stainless steel well, 13m)

2009, September Installation of EGO-2 (acid-cleaned HDPE well, 13 m)

2010, March - Sampling of water from EGO-1 (n=15) and EGO-2 (n=15) [ambient air]. See Figure 4 for data summary.

2010, September - Sampling of water from EGO-1 (n=10) and EGO-2 (n=10) [metal-free, laminar flow, clean air cabinets] using LDPE bottles (UGC), HDPE bottles (GSC) and commercially-available, pre-cleaned PFA (perfluoroalkoxy alkane) bottles for trace metals research. See Figure 5 and 6 for data summary.

2011 March - Sampling of water from EGO-1 (n=10) and EGO-2 (n=10) (metal-free, laminar flow, clean air cabinets) using LDPE bottles (UGC cleaning, GSC cleaning, CBCS cleaning) and HDPE bottles (GSC cleaning). See Figure 7 and 8 for data summary.

2012, May - Installation of EGO-3 (surgical, 316L, stainless steel well, 60 m) and metal-free, laminar flow, clean air cabinet. Collection and description of complete sediment core.

2014 - First set of measurements of trace elements in EGO-3, from the SWAMP laboratory at the University of Alberta. Fifteen additional sets of measurements from this point in time to 2019.

**Figure 2** - Approximate timeline of testing of the groundwater, starting with the original artesian flow at the farmhouse, through to the development of the EGO wells.

The brass valve on the artesian flow at the farmhouse property was replaced with a stainless steel valve in May 2007 (Figure 2). A second time series was undertaken in October 2007 for a long list of trace elements. While the stainless steel valve reduced the Pb concentration in first-draw water by a factor of approximately 500 times, there was still an issue with Cr and to a lesser extent Ni in first-draw water (Box 6). The new valve, however, did nothing to eliminate or even to reduce the risk of contamination from the galvanized steel pipe that had been installed perhaps a century earlier. Thus, there was a need for a dedicated groundwater sampling well to obtain reliable data for trace elements in this artesian spring water.

## 2.2 2009 to Date: Creation of the Elmvale Groundwater Observatory

Based on the hydrogeological study prepared for a local fish farm (Wilson & Associates, 1997), three new research wells (EGO-1, -2, and -3) were installed up-gradient and cross-gradient from the well at the farmhouse to minimize the risk of contamination from the original galvanized steel well. EGO-1 and EGO-2 are approximately 33 m to the east of EGO-3, which in turn is approximately 45 m north of the original artesian flow at the farmhouse.

### 2.2.1 EGO-1

The first research well was constructed entirely of stainless steel and reached an aquifer at 13 m (i.e., the same depth as the farmhouse well). Installed in May 2009 and flowing at a rate of 1 L/min, as of February 2023 the entire volume of water in this well was exchanged more than approximately 258,000 times since installation. The valve (Figure 2) was designed and built but then disassembled to allow each of the components to be leached in nitric acid. Once the components had been thoroughly cleaned, rinsed in high-purity water, and dried in a clean-air cabinet, they were packed in polyethylene bags and shipped to the farm property in Ontario for installation.

A sketch of the stratigraphy is provided in Figure Box 8-1 (Box 8 ↴). The aquifer sand (at a depth of 13 m) contains abundant calcium carbonate. Particle size analyses presented in Figure Box 8-2 showed that the sand is 56 percent medium sand (630 to 200 μm) and 32 percent coarse sand (630 to 2000 μm). Most of the material is quartz; orthoclase is part of the much finer fraction, and plagioclase is present as subangular grains. The mafic component is around 1 to 2 percent and is present as individual (smaller) grains and very small grains attached to some of the milky quartz. The larger grains are either frosted quartz or, most likely, plagioclase. There is a mix of angular to subangular to rounded grains, indicating different transport times and/or mechanical crushing; this may also be a result of different hardness. Having established the stratigraphy of the sediments and the depth of the aquifer, it was then possible to design and install a second well, built entirely of plastic.

### 2.2.2 EGO-2

Cadmium and Pb are commonly used as stabilizers in the manufacture of polyvinyl chloride (PVC; Belarra et al., 1989, 1990) and these metals leach from this plastic (Nakashima et al., 2012). So, even though PVC is commonly used to construct groundwater-monitoring wells, this material had to be avoided. Instead, for EGO-2, high-density polyethylene (HDPE) was selected for construction. All necessary materials were constructed of HDPE, including nose cone, screens, and pipes, obtained from Rotek in Denmark via their distributor in Germany, Carl Hamm. The parts were shipped to the University of Heidelberg, leached in nitric acid, rinsed in high-purity water, then packed and sealed in polyethylene bags and shipped to the farm property in Canada for installation.

The valve for this new well (Figure 2) was built using a combination of polypropylene (PP) and polytetrafluoroethylene (PTFE, commonly known as Teflon®). Again, the valve was disassembled for cleaning in nitric acid, then rinsed in high-purity water and dried in a clean-air cabinet before being shipped to the farm property in Ontario for installation. This new well, EGO-2, was installed approximately 3 m from EGO-1. To minimize the risk of contamination of water from the stainless steel used to construct EGO-1, EGO-2 was installed hydrologically up-gradient; again, this is based on the report by Wilson and Associates (1997). Since it was installed in September 2009, the volume of water in the well has been exchanged more than approximately 252,000 times.

### 2.2.3 EGO-3

This well, constructed entirely of surgical stainless steel (316 L), was installed in May 2012, hydrologically down-gradient from EGO-1 and EGO-2 (again, based on the Wilson & Associates hydrogeology report, 1997). There is no concern regarding possible contamination of the water in EGO-3 from the farmhouse well, EGO-1, nor from EGO-2, because each of these wells samples groundwater from an aquifer at 13 m whereas EGO-3 samples water from an aquifer at a depth of 58 to 60 m. The water in EGO-3 flows at a rate of 1.3 L/min. Since it was installed, the entire volume of water in the well has been exchanged almost 62,000 times. The valve for this new well (Figure 2) was built using 316 L stainless steel. The valve was disassembled for cleaning in nitric acid in the metal-free, ultraclean SWAMP laboratory, rinsed with high-purity water, air-dried in a clean-air cabinet, packed in polyethylene bags, then shipped to the farm property in Ontario for installation.

At this site, 60 m of sediment was recovered and examined in detail as part of an MSc thesis (Mulligan, 2013). A summary of the stratigraphy of this site, redrawn from Mulligan (2013), is shown in Figure 3.

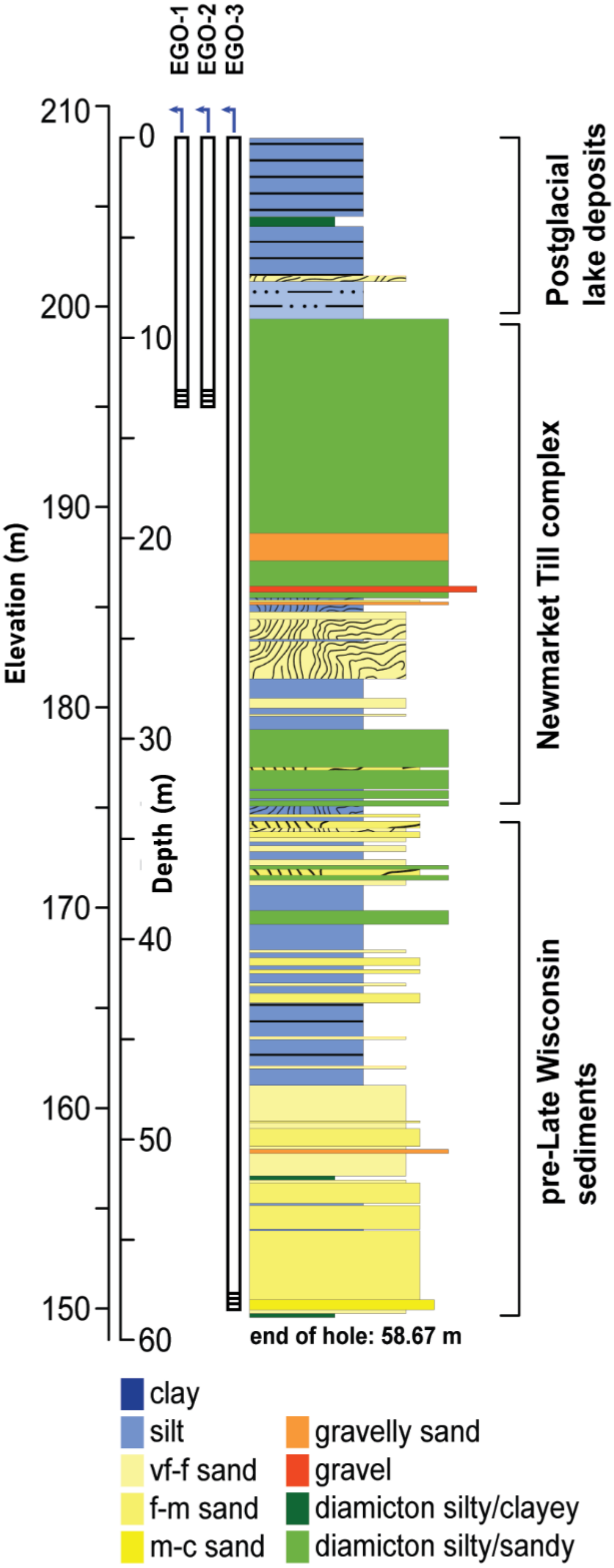

**Figure 3** - Stratigraphy of the sediments at EGO-3 (redrawn from Mulligan, 2013). Depths are given in meters below ground surface - mbgs of the EGO wells and elevations are provided in meters above sea level (masl).

# 3 Major Ion Chemistry

Water samples collected by the Ontario Geological Survey from EGO-1 and EGO-3 were analyzed in the field for pH, electrical conductivity (EC), dissolved oxygen (DO), and oxidation-reduction (redox) potential, and in their laboratory for alkalinity, dissolved organic carbon (DOC), and major ions (Table 2). The water from EGO-3 (60 m) is much more reducing, with slightly greater EC and bicarbonate, more Ca and less Sr, and ten times more Fe than the water from EGO-1 (13 m).

**Table 2 -** Parameters measured in the field (October 2018) and major constituents EGO-1 and EGO-3.

| **Parameter** | **Formula** | **Measurement units** | **EGO-1** | **EGO-3** |
|---|---|---|---|---|
| Field and bulk parameters | | | | |
| Temperature | - | °C | 9.5 | 9.4 |
| pH | pH | pH units | 7.8 | 7.8 |
| Electrical conductivity | EC | µS/cm | 310.0 | 330.0 |
| Oxidation-reduction potential | Eh | mV | 0 | -169 |
| Total dissolved solids | TDS | mg/L | 283.0 | 329.0 |
| Hardness (for mg/L multiply by 17.1) | - | grains per US gal | 9.1 | 10.1 |
| Dissolved organic carbon | DOC | mg/L | 2.5 | 2.4 |
| Dissolved inorganic carbon | DIC | mg/L | 38.0 | 41.0 |
| Bacteriological parameters | | | | |
| Total coliforms | - | counts/100 ml | 0 | 0 |
| Fecal coliforms | - | counts/100 ml | 0 | 0 |
| Dissolved gases | | | | |
| Dissolved oxygen | $O_2$ | % Saturation | - | - |
| Hydrogen sulfide* | $H_2S$ | mg/L | - | 0.05 |
| Methane** | $CH_4$ | $L/m^3$ | - | - |
| Major constituents | | | | |
| Calcium | $Ca^{2+}$ | mg/L | 28.0 | 38.0 |
| Magnesium | $Mg^{2+}$ | mg/L | 21.0 | 19.0 |
| Sodium | $Na^+$ | mg/L | 5.0 | 7.0 |
| Potassium | $K^+$ | mg/L | 1.7 | 1.9 |
| Bicarbonate | $HCO_3^-$ | mg/L | 198.0 | 235.0 |
| Sulfate | $SO_4^{2-}$ | mg/L | 18.0 | 19.0 |
| Chloride | $Cl^-$ | mg/L | 0.7 | 0.9 |
| Bromide | $Br^-$ | mg/L | < 0.02 | 0.02 |
| Fluoride | $F^-$ | mg/L | 0.21 | 0.23 |
| Iodide | $I^-$ | µg/L | < 0.01 | < 0.01 |
| Nitrate | $NO_3^-$ | mg/L (as N) | < 0.02 | < 0.02 |
| Nitrite | $NO_2^-$ | mg/L (as N) | < 0.01 | < 0.01 |
| Ammonia | $NH_3$ | mg/L (as N) | 0.5 | 0.21 |
| Organic nitrogen | Organic N | mg/L (as N) | < 0.1 | < 0.05 |
| Phosphate | $PO_4^{3-}$ | mg/L | < 0.04 | < 0.04 |
| Iron | Fe | mg/L | 0.01 | 0.10 |
| Strontium | $Sr^{2+}$ | mg/L | 1.2 | 0.5 |
| Silicon | Si | mg/L | 8.5 | 6.9 |

# 4 Tritium Activity

Tritium ( $^3H$) in precipitation reached its zenith between 1962 and 1965 because of open-air nuclear weapons testing, and the greatly elevated concentrations of $^3H$ that resulted has allowed this radionuclide to be used as a tool for dating recent (i.e., post–1953, or post–bomb) groundwater (Robertson & Cherry, 1989). Water samples from the farmhouse and the EGO research wells were measured for their tritium activity several times over the years, both at the University of Heidelberg and the University of Ottawa (Table Box 4-1) Summary of Tritium Activity Measurements.

To date, no tritium has been detected—neither in the artesian flow that supplies the farmhouse nor in any of the three wells of the EGO. Water samples from other artesian flows in the area were also measured for their tritium activity over the years, and these findings are summarized in Table Box 4-2. Many of the artesian flows in the area contain modern levels of tritium, which indicates that many of these aquifers represent water younger than approximately CE 1950. For the reader’s convenience, all of the SI Tables are provided in Box 4.

# 5 Determination of Trace Elements Using ICP-MS

Water samples from the farmhouse, EGO-1 and EGO-2, were analyzed at the University of Heidelberg using sector-field ICP-MS (Element 2, Thermo Fisher Scientific). The following isotopes were measured using low mass resolution: $^{7}$Li, $^{9}$Be, $^{74}$Ge, $^{75}$As, $^{85}$Rb, $^{88}$Sr, $^{98}$Mo, $^{109}$Ag, $^{111}$Cd, $^{121}$Sb, $^{125}$Te, $^{138}$Ba, $^{184}$W, $^{205}$Tl, $^{208}$Pb, $^{209}$Bi, $^{232}$Th, and $^{238}$U. For the following isotopes, medium mass resolution was used to resolve spectral interferences: $^{23}$Na, $^{24}$Mg, $^{27}$Al, $^{44}$Ca, $^{45}$Sc, $^{47}$Ti, $^{51}$V, $^{52}$Cr, $^{55}$Mn, $^{56}$Fe, $^{59}$Co, $^{60}$Ni, $^{63}$Cu, and $^{64}$Zn. Details regarding the ICP-MS measurements—including calibration, blank values, limits of detection, accuracy, and precision are provided in publications about trace elements in polar snow and ice by Krachler and others (2004a, 2004b, 2005a).

Water samples collected from EGO-3 were analyzed in the SWAMP laboratory at the University of Alberta using an Element XR (Thermo Fisher Scientific) for the bottle leaching study and quadrupole ICP-MS (either ICAP Qc or ICAP RQ, both from Thermo Fisher Scientific) for the groundwater. The relevant analytical details regarding these measurements are provided in the published studies of trace elements in the Athabasca River, Alberta, Canada (Bicalho et al., 2017; Cuss et al., 2018; Donner et al., 2017, 2018; Javed et al., 2017; Shotyk et al., 2017).

# 6 Trace Elements in Groundwater: Influence of Well Construction Materials

Selected results are shown for water samples collected from the farmhouse, EGO-1 and EGO-2 (Figure 4), with the complete set of measurements summarized in Table Box 9-1 of Box 9↴. For Ag, Bi, Cd, Cr, Cu Fe, Ni, Pb, Te, and Zn, concentrations were far greater in the groundwater from the artesian flow at the farmhouse. At the farmhouse well, the brass valve had already been replaced with one made of stainless steel. Also, the water had been allowed to flow for 75 minutes before a water sample was collected. With a flow rate of approximately 10 L/min, the volume of water in this well is replaced approximately 19 times per hour. Allowing the well to flush for 75 minutes means that the entire volume of water in the well had been replaced at least 22 times. Thus, the elevated concentrations of trace elements listed above are most likely due to contributions from the galvanized steel pipe, even though the water had been flowing continuously through the same pipe for decades. For perspective and context, the Pb concentrations were 82 ng/L (farmhouse), 8.0 ng/L (EGO-1), and 3.9 ng/L (EGO-2).

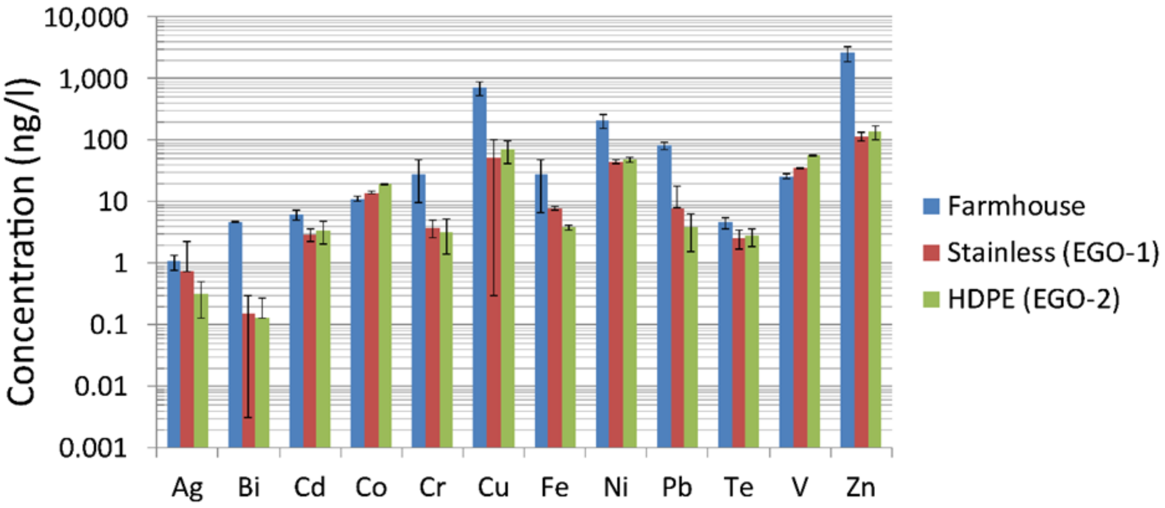

**Figure 4** - Trace elements in groundwater (ng/L) from farmhouse (galvanized steel pipe), EGO-1, and EGO-2. The farmhouse was sampled in March 2009 (n=3) whereas EGO-1 (n=15) and EGO-2 (n=15) were sampled in March 2010. The complete set of analytical data is presented in Table Box 9-1 of Box 9.

This comparison showed that the water from the farmhouse contained the greatest concentrations of Fe (27.5 ± 20.9 µg/L, n=3). Moreover, the stainless steel well (EGO-1) had greater concentrations of Fe (8.0 ± 0.7 µg/L, n=15) compared to the HDPE well (EGO-2) with 3.9 ± 0.4 µg/L Fe (n=15). The water from all three wells was sampled at a depth of 13 m. Given that EGO-1 and EGO-2 are only about 55 m from the flow at the farmhouse, we assume that all three wells are sampling water from the same aquifer.

The chemical composition of 316 L (surgical) stainless steel, in weight percent, is approximately Cr 17 to 19, Ni 13 to 15, Mn < 2, Mo 2.25 to 3, and Cu < 0.5 (Andersen, 2013).

Given the abundance of Cr and Ni in stainless steel, both of these metals should serve as sensitive indicators of any potential corrosion from the EGO-1 well. Examination of the data, failed to reveal significant differences in concentrations of Cr in water from EGO-1 (3.8 ± 1.2 ng/L, n=15) versus EGO-2 (3.3 ± 1.9 ng/L, n=15). Similarly, there were no significant differences in concentrations of Ni in water from EGO-1 (44.9 ± 3.1 ng/L) versus EGO-2 (48.5 ± 3.9 ng/L).

Finally, there were no significant differences in concentrations of Cu in water from EGO-1 (51.5 ± 51.2 ng/L) versus EGO-2 (71.0 ± 28.6 ng/L). Given that the pH of the water is 7.8, with abundant Ca, Mg, and carbonate alkalinity (Table 2), detectable corrosion of the stainless steel well seems unlikely. Thus, the large differences in Fe concentrations are not due to the materials used to construct the wells but could reflect variations in water chemistry within the aquifer.

The comparison between EGO-1 and EGO-2 provided a very important additional observation. Water from the HDPE well (EGO-2) yielded significantly greater concentrations of V than the stainless steel well (EGO-1). Specifically, the V concentrations were 57.7 ± 1.30 ng/L (n=15) in water from the HDPE well versus 35.6 ± 1.4 ng/L V (n=15) from the stainless steel well. The most likely reason for the elevated concentration of V from the HDPE well is the fact that vanadium compounds are commonly used as catalysts in the production of HDPE (Mortimer, 1976; Nomura & Zhang, 2011). Thus, even though the well is constructed entirely of plastic, it yields greater concentrations of V in groundwater samples than the stainless steel well that is constructed entirely of metal. Plastic alone, therefore, is not necessarily a solution to reducing the risk of metal contamination. Rather, each plastic must be evaluated on a case-by-case basis for each of the elements of interest.

Two other elements appear to be similarly affected: Co, 19.0 ± 0.40 ng/L (n=15) in water from HDPE versus 14.1 ± 0.50 ng/L (n=15) from stainless steel, and Tl, 0.89 ± 0.10 ng/L in water from HDPE versus 0.69 ± 0.05 ng/L in water from stainless steel. The small but statistically significant difference in Tl concentrations between the two types of wells, at levels below 1 ng/L, is a reminder of the importance of extremely accurate and precise determinations of trace element concentrations and the need for ultraclean laboratory procedures and protocols for sampling, handling, and analysis.

# 7 Trace Elements in Groundwater: Which Plastic Bottle is Best for Sampling?

To determine the most suitable bottle for trace metals research, water was collected from EGO-1 and EGO-2 using acid-cleaned, low-density polyethylene (LDPE), high-density polyethylene (HDPE), and perfluoroalkoxy alkane (PFA) bottles.

## 7.1 EGO-1 Results: Influence of Bottle Composition

The LDPE bottles performed the worst concerning Ag, As, Bi, Co, Cu, Pb, Sb, Th, and Zn (Figure 5). The LDPE bottles were especially poor regarding Pb and Zn (Figure 5). For example, Pb concentrations were 44.8 ± 110 ng/L (n=15) in LDPE, 2.55 ± 1,420 ng/L (n=10) in PFA, and 1.51 ± 114 ng/L (n=10) in HDPE. The extremely large variation in these results—reflected in the standard deviations—indicates a very high probability of external contamination and removes any opportunity for blank correction.

The bottles made of HDPE were by far the worst in regard to Al and V (Figure 5). Vanadium concentrations, for example, were 24.7 ± 6.7 ng/L (n=15) in LDPE, 23.0 ± 2.3 ng/L (n=10) in PFA, and 177 ± 60 ng/L (n=10) in HDPE. Even Al, which is one of the more abundant trace elements in groundwater, showed the same trend: 0.81 ± 0.89 μg/L (n=15) in LDPE, 0.59 ± 0.07 μg/L (n=10) in PFA, and 3.78 ± 0.91 μg/L (n=10) in HDPE.

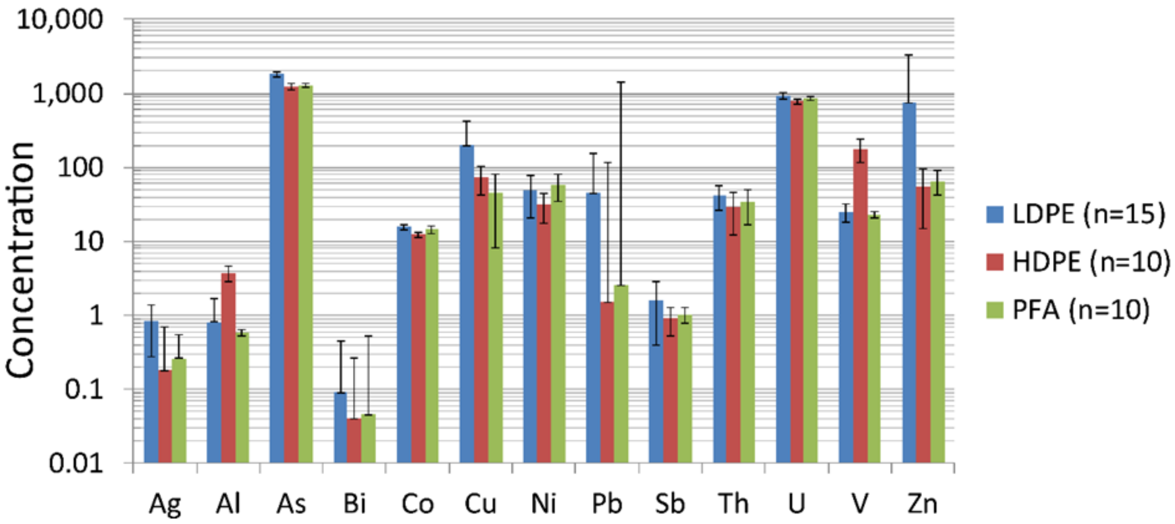

**Figure 5** - Selected trace elements in groundwater from EGO-1 (stainless steel) sampled using acid-cleaned LDPE (n=15), HDPE (n=10), and PFA bottles (n=10). Water samples were collected in September 2010. Concentrations are ng/L except for Al (μg/L) and Th (pg/L). The complete set of analytical data is presented in Table Box 9-2 of Box 9.

## 7.2 EGO-2 Results: Influence of Bottle Composition

Again, LDPE performed the worst in terms of As, Cu, Pb, and Zn (Figure 6). The results obtained for Pb were especially disappointing. For example, Pb concentrations were 7.7 ± 191 ng/L (LDPE), 1.4 ± 92 ng/L (PFA) and 1.0 ± 1.0 ng/L (HDPE). The poor performance of the LDPE bottles was surprising, given their recommendation for work on trace metals in polar snow and ice (Boutron, 1990).

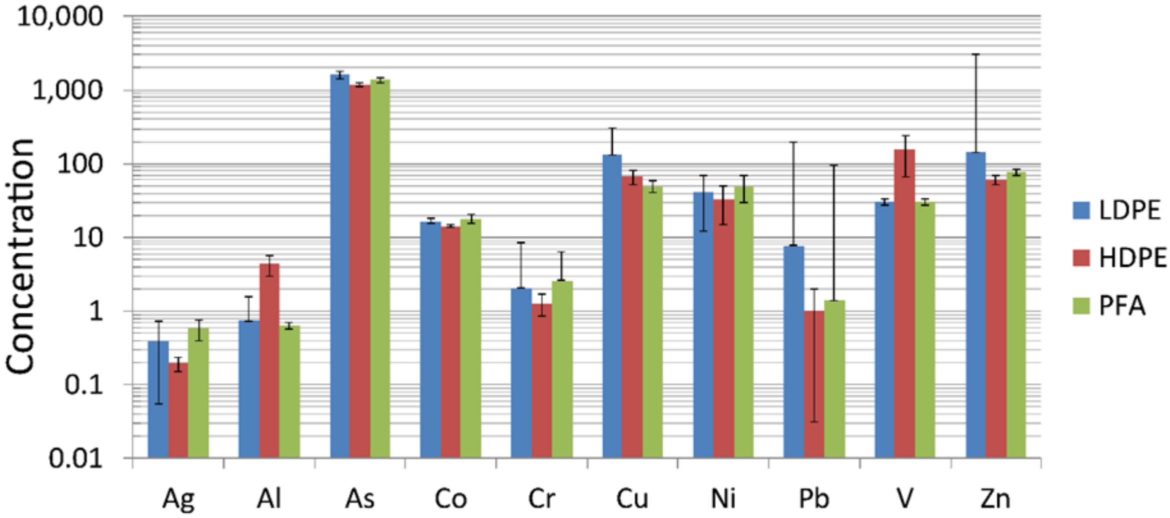

**Figure 6** - Selected trace elements in groundwater from EGO-2 (acid-cleaned HDPE) sampled using acid-cleaned LDPE (n=15), HDPE (n=10), and PFA bottles (n=10). Water samples were collected in September 2010. Concentrations are ng/L except for Al (µg/L). The complete set of analytical data is presented in Table Box 9-3 of Box 9.

To be sure that the problem was the bottles themselves and not the cleaning procedure used in the laboratory, three cleaning procedures were evaluated using LDPE bottles:

1) the method used at that time in our laboratory at the Institut für Umweltgeochemie (UGC) of the University of Heidelberg, which was a modification of the procedure described by Nriagu and others (1993);
2) the method used at the Geological Survey of Canada (GSC); and
3) a commercially available system for acid-cleaning of plasticware for trace metals research called a Commercial Bottle Cleaning System (CBCS).

Both EGO-1 and EGO-2 were resampled, using the LDPE bottles prepared in these ways but also using HDPE bottles cleaned at the GSC.

## 7.3 EGO-1 Results: Influence of Cleaning Procedure

In water samples collected from EGO-1, the LDPE bottles cleaned at the GSC yielded lower values for Pb and Zn (Figure 7). However, much lower values for both metals were obtained using HDPE bottles. In the case of Pb, for example, LDPE bottles yielded 17.3 ± 16.7 ng/L (UGC), 7.7 ± 4.2 ng/L (GSC), and 37.7 ± 33.8 ng/L (CBCS); in contrast, the HDPE bottles yielded 3.0 ± 0.88 ng/L (Figure 7).

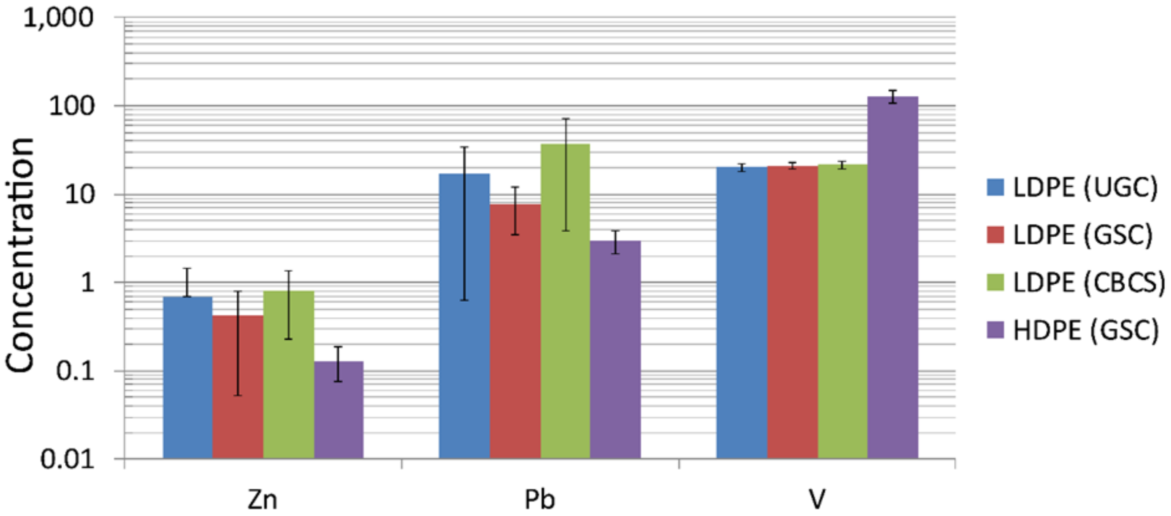

**Figure 7** - Selected trace elements in groundwater from EGO-1 (stainless steel) sampled in March 2011. The LDPE bottles were cleaned in Heidelberg (UGC, n=10), Ottawa (GSC, n=10), and using CBCS (n=10). The HDPE bottles (n=10) were cleaned in Ottawa (GSC). Concentrations are µg/L (Zn) or ng/L (Pb and V). The complete set of analytical data is presented in Table Box 9-4 of Box 9.

## 7.4 EGO-2 Results: Influence of Cleaning Procedure

In water collected from EGO-2, the concentrations of Cr, Pb, and Zn in the HDPE bottles were dwarfed by those obtained from LDPE bottles, regardless of the cleaning procedure (Figure 8). For example, in the case of Pb, LDPE bottles yielded 24.7 ± 19.8 ng/L (UGC), 475 ± 983 ng/L (GSC), and 104 ± 916 ng/L (CBCS); in contrast, the HDPE bottles yielded 1.05 ± 0.3 ng/L (Figure 8).

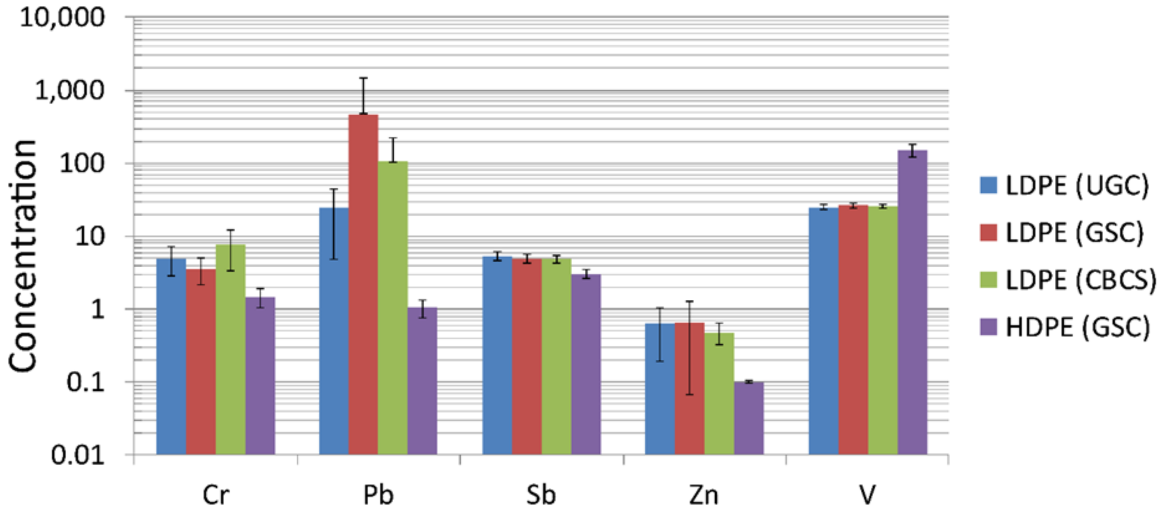

**Figure 8** - Selected trace elements in groundwater from EGO-2 (acid-cleaned HDPE) sampled in March 2011. The LDPE bottles were cleaned in Heidelberg (UGC, n=10), Ottawa (GSC, n=10), and using CBCS (n=10). The HDPE bottles (n=10) were cleaned in Ottawa (GSC). Concentrations are µg/L (Zn) or ng/L (Cr, Pb, Sb, and V). The complete set of analytical data is presented in Table Box 9-5 of Box 9.

A summary of Pb concentrations in selected groundwater samples, by well and bottle type, is provided in Figure 9. By the time these data were collected, it had become clear to us that the LDPE bottles simply could not be used for studies of trace metals such as Pb in groundwater—regardless of the cleaning procedure used—given that the range in Pb concentrations spanned three orders of magnitude. In contrast, HDPE bottles had provided much lower and more consistent Pb concentrations.

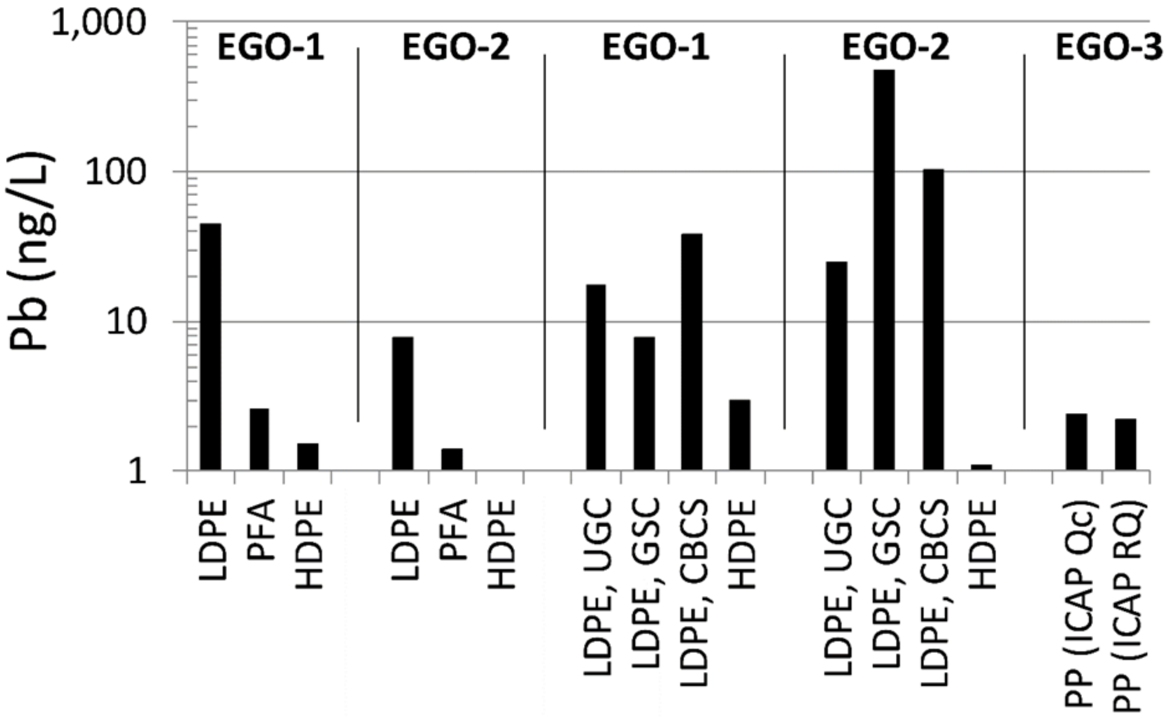

**Figure 9** - Lead concentrations (ng/L) in selected groundwater samples from EGO-1, EGO-2, and EGO-3 collected in LDPE, HDPE, PFA, and polypropylene (PP) bottles. Lead concentrations in LDPE bottles throughout the study ranged over three orders of magnitude, regardless of the cleaning procedure used. Acid-cleaned bottles made of HDPE, PFA, and PP provide far more consistent Pb concentrations.

## 7.5 Vanadium from HDPE Well Construction Materials and Bottles

As shown in Figure 10, for groundwater sampled in LDPE bottles, the concentrations of V in water from the HDPE well (EGO-2) were slightly but significantly greater than in water from the stainless steel well (EGO-1). This difference must be due to leaching from the HDPE well casing. It is a testament to the precision of the ICP-MS measurements that this small but statistically significant difference in V concentrations can be detected, even though the HDPE well sections, screen, and fittings were acid-cleaned before the well was constructed and water in the flowing artesian well is continually refreshed. When sampled in HDPE bottles, water from EGO-1 and EGO-2 both yield extremely erroneous V concentrations (Figure 10), even though the bottles were previously acid-cleaned. Like the Pb problem associated with LDPE bottles, no amount of leaching in nitric acid will solve the issue of V leaching from HDPE bottles. We concluded that there are problems with both LDPE and HDPE bottles concerning sampling groundwater for trace metals.

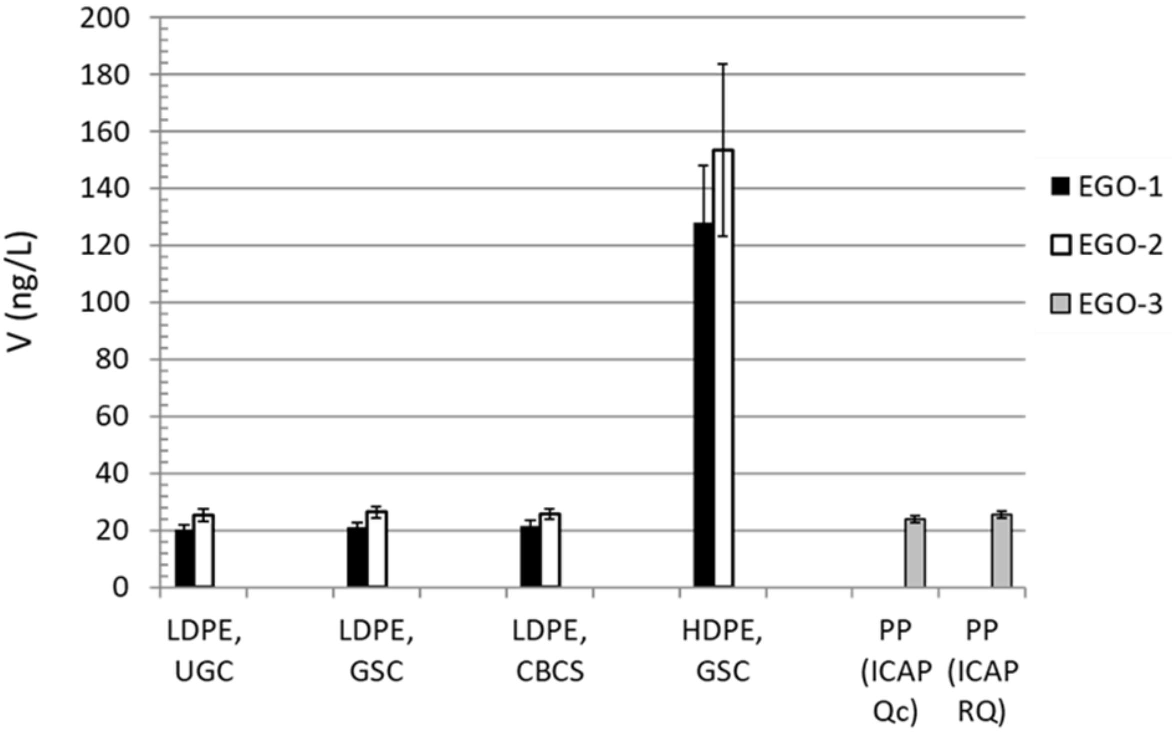

**Figure 10** - Vanadium contamination of groundwater from the acid-cleaned HDPE well (EGO-2) and acid-cleaned HDPE bottles (GSC). Leaching of V from the HDPE bottles has a far greater impact on the measured V concentrations than leaching of V from the HDPE well. However, leaching of V from the HDPE well is significantly greater than V leaching from the stainless steel well. Vanadium concentrations in groundwater from EGO-3, collected in PP bottles, are shown for comparison. All concentrations in units of ng/L.

## 7.6 Polypropylene: The Best Bottle for Sampling Groundwater for Trace Elements?

Following the construction of EGO-3, further research on leaching of trace elements from plastic sampling bottles began in the SWAMP laboratory at the University of Alberta. One subject of contemporary environmental concern in Alberta is the emission of trace elements to the atmosphere and to surface water from open-pit bitumen mining and upgrading. Given that V is the most abundant trace metal in bitumen (Bicalho et al., 2017), the accurate and precise determination of V concentrations in natural water such as the Athabasca River (Shotyk et al., 2017) was of paramount importance. This need immediately ruled out the use of HDPE bottles, but because elements such as Pb were also of concern, LDPE bottles could not be used. Teflon bottles were certainly an option, but—given their very high cost and the number of bottles needed to study the Lower Athabasca River watershed—other options had to be considered. Also, experience collecting groundwater samples from EGO-1 (Figure 5) and EGO-2 (Figure 6) showed that use of Teflon bottles was not a guarantee that reliable data would be obtained for all trace elements of interest.

Five types of bottles were tested in triplicate: LDPE, brown and transparent HDPE, PP (polypropylene), and FEP (fluorinated ethylene propylene). The bottles were cleaned using the SWAMP laboratory method (described in Section 8 of this book), which is a modification of the procedure described by Nriagu and others (1993). Afterward, four bottles of each type were filled with 2 percent nitric acid; the nitric acid had been purified by sub-boiling distillation twice in a quartz still housed in a PP Class 100 clean-air cabinet. Trace element concentrations were measured in one of each bottle type after 1, 6, 12, and 24 weeks of storage. The list of analytes included Ag, Al, As, Ba, Be, Bi, Cd, Co, Cr, Cu, Fe, Ga, Li, Mn, Mo, Ni, Pb, Rb, Re, Sb, Sc, Se, Sr, Te, Th, Tl, U, V, Y, and Zn.

Overall, only 29 percent of measurements were greater than the detection limit. There were no trends of increasing concentration over storage time for any element or bottle type, indicating that contamination levels, if present, were not related to bottle material. The detection limits for Al, Fe, and Zn were high and quite variable, such that these elements were excluded from the comparison (102 to 380, 22 to 153, and 21 to 258 ng/L, respectively). For the remaining elements, results were considered for each bottle type only when two or more of the three measured values were greater than the detection limit (i.e., measurable at more than one time point).

The mean measurable concentrations of Cd, Th, and Y were similar in all bottles (0.3 to 0.8, 1.6 to 3.2, and 0.4 to 0.5 ng/L, respectively). Selenium was present at mean concentrations of 12 to 15 ng/L for all bottle types except for PP. The water from all bottles except for LDPE contained measurable concentrations of Ag (1.7 to 2.4 ng/L); however, several other elements were consistently present at measurable concentrations in the LDPE leaching water, including Ga, Mo, Pb, Rb, Re, Sb, and Sr (0.2 to 4 ng/L). Nickel was present at concentrations of 10 to 54 ng/L for all four time points in the water from the FEP bottles, indicating consistent background contamination. The mean concentrations of Ga and Rb were comparable in water from HDPE and PP bottles (0.6 to 0.7 and 2.4 to 2.5 ng/L, respectively). The only remaining differences between the water from HDPE and PP bottles were the presence/absence of measurable Pb (0.6 ng/L in PP) and Re (0.2 ng/L in HDPE). The results of this intercomparison are shown in Figure 11.

Considering the measurable concentrations of all elements in the leaching test, PP was chosen as the optimal bottle for collecting groundwater samples. The blank values obtained from acid-cleaned PP bottles, after leaching for one year in nitric acid, are shown in Figure 12.

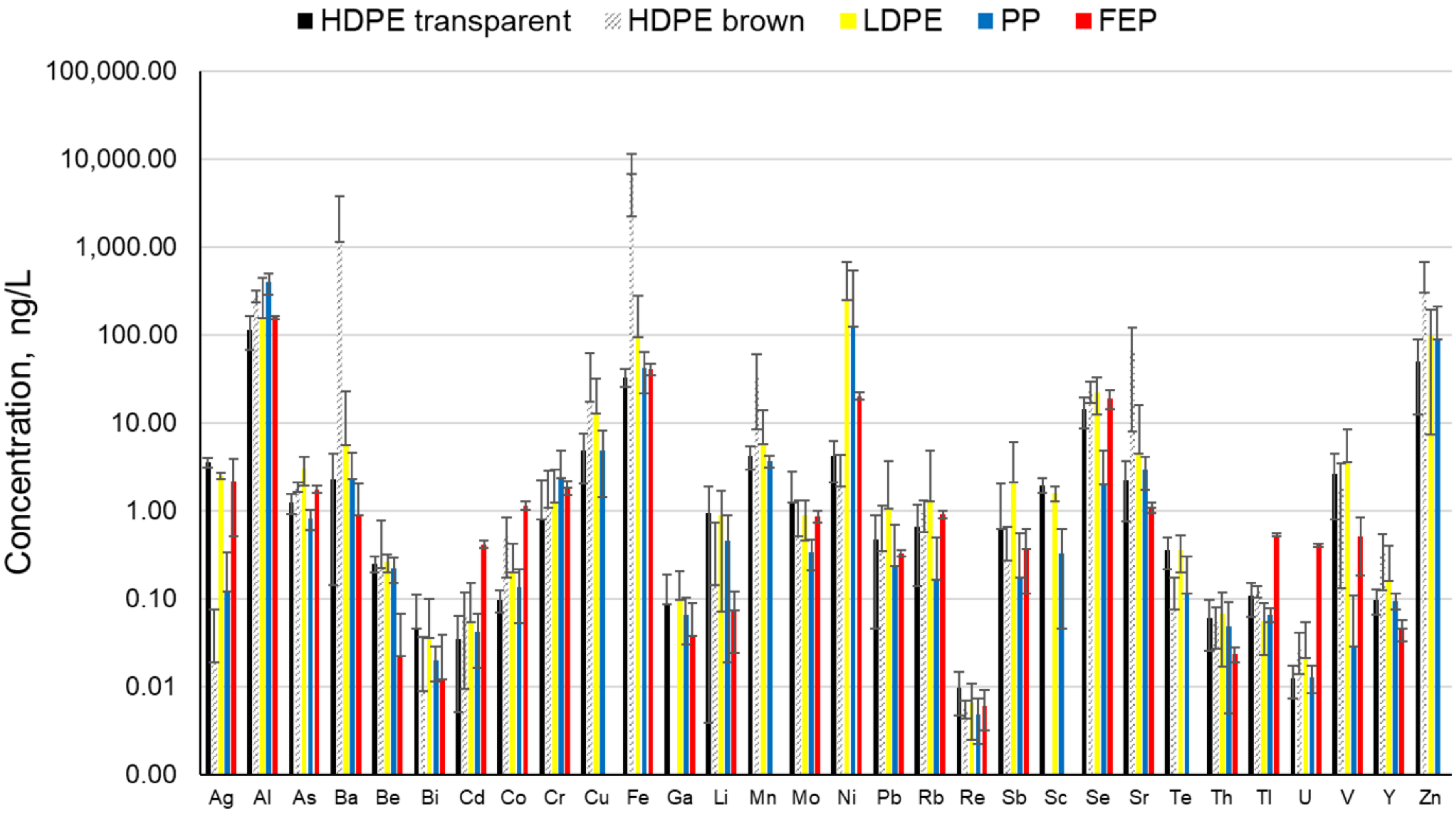

**Figure 11** - Blank values (ng/L) of acid-cleaned plastic bottles (brown and transparent HDPE, LDPE, PP, and FEP), measured after 1 year of leaching in 2 percent $HNO_3$, purified twice by sub-boiling distillation, in a high-purity quartz still. Considering the measurable concentrations of all elements in the leaching test, PP was chosen as the optimal bottle for collecting groundwater samples.

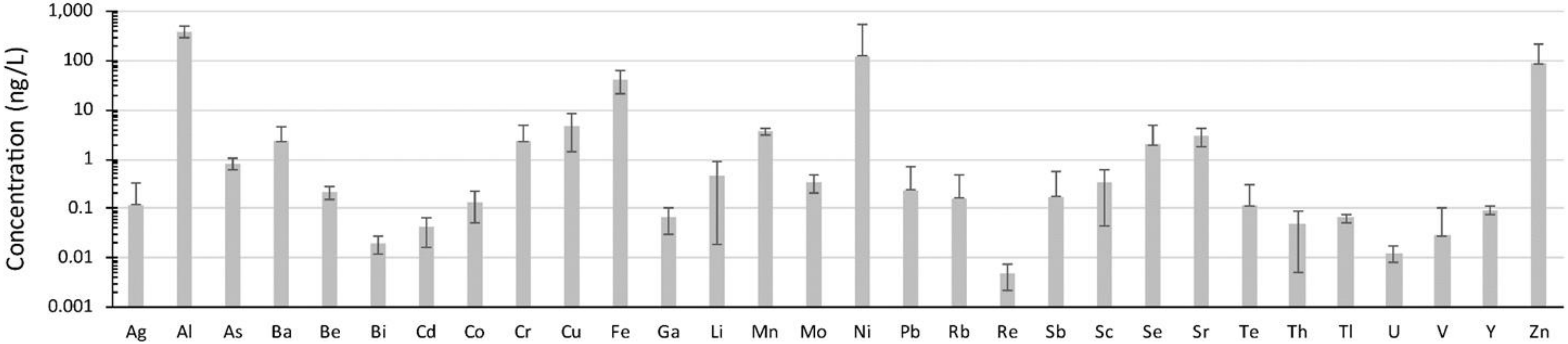

**Figure 12** - Blank values (ng/L) of acid-cleaned polypropylene bottles (PP), measured after 1 year of leaching in 2 percent HNO3, purified twice by sub-boiling distillation in a high-purity quartz still.

# 8 SWAMP Laboratory Cleaning Procedure for Polypropylene Bottles

Based on experience to date in the SWAMP laboratory at the University of Alberta, the recommended procedure for cleaning PP bottles is summarized briefly as follows:

1. Soak for minimum one day in soapy water (2 to 5 percent volume/volume Fisher Versa Clean™).
2. Rinse thoroughly with ASTM (American Society for Testing and Materials) Type II water.
3. Soak for minimum one day in 5 percent weight/weight (w/w) HCl (Trace grade).
4. Rinse with ASTM Type II water.
5. Soak for minimum seven days in 10 percent w/w $HNO_3$ (Trace grade).
6. Rinse with ASTM Type II water.
7. Leach for six to eight hours at 80 °C with fresh 10 percent w/w $HNO_3$ (Trace grade).
8. Rinse three times with ASTM Type II water.
9. Rinse three times with ASTM Type I water.

The bottles are then allowed to air dry in a metal-free (PP) Class 100 laminar-flow clean-air cabinet. Once the bottles are dry, the lids are put on and then the bottles are packed in PE (polyethylene) Ziplock bags in preparation for work in the field.

Although acid cleaning of plastic bottles can be accomplished to a great extent with nitric acid alone, experience has shown that the addition of hydrochloric acid may further improve blank values for Pb (Shuanquan Zhang, personal communication, February 12, 2023). Nitric acid alone will oxidize organic contaminants, provide the low pH needed to dissolve any metal-bearing particles, and provide the hydrogen ions needed to penetrate the polymer surface and displace any metal ions found there. The added benefit of HCl is probably due to complexation. Chloride ions forms very stable complexes with Pb (Luo & Miller, 2007), and the formation of lead chloride complexes in solution will further promote the release of Pb from the polymer.

# 9 Filtration

All trace element data presented in this book for Elmvale area groundwater represent unfiltered water samples. However, the water is collected into acid-cleaned bottles containing 2 ml/L of concentrated nitric acid (purified twice by sub-boiling distillation). With this concentration of nitric acid, the EGO water is acidified to pH 1.7, which preserves the trace metals of interest.

While the use of 0.45 µm membrane filters to treat water prior to analysis is standard practice (Cuss et al., 2020), blank values remain a challenge (Rausch et al., 2006). We have not yet found a filter material that will provide the extremely low blank values needed to be able to analyze Pb in water samples from EGO. In a study comparing filtered and unfiltered groundwater (Reimann et al., 1999), very small differences were found for most elements, but the challenge of contamination from the filters was noted. Within the *dissolved* fraction—that is, < 0.45 µm—we acknowledge that some trace elements may be partly or even predominantly associated with colloids (Novikov et al., 2006; Sañudo-Wilhelmy et al., 2002). Acidifying the water upon collection will most likely destroy many if not most of the metal-bearing colloids.

We have not yet investigated the importance of colloidal forms of trace elements in EGO groundwater. Indeed, it has proven extremely challenging to measure the total concentrations of many trace elements after acidification because they are already exceptionally low.

# 10 Trace Elements in Contemporary Snow

As part of the groundwater studies described in this book, trace elements were also determined in contemporary snow from southern Ontario, Canada, including the Elmvale area (Shotyk et al., 2010). Chalcophile trace elements were highly enriched in snow compared to their crustal abundance. For example, the crustal enrichment factor for Pb—calculated using Sc as the conservative, lithophile reference element—was almost always greater than 100, and sometimes exceeded 1,000 (Figure 13). In other words, particulate matter in the snow today is enriched in Pb relative to Earth's crust by 100 to 1,000 times. Enrichments such as these reflect the long-range atmospheric transport of sub-micron aerosols formed from high-temperature combustion processes such as smelting and refining, coal combustion, and waste incineration (Nriagu, 1990).

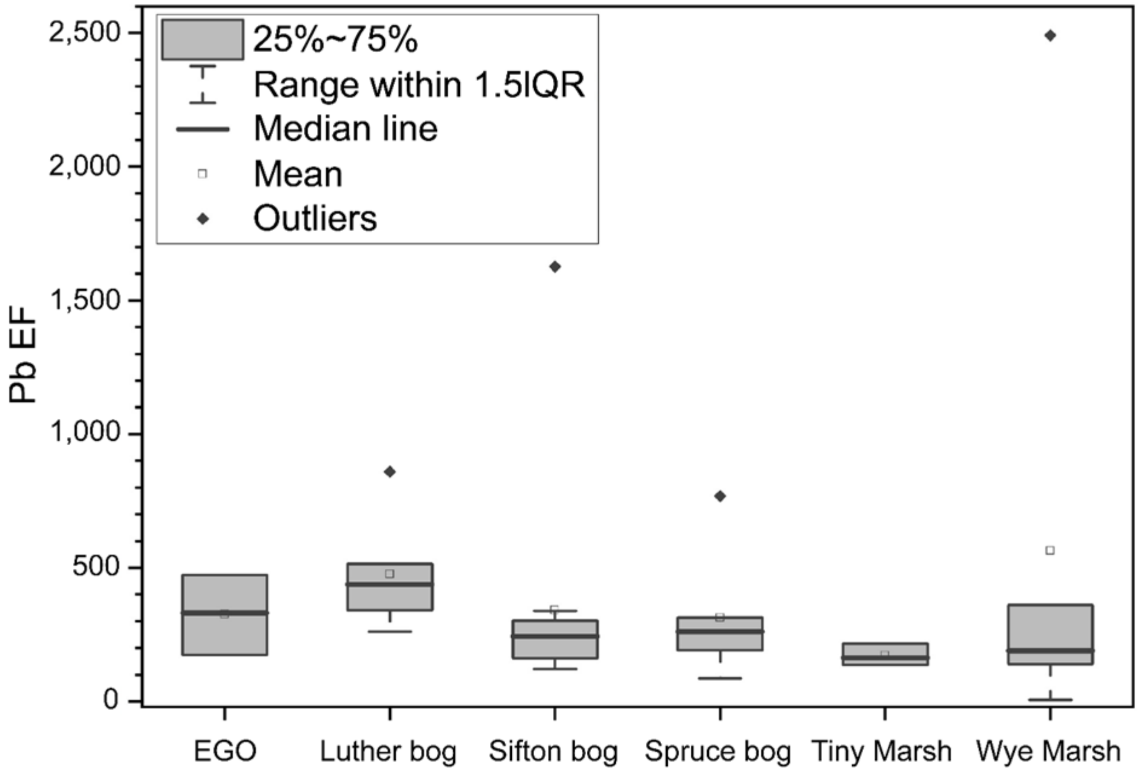

**Figure 13** - Box and whisker plots showing the crustal enrichment factor (EF) for Pb in individual snow samples from southern Ontario, Canada, collected during February and March 2009: Sifton Bog, London; Luther Bog, Grand Valley; Elmvale Groundwater Observatory; Tiny Marsh and Wye Marsh, Tiny Township; and Spruce Bog, Algonquin Provincial Park. The EF for Pb was calculated using the Pb/Sc ratio found in the snow sampled, normalized to the corresponding ratio in the Upper Continental Crust (from Rudnick & Gao, 2014). IQR refers to Interquartile Range.

Given the extremely low concentrations of Pb in groundwater (~ 1 ng/L), a rough calculation showed that contamination of groundwater by Pb that is present in ambient air during sampling is a real risk. In fact, contamination of water samples by ambient air might help to explain the extreme variability in most of the Pb concentration data obtained from early analyses of groundwater from EGO-1 and EGO-2.

# 11 Laminar-Flow Clean-Air Cabinets for Groundwater Sampling Wells

To minimize the risk of groundwater contamination from ambient air, each EGO well is housed within a custom-built, laminar-flow, clean-air, cabinet with HEPA filtration (Figure 2). For EGO-1 and EGO-2, the cabinets are metal-free; for EGO-3, an anodized aluminum frame was constructed. The fans that blow air through the HEPA filters create directional flow within the cabinet, forcing air to exit the cabinet from the bottom. A hand-held laser particle counter was used to evaluate the effectiveness of the cabinets for EGO-1 and EGO-2. Compared to ambient air with approximately $5 \times 10^5$ particles $> 0.3$ µm per $ft^3$, no particles could be detected within the cabinets. For perspective, by definition, Class 100 laminar-flow benches that are commonly used in clean laboratories are certified to contain less than 100 particles $> 0.3$ µm per $ft^3$. Thus, air quality within the EGO clean-air cabinets is better than Class 100.

Since September 2010, all water samples collected at the EGO were sampled from within one of these clean-air cabinets. For comparatively abundant lithophile trace elements such as Al, Ba, Fe, Mn, and Sr, and for elements naturally enriched in groundwater such as As, Mo, and U, the risk of water sample contamination by ambient air may be negligible. However, given the extent of enrichment of elements such as Cd, Pb, and Sb in contemporary aerosols, this step is seen as a necessary precaution to minimize the risk of contamination for all potentially toxic chalcophile elements having extremely low natural abundance in the groundwater at the study site (e.g., Ag, Bi, Cd, Pb, Sb, Te, and Tl). At the very least, it is an extremely helpful precaution to minimize the risk of sample contamination.

# 12 Housing the Wells of the Elmvale Groundwater Observatory

Both EGO-1 and EGO-2 are housed within a small wooden cabin, approximately 4 m × 2 m (as depicted in Box 8). The cabin was needed to protect the wells from farm vehicle traffic, for example, but also to allow sample collection during precipitation events (a single drop of rainwater would easily ruin a groundwater sample).

Prior to construction, the moist, fine-grained, clay-rich soil was excavated and replaced with crushed stone to ensure that the base of the building stays dry. Ten concrete footings were installed to support the structure. Untreated wood was used to avoid possible contamination by As or Cu. When they are not in use, each well is covered with a plastic tube sealed by a lid to prevent water splashing inside the cabin. The enclosed wells are then covered with an insulated wooden box for protection and to prevent freezing. Both wells drain via underground pipe to the nearby Wye River.

The cabin includes wooden shelves for storage, a wooden table for sample handling and writing, and three windows for lighting. The cabin has electricity and is fully insulated and lined with pine paneling, and equipped with a small space heater so it can be used year-round. To help maintain the quality of air within the cabin during sampling, two additional HEPA air filter systems were added outside the clean-air cabinets. Clean lab clothing is used during water sampling including hair nets and shoulder-length PE gloves. Plastic boxes with tight-fitting lids are used to store plastic labware and clean lab clothing at the site. A pull-down ladder leads to a loft that provides additional storage space and overnight accommodation, if necessary.

A much smaller cabin, constructed in a similar fashion, houses EGO-3 (as depicted in Box 8). EGO-3 also has a plastic sleeve to prevent splashing when it is not in use. The water from EGO-3 drains to the cabin housing EGO-1 and EGO-2, and from there to the Wye River. Both cabins have overhanging roofs and cedar porches to allow users to remove their boots and coats before entering the cabins for water sampling.

# 13 The Abundance of Trace Elements in Pristine Groundwater

The most robust set of trace element data for the shallow aquifer (13 m) is from the water samples collected from EGO-2 using HDPE bottles (n=10). This data, obtained using sector-field ICP-MS in Heidelberg, is summarized in (Figure 14). For this figure, V concentration data obtained using HDPE bottles could not be used for the reasons discussed earlier. Instead, the value for V presented in Figure 14 (22.1 ng/L) is compiled from five sets of separate measurements of 55 samples collected from EGO-1 using LDPE bottles.

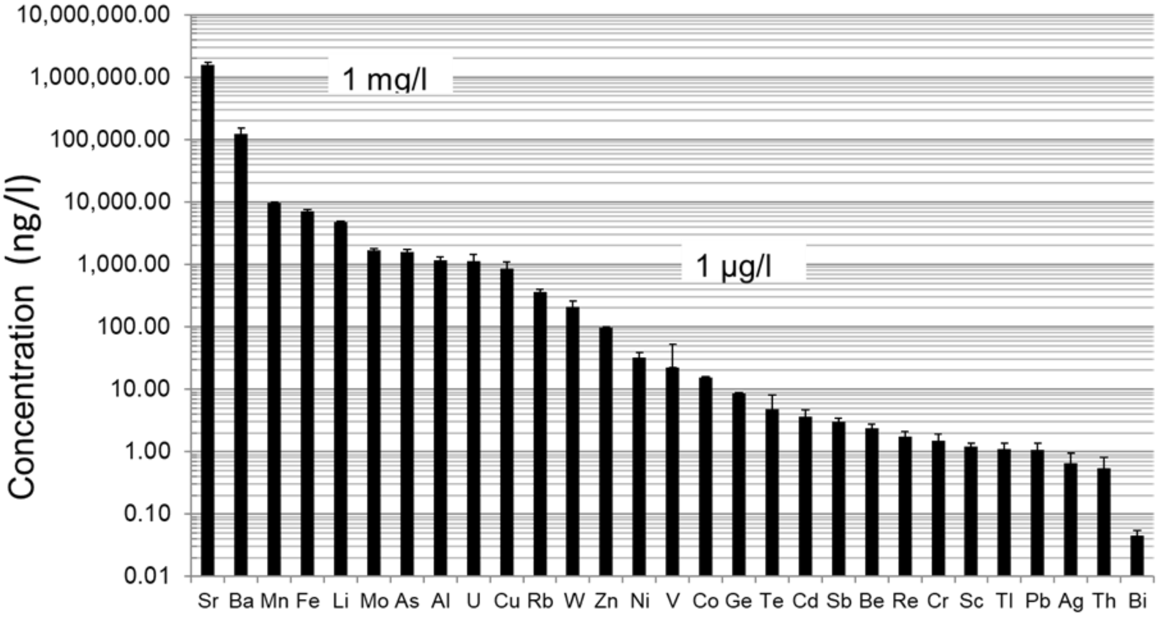

**Figure 14** - Abundance of trace elements in groundwater (ng/L) sampled using acid-cleaned HDPE bottles (n=10) from the acid-cleaned HDPE well (EGO-2) within a metal-free, laminar-flow, clean-air cabinet. The value for V (22.1 ng/L) was compiled from five sets of separate measurements in 55 samples collected from EGO-1 using LDPE bottles during September 2010 and March 2011. The complete set of analytical data is presented in Table Box 9-6 of Box 9.

The most robust set of trace element data for the deep aquifer (60 m) is from the water samples collected from EGO-3 using PP bottles in October 2020. These data, summarized in Figure 15, represent ten bottles, nine of which were analyzed six times and one four times in the SWAMP laboratory using a quadrupole ICP-MS (ICAP RQ).

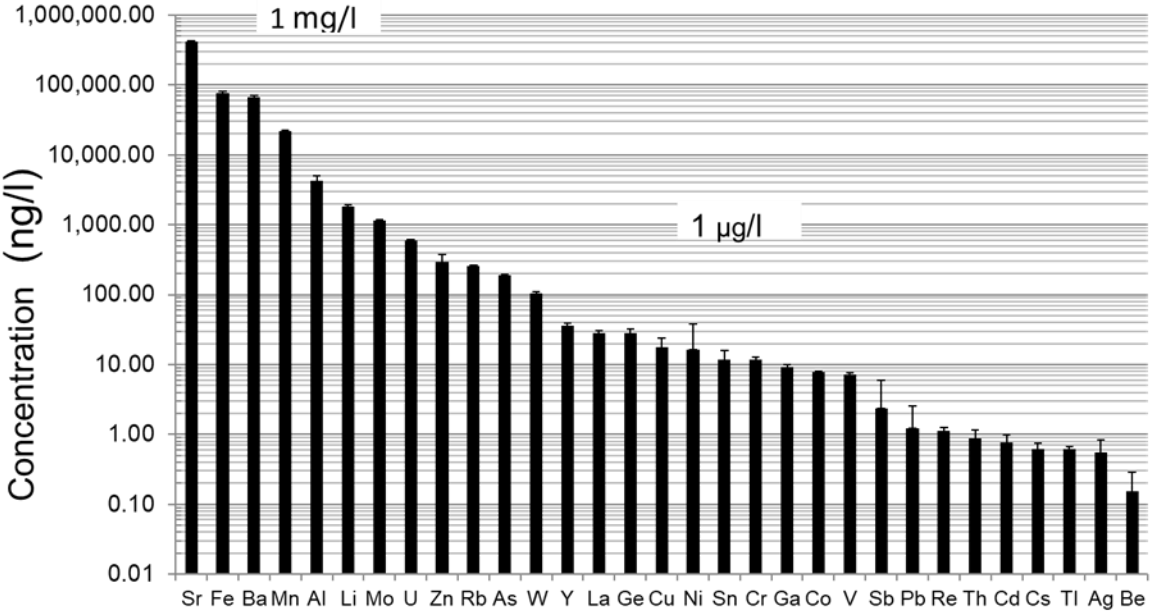

**Figure 15** - Abundance of trace elements in groundwater (ng/L) sampled from EGO-3 (60 m, 316 L stainless steel), collected in ten acid-cleaned PP bottles and analyzed (n=58) using the ICP-MS (ICAP RQ).

The trace metal concentration data from these two aquifers are compared in Figure 16. While most elements are common to the two data sets, the EGO-2 analyses did not include Cs, Ga, and Y; they were simply not requested at the time. Likewise, the EGO-3 analyses did not include Bi, Ge, Te, and W; again, these were not requested. The EGO-3 data set also does not include Sc, simply because this element requires medium mass resolution of ICP-MS to be able to separate Sc ions from a long list of molecular species that interfere in the mass spectrum (Prohaska et al., 1999).

As noted earlier, the deeper groundwater is much more reducing: an Eh value of −169 mV was measured at EGO-3 (60 m) compared to 0 mV at EGO-1 (13 m). The water from EGO-3 contains twice as much Mn and ten times more Fe than EGO-2 but a factor of ten less As and lower concentrations of Mo and U (Figure 16). There are also differences in Al, Cr, Cu, Ni, and Zn. However, a more detailed comparison of the two aquifers is not justified at this stage because

1) they were sampled at two different times;
2) two different types of plastic bottles were used for sampling, with slightly different cleaning methods; and
3) two different kinds of ICP-MS instruments were employed.

To compare in detail possible differences in water quality between the two aquifers, water samples need to be collected at the same time from all three wells (EGO-1, EGO-2, and EGO-3) within their laminar-flow, clean-air cabinets using acid-cleaned PP bottles and measured for the same set of elements using a single ICP-MS instrument.

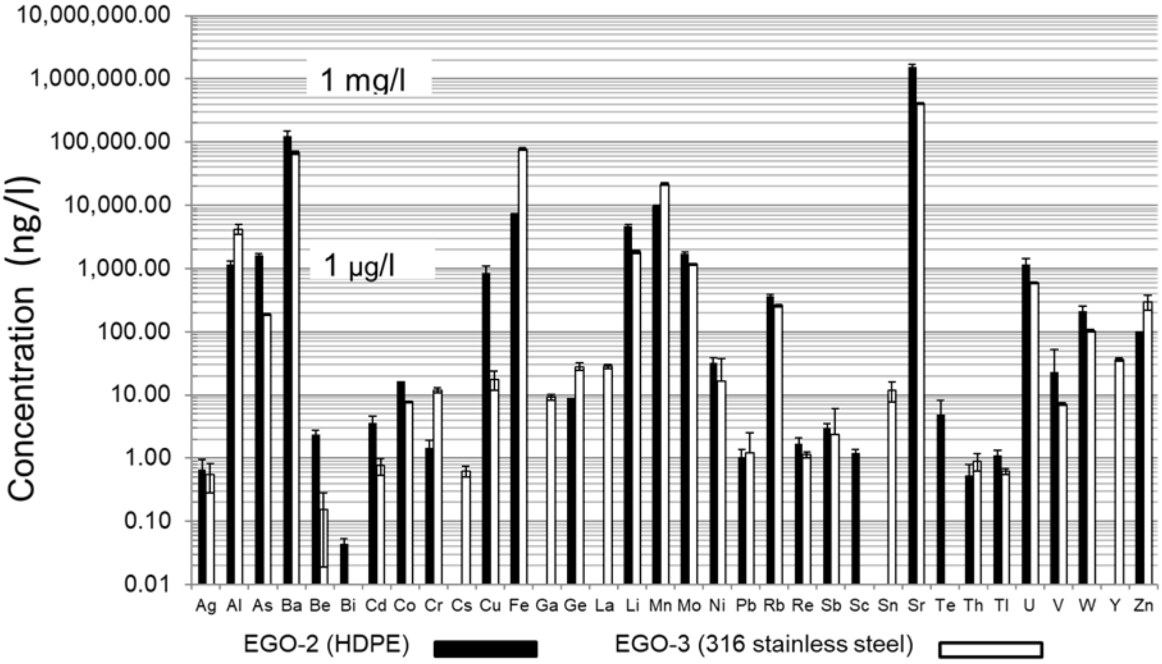

**Figure 16** - Comparison of the abundance of trace elements in groundwater from EGO-2 (13 m) and EGO-3 (60 m). The groundwater from EGO-3 contains twice as much Mn and ten times more Fe than EGO-2 but a factor of ten less As and significantly lower concentrations of Mo and U.

# 14 Trace Elements in Groundwater, in Perspective

The most reliable set of Pb measurements for EGO-2 water yielded 1.05 ± 0.3 ng/L and 1.23 ± 1.32 ng/L for EGO-3. For perspective, ancient ice from the glacier on Devon Island in the Canadian Arctic, which dates from about 3,300 to 7,900 years BP, was found to contain 5.1 ± 1.4 ng/L Pb (n=6; Zheng et al., 2007). Like the groundwater data from EGO-1 and EGO-2, the ice core data were obtained from the same laboratory at the University of Heidelberg using the same sector-field ICP-MS and HDPE bottles that were cleaned using the procedure employed at the GSC. Thus, the Pb concentrations obtained from EGO-2 using HDPE bottles can directly be compared with the ice core data. We concluded that the water of the EGO contain lower concentrations of Pb than ancient Arctic ice. Moreover, other elements—including Ag, Cd, and Cr—may be at or below the levels found in ancient ice (Figure 17). It is well established that only specialized, metal-free, ultraclean laboratories, procedures, and protocols, and the most sensitive mass spectrometers, are capable of reliably determining the concentrations of trace metals in ancient Arctic ice. A list of relevant publications concerning methods, procedures, and protocols for trace element research is provided in Box 2.

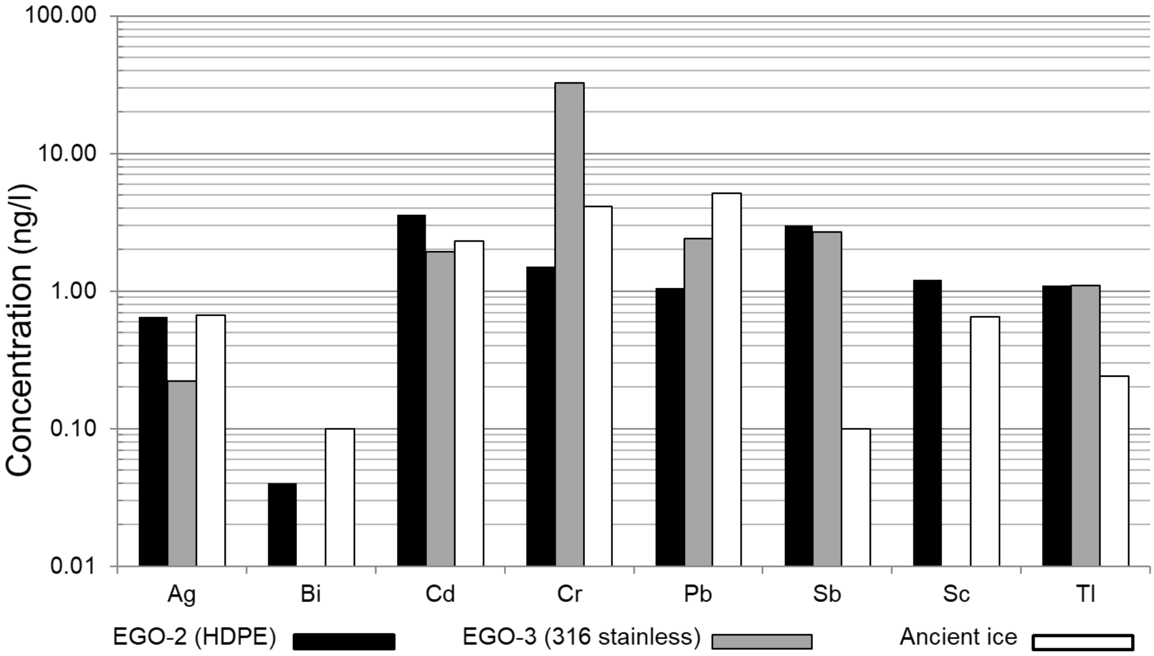

**Figure 17** - Selected trace elements in groundwater from EGO-2 and EGO-3 versus ancient Arctic ice (ca. 3,300 to 7,900 years BP). Ice core data from Zheng (2008). Notice that both EGO-1 and EGO-2 yield lower Pb concentrations than the cleanest ice layers.

The data presented here show that many of the trace elements of interest in pristine groundwater are present at lower concentrations than those found in ancient Arctic ice. Moreover, unless the extreme precautions described here are used to avoid trace element contamination during sampling and analysis, it will be difficult to compare results between studies. For example, the concentrations of many trace elements measured in EGO-3 water collected in PP bottles (Figure 15) are much lower than the *natural baseline* values presented for groundwater in carbonate aquifers of central Italy that was collected in HDPE bottles (Morgantini et al., 2009). Specifically, concentrations in EGO-3 water were lower by two times for Cu, six times for Cd, 13 times for Sb, 32 times for V (presumably because of leaching from HDPE bottles), 37 times for Ni, 133 times for Zn, 748 times for Cr, and 820 times for Pb.

# 15 Implications and Applications

Our first measurements of the isotopic composition of Pb ($^{206}\text{Pb}$, $^{207}\text{Pb}$, $^{208}\text{Pb}$) in artesian flows of the area—in water collected almost 20 years ago—yielded values that were much less radiogenic and Pb/Sc ratios that were much greater than would be expected from pristine groundwater in this region. Thus, we realized early on in this research that most of the Pb we were measuring in the water samples was from our own contamination.

During the subsequent nearly two decades, starting at the University of Heidelberg and now continuing at the University of Alberta, we have documented leaching of trace elements from a number of sources:

- brass and galvanized steel (Ag, As, Cu, Pb, Sb, Tl, Zn);
- Pb (and Sc) from high-purity titanium;
- Sb and Sn from pewter;
- As, Pb, Sb, and Th from glass;
- Zn from rubber;
- Sb from PET plastic;
- Ge and Ti from Japanese antimony-free PET;
- Sb from mixed (recycled) plastic;
- Pb from LDPE; and
- Al and V from HDPE.

Our experience to date is briefly summarized in Box 3, which provides a list of recommended materials for research on trace elements in natural water and materials to avoid.

For studies that involve multi-element analysis (as our studies have), we concluded there is no perfect material for sampling groundwater. However, some materials are far worse, and some are far better. Each material must be carefully selected and evaluated on a case-by-case and element-by-element basis. In light of the results presented here, our goal is for readers to develop a more critical view of published data on trace elements in groundwater, as well as precipitation, surface water, and drinking water.

Several of the flowing artesian wells that have been sampled in the Elmvale area have modern levels of tritium (Box 4) and yet share the extremely low concentrations of trace metals such as Pb. Given the extent of atmospheric contamination by anthropogenic Pb in northeastern North America since industrialization (Shotyk & Krachler, 2010; Shotyk et al., 2016), the cumulative Pb insult to aquatic and terrestrial ecosystems is on the order of 1 to 2 grams per square meter.[5] The extremely low concentrations of Pb (ng/L) found in the modern groundwater of the Elmvale region suggest rapid and effective filtration of the

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[5] To convert square meters to square feet, multiply the number of square meters by 10.8.

water by soil in the recharge zone. The mechanism of removal of Pb and other trace elements by soil particles along the infiltration flow path warrants investigation.

# 16 Organic Contaminants

While the focus of our research has been on trace elements in groundwater, the Elmvale area is an agricultural region, and questions had been raised within the community regarding organic contaminants such as pesticides. To address this issue, water sampled from EGO-1 in May 2009 and EGO-3 in May 2015 were analyzed for a long list of organic contaminants; none were detected. The methods used and the main findings are briefly described in this section.

Analyses were conducted by the Laboratory of Water and Soil Protection, Canton of Berne, Switzerland (Dr. Jean Daniel Berset) and by Innotech Alberta, Vegreville, Alberta, Canada. The original reports from the Laboratory of Water and Soil Protection, Canton of Berne, Switzerland, are presented in Box 5. The list of pesticides analyzed by Innotech Alberta, Vegreville, Alberta, Canada, along with limits of detection and quantification, are given in Box 6.

## 16.1 Analyses by the Laboratory of Water and Soil Protection

### 16.1.1 Materials and Methods

In May 2009, groundwater samples were obtained in triplicate from EGO-1, as well as the Parnell flow and the Elmvale Water Kiosk on County Road 27. The 250-ml all-glass brown sampling bottles had been precleaned and provided by the Laboratory of Water and Soil Protection, Canton of Berne, Switzerland. After collection, the samples were sent in a cooler box to the same laboratory for analysis, where they were analyzed within 48 hours of receipt.

Samples were first analyzed for volatile organic contaminants (VOC) such as chlorinated hydrocarbons, BTEX (benzene, toluene, ethylbenzene, and xylenes), and MTBE and ETBE. BTEX and MTBE and ETBE are characteristic tracers for traffic emissions. Samples were analyzed by combined static headspace (HS) – HRGC-EI-SIM-mass spectrometry. The LOQ (limit of quantification defined as signal/noise 10:1) was 0.10 μg/L (100 ng/L).

In a second step, samples were analyzed for selected pesticides (herbicides, insecticides) such as triazines, organophosphates, phenylurea herbicides, and chloroacetanilide herbicides, which are among the most important ones. Moreover, selected metabolites such as DEA, DIPA, and the OXA and ESA—metabolites of Metolachlor and Propachlor—as well as some acidic herbicides such as Bentazon and Mecoprop—were analyzed. Samples were not treated (e.g., enrichment procedures) but analyzed by direct injection of the water samples to minimize laboratory contamination. The analysis was performed using HPLC-tandem mass spectrometry on an API 5000 (HPLC-MSMS) in the so-called MRM (multiple reaction monitoring) mode. This mode is mainly used for quantification, is highly specific and very sensitive, and virtually excludes false positive results. The LOQ obtained was 20 ng/L. The LOD are around 1 ng/L for most of the compounds.

### 16.1.2 Results of the Laboratory Analyses

The original laboratory reports are given in Box 5 (reproduced with permission). The samples identified as *HWY-27* are from the Elmvale Water Kiosk on County Road 27, and *New Well* refers to EGO-1.

VOC: The samples did not contain any traces of VOCs. These compounds in the samples were normally << LOD (30 ng/L) and can be considered *very clean* in this regard.

Pesticides: None of the samples had detectable traces of pesticides. This was considered unusual because pesticides such as Atrazine, desethyl-Atrazine, Propazine, and Simazine are commonly detected up to 50 ng/L in groundwater samples. In fact, pesticides are a major group of organic contaminants typically found in groundwater samples. Using the API 5000 HPLC-MSMS signals down to 1 ng/L for most of the compounds can be seen in typical samples. However, not even such traces could be detected in the samples from the Elmvale area.

### 16.1.3 Conclusions

> *"The Elmvale groundwater samples analyzed for VOC and pesticides, two major groups of organic contaminants found in groundwater, are predominantly free of these compounds. None of the samples contained any traces of frequently detected pesticides such as Atrazine, Propazine, and Simazine as well as some important metabolites. It can therefore be concluded that these waters {sic] are of exceptional quality as encountered in the analysis of spring water. (Jean-Daniel Berset, Berne, Switzerland, May 2009)."*

## 16.2 Analyses by Innotech Alberta

In May 2015, groundwater samples were obtained in triplicate from EGO-3. Again, pre-cleaned, 250-ml all-glass brown bottles were used for sampling. After collection, the samples were sent in a cooler box to Dr. Alberto Pereira at Innotech Alberta in Vegreville, Alberta, Canada. A scan was performed for 75 pesticides but all were < LOD. The results are listed in Box 6.

# 17 Why is this Groundwater so Clean?

The groundwater from EGO has proven to be truly remarkable and possibly unique: nitrate and phosphate are below detection, chloride concentrations resemble continental rainwater values, a very long list of organic contaminants are all below the available limits of detection, and Pb is below the levels found in ancient Arctic ice.

These observations lead to a further question: Why is this water so clean? Is it simply because of the great effort that was made to analyze it while avoiding sample contamination? In other words, if this water had been tested for trace elements using conventional approaches, would the remarkable quality of the water have gone unrecognized? Or, with respect to Pb, is this water so pure simply because it is ancient glacial water that predates the onset of lead mining and metallurgy that began approximately 5,000 years ago? Or are there physical and biogeochemical processes taking place in the recharge area that remove Pb and other trace elements from modern atmospheric precipitation? Or is it a combination of all these factors?

Elmvale is located within 115 km of Toronto, Canada's largest metropolitan area and home to almost half of the province of Ontario's population. Flowing artesian groundwater of this quality so close to an enormous urban area represents a tremendous natural asset for any society. Growing urbanization, however, represents the greatest threat to this groundwater and its quality. Understanding these groundwater flow systems so as to protect them and their quality for future generations is an urgent matter of great societal importance.

# 18 Geological Context

The remarkably pure water of the natural springs and artesian wells described in this book are found at the juncture of Springwater, Tiny, and Tay Townships in the northern half of Simcoe County, a region traditionally known as Huronia, in the province of Ontario, Canada. The area is located in glacial terrane typified by uplands to the east and a clay plain (lowlands) to the west (Figure 18a), terminating approximately at the eastern shore of Georgian Bay. Uplands are composed mainly of ice-contact drift at the surface that grades into thinly intercalated diamicton and glaciofluvial sediments and some thicker units with depth. This sequence of lithofacies contains numerous mostly thin aquifers and aquitards (Figure 18b). It has been postulated that highlands east of the area provide significant recharge, along with infiltration from terraces and valleys that lie along the east-to-west hydrologic flow path and adjacent to the area of interest; fossil water within glacial sediments and rising from the underlying bedrock are also potential sources of water. The possible origins, ages, residence times, and mixing are supported by preliminary isotopic results but require further examination.

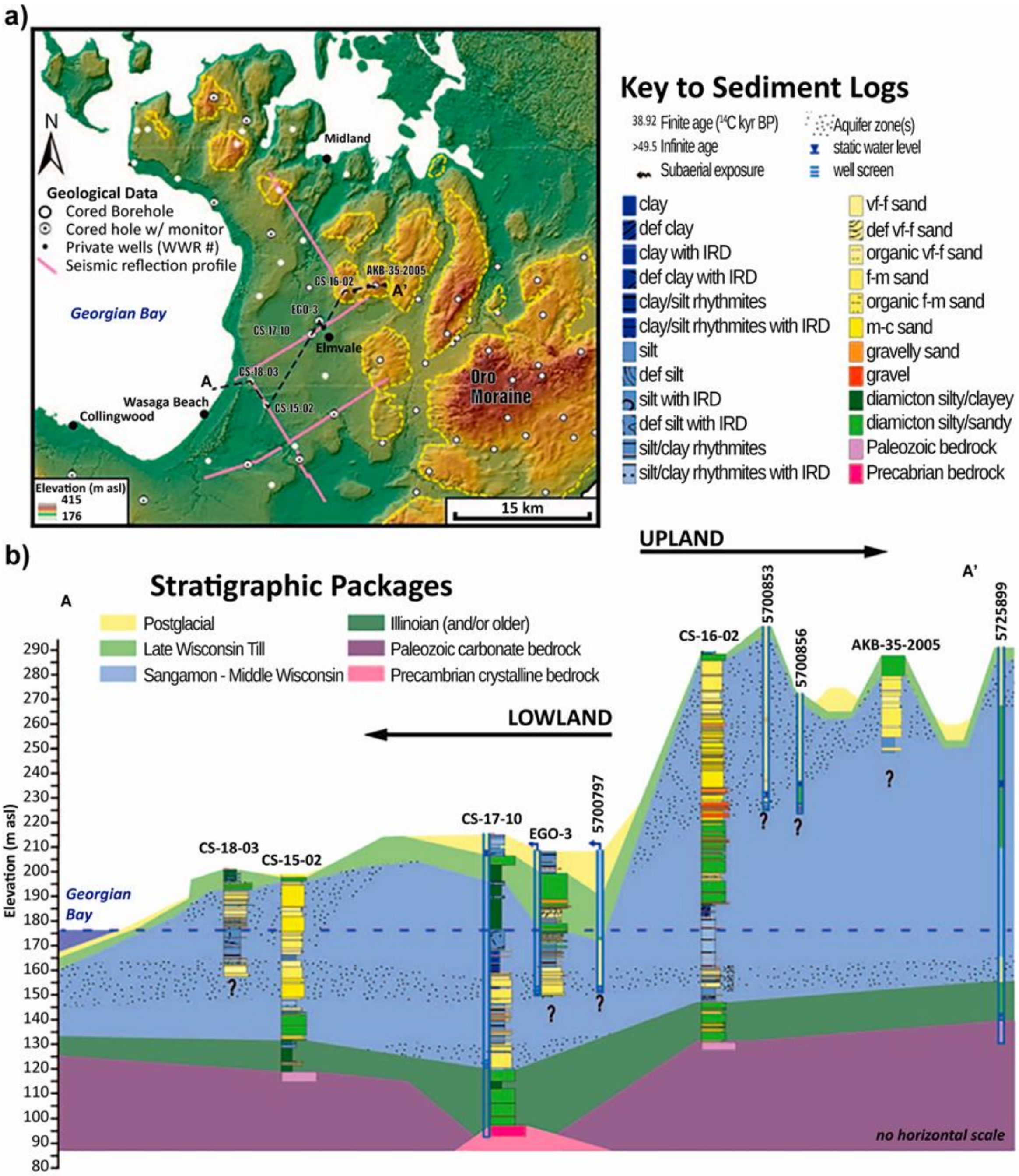


**Figure 18** - a) Map showing a digital elevation model of the study area and surrounding region, indicating locations of high-quality subsurface geological (Burt & Dodge, 2011; Mulligan, 2018) and geophysical data (Pugin et al., 2019). Dashed yellow lines denote the margins of individual uplands, which are accentuated by shoreline erosion in postglacial lakes. b) The cross-sectional profile shows detailed lithology of sediments observed in cored boreholes and simplified stratigraphic sequences reported in water wells sampled for geochemistry (Priebe et al., 2019). Background colors denote the architecture of major stratigraphic packages, with stippled regions showing inferred geometry of distinct coarse-grained bodies within the sequence. The dashed blue line denotes the surface elevation of Georgian Bay. Question marks denote that conditions are unknown below the end of the boreholes/wells were not drilled to bedrock.

The northeast–southwest trending valleys (lowlands) that separate uplands are due to subglacial fluvial erosion (Burt & Dodge, 2011; Mulligan & Bajc, 2018; Mulligan et al., 2018). The resulting uplands adjacent to the clay plain rise to an elevation of 310 masl with depth to bedrock of ≈170 m; the uplands undulate, gaining elevation in an eastward direction. The clay plain (glacial lake sediments) begins as a thin layer of silty clay that drapes off the uplands and associated terraces (≈240 to 275 masl) and thickens to ≈20 m toward Georgian Bay, terminating in a bluff close to the existing shoreline; this was once the bottom of Lake Algonquin during the retreat of Wisconsin glaciation. This upper clay layer lies beneath a thin soil layer and is the confining bed for many of the shallower artesian wells in the area including EGO-1 and EGO-2 (≈13 m). The clay layer also acts as a barrier to infiltration, resulting in a thin, perched water table throughout much of the terrace and lowland areas.

At the bluff, water can be seen seeping from beneath and flowing over the top of the clay toward Georgian Bay. The glacially scoured and filled valley below the clay plain varies from ≈70 to 100 m deep; it is composed of complex layers of lithofacies, most of which are thinly bedded, lying above Illinoian glacial deposits and Paleozoic or Precambrian (Canadian Shield) bedrock. Multiple artesian aquifers exist in this postglacial stack of sediments. Hydrogeological work supports the existence of a "leaky" aquifer–aquitard system from the surface to the valley floor (Gerber et al., 2001).

Now that the water has been identified as pristine, an opportunity has been created to determine the causal relationships between the quality of the water and the physical, chemical, and biological processes that together have produced this amazing resource. These factors begin with inputs from anthropogenic and natural sources that contribute compounds to the soils, continue within the aquifers of the glacial sediments, and terminate at discharge points.

To date, no study has been conducted to determine the relative importance of the many factors that control the evolution of this groundwater. This research is critical to understanding the relevant processes and filling a significant knowledge gap that can potentially impact policy on resource use and protection, as well as generating a model for understanding groundwater evolution in similar geological settings.

# 19 Summary

During the past decades, similar analytical challenges were identified and overcome in regard to trace element analyses of seawater, polar snow and ice, surface water, and drinking water. Here, a summary of experience collecting groundwater from artesian springs and flowing wells in the Elmvale area of southern Ontario was provided for determination of trace elements. Emphasis is placed on potentially toxic heavy metals such as Ag, Cd, Pb, Sb, and Tl, which are of great contemporary environmental interest.

Groundwater sampling from existing galvanized steel pipes, often with brass valves, is inappropriate because of the leaching of many chalcophile elements (Cu, Pb, Sb, and Zn) from both materials. Instead, dedicated groundwater sampling wells were designed and constructed in stainless steel acid-cleaned HDPE and surgical (316 L) stainless steel. Although the HDPE well components had been leached in nitric acid, we found measurable leaching of V from this plastic. Surgical stainless steel is an excellent choice for these types of investigations and is readily available.

Bottles made of LDPE proved problematic for a long list of trace elements and performed particularly badly for Pb, the trace metal of greatest environmental concern. A number of cleaning procedures were evaluated, but none yielded satisfactory results using LDPE bottles to sample for Pb. In contrast, HDPE bottles provided excellent results for Pb but leached V. Some part of the variability in the trace element concentration data could be due to ambient air, but metal-free, laminar-flow, clean-air cabinets eliminated this factor.

Based on a comparison of LDPE, HDPE, PP, and FEP bottles, PP is recommended, providing excellent blank values for V, Pb, and the other elements of interest. Cleaning the sampling bottles with soap, followed by leaching in HCl and then in sub-boiled $HNO_3$, with a final rinse in high-purity water—all within a metal-free clean lab environment—is critical for this work.

In brief, to reliably determine the concentrations of potentially toxic chalcophile elements in artesian groundwater flow systems, we recommend surgical stainless steel wells, metal-free, laminar-flow, clean-air cabinets, and acid-cleaned PP bottles. Using this approach, in the pristine groundwater of the Elmvale area we find concentrations of approximately (ng/L) Ag 0.3, Bi 0.2, Cd 2, Pb 1, Sb 1, and Tl 0.5. These results document the natural filtration of water by soil and sediments and provide baseline values for comparison with bottled water and tap water but can also be used to estimate the human health exposure to trace elements among Indigenous peoples inhabiting the region in the past.

For hydrogeochemical studies, lithophile trace elements such as Rb and Sr, which are not measurably affected by galvanized steel pipes, can be determined in water sampled from the many flowing artesian wells and springs found in the area. Also, elements such as As, Mo, and U, which are naturally enriched in anoxic groundwater compared to surface water, are not affected by galvanized steel pipes and also show potential as groundwater tracers.

# 20 Exercises

## Exercise 1

In December 2005, Ontario Ministry of Environment (MOE) staff scientists explained to the senior author that they had been measuring unusual concentrations of Sb in water samples and had been experiencing high and unstable blank values. What is the most obvious possible cause of the problem?

Solution to Exercise 1↴

## Exercise 2

In April 2006, the senior author was given the opportunity to sample groundwater at Site 41, a proposed landfill in Tiny Township approximately 3.7 km due north of EGO. This was done together with staff and technicians from a consultancy working under contract to Simcoe County using the groundwater sampling protocols of the MOE.

In essence, water was collected from standing wells by pumping. The water was allowed to run until it was deemed clear by visual inspection and then filtered through a 0.45 μm filter to obtain the dissolved fraction, which was analyzed for trace elements. Even though the shallow groundwater was only a few kilometers from EGO, trace element concentrations in these samples were far greater. For example, Cr concentrations at Site 41 were in the range of 26 to 847 ng/L versus 1 ng/L in EGO-2 and 10 ng/L in EGO-3 (Figure 16). Similarly, Pb at Site 41 was in the range 13 to 498 ng/L, versus 1 ng/L in water from EGO-2 and EGO-3 (Figure 16).

Other elements that were far more abundant at Site 41 were Cd, Co, Cu, Tl, V, and Zn. Assuming that the sampling wells at Site 41 were either sampling the same shallow aquifer as the EGO-1 and EGO-2 wells, or different shallow aquifers that have the same chemical composition, how could the concentrations of many trace elements in the groundwater at Site 41 be so much greater?

Solution to Exercise 2↴

## Exercise 3

Conventional groundwater sampling of standing wells by pumping presents the risk of introducing metal-containing colloids into the samples. How could the possible introduction of colloids using the conventional groundwater sampling protocol be evaluated using a trace metal that is comparatively easy to measure?

Solution to Exercise 3↴

## Exercise 4

What steps must be taken to avoid sample contamination by Pb and other chalcophile trace elements during collection, preparation, and analysis of groundwater?

Solution to Exercise 4↴

## Exercise 5

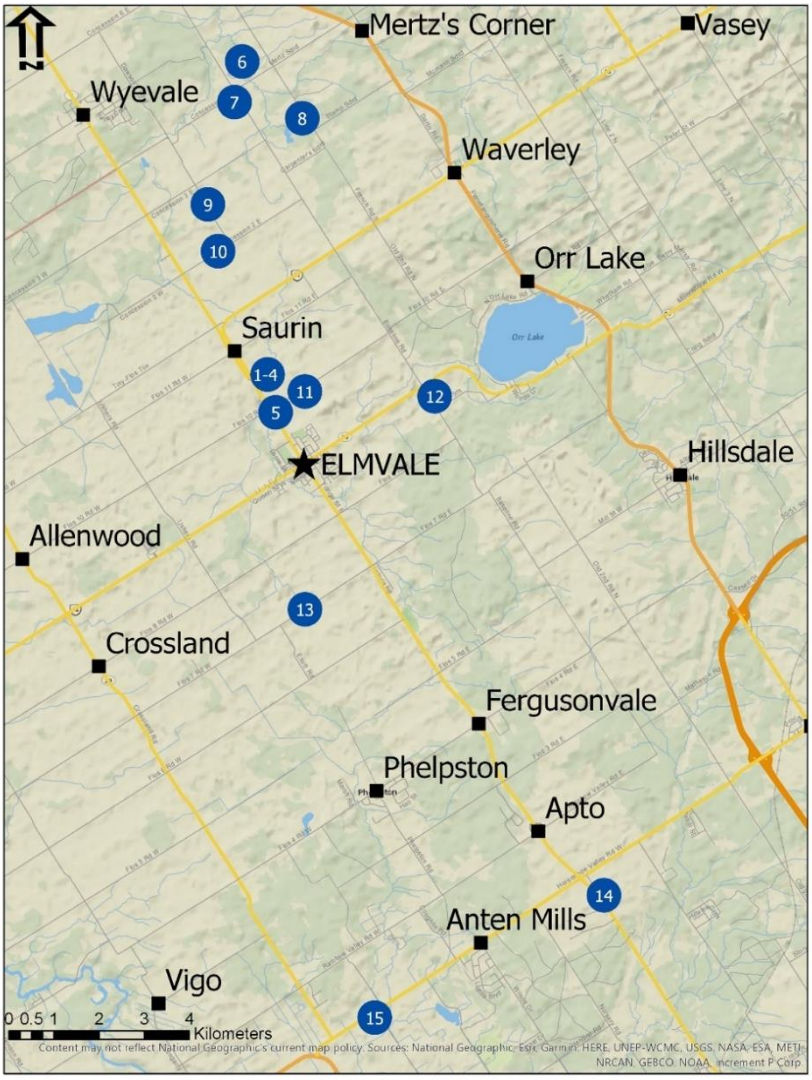
Could the solubility of lead carbonate ($PbCO_3$, $K_{sp} = 17.4 \times 10^{-14}$) or lead phosphate ($Pb_3(PO_4)_3$, $K_{sp} = 3 \times 10^{-44}$) explain the very low Pb concentrations of the EGO groundwater?

Assume pH 8, $P_{CO_2} = 10^{-2.5}$ atm and $PO_4^{3-} = 10$ µg/L, and that the thermodynamic activities of all species are equal to their concentrations.

Solution to Exercise 5↴

# 21 Boxes

## Box 1 – Sampled Artesian Flow in the Area of the Elmvale Groundwater Observatory



| | | | |
|---|---|---|---|
| 1 | Original artesian well, Shotyk farmhouse | 8 | Pigeon flow |
| 2 | EGO-1 | 9 | Greidanus household flow |
| 3 | EGO-2 | 10 | Roy Nahuis household |
| 4 | EGO-3 | 11 | Temolder flow |
| 5 | Elmvale Water Kiosk | 12 | Belluz flow |
| 6 | Former Site 41 lands (where standing wells were sampled) | 13 | Stone household flow |
| | | 14 | Archer flow |
| 7 | Parnell flow | 15 | Burgsma flow |

**Figure Box 1-1 -** Map showing the locations of the artesian flows in the area, sampled to date (as of March 18, 2019).

Return to where text linked to Box 1↥

## Box 2 – Publications on Clean-Lab Methods, Procedures, and Protocols for Trace Elements Research

Adeloju, S. B., & Bond, A. M. (1985). Influence of laboratory environment on the precision and accuracy of trace element analysis. *Analytical Chemistry*, *57*(8), 1728–1733. https://doi.org/10.1021/ac00285a050↗.

Ahlers, W. W., Reid, M. R., Kim, J. P., & Hunter, K. A. (1990). Contamination free sample collection and handling protocols for trace elements in natural fresh waters. *Australian Journal of Marine and Freshwater Research*, *41*(6), 713–720.

Benoit, G. (1994). Clean technique measurement of Pb, Ag, and Cd in fresh water: A redefinition of metal pollution. *Environmental Science & Technology* 1994, *28*(11), 1987–1991. https://doi.org/10.1021/es00060a033↗.

Berman, S. S., Yeats, P. A., & Kremling, K. (1985). Sample of seawater for trace metals. Critical Reviews in Analytical Chemistry, *16*(1), 1–14. https://doi.org/10.1080/10408348508542783↗.

Boutron, C. F. (1990). A clean laboratory for ultralow concentration heavy metal analysis. Fresenius Journal of Analytical Chemistry, *337*(5), 482–491. https://doi.org/10.1007/BF00322850↗.

Bruland, K. W., Franks, R. P., Knauer, G. A., & Martin, J. H. (1979). Sampling and analytical methods for the determination of copper, cadmium, zinc, and nickel at the nanogram per liter level in sea water. Analytica Chimica Acta, *105*(1), 233–245. https://doi.org/10.1016/S0003-2670(01)83754-5↗.

Creasey, C. L., & Flegal, A. R. (1999). Elemental analyses of groundwater: Demonstrated advantage of low-flow sampling and trace-metal clean techniques over standard techniques. *Hydrogeology Journal*, *7*(2), 161–167. https://doi.org/10.1007/s100400050188↗.

Field, M. P., & Sherrell, R. M. (2003). Direct determination of ultra-trace levels of metals in fresh water using desolvating micronebulization and HR-ICP-MS: Application to Lake Superior waters. Journal of Analytical Atomic Spectrometry 2003, *18*(3), 254–259. https://doi.org/10.1039/b210628k↗.

Gorlach, U., & Boutron, C. F. (1990). Preconcentration of lead, cadmium, copper and zinc in water at the pg $g^{-1}$ level by non-boiling evaporation. Analytica Chimica Acta, *236*(2), 391–398. https://doi.org/10.1016/S0003-2670(00)83339-5↗.

Gretzinger, K., Kotz, L., Tschöpel, P., & Tölg, G. (1982). Causes and elimination of systematic errors in the determination of iron and cobalt in aqueous solutions in the ng/ml and pg/ml range. *Talanta*, *29*(11), Part 2, 1011–1018. https://doi.org/10.1016/0039-9140(82)80242-7↗.

Hughes, R., Muerau, P. C., & Gundersen, G. (1971). Ultrapure water. Preparation and quality. *Analytical Chemistry*, *43*(6), 691–696. https://doi.org/10.1021/ac60301a006↗.

Kosta, L. (1982). Contamination as a limiting parameter in trace analysis. *Talanta*, *29*(11), Part 2, 985–992. https://doi.org/10.1016/0039-9140(82)80239-7↗.

Kuehner, E. C., Murphy, T. J., Alvarez, R., & Paulsen, P. J. (1972). Production and analysis of special high-purity acids purified by sub-boiling distillation. *Analytical Chemistry*, *44*(12), 2050–2056. https://doi.org/10.1021/ac60320a016↗.

Liu, Y., Hou S., & Zhang, Y. (2009). The acid cleaning method of labware for trace element analysis in snow and ice samples. *Sciences in Cold and Arid Regions*, *1*(6), 502–508.

MacDougall, D., Amore, F. J., Cox, G., Crosby, D. G., Estes, F. L., Freeman, D. H., Gibbs, W. E., Gordon, G. E., Keith, L.H., Lal, J., Langner, R. R., McClelland, N. I., Phillips, W. F., Pojasek, R. B., Sievers, R. E., Smerko, R. G., Wimert, D. C., Crummett, W. B., Libby, R., …Taylor, J. K. (1980). Guidelines for data acquisition and data quality evaluation in environmental chemistry. *Analytical Chemistry*, *52*(14), 2242–2249. https://doi.org/10.1021/ac50064a004↗.

Mart, L. (1982). Minimization of accuracy risks in voltammetric ultratrace determination of heavy metals in natural waters. *Talanta*, *29*(11), Part 2, 1035–1040 https://doi.org/10.1016/0039-9140(82)80246-4↗.

Mitchell, J. W. (1973). Ultrapurity in trace analysis. *Analytical Chemistry*, *45*(6), A492.

Mitchell, J. W. (1982). Purification of analytical reagents. *Talanta*, *29*(11), 993–1002. https://doi.org/10.1016/0039-9140(82)80240-3↗.

Mitchell, R. L. (1960). Contamination problems in soil and plant analysis. Journal of the Science of Food and Agriculture, 11(10), 553–560. https://doi.org/10.1002/jsfa.2740111001↗.

Moody, J. R. (1982). NBS clean laboratories for trace-element analysis. *Analytical Chemistry*, *54*(13), 1358. https://doi.org/10.1021/ac00250a001↗.

Moody, J. R., Wissink, C. E., & Beary, E. S. (1989). Design principles for a large high-efficiency sub-boiling still. *Analytical Chemistry*, *61*(8), 823–827. https://doi.org/10.1021/ac00183a008↗.

Moody, J. R., & Beary, E. S. (1982). Purified reagents for trace metal analysis. *Talanta*, *29*(11), 1003–1010. https://doi.org/10.1016/0039-9140(82)80241-5↗.

Murphy, T. J. (1976). The role of the analytical blank in accurate trace analysis. In P. D. LaFleur (Ed.), *Accuracy in trace analysis: Sampling, sample handling, analysis, Volume. 422: NBS special publication* (p. 645). US Department of Commerce, National Bureau of Standards.

Nakayama, E., Suzuki, Y., Fujiwara, K., & Kitano, Y. (1989). Chemical analyses of seawater for trace-elements: Recent progress in Japan on clean sampling and chemical speciation of trace elements: A review. *Analytical Sciences*, *5*(2), 129-139. https://doi.org/10.2116/analsci.5.129↗.

Namiesnik, J. (2002). Trace analysis - Challenges and problems. *Critical Reviews in Analytical Chemistry*, *32*(4), 271–300. https://doi.org/10.1080/10408340290765579↗.

Nriagu, J. O., Lawson G., Wong, H. K. T., & Azcue, J. M. (1993). A protocol for minimizing contamination in the analysis of trace metals in Great Lake Waters. *Journal of Great Lakes Research*, *19*(1), 175–182. https://doi.org/10.1016/S0380-1330(93)71207-1↗.

Paulsen, P. J., Beary, E. S., Bushee, D. S., & Moody, J. R. (1988). Inductively coupled plasma mass spectrometric analysis of ultrapure acids. *Analytical Chemistry*, *60*(10), 971–975. https://doi.org/10.1021/ac00161a005↗.

Rodushkin, I., Engstrom, E., & Baxter, D. C. (2010). Sources of contamination and remedial strategies in the multi-elemental trace analysis laboratory. *Analytical and Bioanalytical Chemistry*, *396*(1), 365–377. https://doi.org/10.1007/s00216-009-3087-z↗.

Rossmann, R., & Barres, J. (1988). Trace element concentrations in near-surface waters of the Great Lakes and methods of collection, storage, and analysis. *Journal of Great Lakes Research*, *14*(2), 188–204. https://doi.org/10.1016/S0380-1330(88)71548-8↗.

Sharma, M., Chen, C., & Blazina, T. (2012). Osmium contamination of seawater samples stored in polyethylene bottles. Limnology and Oceanography: Methods, *10*, 618–630. https://doi.org/10.4319/lom.2012.10.618↗.

Smith, J. C., & Schwarz, K. (1967). A controlled environment system for new trace element deficiencies. *Journal of Nutrition*, *93*(2), 182–188. https://doi.org/10.1093/jn/93.2.182↗.

Sturgeon, R., Berman, S. S., & Kremling, K. (1987). Sampling and storage of natural water for trace metals. Critical Reviews in Analytical Chemistry, *18*(3), 209–244. https://doi.org/10.1080/10408348708542804↗.

Thiers, R. E. (1957). Contamination in trace element analysis and its control. In D. Glick (Ed.), *Methods of Biochemical Analysis: Vol. 5* (pp. 273–335). Interscience Publishers.

Tramontano, J. M., Scudlark, J. R., & Church, T. M. (1987). A method for the collection, handling, and analysis of trace metals in precipitation. *Environmental Science & Technology*, *21*(8), 749–753. https://doi.org/10.1021/es00162a003↗.

Zief, M., & Mitchell, J. W. (1976). Contamination control in trace element analysis. *Chemical Analysis*, *47*. Wiley.

**Return to where text linked to Box 2↥**

## Box 3 – Recommended Materials for Research on Trace Elements in Natural Water and Materials to Avoid

Findings are unpublished unless indicated otherwise.

**Brass** is a Cu – Zn alloy with minimum 1 percent by weight Pb. It leaches these metals but also contains Ag, As, Sb, and Tl.

**Steel** leaches Pb. Galvanized steel contains Zn but also Cd.

**Titanium alloys** leach Pb.

**Pewter** leaches Sb and Sn (Krachler & Shotyk, 2009).

**Glass** leaches Pb (lead is a glass additive) but may also leach As and Sb (used as opacifiers in glass manufacture) as well as Th and Zn, depending on the glass composition (Furneisen, 2010; Krachler & Shotyk, 2009; Shotyk & Krachler, 2007a).

**Rubber** leaches Zn; zinc oxide is used in the manufacture of rubber.

**PET (polyethylene terephthalate)** leaches Sb; antimony trioxide is used as the catalyst to manufacture PET, which typically contains 250 mg/kg of Sb (Shotyk et al., 2006, Shotyk & Krachler, 2007).

**Japanese PET** leaches Ti and Ge; PET manufactured in Japan employs a titanium catalyst, but this creates a yellow plastic; germanium is added to clarify the polymer (Shotyk & Krachler, 2007b).

**High-density polyethylene (HDPE)** leaches Al and V; both metals are employed as catalysts, and which is used depends on the manufacturer (Shotyk et al., 2017).

**Low-density polyethylene (LDPE)** leaches Pb.

**Mixed plastics (e.g. recycled)**, depending on the mix of plastics used in recycling, will leach—for example, V and Sb (Chen et al., 2003).

**Polyvinyl chloride (PVC)** contains Cd and Pb (Nakashima et al., 2012).

**Return to where text linked to Box 3**↥

## Box 4 – Summary of Tritium Activity Measurements

**Table Box 4-1 -** Summary of tritium activity measurements at the farmhouse and EGO wells.

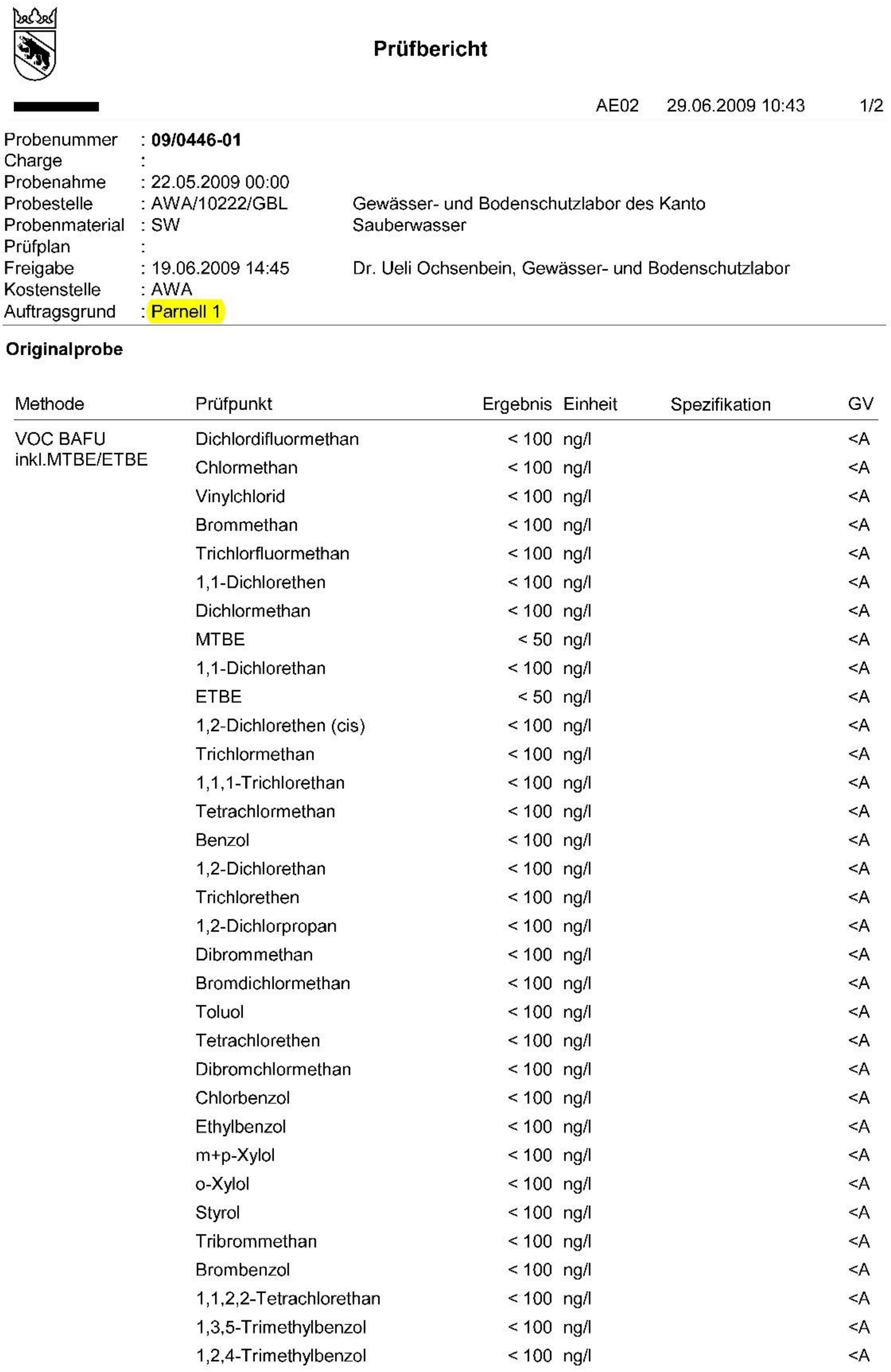
| Year of collection | Location | Tritium activity (TU) | Laboratory (analyst) |
|---|---|---|---|
| 2006 | Farmhouse | < LOD | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Farmhouse | < LOD | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Farmhouse (duplicate) | < LOD | University of Heidelberg (W. Aeschbach-Hertig) |
| 2009 | EGO-1 | < LOD | University of Heidelberg (W. Aeschbach-Hertig) |
| 2013 | EGO-1 | < LOD | University of Ottawa (I.D. Clark) |
| 2013 | EGO-2 | < LOD | University of Ottawa (I.D. Clark) |
| 2013 | EGO-3 | < LOD | University of Ottawa (I.D. Clark) |
| 2018 | EGO-1 | < LOD | University of Ottawa (I.D. Clark) |
| 2018 | EGO-3 | < LOD | University of Ottawa (I.D. Clark) |

**Table Box 4-2 -** Summary of tritium activity measurements in other artesian flows in the area.

| Year of collection | Location | Tritium activity (TU) | Laboratory (analyst) |
|---|---|---|---|
| 2006 | Parnell | 9.52 ± 0.88 | University of Heidelberg (W. Aeschbach-Hertig) |
| 2006 | Parnell | 9.97 ± 0.9 | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Parnell | 10.6 ± 0.93 | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Temolder (bush) | 14.3 ± 1.29 | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Temolder (barn) | 15.1 ± 1.06 | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Pigeon | 12.1 ± 1.05 | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Pigeon (duplicate) | 11.1 ± 0.95 | University of Heidelberg (W. Aeschbach-Hertig) |
| 2008 | Elmvale Water Kiosk | < LOD | University of Heidelberg (W. Aeschbach-Hertig) |

Return to where text linked to Box 4↥

# Box 5 – Organic Contaminants EGO-1 (Canton of Berne)



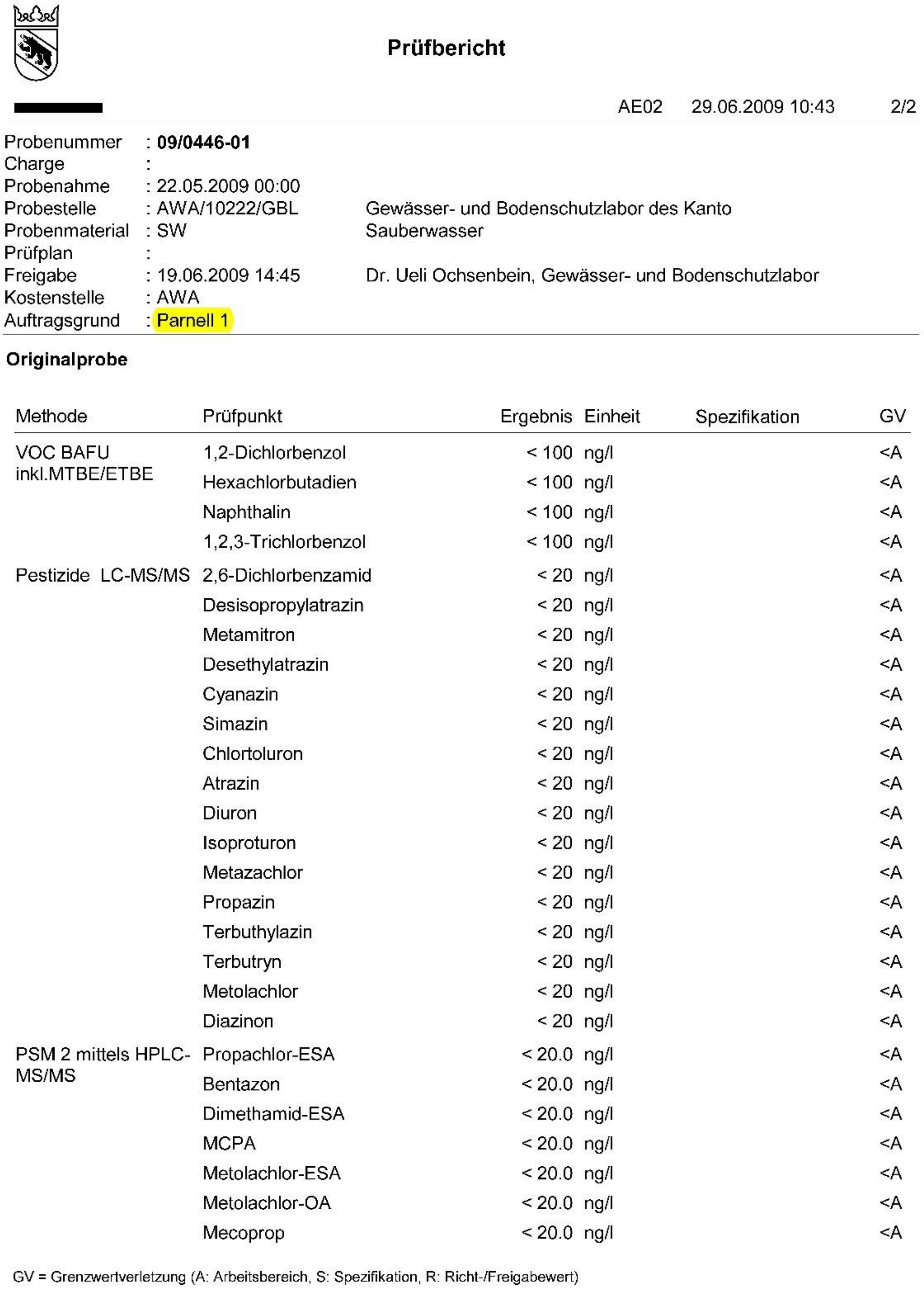
**Prüfbericht**

AE02 29.06.2009 10:43 1/2

Probenummer : **09/0446-01**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : Parnell 1

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



**Prüfbericht**

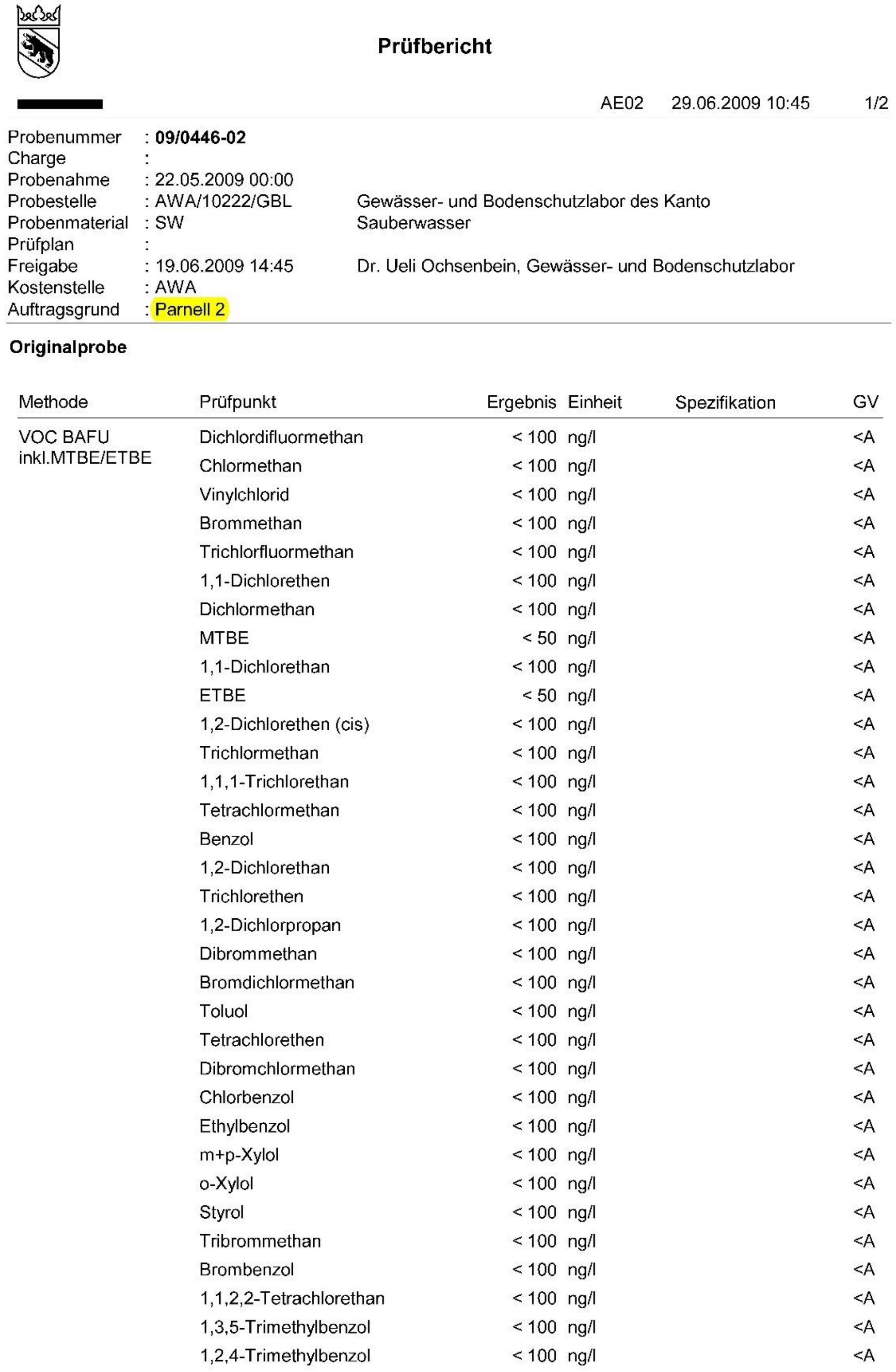
AE02 29.06.2009 10:43 2/2

Probenummer : **09/0446-01**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : Parnell 1

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



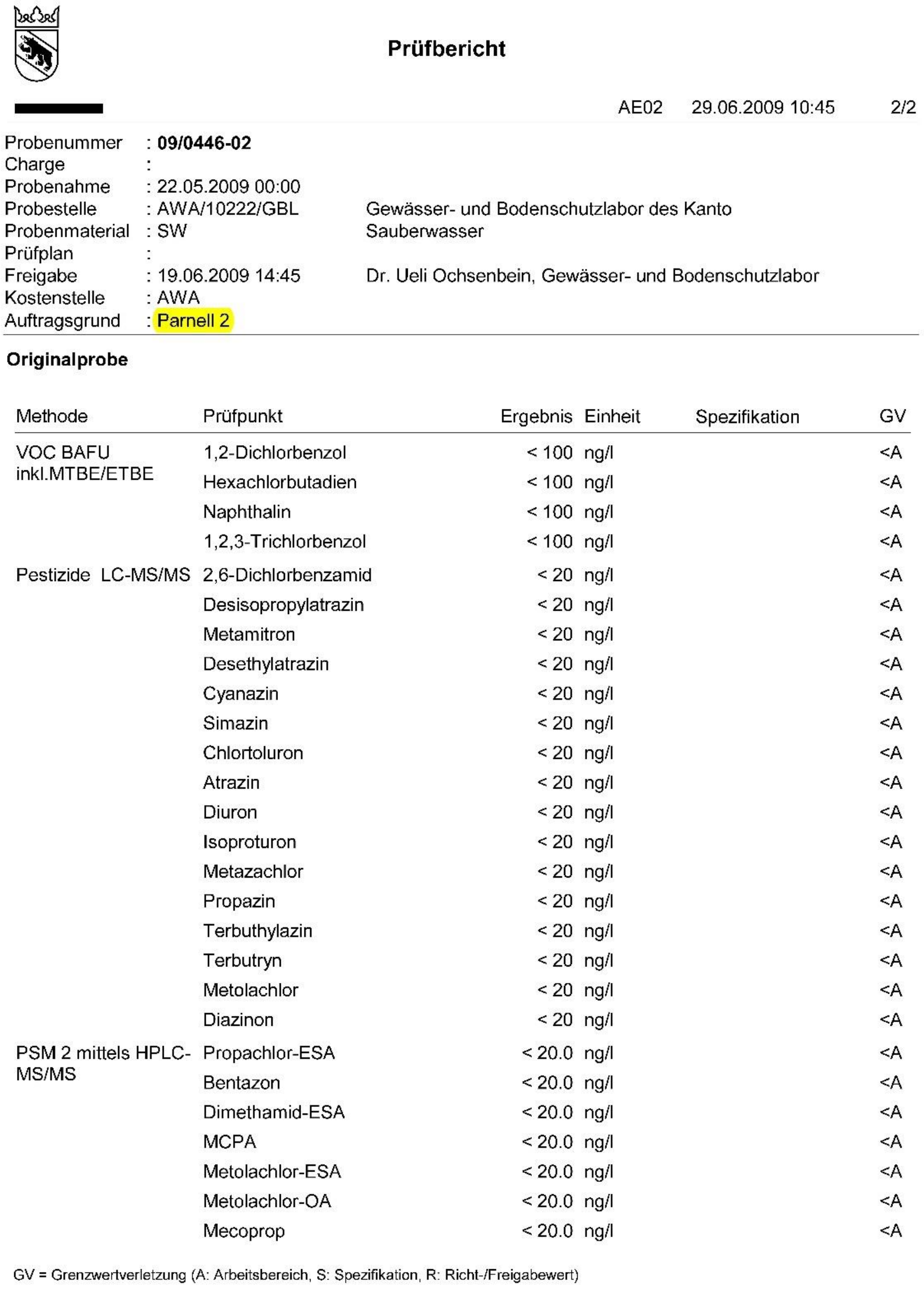
## Prüfbericht

AE02 29.06.2009 10:45 1/2

Probenummer : **09/0446-02**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : Parnell 2

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



## Prüfbericht

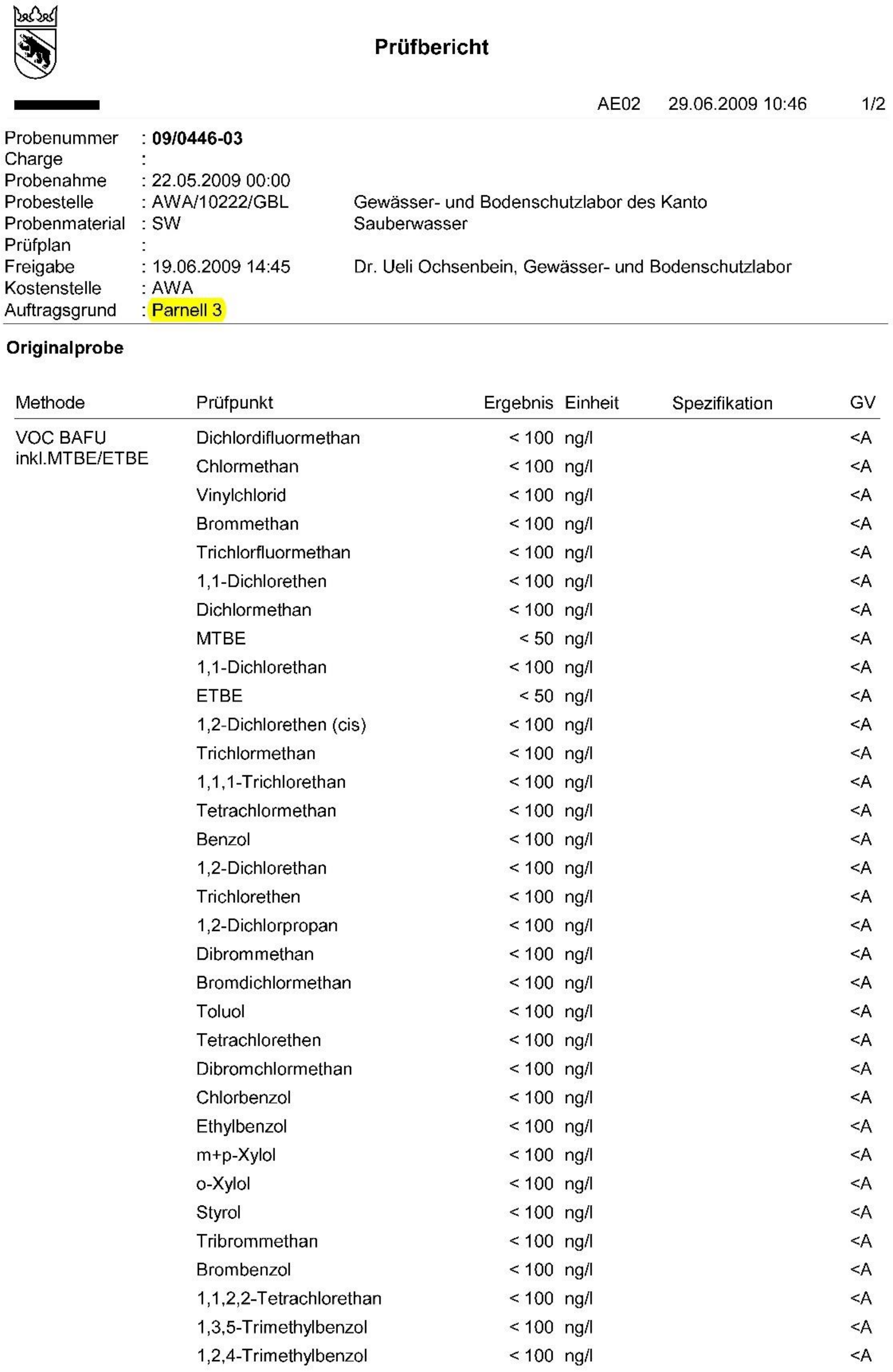
AE02 29.06.2009 10:45 2/2

| | | |
|---|---|---|
| Probenummer | : **09/0446-02** | |
| Charge | : | |
| Probenahme | : 22.05.2009 00:00 | |
| Probestelle | : AWA/10222/GBL | Gewässer- und Bodenschutzlabor des Kanto |
| Probenmaterial | : SW | Sauberwasser |
| Prüfplan | : | |
| Freigabe | : 19.06.2009 14:45 | Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor |
| Kostenstelle | : AWA | |
| Auftragsgrund | : Parnell 2 | |

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



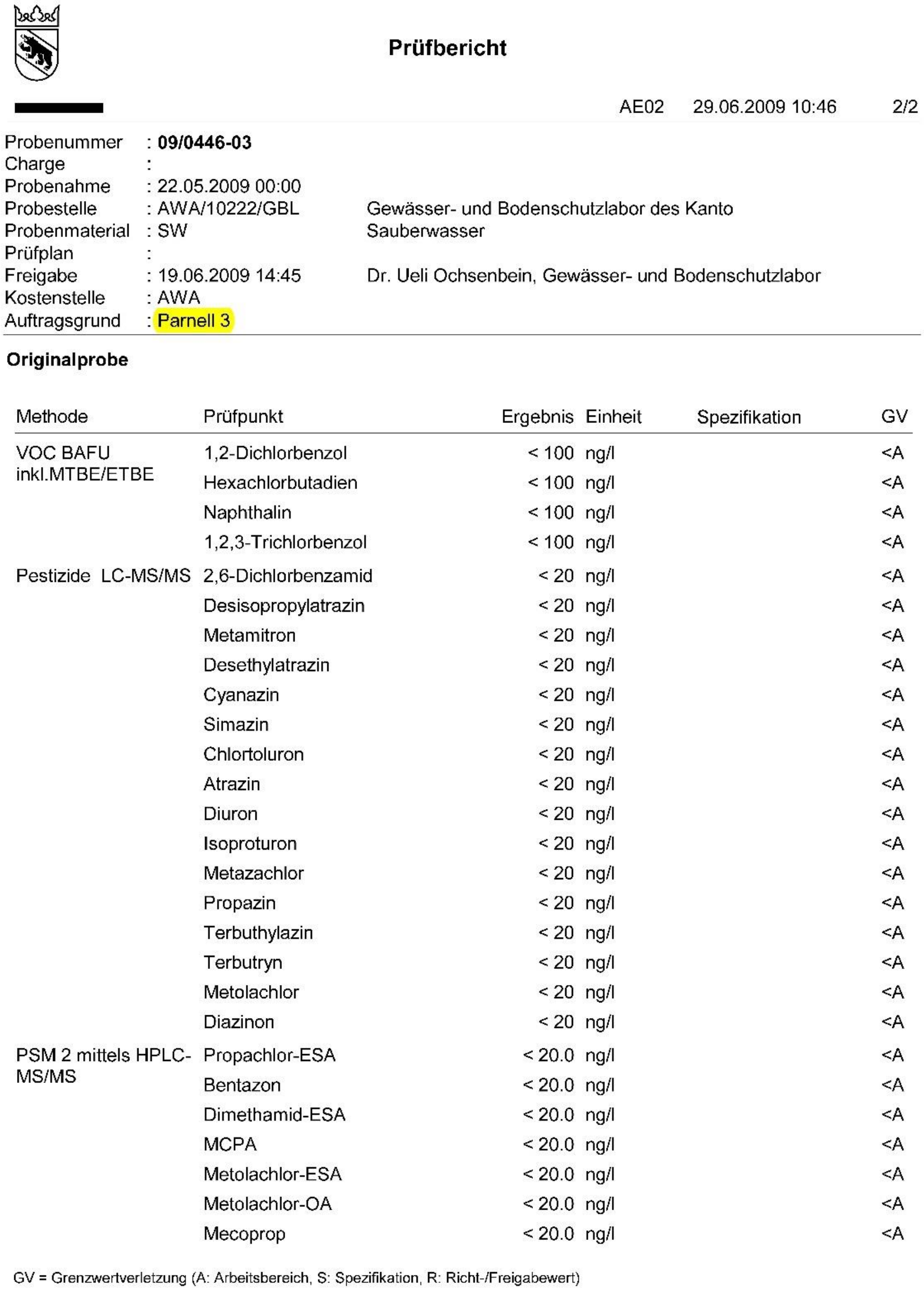
**Prüfbericht**

AE02 29.06.2009 10:46 1/2

Probenummer : **09/0446-03**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : Parnell 3

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



**Prüfbericht**

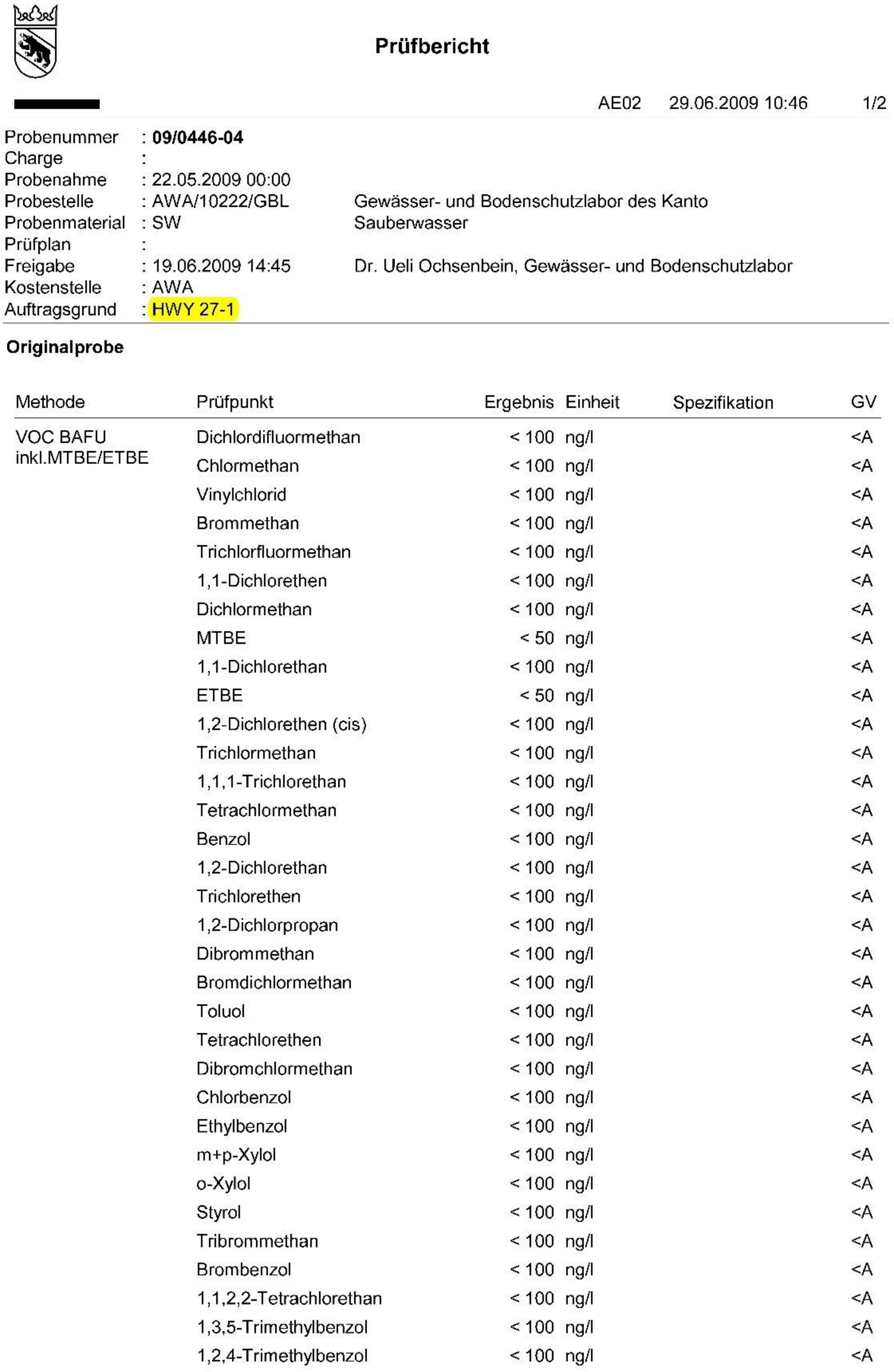
AE02 29.06.2009 10:46 2/2

Probenummer : **09/0446-03**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : Parnell 3

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



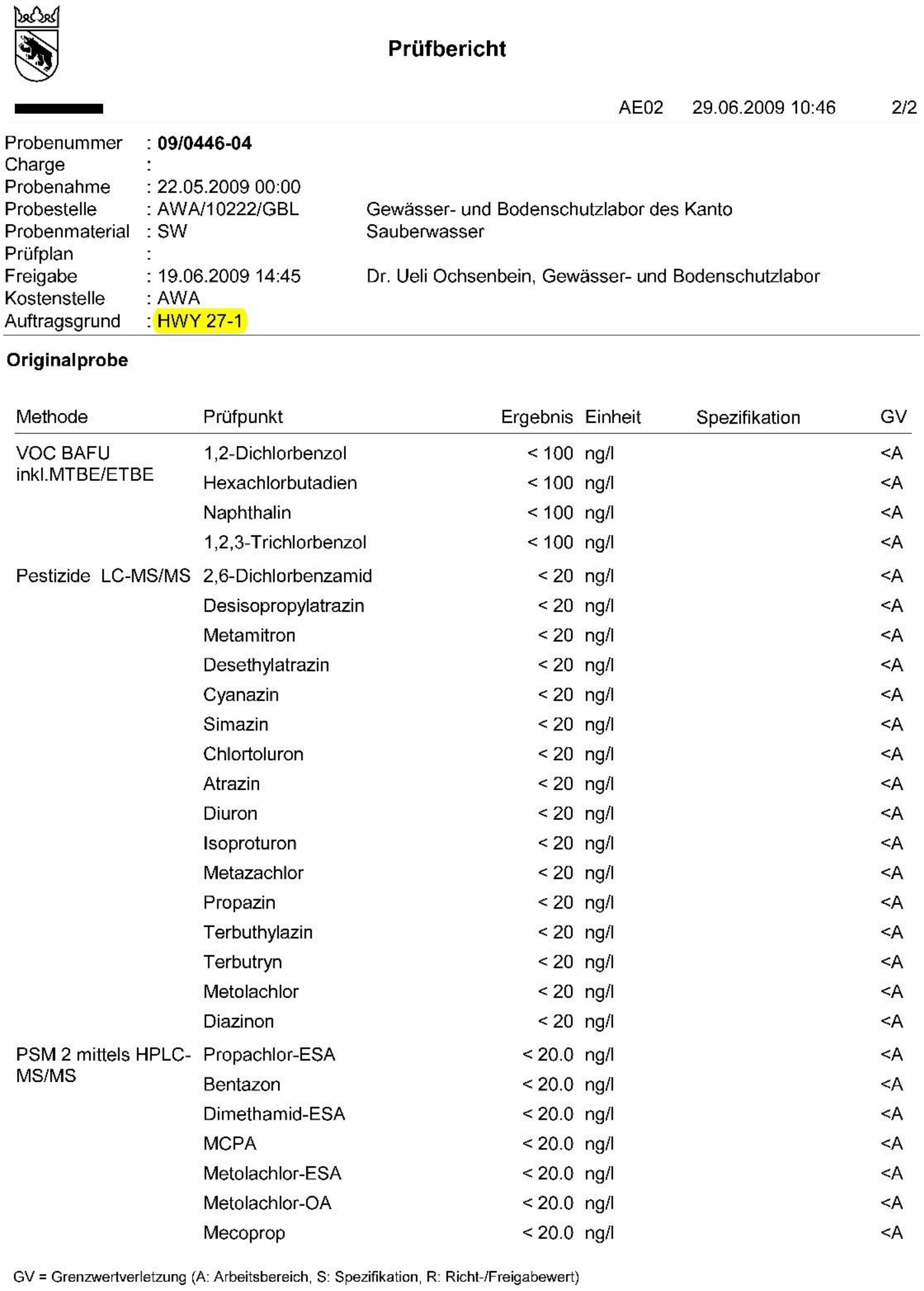
## Prüfbericht

AE02 29.06.2009 10:46 1/2

Probenummer : **09/0446-04**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : HWY 27-1

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



## Prüfbericht

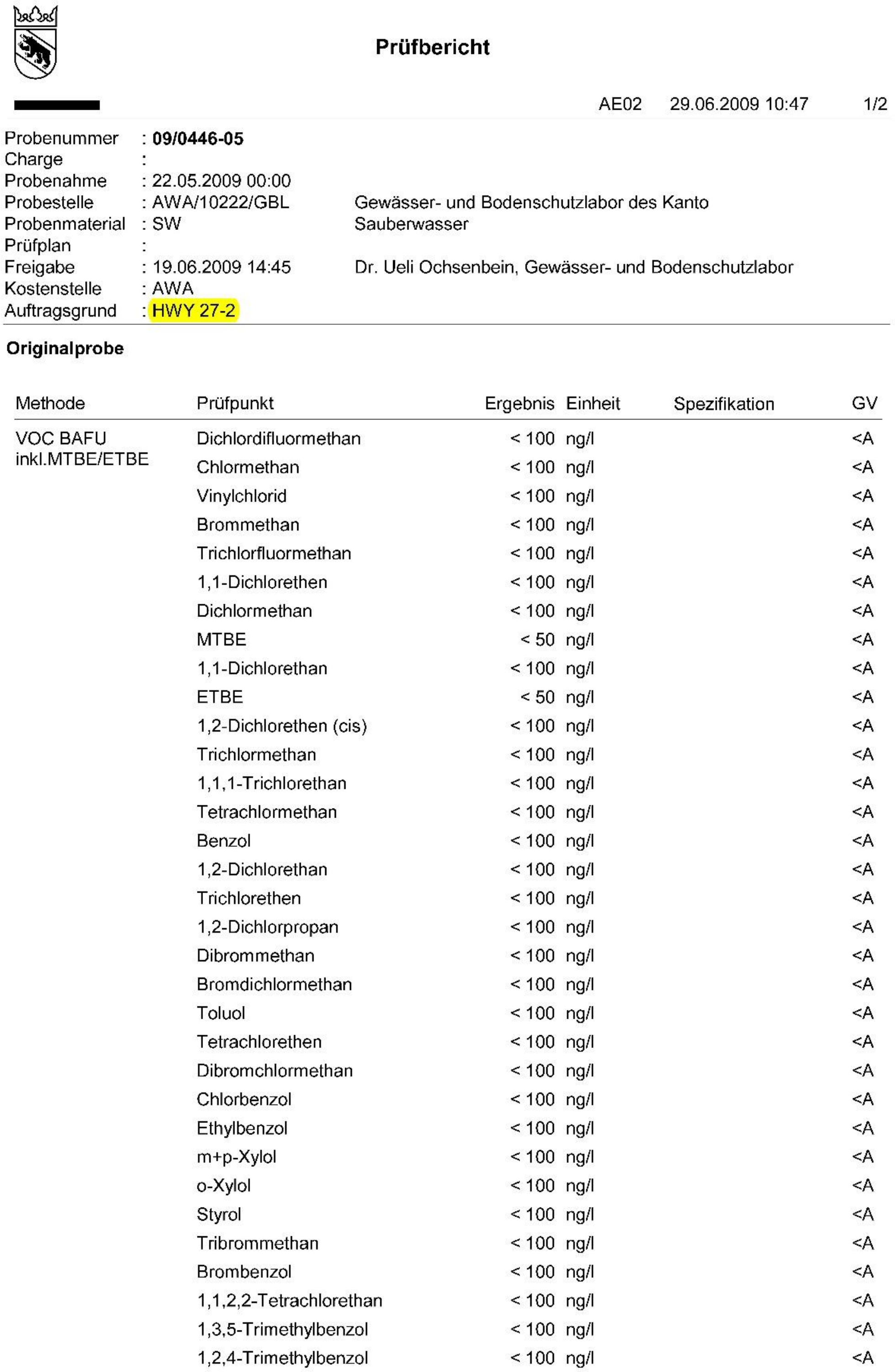
AE02 29.06.2009 10:46 2/2

Probenummer : **09/0446-04**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : HWY 27-1

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



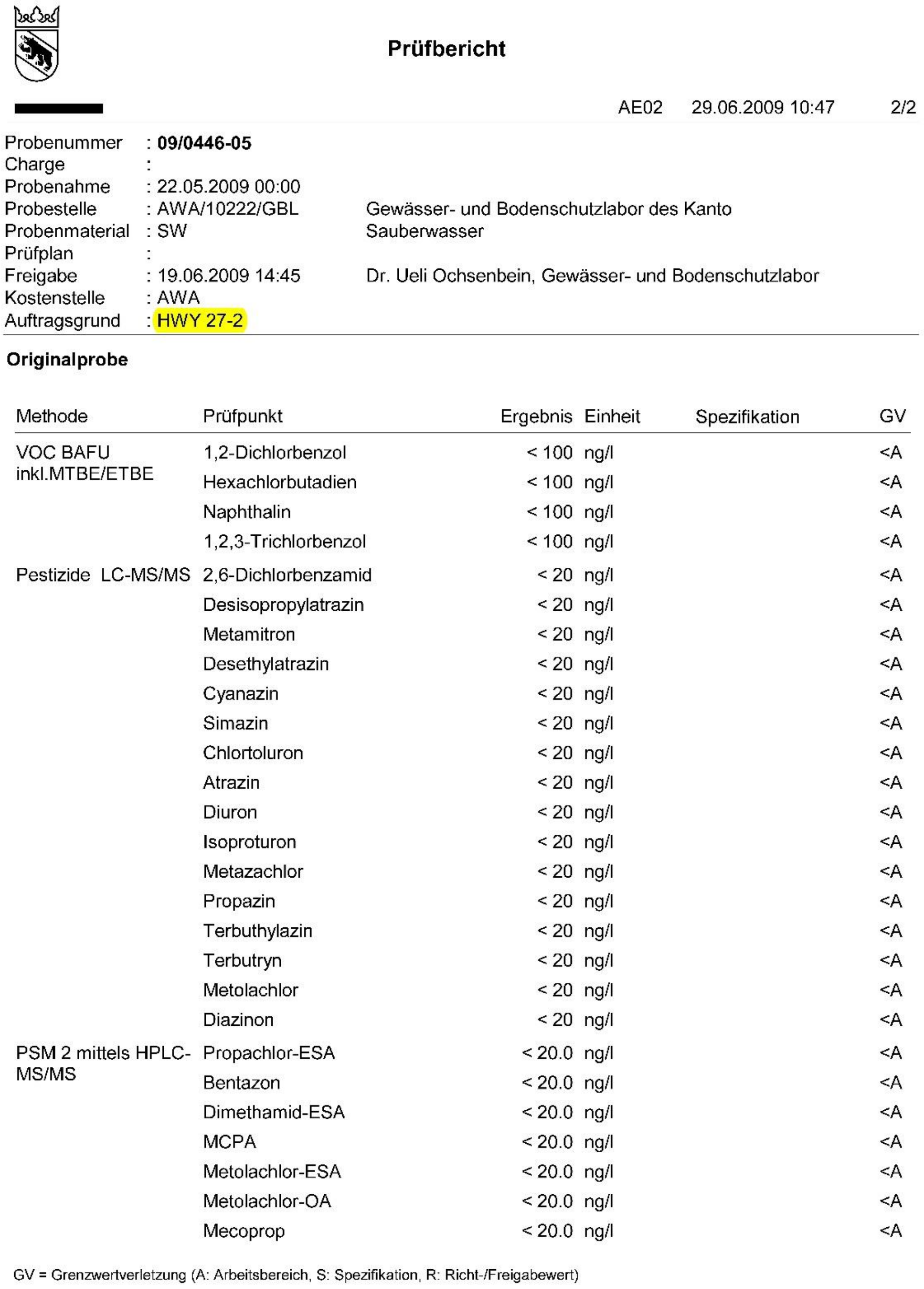
## Prüfbericht

AE02 29.06.2009 10:47 1/2

| | | |
|---|---|---|
| Probenummer | : **09/0446-05** | |
| Charge | : | |
| Probenahme | : 22.05.2009 00:00 | |
| Probestelle | : AWA/10222/GBL | Gewässer- und Bodenschutzlabor des Kanto |
| Probenmaterial | : SW | Sauberwasser |
| Prüfplan | : | |
| Freigabe | : 19.06.2009 14:45 | Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor |
| Kostenstelle | : AWA | |
| Auftragsgrund | : HWY 27-2 | |

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



**Prüfbericht**

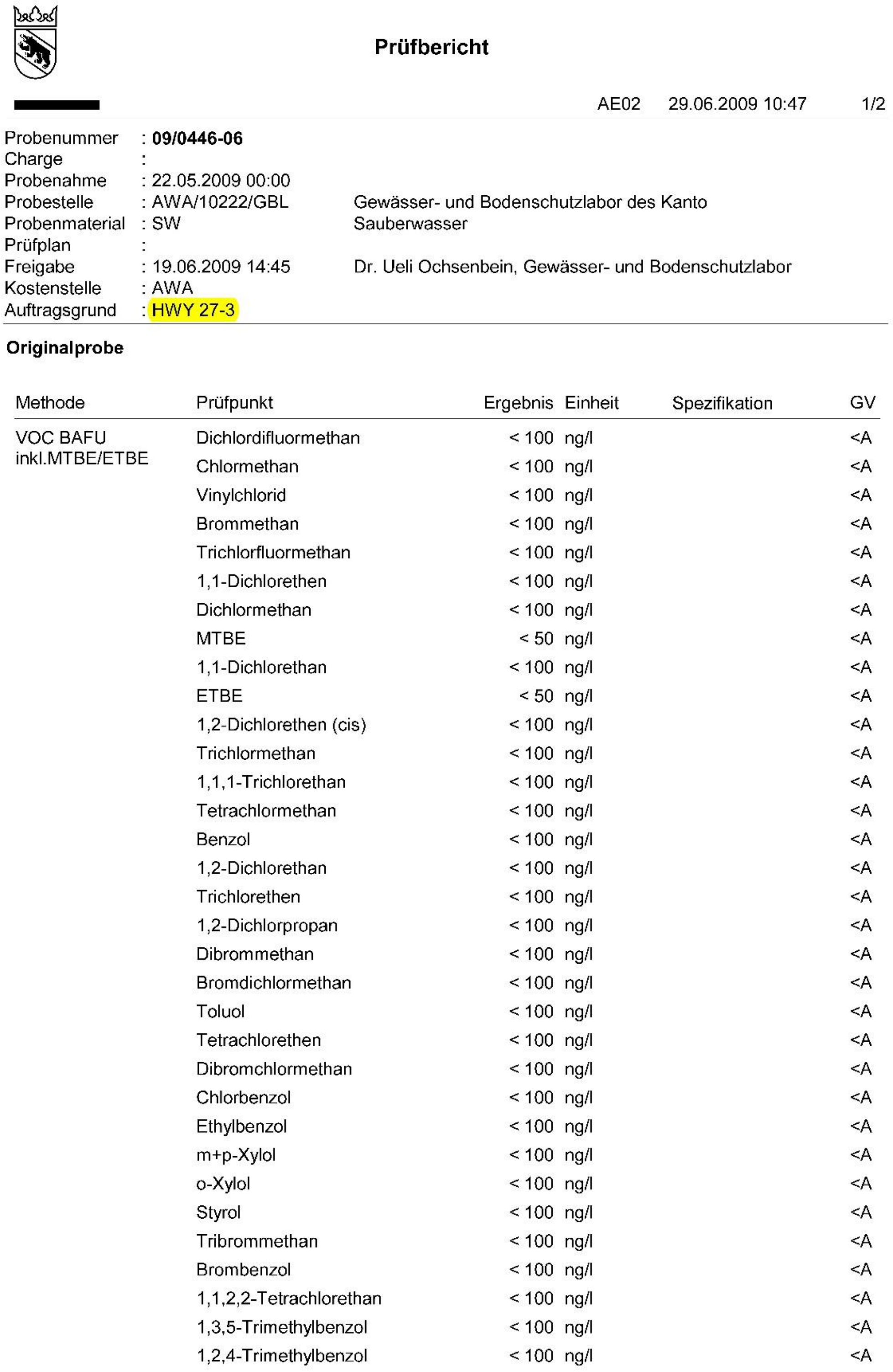
AE02 29.06.2009 10:47 2/2

Probenummer : **09/0446-05**
Charge :
Probenahme : 22.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : HWY 27-2

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



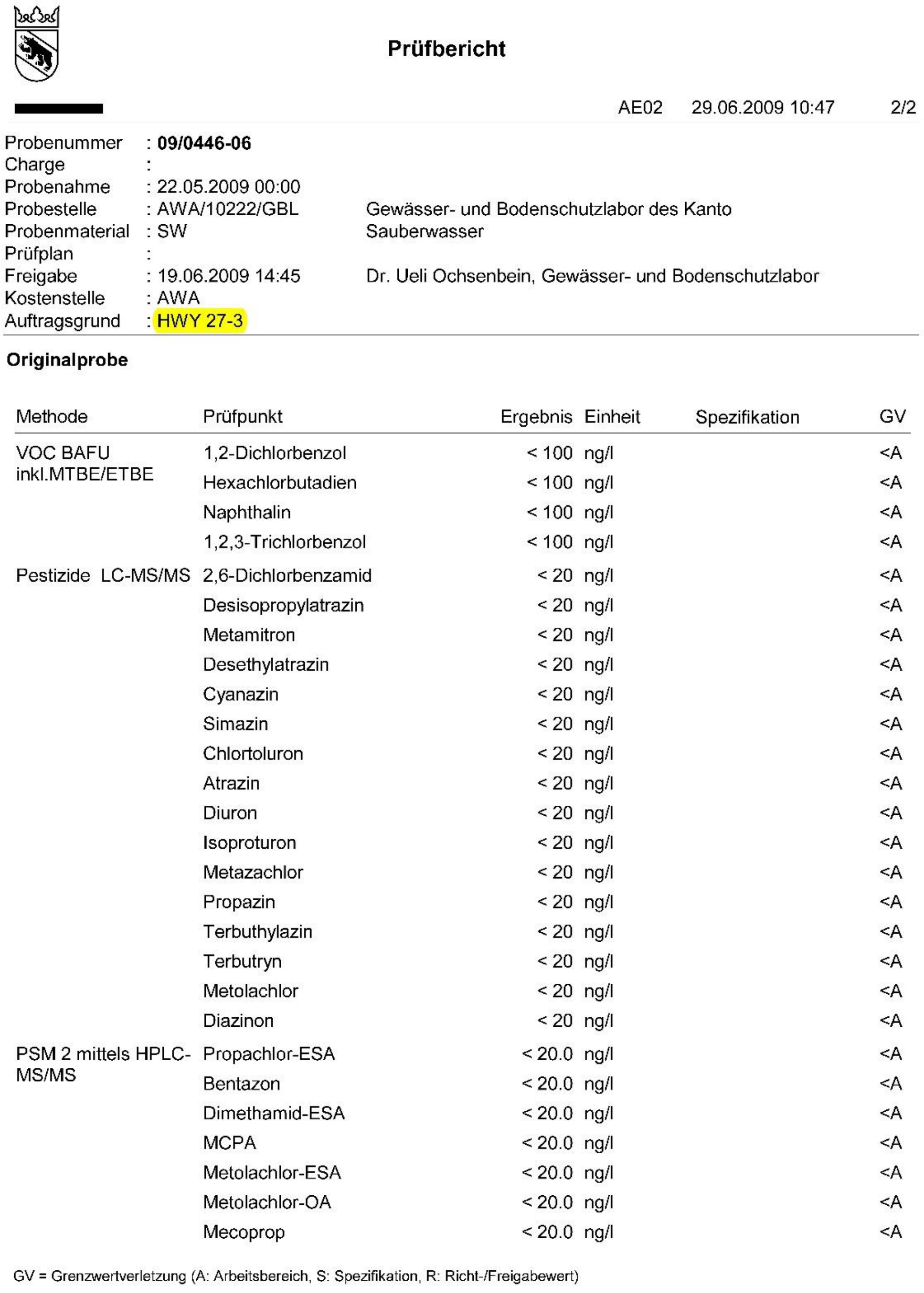
**Prüfbericht**

AE02 29.06.2009 10:47 1/2

|  |  |  |
|---|---|---|
| Probenummer | : **09/0446-06** |  |
| Charge | : |  |
| Probenahme | : 22.05.2009 00:00 |  |
| Probestelle | : AWA/10222/GBL | Gewässer- und Bodenschutzlabor des Kanto |
| Probenmaterial | : SW | Sauberwasser |
| Prüfplan | : |  |
| Freigabe | : 19.06.2009 14:45 | Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor |
| Kostenstelle | : AWA |  |
| Auftragsgrund | : HWY 27-3 |  |

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l |  | <A |
|  | Chlormethan | < 100 | ng/l |  | <A |
|  | Vinylchlorid | < 100 | ng/l |  | <A |
|  | Brommethan | < 100 | ng/l |  | <A |
|  | Trichlorfluormethan | < 100 | ng/l |  | <A |
|  | 1,1-Dichlorethen | < 100 | ng/l |  | <A |
|  | Dichlormethan | < 100 | ng/l |  | <A |
|  | MTBE | < 50 | ng/l |  | <A |
|  | 1,1-Dichlorethan | < 100 | ng/l |  | <A |
|  | ETBE | < 50 | ng/l |  | <A |
|  | 1,2-Dichlorethen (cis) | < 100 | ng/l |  | <A |
|  | Trichlormethan | < 100 | ng/l |  | <A |
|  | 1,1,1-Trichlorethan | < 100 | ng/l |  | <A |
|  | Tetrachlormethan | < 100 | ng/l |  | <A |
|  | Benzol | < 100 | ng/l |  | <A |
|  | 1,2-Dichlorethan | < 100 | ng/l |  | <A |
|  | Trichlorethen | < 100 | ng/l |  | <A |
|  | 1,2-Dichlorpropan | < 100 | ng/l |  | <A |
|  | Dibrommethan | < 100 | ng/l |  | <A |
|  | Bromdichlormethan | < 100 | ng/l |  | <A |
|  | Toluol | < 100 | ng/l |  | <A |
|  | Tetrachlorethen | < 100 | ng/l |  | <A |
|  | Dibromchlormethan | < 100 | ng/l |  | <A |
|  | Chlorbenzol | < 100 | ng/l |  | <A |
|  | Ethylbenzol | < 100 | ng/l |  | <A |
|  | m+p-Xylol | < 100 | ng/l |  | <A |
|  | o-Xylol | < 100 | ng/l |  | <A |
|  | Styrol | < 100 | ng/l |  | <A |
|  | Tribrommethan | < 100 | ng/l |  | <A |
|  | Brombenzol | < 100 | ng/l |  | <A |
|  | 1,1,2,2-Tetrachlorethan | < 100 | ng/l |  | <A |
|  | 1,3,5-Trimethylbenzol | < 100 | ng/l |  | <A |
|  | 1,2,4-Trimethylbenzol | < 100 | ng/l |  | <A |



## Prüfbericht

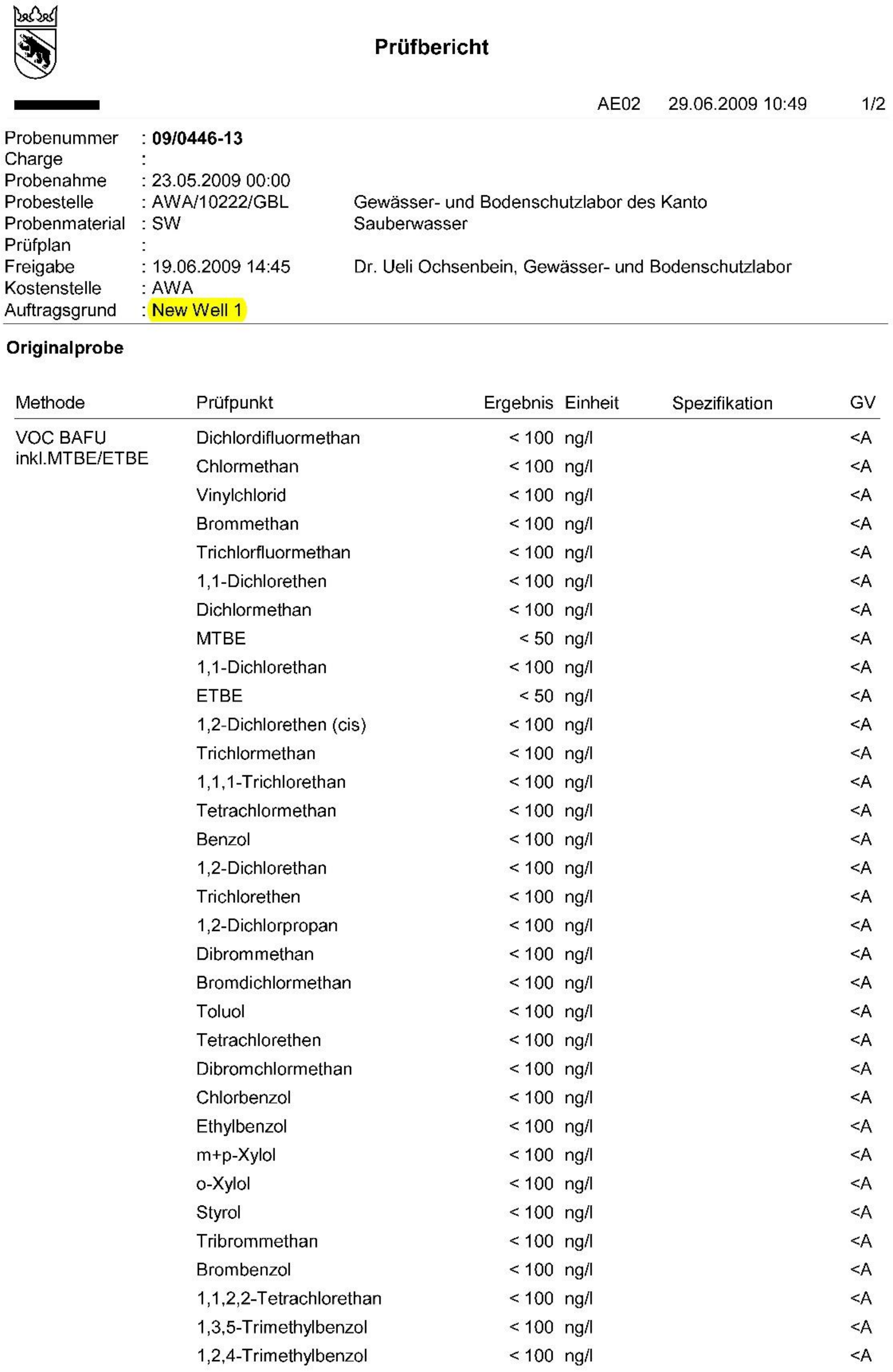
AE02 29.06.2009 10:47 2/2

| | | |
|---|---|---|
| Probenummer | : **09/0446-06** | |
| Charge | : | |
| Probenahme | : 22.05.2009 00:00 | |
| Probestelle | : AWA/10222/GBL | Gewässer- und Bodenschutzlabor des Kanto |
| Probenmaterial | : SW | Sauberwasser |
| Prüfplan | : | |
| Freigabe | : 19.06.2009 14:45 | Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor |
| Kostenstelle | : AWA | |
| Auftragsgrund | : HWY 27-3 | |

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



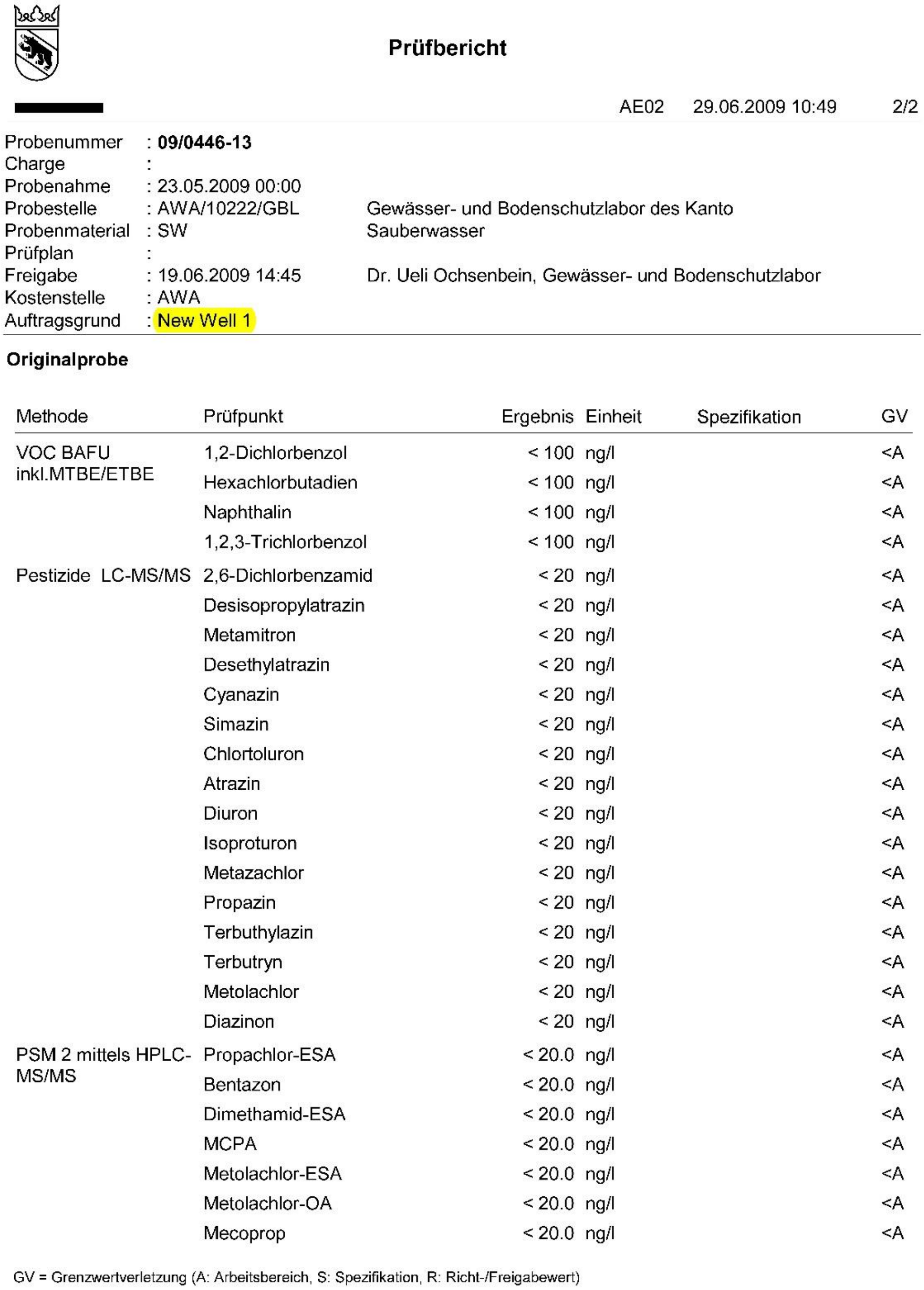
**Prüfbericht**

AE02 29.06.2009 10:49 1/2

Probenummer : **09/0446-13**
Charge :
Probenahme : 23.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : New Well 1

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



**Prüfbericht**

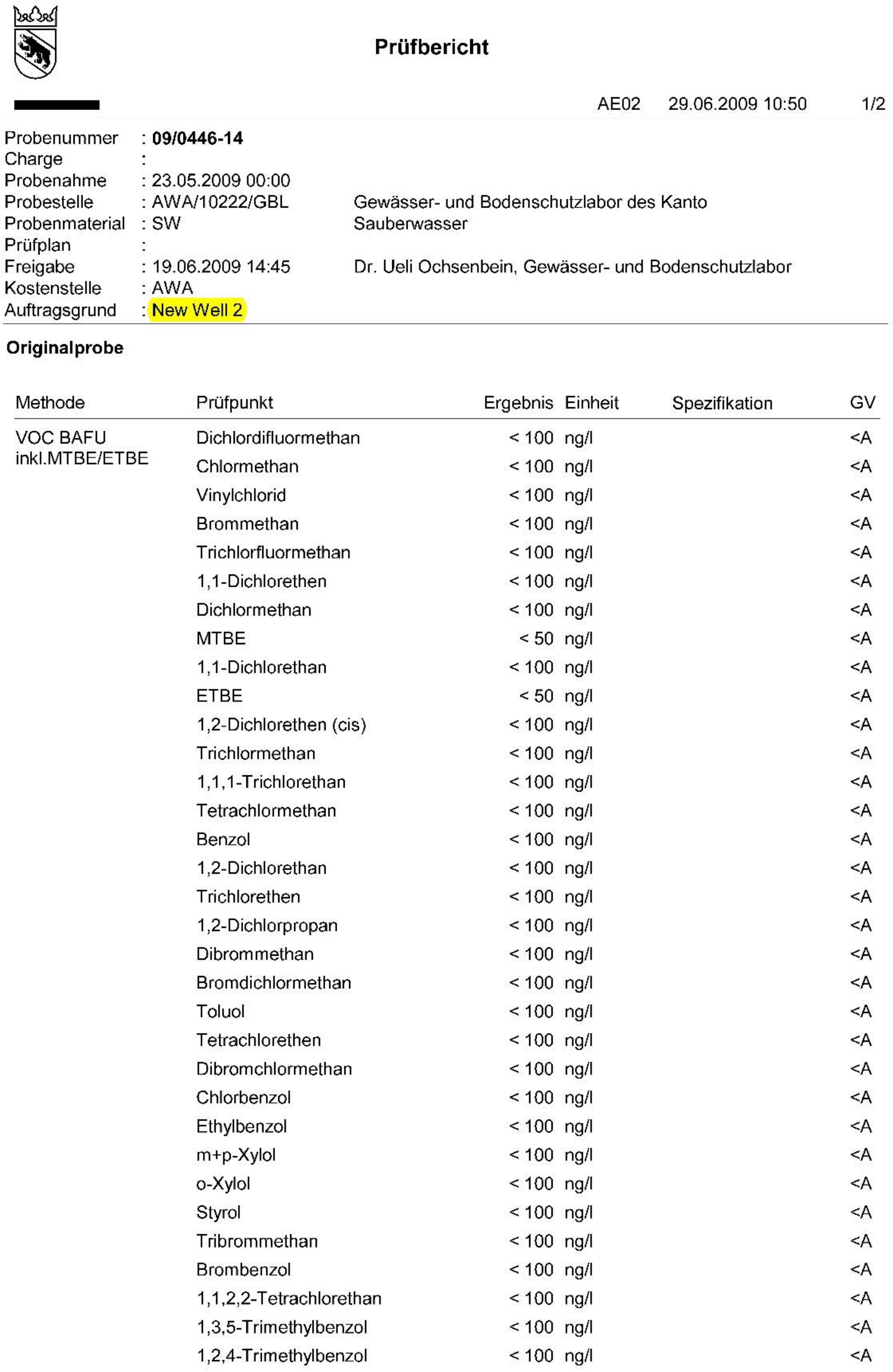
AE02 29.06.2009 10:49 2/2

Probenummer : **09/0446-13**
Charge :
Probenahme : 23.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : New Well 1

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



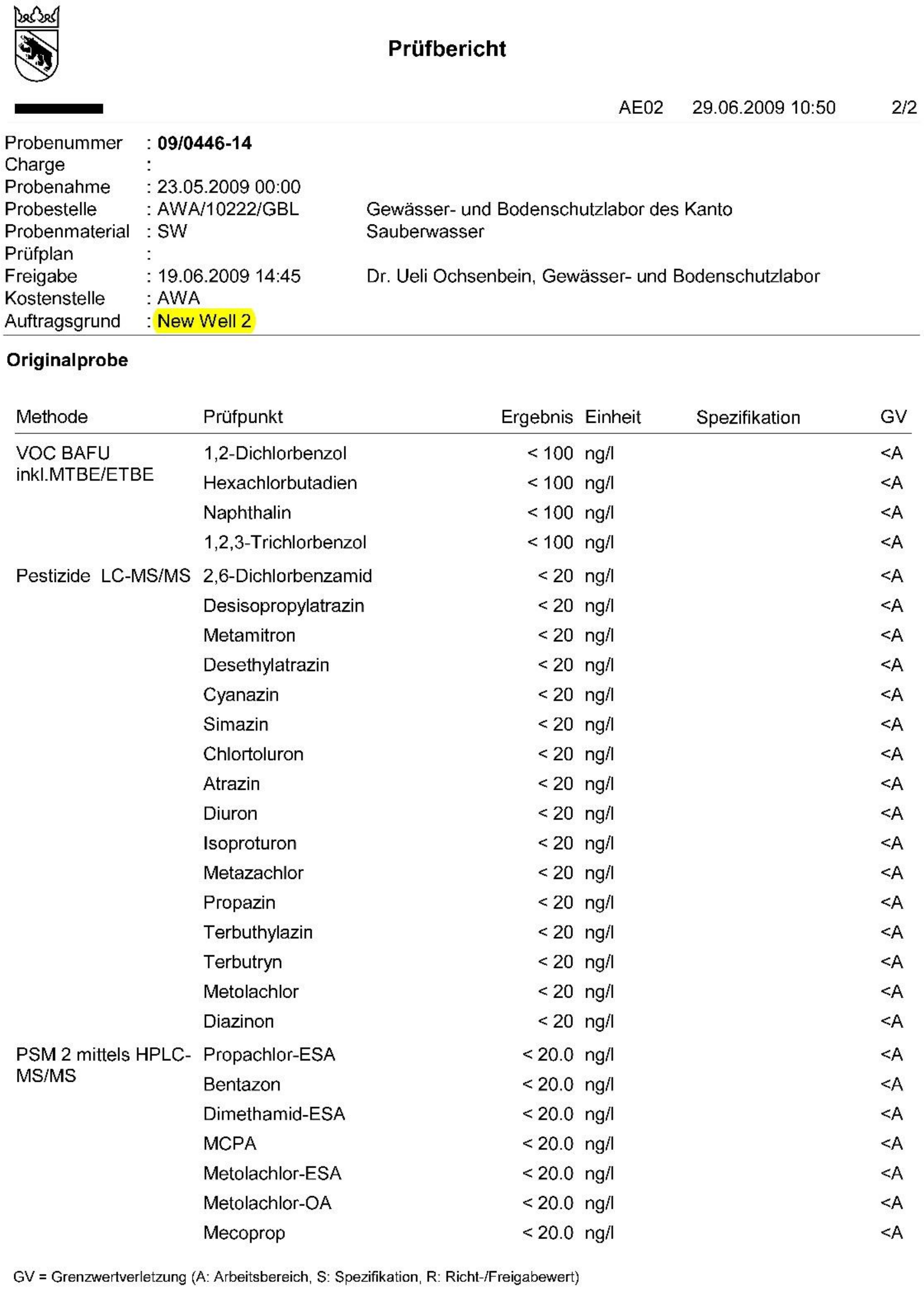
## Prüfbericht

AE02 29.06.2009 10:50 1/2

Probenummer : **09/0446-14**
Charge :
Probenahme : 23.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : New Well 2

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



## Prüfbericht

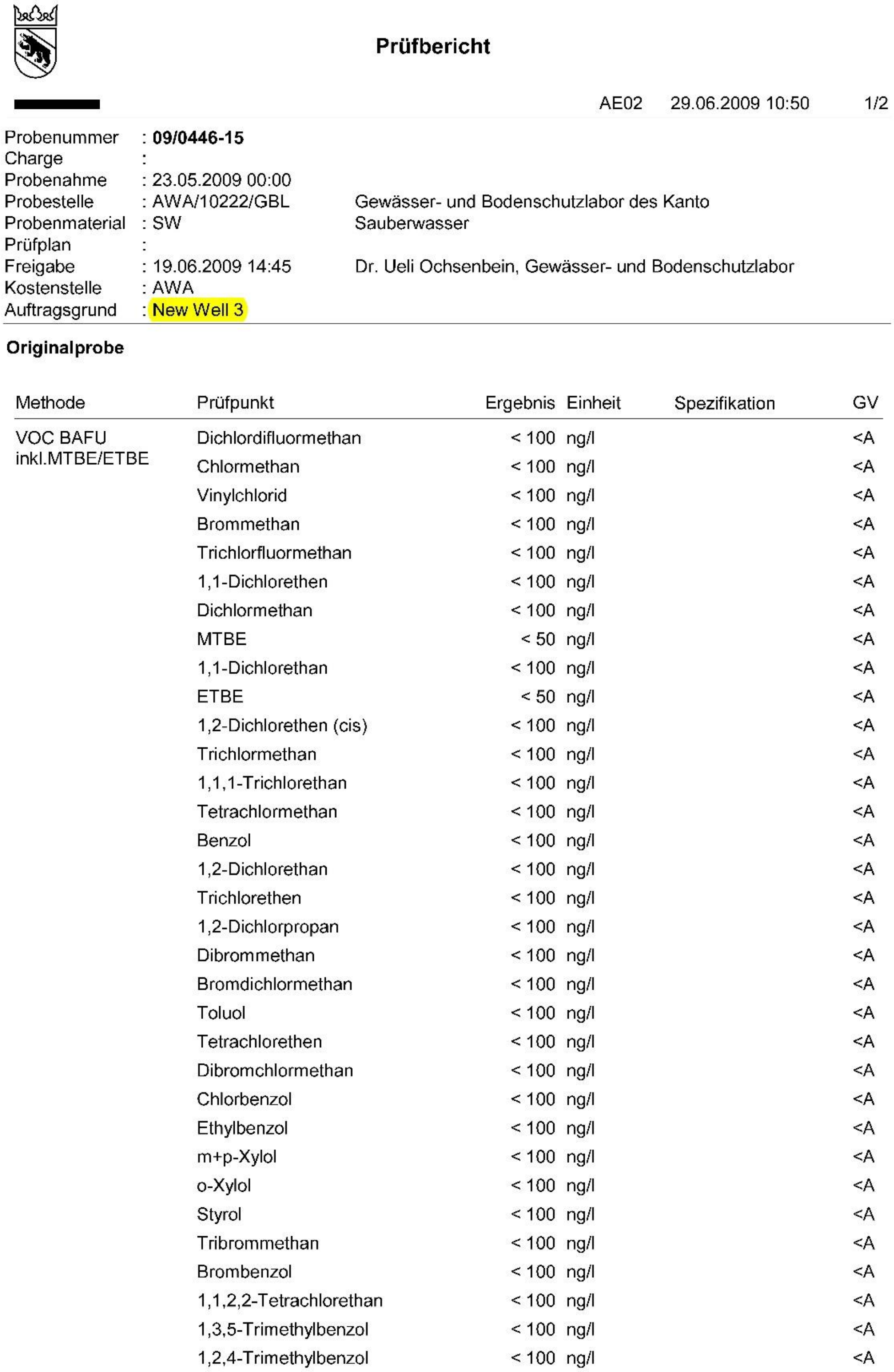
AE02 29.06.2009 10:50 2/2

Probenummer : **09/0446-14**
Charge :
Probenahme : 23.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : New Well 2

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)



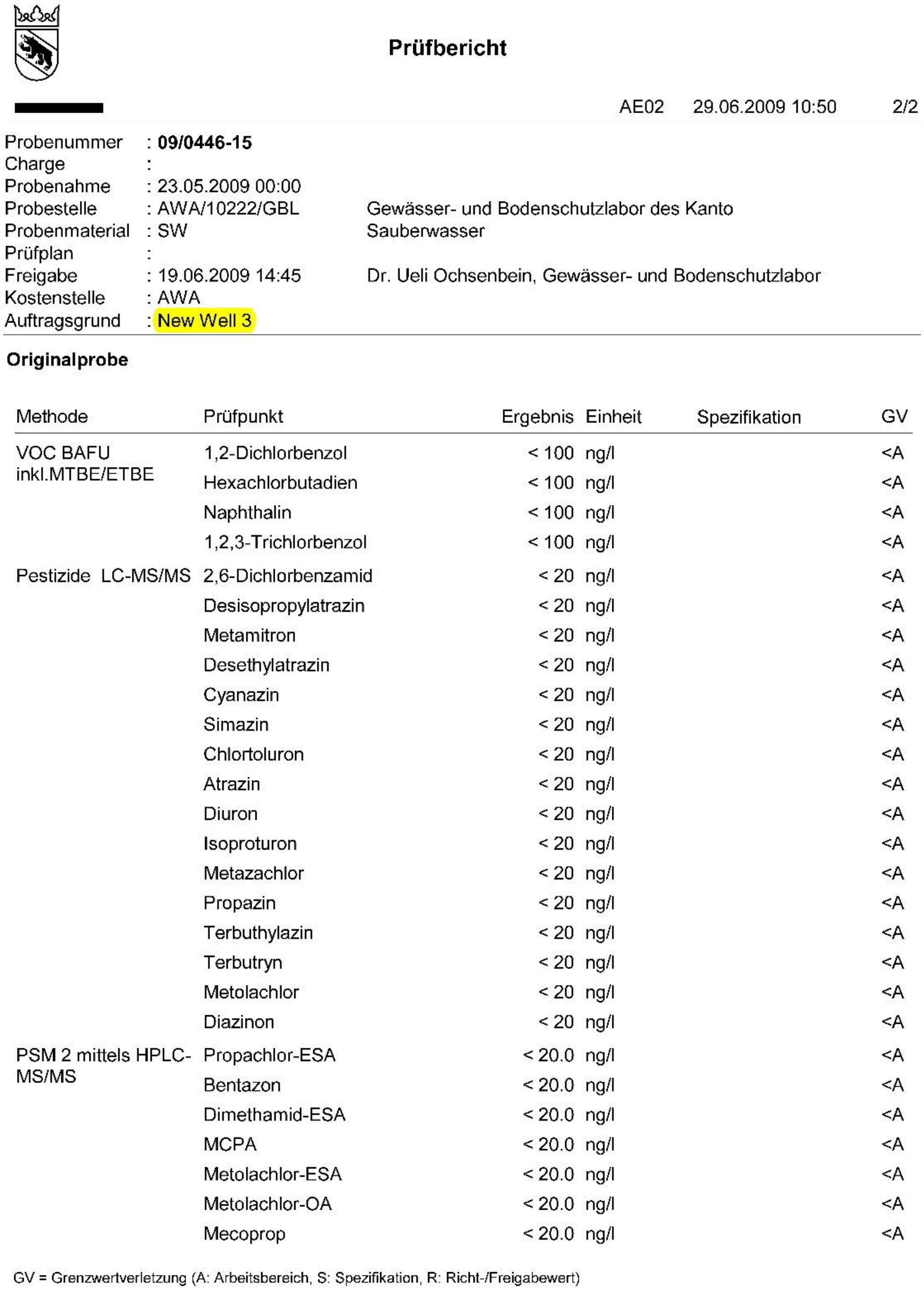
**Prüfbericht**

AE02 29.06.2009 10:50 1/2

Probenummer : **09/0446-15**
Charge :
Probenahme : 23.05.2009 00:00
Probestelle : AWA/10222/GBL Gewässer- und Bodenschutzlabor des Kanto
Probenmaterial : SW Sauberwasser
Prüfplan :
Freigabe : 19.06.2009 14:45 Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor
Kostenstelle : AWA
Auftragsgrund : New Well 3

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | Dichlordifluormethan | < 100 | ng/l | | <A |
| | Chlormethan | < 100 | ng/l | | <A |
| | Vinylchlorid | < 100 | ng/l | | <A |
| | Brommethan | < 100 | ng/l | | <A |
| | Trichlorfluormethan | < 100 | ng/l | | <A |
| | 1,1-Dichlorethen | < 100 | ng/l | | <A |
| | Dichlormethan | < 100 | ng/l | | <A |
| | MTBE | < 50 | ng/l | | <A |
| | 1,1-Dichlorethan | < 100 | ng/l | | <A |
| | ETBE | < 50 | ng/l | | <A |
| | 1,2-Dichlorethen (cis) | < 100 | ng/l | | <A |
| | Trichlormethan | < 100 | ng/l | | <A |
| | 1,1,1-Trichlorethan | < 100 | ng/l | | <A |
| | Tetrachlormethan | < 100 | ng/l | | <A |
| | Benzol | < 100 | ng/l | | <A |
| | 1,2-Dichlorethan | < 100 | ng/l | | <A |
| | Trichlorethen | < 100 | ng/l | | <A |
| | 1,2-Dichlorpropan | < 100 | ng/l | | <A |
| | Dibrommethan | < 100 | ng/l | | <A |
| | Bromdichlormethan | < 100 | ng/l | | <A |
| | Toluol | < 100 | ng/l | | <A |
| | Tetrachlorethen | < 100 | ng/l | | <A |
| | Dibromchlormethan | < 100 | ng/l | | <A |
| | Chlorbenzol | < 100 | ng/l | | <A |
| | Ethylbenzol | < 100 | ng/l | | <A |
| | m+p-Xylol | < 100 | ng/l | | <A |
| | o-Xylol | < 100 | ng/l | | <A |
| | Styrol | < 100 | ng/l | | <A |
| | Tribrommethan | < 100 | ng/l | | <A |
| | Brombenzol | < 100 | ng/l | | <A |
| | 1,1,2,2-Tetrachlorethan | < 100 | ng/l | | <A |
| | 1,3,5-Trimethylbenzol | < 100 | ng/l | | <A |
| | 1,2,4-Trimethylbenzol | < 100 | ng/l | | <A |



**Prüfbericht**

AE02 29.06.2009 10:50 2/2

| | | |
|---|---|---|
| Probenummer | : **09/0446-15** | |
| Charge | : | |
| Probenahme | : 23.05.2009 00:00 | |
| Probestelle | : AWA/10222/GBL | Gewässer- und Bodenschutzlabor des Kanto |
| Probenmaterial | : SW | Sauberwasser |
| Prüfplan | : | |
| Freigabe | : 19.06.2009 14:45 | Dr. Ueli Ochsenbein, Gewässer- und Bodenschutzlabor |
| Kostenstelle | : AWA | |
| Auftragsgrund | : New Well 3 | |

**Originalprobe**

| Methode | Prüfpunkt | Ergebnis | Einheit | Spezifikation | GV |
|---|---|---|---|---|---|
| VOC BAFU inkl.MTBE/ETBE | 1,2-Dichlorbenzol | < 100 | ng/l | | <A |
| | Hexachlorbutadien | < 100 | ng/l | | <A |
| | Naphthalin | < 100 | ng/l | | <A |
| | 1,2,3-Trichlorbenzol | < 100 | ng/l | | <A |
| Pestizide LC-MS/MS | 2,6-Dichlorbenzamid | < 20 | ng/l | | <A |
| | Desisopropylatrazin | < 20 | ng/l | | <A |
| | Metamitron | < 20 | ng/l | | <A |
| | Desethylatrazin | < 20 | ng/l | | <A |
| | Cyanazin | < 20 | ng/l | | <A |
| | Simazin | < 20 | ng/l | | <A |
| | Chlortoluron | < 20 | ng/l | | <A |
| | Atrazin | < 20 | ng/l | | <A |
| | Diuron | < 20 | ng/l | | <A |
| | Isoproturon | < 20 | ng/l | | <A |
| | Metazachlor | < 20 | ng/l | | <A |
| | Propazin | < 20 | ng/l | | <A |
| | Terbuthylazin | < 20 | ng/l | | <A |
| | Terbutryn | < 20 | ng/l | | <A |
| | Metolachlor | < 20 | ng/l | | <A |
| | Diazinon | < 20 | ng/l | | <A |
| PSM 2 mittels HPLC-MS/MS | Propachlor-ESA | < 20.0 | ng/l | | <A |
| | Bentazon | < 20.0 | ng/l | | <A |
| | Dimethamid-ESA | < 20.0 | ng/l | | <A |
| | MCPA | < 20.0 | ng/l | | <A |
| | Metolachlor-ESA | < 20.0 | ng/l | | <A |
| | Metolachlor-OA | < 20.0 | ng/l | | <A |
| | Mecoprop | < 20.0 | ng/l | | <A |

GV = Grenzwertverletzung (A: Arbeitsbereich, S: Spezifikation, R: Richt-/Freigabewert)

Return to where text linked to Box 5 ↥

# Box 6 – List of Pesticides Investigated by Innotech Alberta

EGO-3 well, sampled in triplicate, May 2015. All compounds were < LOD (limit of detection).

| **Parameter** | **Units** | **Detection limit** | **Quantification limit** |
|---|---|---|---|
| 2,4-D | ug/L | 0.005 | 0.00625 |
| 2,4-DB | ug/L | 0.005 | 0.00625 |
| 2,4-Dichlorophenol | ug/L | 0.005 | 0.00625 |
| 2,4-DP | ug/L | 0.004 | 0.00625 |
| 4-Chloro-2-methylphenol | ug/L | 0.008 | 0.00625 |
| Aldicarb | ug/L | 0.3 | 0.5 |
| Aldicarb sulfone | ug/L | 0.007 | 0.0125 |
| Aldicarb sulfoxide | ug/L | 0.002 | 0.0125 |
| Aldrin | ug/L | 0.004 | 0.00625 |
| alpha-BHC | ug/L | 0.005 | 0.00625 |
| alpha-Endosulfan | ug/L | 0.004 | 0.00625 |
| Aminopyralid | ug/L | 0.02 | 0.0625 |
| Atrazine | ug/L | 0.002 | 0.00625 |
| Bentazon | ug/L | 0.005 | 0.0125 |
| Bromacil | ug/L | 0.02 | 0.03125 |
| Bromoxynil | ug/L | 0.004 | 0.00625 |
| Carbathiin | ug/L | 0.09 | 0.125 |
| Chlorothalonil | ug/L | 0.007 | 0.0125 |
| Chlorpyrifos | ug/L | 0.02 | 0.025 |
| Clodinafop acid metabolite | ug/L | 0.02 | 0.0313 |
| Clodinafop-propargyl | ug/L | 0.02 | 0.0313 |
| Clopyralid | ug/L | 0.03 | 0.125 |
| Cyanazine | ug/L | 0.02 | 0.03125 |
| Desethyl atrazine | ug/L | 0.004 | 0.03125 |
| Desisopropyl atrazine | ug/L | 0.01 | 0.03125 |
| Diazinon | ug/L | 0.007 | 0.0125 |
| Dicamba | ug/L | 0.02 | 0.025 |
| Diclofop-methyl | ug/L | 0.008 | 0.0313 |
| Dieldrin | ug/L | 0.004 | 0.00625 |
| Dimethoate | ug/L | 0.005 | 0.00625 |
| Disulfoton | ug/L | 0.02 | 0.125 |
| Diuron | ug/L | 0.02 | 0.125 |
| Ethalfluralin | ug/L | 0.003 | 0.00625 |
| Ethion | ug/L | 0.08 | 0.125 |
| Ethofumesate | ug/L | 0.007 | 0.0125 |
| Fenoxaprop-P-ethyl | ug/L | 0.03 | 0.0313 |
| Fluazifop | ug/L | 0.004 | 0.00625 |
| Fluroxypyr | ug/L | 0.009 | 0.0125 |
| gamma-BHC | ug/L | 0.006 | 0.00625 |
| Guthion | ug/L | 0.09 | 0.125 |

| | | | |
|---|---|---|---|
| Hexaconazole | ug/L | 0.004 | 0.00625 |
| Imazamethabenz-methyl | ug/L | 0.005 | 0.03125 |
| Imazamox | ug/L | 0.007 | 0.0125 |
| Imazethapyr | ug/L | 0.03 | 0.0313 |
| Iprodione | ug/L | 0.03 | 0.03125 |
| Linuron | ug/L | 0.02 | 0.03125 |
| Malathion | ug/L | 0.007 | 0.0625 |
| MCPA | ug/L | 0.003 | 0.00625 |
| MCPB | ug/L | 0.02 | 0.0313 |
| MCPP | ug/L | 0.004 | 0.00625 |
| Metalaxyl-M | ug/L | 0.007 | 0.0125 |
| Methomyl | ug/L | 0.1 | 0.125 |
| Metolachlor | ug/L | 0.003 | 0.00625 |
| Metribuzin | ug/L | 0.008 | 0.0125 |
| Napropamide | ug/L | 0.02 | 0.03125 |
| Oxycarboxin | ug/L | 0.002 | 0.03125 |
| p,p-Methoxychlor | ug/L | 0.02 | 0.03125 |
| Parathion | ug/L | 0.004 | 0.00625 |
| Phorate | ug/L | 0.004 | 0.025 |
| Picloram | ug/L | 0.007 | 0.0125 |
| Propiconazole | ug/L | 0.009 | 0.03125 |
| Pyridaben | ug/L | 0.02 | 0.0313 |
| Quinclorac | ug/L | 0.003 | 0.00625 |
| Quizalofop | ug/L | 0.02 | 0.0625 |
| Simazine | ug/L | 0.004 | 0.00625 |
| Terbufos | ug/L | 0.01 | 0.0313 |
| Thiamethoxam | ug/L | 0.005 | 0.0625 |
| Triallate | ug/L | 0.008 | 0.0125 |
| Triclopyr | ug/L | 0.006 | 0.0125 |
| Trifluralin | ug/L | 0.002 | 0.00625 |
| Vinclozolin | ug/L | 0.01 | 0.0125 |

**Return to where text linked to Box 6↥**

## Box 7 – Time Series of Elements

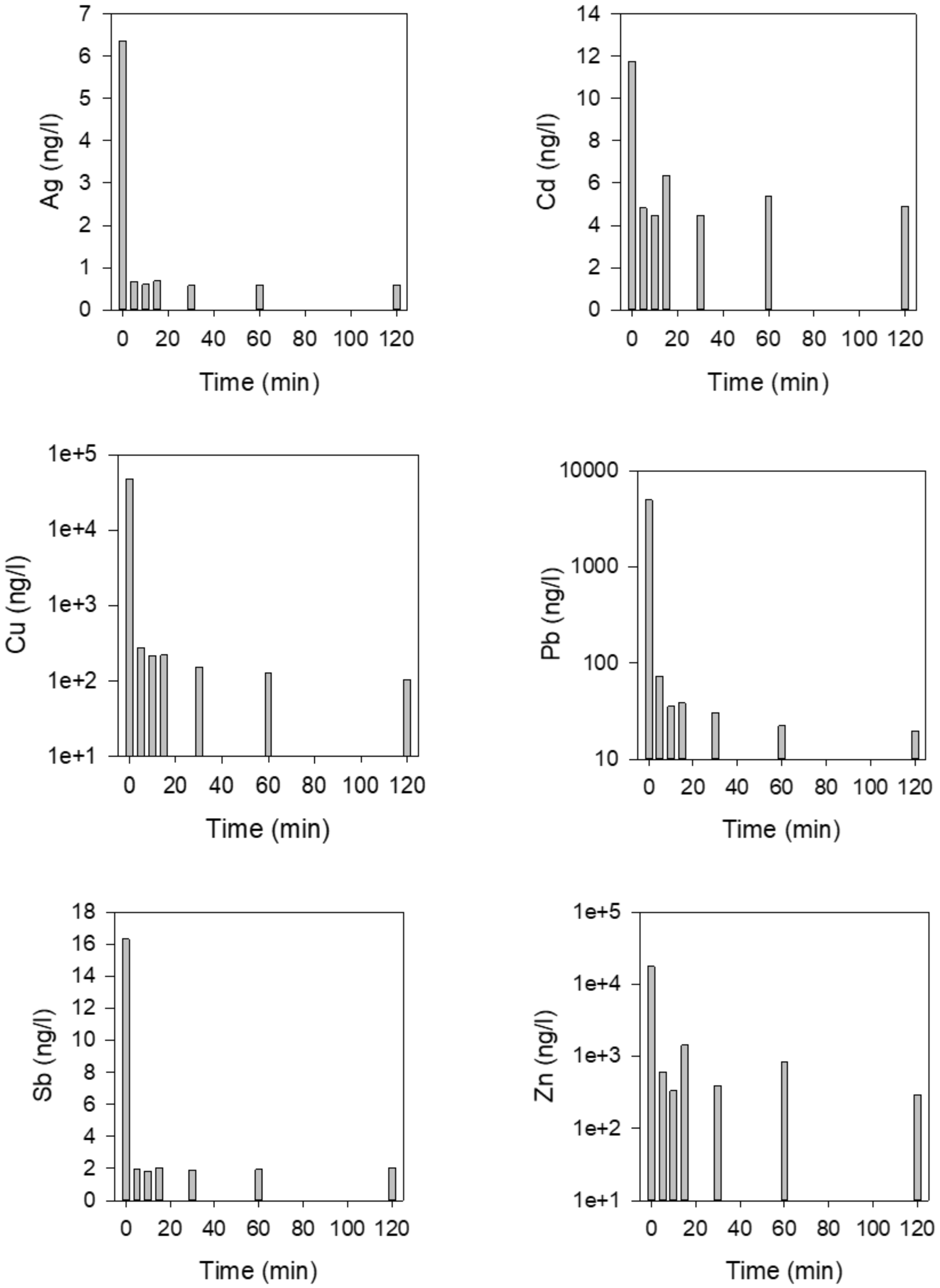


**Figure Box 7-1 -** Time series of elements released from the original brass valve on the farmhouse well: silver (Ag), cadmium (Cd), copper (Cu), lead (Pb), antimony (Sb), and zinc (Zn). Water samples were collected in July 2005 and analyzed using sector-field ICP-MS at the University of Heidelberg. All concentrations in units of ng/L.

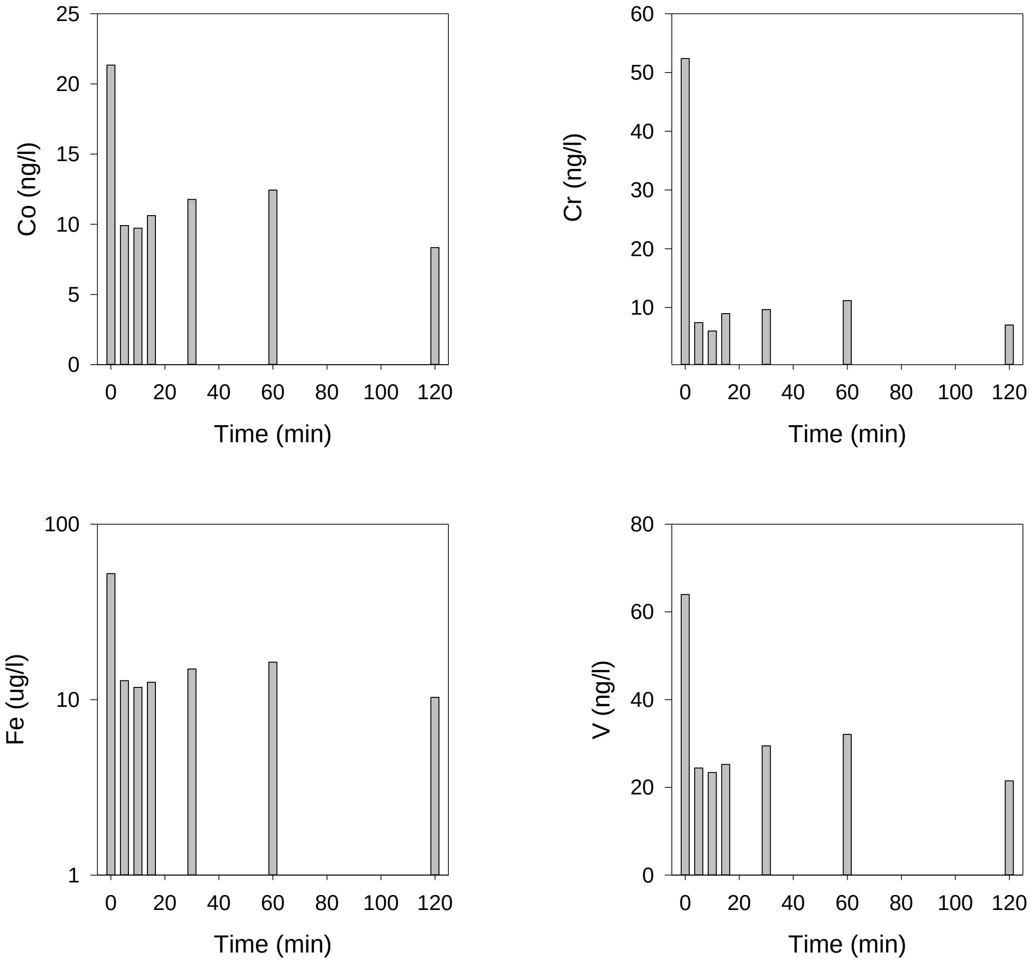


**Figure Box 7-2 -** Time series of elements released from the original brass valve on the farmhouse well: cobalt (Co), chromium (Cr), iron (Fe), and vanadium (V). Water samples were collected in July 2005 and analyzed using sector-field ICP-MS at the University of Heidelberg. Concentrations in units of ng/L except for Fe (µg/L).

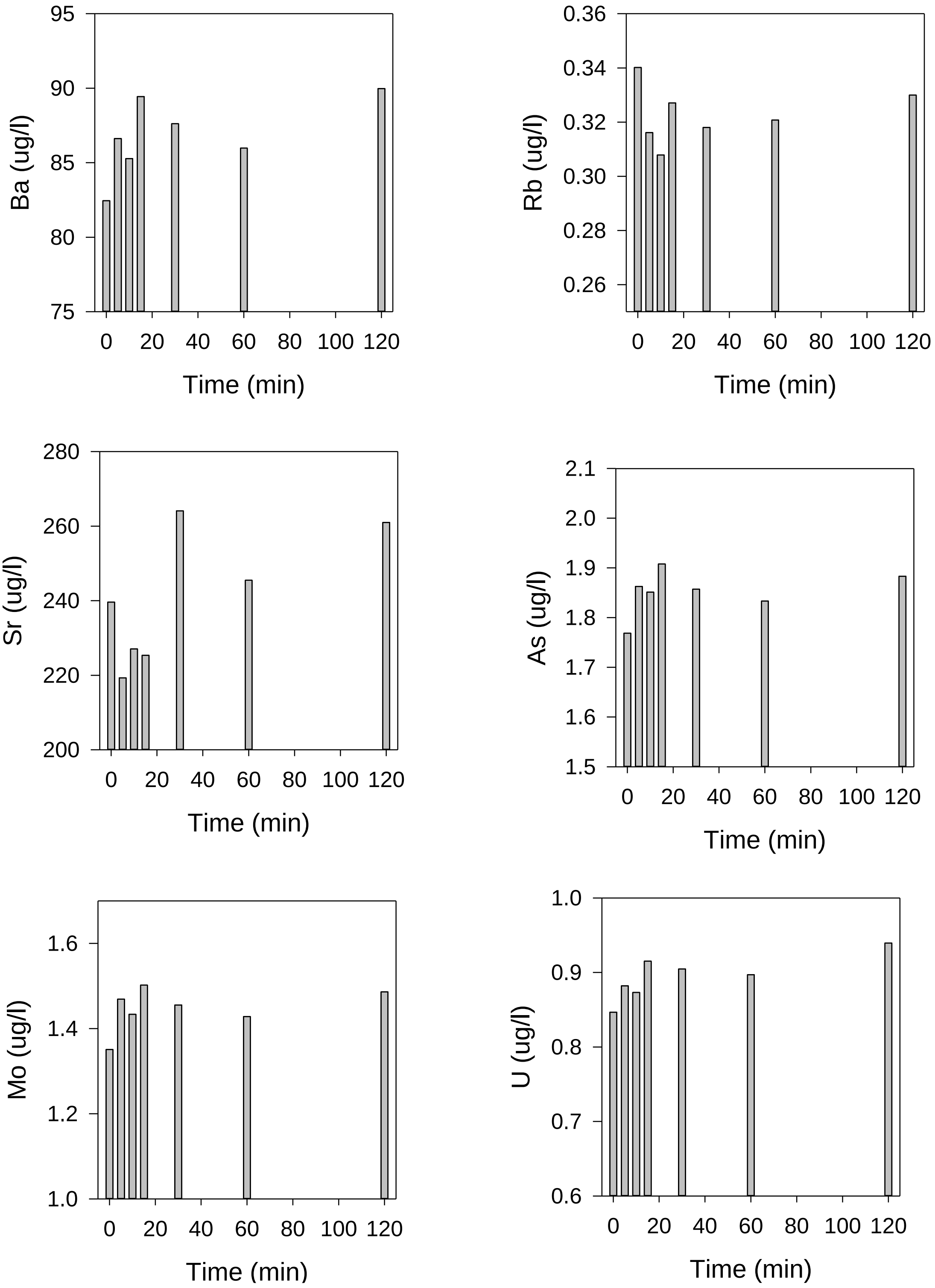


**Figure Box 7-3 -** Time series of elements released from the original brass valve on the farmhouse well: barium (Ba), rubidium (Rb), strontium (Sr), arsenic (As), molybdenum (Mo), and uranium (U). Water samples were collected in July 2005 and analyzed using sector-field ICP-MS at the University of Heidelberg. All concentrations in units of µg/L.

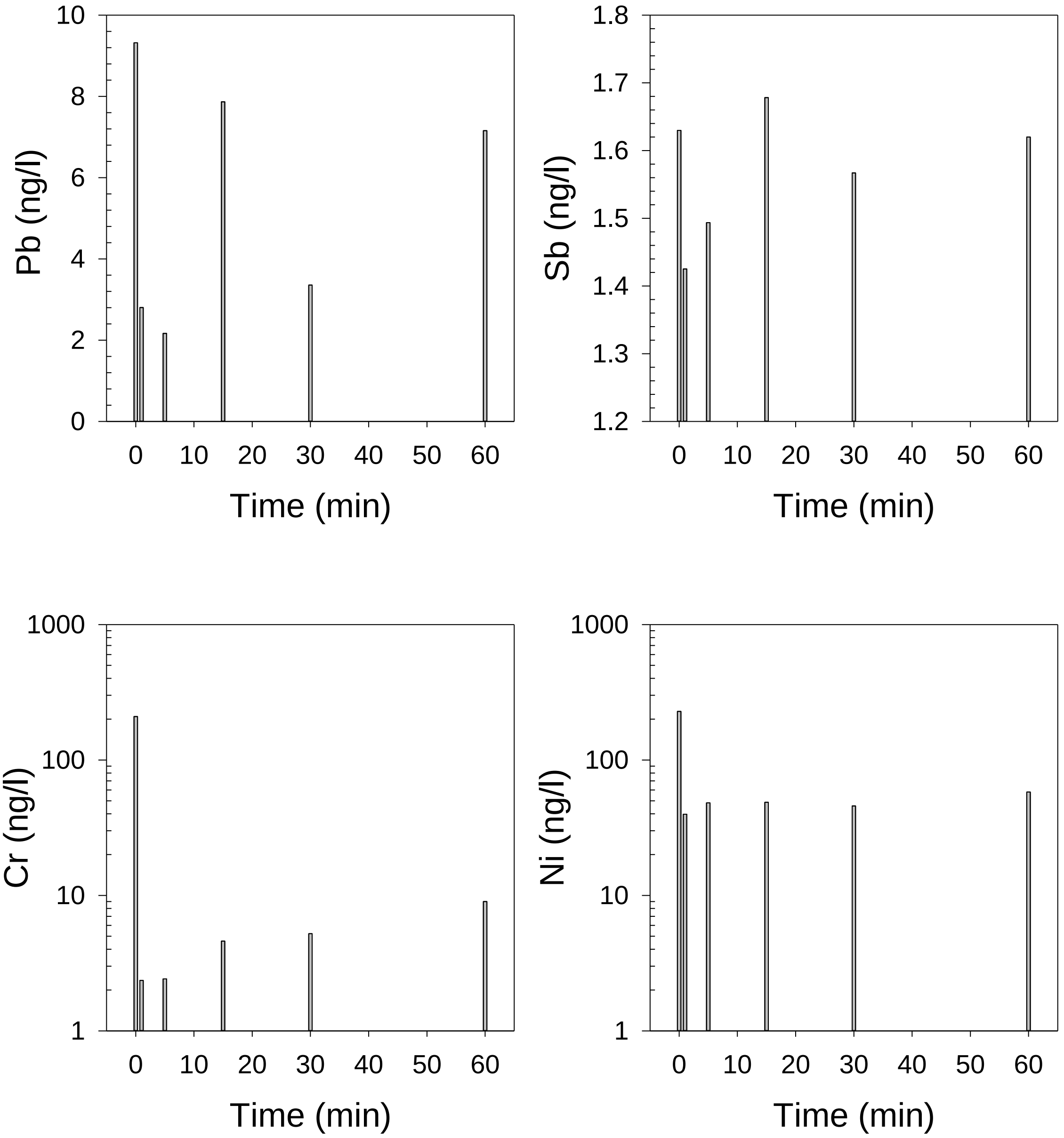


**Figure Box 7-4 -** Time series of elements released from the new stainless steel valve on the farmhouse well: lead (Pb), antimony (Sb), nickel (Ni), and chromium (Cr). Water samples were collected in May 2007 and analyzed using sector-field ICP-MS at the University of Heidelberg. All concentrations in units of ng/L.

Return to where text linked to Box 7↥

## Box 8 – Stratigraphy and Particle Size Analysis

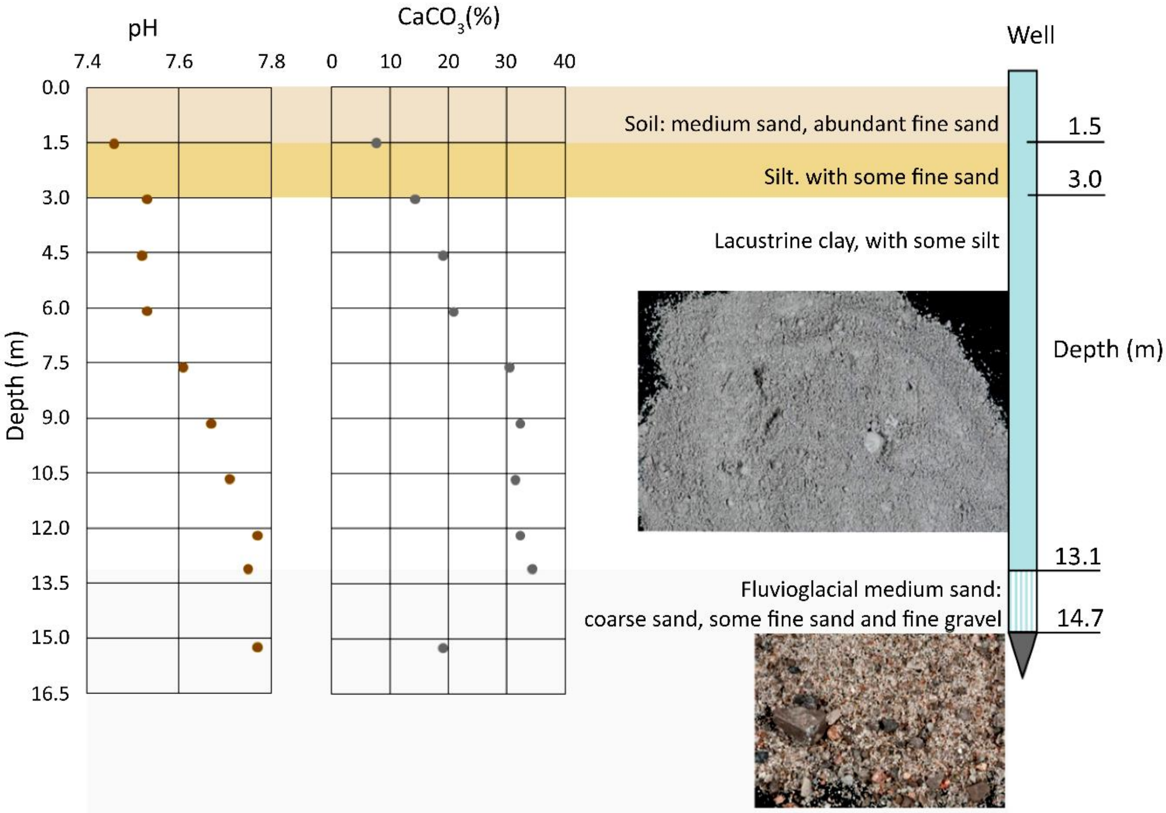


**Figure Box 8-1 -** Schematic illustration of the stratigraphy of EGO-1 and EGO-2, including pH and calcium carbonate content of sediments.

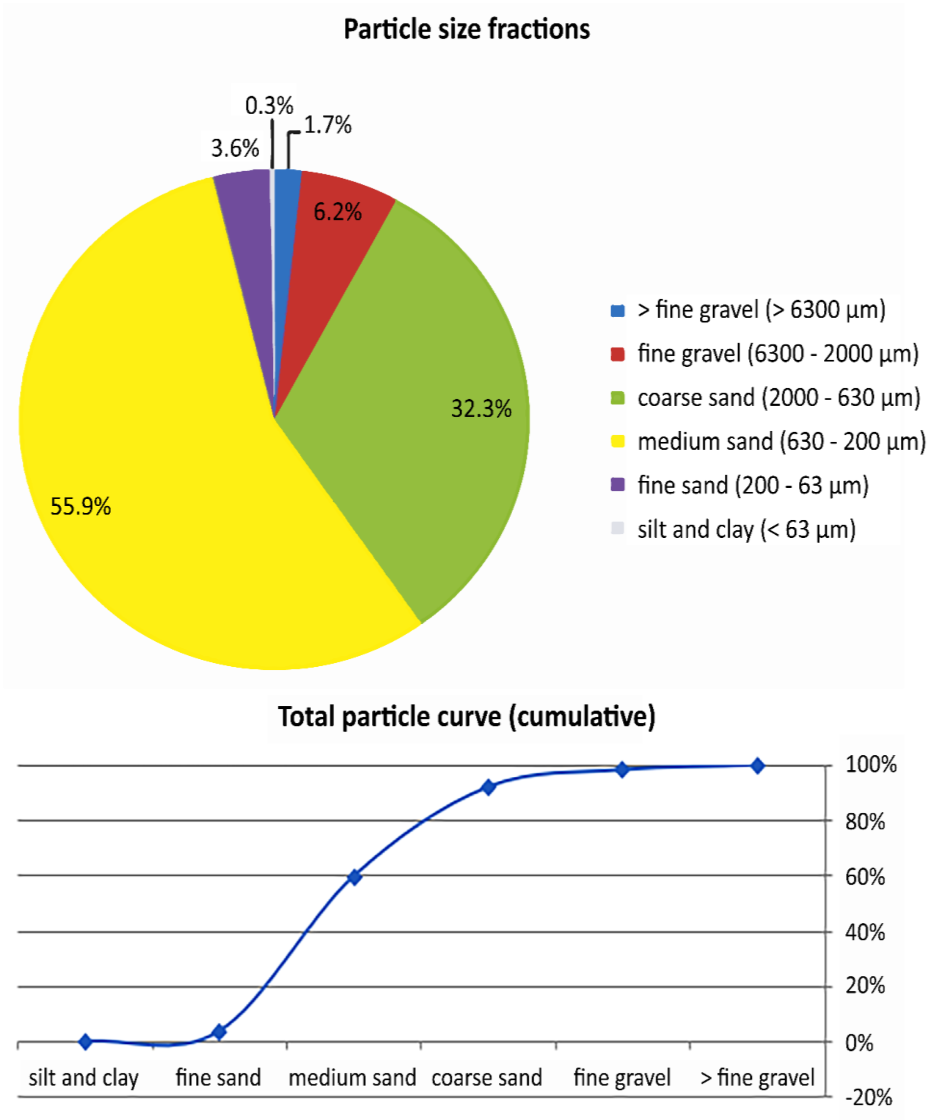


**Figure Box 8-2 -** Particle size analysis of aquifer sand, EGO-1 and EGO-2.

EGO-1 and EGO-2, wooden cabin.

EGO-3, wooden cabin.

**Figure Box 8-3** - Wooden cabins housing the EGO wells.

Return to where text linked to Box 8↥

## Box 9 – Concentrations of Trace Elements in Groundwater

**Box Table 9-1 -** Concentrations of trace elements in groundwater from farmhouse well, EGO-1 stainless steel well, and EGO-2 high-density polyethylene. Water samples were collected in 2009 and 2010. Trace elements were analyzed using sector field ICP-MS (Element 2), University of Heidelberg, Germany. RSD is relative standard deviation.

| | | Original farmhouse well (March, 2009) | | | EGO-1 stainless steel well (March, 2010) | | | EGO-2 HDPE well (March, 2010) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **Concentration** | **Standard deviation (n=3)** | **RSD (%)** | **Concentration** | **Standard deviation (n=15)** | **RSD (%)** | **Concentration** | **Standard deviation (n=15)** | **RSD (%)** |
| Ag | ng/L | 1.1 | 0.30 | 28.2 | 0.75 | 1.54 | 206 | 0.32 | 0.19 | 59.6 |
| Al | µg/L | 3.2 | 0.81 | 25.2 | 0.63 | 0.09 | 13.7 | 0.69 | 0.05 | 7.7 |
| As | µg/L | 1.8 | 0.02 | 1.1 | 1.58 | 0.12 | 7.7 | 1.45 | 0.11 | 7.3 |
| Ba | µg/L | 109 | 1.12 | 1 | 89.5 | 9.5 | 10.6 | 86.2 | 8.7 | 10.1 |
| Be | ng/L | 1.3 | 0.07 | 5.2 | 0.81 | 0.3 | 36.9 | 0.86 | 0.26 | 30.6 |
| Bi | ng/L | 4.6 | 0.12 | 2.5 | 0.15 | 0.15 | 97.9 | 0.13 | 0.15 | 113 |
| Ca | mg/L | 30.2 | 0.18 | 0.6 | 31.6 | 1.4 | 4.3 | 31 | 1 | 3.2 |
| Cd | ng/L | 6.2 | 1.12 | 18 | 2.9 | 0.7 | 23.3 | 3.4 | 1.3 | 39.4 |
| Co | ng/L | 11.2 | 1.04 | 9.3 | 14.1 | 0.5 | 3.5 | 19 | 0.4 | 2.3 |
| Cr | ng/L | 28.7 | 19.1 | 66.7 | 3.8 | 1.2 | 32.4 | 3.3 | 1.9 | 56.8 |
| Cu | ng/L | 713 | 189 | 26.5 | 51.5 | 51.2 | 99.4 | 71 | 28.6 | 40.3 |
| Fe | µg/L | 27.5 | 20.9 | 75.9 | 8.0 | 0.7 | 8.4 | 3.9 | 0.4 | 9.8 |
| Ge | ng/L | 13.4 | 0.61 | 4.5 | 7.1 | 0.4 | 5.5 | 7.1 | 0.4 | 5.2 |
| Li | µg/L | 3.5 | 0.04 | 1.1 | 3.7 | 0.4 | 10.1 | 3.5 | 0.2 | 5 |
| Mg | mg/L | 18.5 | 0.12 | 0.6 | 23.8 | 1.3 | 5.3 | 23.5 | 1.3 | 5.5 |
| Mn | µg/L | 8.5 | 0.15 | 1.7 | 8.6 | 0.6 | 7.5 | 9.3 | 0.6 | 6.4 |
| Mo | µg/L | 0.7 | 0.15 | 22.4 | 1.4 | 0.1 | 9.4 | 1.4 | 0.1 | 6.3 |
| Na | mg/L | 9.7 | 0.06 | 0.6 | 8.1 | 0.2 | 2.7 | 8.3 | 0.3 | 3.1 |
| Ni | ng/L | 210 | 52.1 | 24.8 | 44.9 | 3.1 | 6.8 | 48.5 | 3.9 | 8 |
| Pb | ng/L | 82.2 | 10.7 | 13.1 | 8.0 | 9.9 | 124 | 3.9 | 2.4 | 60 |
| Rb | ng/L | 313 | 3.1 | 1.0 | 325 | 18 | 6 | 321 | 15 | 5 |
| Re | ng/L | 1.4 | 0.01 | 0.9 | 1.27 | 0.12 | 9.7 | 1.23 | 0.11 | 8.7 |
| Sb | ng/L | 1.8 | 0.35 | 19.6 | 1.27 | 0.34 | 27.2 | 1.29 | 0.28 | 21.8 |
| Sc | ng/L | 1.2 | 0.42 | 34.1 | 5.64 | 1.69 | 30.0 | 5.10 | 1.42 | 27.9 |
| Sr | mg/L | 1.2 | 0.01 | 1.2 | 1.75 | 0.21 | 11.8 | 1.71 | 0.18 | 10.2 |
| Te | ng/L | 4.7 | 0.97 | 20.7 | 2.55 | 0.87 | 33.9 | 2.74 | 0.82 | 29.8 |
| Th | pg/L | 1020 | 569 | 55.9 | 49 | 35 | 71 | 41 | 13 | 31 |
| Tl | ng/L | 1.1 | 0.03 | 3.0 | 0.69 | 0.05 | 7.4 | 0.89 | 0.1 | 11.2 |
| U | ng/L | 870 | 18.9 | 2.2 | 846 | 100 | 12 | 840 | 71 | 8 |
| V | ng/L | 25.9 | 2.4 | 9.4 | 36 | 1 | 4 | 58 | 1 | 2 |
| W | ng/L | 60.8 | 13.2 | 21.6 | 139 | 15 | 11 | 142 | 10 | 7 |

**Table Box 9-2 -** Concentrations of trace elements in groundwater from EGO-1 (stainless steel) well, collected in different bottle types: commercially available, precleaned PFA bottles for trace metals research, and acid-cleaned LDPE (Heidelberg) and HDPE (GSC). Water samples were collected in September 2010. Trace elements were analyzed using sector field ICP-MS (Element 2), University of Heidelberg, Germany. RSD is relative standard deviation.

| | | **PFA** | | | **LDPE (University of Heidelberg)** | | | **HDPE (GSC, Ottawa)** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=15)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** |
| Ag | ng/L | 0.26 | 0.29 | 111 | 0.8 | 0.6 | 66.4 | 0.18 | 0.52 | 288 |
| Al | µg/L | 0.59 | 0.07 | 11.8 | 0.8 | 0.9 | 111 | 3.78 | 0.91 | 24 |
| As | µg/L | 1300 | 79.8 | 6.2 | 1,830 | 152 | 8.3 | 1,240 | 117 | 9.5 |
| Ba | µg/L | 101 | 6.44 | 6.4 | 109 | 9.8 | 9 | 92 | 8.79 | 9.6 |
| Be | ng/L | 1.09 | 0.08 | 7.3 | 1.1 | 0.1 | 11.5 | 1.18 | 0.31 | 26.3 |
| Bi | ng/L | 0.05 | 0.48 | 1,050 | 0.1 | 0.4 | 388 | 0.04 | 0.22 | 554 |
| Ca | mg/L | 30.4 | 2.04 | 6.7 | 34.5 | 2.5 | 7.3 | 28.6 | 2.15 | 7.5 |
| Cd | ng/L | 1.68 | 0.33 | 19.5 | 1.7 | 0.4 | 26.5 | 1.67 | 0.34 | 20.3 |
| Co | ng/L | 14.5 | 1.73 | 12.0 | 15.7 | 1.3 | 8.0 | 12.3 | 1.15 | 9.4 |
| Cr | ng/L | 3.86 | 25.9 | 672 | 4.8 | 10.4 | 216 | 1.77 | 0.89 | 50 |
| Cu | ng/L | 44.7 | 36.6 | 81.9 | 199 | 226 | 113 | 72.5 | 30 | 41.4 |
| Fe | µg/L | 7.38 | 0.63 | 8.5 | 8.3 | 1.1 | 13.1 | 7.38 | 0.66 | 8.9 |
| Ge | ng/L | 8.49 | 0.44 | 5.2 | 7.7 | 0.7 | 9.1 | 8.08 | 0.42 | 5.2 |
| Li | µg/L | 4.38 | 0.28 | 6.5 | 4.7 | 0.4 | 9.4 | 3.96 | 0.36 | 9.2 |
| Mg | mg/L | 22.4 | 1.49 | 6.7 | 25 | 1.8 | 7.3 | 21 | 1.43 | 6.8 |
| Mn | µg/L | 8.45 | 0.55 | 6.5 | 9.4 | 0.6 | 6.5 | 7.82 | 0.58 | 7.4 |
| Mo | µg/L | 1.47 | 0.09 | 6.4 | 1.3 | 0.2 | 13.1 | 1.37 | 0.15 | 10.8 |
| Na | mg/L | 7.2 | 0.53 | 7.4 | 8.1 | 0.6 | 7.8 | 6.74 | 0.5 | 7.4 |
| Ni | ng/L | 58.3 | 23 | 39.4 | 49.5 | 28.5 | 57.5 | 31.3 | 13.8 | 44.2 |
| Pb | ng/L | 2.55 | 1,420 | 55,500 | 44.9 | 110 | 245 | 1.51 | 114 | 7,530 |
| Rb | ng/L | 0.32 | 0.02 | 6.5 | 0.4 | 0 | 8.7 | 0.3 | 0.03 | 9.7 |
| Re | ng/L | 1.3 | 0.09 | 6.7 | 1.4 | 0.1 | 8.5 | 1.22 | 0.12 | 9.5 |
| Re | ng/L | 1.27 | 0.08 | 6.5 | 1.4 | 0.1 | 8.3 | 1.19 | 0.11 | 9.3 |
| Sb | ng/L | 1.03 | 0.24 | 23.3 | 1.6 | 1.2 | 75 | 0.91 | 0.39 | 42.6 |
| Sc | ng/L | 0.47 | 0.09 | 19.4 | 0.5 | 0.1 | 21.3 | 0.34 | 0.26 | 75.6 |
| Sr | mg/L | 1.35 | 0.08 | 6.3 | 1.48 | 0.13 | 8.5 | 1.24 | 0.14 | 11.4 |
| Te | ng/L | 1.4 | 0.16 | 11.5 | 1.4 | 0.1 | 5.9 | 1.34 | 0.15 | 10.9 |
| Th | pg/L | 33.6 | 16.4 | 48.9 | 41.6 | 15.6 | 37.5 | 29 | 16.7 | 57.5 |
| Tl | ng/L | 0.66 | 0.05 | 7.9 | 0.7 | 0.1 | 8.9 | 0.57 | 0.06 | 11.2 |
| U | ng/L | 854 | 49.5 | 5.8 | 923 | 83.2 | 9 | 782 | 71 | 9.1 |
| V | ng/L | 23 | 2.27 | 9.9 | 24.7 | 6.7 | 27.2 | 177 | 60.4 | 34.1 |
| W | ng/L | 142 | 10.4 | 7.3 | 114 | 22.2 | 19.4 | 125 | 18.1 | 14.5 |
| W | ng/L | 142 | 10.4 | 7.3 | 113 | 22 | 19.4 | 123 | 18.3 | 14.8 |
| Zn | ng/L | 66.2 | 24.4 | 36.9 | 754 | 2,570 | 341 | 54.6 | 39.3 | 72.1 |

**Table Box 9-3 -** Concentrations of trace elements in groundwater from EGO-2 (HDPE) well, collected in different bottle types: commercially available, precleaned PFA bottles for trace metals research, and acid-cleaned LDPE (Heidelberg) and HDPE (GSC). Water samples were collected in September 2010. Trace elements were analyzed using sector field ICP-MS (Element 2), University of Heidelberg, Germany. RSD is relative standard deviation.

| | | PFA | | | LDPE (University of Heidelberg) | | | HDPE (GSC, Ottawa) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **PFA Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=15)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** |
| Ag | ng/L | 0.6 | 0.2 | 29.9 | 0.4 | 0.3 | 85.6 | 0.2 | 0 | 23 |
| Al | µg/L | 0.6 | 0.1 | 10 | 0.7 | 0.8 | 110 | 4.3 | 1.4 | 31.7 |
| As | µg/L | 1,370 | 127 | 9.3 | 1,610 | 184 | 11.5 | 1200 | 73.2 | 6.1 |
| Ba | µg/L | 100 | 9.5 | 9.5 | 93.7 | 12 | 12.8 | 86.7 | 4.9 | 5.6 |
| Be | ng/L | 1.2 | 0.1 | 8.9 | 1.2 | 0.2 | 14.1 | 1 | 0.1 | 7.5 |
| Bi | ng/L | 0.1 | 0.2 | 273 | 0.1 | 0.2 | 273 | 0 | 0 | 34.8 |
| Ca | mg/L | 30.3 | 2.6 | 8.7 | 30.6 | 3.4 | 11.1 | 27.2 | 1.4 | 5.1 |
| Cd | ng/L | 1.5 | 0.2 | 11.9 | 1.7 | 0.5 | 29.8 | 1.8 | 0.1 | 5.1 |
| Co | ng/L | 18 | 2.5 | 13.7 | 16.8 | 1.6 | 9.3 | 14.3 | 0.6 | 4.5 |
| Cr | ng/L | 2.6 | 3.8 | 145 | 2.1 | 6.3 | 306 | 1.3 | 0.4 | 33 |
| Cu | ng/L | 49.1 | 8.5 | 17.4 | 133 | 168 | 127 | 67.1 | 15.6 | 23.2 |
| Fe | µg/L | 5.4 | 0.4 | 8.3 | 6 | 0.6 | 9.5 | 4.9 | 0.3 | 5.2 |
| Ge | ng/L | 8.7 | 0.5 | 6 | 7.5 | 1.2 | 16.5 | 8 | 0.3 | 4.1 |
| Li | µg/L | 4.4 | 0.4 | 9.2 | 4.2 | 0.5 | 12.4 | 3.9 | 0.2 | 5 |
| Mg | mg/L | 22.6 | 2 | 8.9 | 22.9 | 2.5 | 10.9 | 20.6 | 0.8 | 3.9 |
| Mn | µg/L | 9.2 | 0.8 | 8.7 | 9.3 | 1.0 | 10.9 | 8.3 | 0.4 | 4.5 |
| Mo | µg/L | 1.5 | 0.1 | 9.2 | 1.3 | 0.2 | 14.5 | 1.3 | 0.1 | 5.4 |
| Na | mg/L | 7.4 | 0.7 | 9 | 7.6 | 0.9 | 11.9 | 6.8 | 0.4 | 5.6 |
| Ni | ng/L | 49 | 19.6 | 40 | 41.1 | 28.7 | 69.9 | 32.9 | 17.7 | 54 |
| Pb | ng/L | 1.4 | 92.1 | 6,600 | 7.7 | 191 | 2,480 | 1 | 1 | 96.8 |
| Rb | ng/L | 0.3 | 0 | 9.4 | 0.3 | 0 | 12 | 0.3 | 0 | 4.9 |
| Re | ng/L | 1.3 | 0.1 | 9.4 | 1.3 | 0.2 | 12.7 | 1.2 | 0.6 | 47.1 |
| Re | ng/L | 1.3 | 0.1 | 10.1 | 1.3 | 0.2 | 12.3 | 1.1 | 0.5 | 47.9 |
| Sb | ng/L | 1.1 | 0.1 | 11.3 | 1.1 | 1.9 | 168 | 0.9 | 0.1 | 9.5 |
| Sc | ng/L | 0.5 | 0.1 | 14.7 | 0.5 | 0.1 | 13.7 | 0.4 | 0 | 11 |
| Sr | mg/L | 1.29 | 0.26 | 20.5 | 1.35 | 0.18 | 13.6 | 1.24 | 0.08 | 6.2 |
| Te | ng/L | 1.6 | 0.3 | 19.5 | 1.4 | 0.1 | 5.5 | 1.4 | 0.1 | 8 |
| Th | pg/L | 48.1 | 9.2 | 19 | 44.9 | 10.8 | 24 | 31.3 | 666 | 2,130 |
| Tl | ng/L | 0.8 | 0.1 | 10.8 | 0.7 | 0.1 | 11.3 | 0.7 | 0 | 4.7 |
| U | ng/L | 888 | 108 | 12.2 | 849 | 106 | 12.5 | 789 | 41.3 | 5.2 |
| V | ng/L | 30.3 | 2.7 | 8.9 | 30.4 | 3.3 | 10.9 | 155 | 88.7 | 57.4 |
| W | ng/L | 163 | 18.6 | 11.4 | 110 | 20.6 | 18.7 | 136 | 8.4 | 6.2 |
| W | ng/L | 162 | 18.3 | 11.3 | 110 | 20.6 | 18.7 | 135 | 8.9 | 6.6 |
| Zn | ng/L | 76.8 | 7.6 | 10 | 145 | 2,840 | 1,950 | 60.3 | 8.3 | 13.8 |

**Table Box 9-4-** Concentrations of trace elements in groundwater from EGO-1 (stainless steel) well, collected in LDPE bottles cleaned using three different procedures and HDPE bottles (GSC). Water samples were collected in March 2011. Trace elements were analyzed using sector field ICP-MS (Element 2), University of Heidelberg, Germany. RSD is relative standard deviation.

| | | **LDPE (Original UGC)** | | | **LDPE (GSC)** | | | **LDPE (CBCS)** | | | **HDPE (GSC)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** |
| Ag | ng/L | 0.89 | 0.55 | 62.6 | 0.53 | 0.23 | 42.4 | 1.23 | 0.88 | 71.8 | 0.64 | 0.29 | 45.1 |
| Al | µg/L | 1.04 | 0.58 | 56 | 0.79 | 0.11 | 14 | 0.98 | 0.22 | 22.8 | 1.01 | 0.13 | 12.4 |
| As | ng/L | 1,720 | 225 | 13.1 | 1,690 | 143 | 8.45 | 1,980 | 192 | 9.68 | 1,690 | 152 | 9.03 |
| Ba | µg/L | 118 | 22.2 | 18.8 | 121 | 22.1 | 18.3 | 126 | 25.4 | 20.1 | 132 | 30.2 | 23 |
| Be | ng/L | 1.29 | 0.15 | 11.5 | 1.74 | 0.24 | 13.5 | 2.18 | 0.30 | 14 | 2.28 | 0.3 | 13.3 |
| Bi | ng/L | 0.14 | 0.05 | 34.9 | 0.08 | 0.03 | 36.6 | 0.13 | 0.06 | 44.6 | 0.05 | 0.02 | 30.7 |
| Ca | mg/L | 32.4 | 2.3 | 7.1 | 33.4 | 1.74 | 5.23 | 34.1 | 2.07 | 6.07 | 33.5 | 1.94 | 5.78 |
| Cd | ng/L | 2.95 | 0.71 | 24.1 | 3.91 | 1.1 | 28.2 | 4.33 | 1.46 | 33.7 | 3.61 | 1.08 | 29.9 |
| Co | ng/L | 13.9 | 0.69 | 4.95 | 14.7 | 0.51 | 3.48 | 14.9 | 0.74 | 5 | 14.4 | 0.34 | 2.34 |
| Cr | ng/L | 3.62 | 1.81 | 50.1 | 3.75 | 1.44 | 38.3 | 18.5 | 19.3 | 104 | 2.21 | 0.33 | 14.9 |
| Cu | µg/L | 0.35 | 0.11 | 29.8 | 0.75 | 0.22 | 29.8 | 0.92 | 0.28 | 30.3 | 0.86 | 0.24 | 27.8 |
| Fe | µg/L | 7.98 | 0.4 | 4.97 | 8.19 | 0.38 | 4.69 | 8.81 | 0.34 | 3.91 | 8.87 | 0.57 | 6.45 |
| Ge | ng/L | 6.99 | 1.23 | 17.6 | 8.13 | 0.35 | 4.29 | 9.77 | 0.93 | 9.55 | 8.55 | 0.17 | 1.95 |
| Li | µg/L | 4.76 | 0.44 | 9.26 | 4.8 | 0.42 | 8.76 | 4.65 | 0.21 | 4.52 | 5.01 | 0.39 | 7.82 |
| Mg | mg/L | 21.7 | 0.8 | 3.7 | 21.5 | 1.19 | 5.51 | 22.4 | 1.36 | 6.06 | 22.6 | 0.71 | 3.14 |
| Mn | µg/L | 8.63 | 0.19 | 2.25 | 9.02 | 0.18 | 2.04 | 9.44 | 0.3 | 3.16 | 9.39 | 0.35 | 3.74 |
| Mo | µg/L | 1.29 | 0.05 | 4.14 | 1.53 | 0.01 | 0.69 | 1.72 | 0.1 | 5.78 | 1.76 | 0.15 | 8.23 |
| Na | mg/L | 6.02 | 1.16 | 19.3 | 6.06 | 1.32 | 21.7 | 6.33 | 1.43 | 22.7 | 6.16 | 1.35 | 22 |
| Ni | ng/L | 39.9 | 8.41 | 21.1 | 42.1 | 9.18 | 21.8 | 52.8 | 21.3 | 40.3 | 37.4 | 7.05 | 18.8 |
| Pb | ng/L | 17.3 | 16.7 | 96.4 | 7.72 | 4.23 | 54.8 | 37.7 | 33.8 | 89.8 | 2.97 | 0.88 | 29.5 |
| Rb | µg/L | 0.32 | 0.01 | 3.34 | 0.33 | 0.01 | 2.43 | 0.36 | 0.02 | 6.5 | 0.37 | 0.04 | 9.84 |
| Re | ng/L | 1.54 | 0.31 | 20.2 | 1.58 | 0.31 | 19.4 | 1.67 | 0.34 | 20.3 | 1.78 | 0.46 | 25.9 |
| Re | ng/L | 1.53 | 0.31 | 20.4 | 1.55 | 0.3 | 19.6 | 1.65 | 0.34 | 21 | 1.76 | 0.47 | 26.8 |
| Sb | ng/L | 8.9 | 7.64 | 85.9 | 3.89 | 0.46 | 11.9 | 4.9 | 0.86 | 17.5 | 3.01 | 0.54 | 17.8 |
| Sc | ng/L | 1.57 | 0.27 | 16.9 | 1.35 | 0.19 | 14.3 | 1.25 | 0.1 | 7.69 | 1.11 | 0.12 | 10.5 |
| Sr | µg/L | 1,380 | 108 | 7.83 | 1,400 | 85.9 | 6.15 | 1,460 | 127 | 8.66 | 1,520 | 170 | 11.2 |
| Te | ng/L | 5.72 | 4.5 | 78.6 | 4.72 | 3.43 | 72.7 | 4.62 | 3.15 | 68.2 | 4.55 | 3.13 | 68.8 |
| Th | ng/L | 0.91 | 0.3 | 32.4 | 0.64 | 0.29 | 45.3 | 0.61 | 0.4 | 66 | 0.48 | 0.25 | 51.6 |
| Tl | ng/L | 1.18 | 0.27 | 23.2 | 1.04 | 0.22 | 21 | 1.01 | 0.21 | 20.7 | 1.03 | 0.25 | 24.3 |
| U | ng/L | 996 | 215 | 21.6 | 1,020 | 217 | 21.4 | 1,060 | 230 | 21.7 | 1,140 | 311 | 27.2 |
| V | ng/L | 20.2 | 1.82 | 9.02 | 21.1 | 1.66 | 7.84 | 21.4 | 1.89 | 8.8 | 128 | 20 | 15.6 |
| W | ng/L | 151 | 29.5 | 19.6 | 179 | 32.4 | 18.1 | 208 | 41.7 | 20.1 | 208 | 51 | 24.6 |
| W | ng/L | 151 | 30.5 | 20.2 | 179 | 33.2 | 18.6 | 208 | 43.6 | 21 | 210 | 53.4 | 25.5 |
| Zn | µg/L | 0.69 | 0.79 | 114 | 0.43 | 0.38 | 86.7 | 0.8 | 0.57 | 71.6 | 0.13 | 0.06 | 43.6 |

**Table Box 9-5 -** Concentrations of trace elements in groundwater from EGO-2 (HDPE) well, collected in LDPE bottles cleaned using three different procedures and HDPE bottles (GSC). Water samples were collected in March 2011. Trace elements were analyzed using sector field ICP-MS (Element 2), University of Heidelberg, Germany. RSD is relative standard deviation.

| | | LDPE (Original UGC) | | | LDPE (GSC) | | | LDPE (CBCS) | | | HDPE (GSC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** |
| Ag | ng/L | 0.84 | 0.35 | 42.1 | 0.65 | 0.26 | 40.4 | 0.99 | 0.43 | 43.7 | 0.65 | 0.30 | 45.3 |
| Al | µg/L | 0.9 | 0.26 | 28.9 | 0.98 | 0.2 | 20.8 | 0.95 | 0.15 | 15.9 | 1.15 | 0.17 | 14.7 |
| As | ng/L | 1,680 | 253 | 15.1 | 1,620 | 175 | 10.8 | 1,850 | 148 | 8.01 | 1,610 | 133 | 8.28 |
| Ba | µg/L | 113 | 20.5 | 18.2 | 119 | 22.6 | 19.1 | 118 | 21.7 | 18.5 | 125 | 26.5 | 21.2 |
| Be | ng/L | 1.19 | 0.19 | 16.1 | 1.63 | 0.19 | 11.9 | 1.92 | 0.23 | 11.8 | 2.34 | 0.43 | 18.2 |
| Bi | ng/L | 0.12 | 0.07 | 55.1 | 0.31 | 0.3 | 97.2 | 0.11 | 0.03 | 31.8 | 0.04 | 0.01 | 20.1 |
| Ca | mg/L | 31.7 | 2.33 | 7.36 | 32.3 | 1.92 | 5.94 | 32.3 | 1.75 | 5.41 | 32.4 | 1.86 | 5.76 |
| Cd | ng/L | 2.64 | 0.61 | 22.9 | 3.91 | 1.03 | 26.3 | 3.94 | 1.11 | 28.1 | 3.6 | 1.07 | 29.8 |
| Co | ng/L | 15.5 | 0.89 | 5.73 | 16.2 | 0.58 | 3.56 | 16.1 | 0.61 | 3.77 | 15.5 | 0.44 | 2.84 |
| Cr | ng/L | 5.01 | 2.09 | 41.7 | 3.62 | 1.44 | 39.9 | 7.69 | 4.28 | 55.6 | 1.47 | 0.42 | 28.4 |
| Cu | µg/L | 0.32 | 0.09 | 29.1 | 0.72 | 0.21 | 29.5 | 0.84 | 0.25 | 29.8 | 0.85 | 0.24 | 28.4 |
| Fe | µg/L | 6.79 | 0.69 | 10.2 | 6.96 | 0.21 | 3.01 | 7.09 | 0.16 | 2.3 | 7.19 | 0.31 | 4.35 |
| Ge | ng/L | 6.53 | 1.04 | 16 | 8.54 | 0.22 | 2.63 | 10.5 | 1.37 | 13 | 8.65 | 0.11 | 1.26 |
| Li | µg/L | 4.62 | 0.41 | 8.78 | 4.89 | 0.49 | 9.99 | 4.49 | 0.24 | 5.39 | 4.73 | 0.25 | 5.39 |
| Mg | mg/L | 22.2 | 0.92 | 4.14 | 22 | 0.78 | 3.53 | 21.8 | 1.55 | 7.12 | 22.5 | 0.74 | 3.3 |
| Mn | µg/L | 9.27 | 0.25 | 2.7 | 9.55 | 0.15 | 1.6 | 9.69 | 0.38 | 3.95 | 9.82 | 0.27 | 2.8 |
| Mo | µg/L | 1.33 | 0.06 | 4.33 | 1.55 | 0.02 | 1.58 | 1.65 | 0.08 | 4.68 | 1.71 | 0.1 | 6.04 |
| Na | mg/L | 6.19 | 1.18 | 19.1 | 6.31 | 1.29 | 20.4 | 6.25 | 1.46 | 23.3 | 6.3 | 1.39 | 22.1 |
| Ni | ng/L | 39.8 | 8.25 | 20.7 | 50.2 | 18.8 | 37.5 | 41.8 | 10.9 | 25.9 | 32.6 | 6.01 | 18.5 |
| Pb | ng/L | 24.7 | 19.8 | 80.3 | 475 | 983 | 207 | 104 | 116 | 112 | 1.05 | 0.3 | 28.6 |
| Rb | µg/L | 0.31 | 0.02 | 5.62 | 0.33 | 0.01 | 3.33 | 0.34 | 0.01 | 3.1 | 0.36 | 0.03 | 8.1 |
| Re | ng/L | 1.53 | 0.29 | 18.9 | 1.63 | 0.34 | 20.8 | 1.58 | 0.30 | 18.7 | 1.77 | 0.4 | 22.8 |
| Re | ng/L | 1.49 | 0.29 | 19.2 | 1.59 | 0.33 | 20.9 | 1.56 | 0.29 | 18.4 | 1.72 | 0.41 | 23.7 |
| Sb | ng/L | 5.41 | 0.68 | 12.5 | 5 | 0.71 | 14.2 | 4.92 | 0.64 | 13.1 | 3.04 | 0.44 | 14.3 |
| Sc | ng/L | 1.89 | 0.28 | 14.8 | 1.52 | 0.15 | 9.91 | 1.39 | 0.15 | 10.9 | 1.22 | 0.13 | 10.8 |
| Sr | µg/L | 1,420 | 122 | 8.58 | 1,480 | 111 | 7.49 | 1,460 | 100 | 6.88 | 1,560 | 154 | 9.91 |
| Te | ng/L | 5.97 | 4.46 | 74.7 | 5.28 | 4.05 | 76.8 | 4.74 | 3.44 | 72.6 | 4.85 | 3.26 | 67.3 |
| Th | ng/L | 1.36 | 0.32 | 23.8 | 0.78 | 0.31 | 39.3 | 0.89 | 0.56 | 63.1 | 0.54 | 0.27 | 49.9 |
| Tl | ng/L | 1.28 | 0.29 | 22.9 | 1.2 | 0.28 | 23.1 | 1.08 | 0.21 | 19.8 | 1.1 | 0.25 | 22.7 |
| U | ng/L | 1,040 | 203 | 19.5 | 1,090 | 246 | 22.6 | 1,060 | 211 | 20 | 1,140 | 280 | 24.5 |
| V | ng/L | 25.2 | 2.19 | 8.68 | 26.4 | 2.05 | 7.76 | 25.6 | 1.77 | 6.93 | 153 | 30.3 | 19.8 |
| W | ng/L | 159 | 37.4 | 23.5 | 190 | 36.4 | 19.1 | 208 | 36.8 | 17.7 | 210 | 46 | 21.9 |
| W | ng/L | 161 | 36.3 | 22.6 | 190 | 37.8 | 19.8 | 207 | 38.1 | 18.4 | 212 | 47.2 | 22.3 |
| Zn | µg/L | 0.63 | 0.43 | 68.4 | 0.67 | 0.6 | 89.5 | 0.48 | 0.16 | 33.2 | 0.1 | 0.00 | 4.28 |

**Table Box 9-6 -** Concentrations of trace elements in groundwater from EGO-1 (stainless steel) well and EGO-2 (HDPE), sampled within clean-air cabinets using HDPE bottles (GSC). Water samples were collected in March 2011. Trace elements were analyzed using sector field ICP-MS (Element 2), University of Heidelberg, Germany. RSD is relative standard deviation.

| | | **EGO-1 stainless steel well, HDPE bottles (GSC)** | | | **EGO-2 HDPE well, HDPE bottles (GSC)** | | |
|---|---|---|---|---|---|---|---|
| **Element** | **Units** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** | **Concentration** | **Standard deviation (n=10)** | **RSD (%)** |
| Ag | ng/L | 0.64 | 0.29 | 45.1 | 0.65 | 0.30 | 45.3 |
| Al | µg/L | 1.01 | 0.13 | 12.4 | 1.15 | 0.17 | 14.7 |
| As | ng/L | 1690 | 152 | 9.03 | 1610 | 133 | 8.28 |
| Ba | µg/L | 132 | 30.2 | 23 | 125 | 26.5 | 21.2 |
| Be | ng/L | 2.28 | 0.30 | 13.3 | 2.34 | 0.43 | 18.2 |
| Bi | ng/L | 0.05 | 0.02 | 30.7 | 0.04 | 0.01 | 20.1 |
| Ca | mg/L | 33.5 | 1.94 | 5.78 | 32.4 | 1.86 | 5.76 |
| Cd | ng/L | 3.61 | 1.08 | 29.9 | 3.6 | 1.07 | 29.8 |
| Co | ng/L | 14.4 | 0.34 | 2.34 | 15.5 | 0.44 | 2.8 |
| Cr | ng/L | 2.21 | 0.33 | 14.9 | 1.47 | 0.42 | 28.4 |
| Cu | µg/L | 0.86 | 0.24 | 27.8 | 0.85 | 0.24 | 28.4 |
| Fe | µg/L | 8.87 | 0.57 | 6.45 | 7.19 | 0.31 | 4.35 |
| Ge | ng/L | 8.55 | 0.17 | 1.95 | 8.65 | 0.11 | 1.26 |
| Li | µg/L | 5.01 | 0.39 | 7.82 | 4.73 | 0.25 | 5.39 |
| Mg | mg/L | 22.6 | 0.71 | 3.14 | 22.5 | 0.74 | 3.3 |
| Mn | µg/L | 9.39 | 0.35 | 3.74 | 9.82 | 0.27 | 2.8 |
| Mo | µg/L | 1.76 | 0.15 | 8.23 | 1.71 | 0.10 | 6.04 |
| Na | mg/L | 6.16 | 1.35 | 22 | 6.30 | 1.39 | 22.1 |
| Ni | ng/L | 37.4 | 7.05 | 18.8 | 32.6 | 6.01 | 18.5 |
| Pb | ng/L | 2.97 | 0.88 | 29.5 | 1.05 | 0.30 | 28.6 |
| Rb | µg/L | 0.37 | 0.04 | 9.84 | 0.36 | 0.03 | 8.1 |
| Re | ng/L | 1.78 | 0.46 | 25.9 | 1.77 | 0.40 | 22.8 |
| Re | ng/L | 1.76 | 0.47 | 26.8 | 1.72 | 0.41 | 23.7 |
| Sb | ng/L | 3.01 | 0.54 | 17.8 | 3.04 | 0.44 | 14.3 |
| Sc | ng/L | 1.11 | 0.12 | 10.5 | 1.22 | 0.13 | 10.8 |
| Sr | µg/L | 1520 | 170 | 11.2 | 1560 | 154 | 9.91 |
| Te | ng/L | 4.55 | 3.13 | 68.8 | 4.85 | 3.26 | 67.3 |
| Th | ng/L | 0.48 | 0.25 | 51.6 | 0.54 | 0.27 | 49.9 |
| Tl | ng/L | 1.03 | 0.25 | 24.3 | 1.1 | 0.25 | 22.7 |
| U | ng/L | 1140 | 311 | 27.2 | 1140 | 280 | 24.5 |
| V | ng/L | 128 | 20 | 15.6 | 153 | 30.3 | 19.8 |
| W | ng/L | 208 | 51 | 24.6 | 210 | 46 | 21.9 |
| W | ng/L | 210 | 53.4 | 25.5 | 212 | 47.2 | 22.3 |
| Zn | µg/L | 0.13 | 0.06 | 43.6 | 0.1 | 0.00 | 4.28 |

Return to where text linked to Box 9↥

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# 23 Exercise Solutions

## Solution Exercise 1

The MOE had been collecting water samples in containers made of polyethylene terephthalate (PET) plastic. This plastic is manufactured using antimony trioxide, $Sb_2O_3$, as a catalyst and contains on the order of 250 mg/kg of Sb. In contrast, water from the Elmvale Groundwater Observatory, for example, contains only 1 ng/L of Sb. Water containing extremely low Sb concentrations placed in a plastic bottle or jar containing very high Sb concentrations will immediately begin to leach Sb from the plastic. Our unpublished work showed a release rate of approximately 50 ng/L of Sb per month from PET plastic into bottled water at room temperature. This phenomenon not only explains why the MOE was having problems measuring Sb at that time but also why all bottled water in PET plastic (except those from Japan, where PET is manufactured using a Ti catalyst) are contaminated by this trace element.

Return to Exercise 1↥

## Solution Exercise 2

The MOE approach to groundwater sampling (pumping water from standing wells) stirs up particles and colloidal materials from the sediments that compose the aquifer. This is immediately apparent from the brown color of the first volumes of water being pumped. The water is pumped until it runs clear, with clarity being judged by visual inspection. The human eye can detect particles as small as approximately 25 µm (approximately one-quarter the diameter of a human hair). Thus, when water runs *clear*, it may contain abundant particles smaller than 25 µm.

Stirring up the sediments, however, adds not only particles but also colloids which, by definition, are suspended particles ranging from approximately 1 nm to 1 µm. When theis groundwater is filtered through 0.45 µm membrane filters, the particles are removed, but the colloids are not. These colloids are the hosts of many trace elements. Thus, the elevated concentrations of many trace elements obtained for the shallow groundwater at Site 41 using the MOE sampling protocol are most likely artifacts caused by the abundance of introduced colloids and the trace elements they contain.

MOE groundwater sampling is restricted to standing wells. In fairness to the MOE, their mandate is to ensure that trace element concentrations in groundwater do not exceed the guidelines for the protection of human health. In other words, the MOE does not need to establish the *true* concentrations of trace elements in drinking water—rather they ensure the measured concentrations are below the guideline values. In contrast, the EGO wells are flowing artesian groundwater wells established to help determine the true concentrations of trace elements in this water and the processes that govern them.

Thus, the MOE and EGO have very different goals. These objectives should be considered when trace element data for groundwater of Ontario, obtained and reported to the public by the MOE, is interpreted from a scientific perspective.

**Return to Exercise 2**↥

## Solution Exercise 3

Using the MOE approach to groundwater sampling described in the solution to Exercise 2 (i.e., pumping water from standing wells), measured concentrations of *dissolved* Al—that is, the fraction obtained after filtration through a 0.45 µm membrane filter—were up to 300 µg/L. In the flowing artesian wells of the Elmvale area, which have been sampled since 2004 (Box 1), Al concentrations in the unfiltered water samples have rarely exceeded 3 µg/L. For example, when they were sampled in April 2006, Al concentrations in the flows at the properties of Belluz, Burgsma, Parnell, Pigeon, Stone, and Temolder were all at or below 3 µg/L. In the pH range 6 to 8, the solubility of Al in chemical equilibrium with Gibbsite—that is, $\mathrm{Al(OH)_3}$—is approximately $10^{-7}$ M, which corresponds to 2.7 µg/L.

In other words, the Al concentrations found in the unfiltered flowing groundwater in the Elmvale study are in excellent agreement with the expected concentrations, based on equilibrium chemical thermodynamics. In contrast, Al concentrations in the groundwater sampled at Site 41 exceed the solubility of aluminum hydroxide by as much as two orders of magnitude.

Aluminum is the most abundant metal in the Earth's crust (approximately 8 weight percent) and is a building block in the structure of all aluminosilicate minerals. This includes the phyllosilicate (clay) minerals occurring in the aquifers addressed in this book and other regions. Introducing particles during groundwater sampling should have, and does have, a profound impact on the measured Al concentrations, even after filtering through a 0.45 µm filter, because of the introduction of Al-bearing colloids. These colloids are presumably mixtures of clay minerals, amorphous Al hydroxide, and organoaluminum complexes.

**Return to Exercise 3**↥

## Solution Exercise 4

1. In the Field

a) Groundwater sampling wells should be constructed of suitable materials—for example, surgical (316 L) stainless steel or polypropylene (PP).

b) Water should be sampled using acid-cleaned bottles, filters, and syringes—for example, PP bottles, PTFE filters, and PP syringes.

c) After filtration, to preserve trace elements, water should be acidified using ultrapure nitric acid equivalent to 2 ml of concentrated acid per liter of sample.

d) Avoid contact between the water sample and ambient air using a clean-air bench (portable Class 100 clean-air benches are available).

2. In the Laboratory

Samples should be processed and handled within metal-free Class 100 clean-air cabinets. When required, only ultrapure reagents (water and acids) should be used. Clean lab practices must be rigorously employed—for example, clean lab clothing including bonnets and gloves must be worn at all times to protect the samples from clothing fibers, hair, and skin; cosmetics and jewelry must be avoided.

For the concentration measurements using, for example, ICP-MS:

a) samples should be introduced to the instrument using acid-cleaned autosampler tubes,

b) the autosampler should be placed within a metal-free Class 100 metal-free cabinet, and

c) autosampler tubing should be leached with 2 percent $HNO_3$ until the blank values are low and constant. Given the low concentrations that may be encountered for many trace elements, trip, field, and lab blanks are each vital to evaluate reproducibility and ascertain data reliability.

Return to Exercise 4↥

## Solution Exercise 5

At this pH and $P_{CO_2}$, the concentration of carbonate will be $10^{-4.6}$ M. With this concentration of carbonate, water in chemical equilibrium with lead carbonate will contain approximately 610 ng/L of Pb, as shown in the following calculations.

**Lead in equilibrium with lead carbonate** at pH 8, with $\log\left(P_{CO_2}\right) = -2.5$ atm

$$\begin{aligned}\log(CO_3^{2-}) &= (\text{-}18.1) + \log\left(P_{CO_2}\right) + 2 \times (\text{pH})\\ &= (\text{-}18.1) + (\text{-}2.5) + 16\\ &= -4.6\ \text{M}\end{aligned}$$

$$\begin{aligned}\log(Pb^{2+}) &= \log K_{sp} - \log(CO_3^{2-})\\ &= (-13.13) - (-4.6)\\ &= -8.53\ \text{M}\\ &= 610\ \text{ng/L}\end{aligned}$$

In chemical equilibrium with lead phosphate at this pH and $PO_4^{3-}$ concentration, the concentration of Pb will be approximately 30 ng/L, as shown in the following calculations.

**Lead in equilibrium with lead phosphate** at pH 8,
with $PO_4^{3-} = 10\ \mu\text{g/L}\ (1.07 \times 10^{-7}\ \text{M})$

$$\begin{aligned}3\log(Pb^{2+}) &= \log K_{sp} - (2\log PO_4^{3-})\\ \log Pb^{2+} &= \frac{(-43.53) - 2\log(1.05 \times 10^{-7})}{3}\\ &= -9.86\ \text{M}\\ &= 29\ \text{ng/L}\end{aligned}$$

The groundwater sampled from the EGO wells contains approximately 1 ng/L of Pb. So, neither the precipitation of lead carbonate nor lead phosphate can explain the extremely low concentrations of Pb in this groundwater.

Return to Exercise 5↑

# 24 About the Authors

**William Shotyk** received his BSc (Agriculture) in soil science and chemistry from the University of Guelph and a PhD in geology from the University of Western Ontario. Following postdoctoral research at the University of California, Riverside, and UWO, he worked as an oberassistent at the University of Berne in Switzerland, where he completed a Habilitation in Geochemistry in 1995. He became a professor at the University of Heidelberg in Germany and director of the Institute of Environmental Geochemistry in October 2000. Dr. Shotyk joined the Department of Renewable Resources at the University of Alberta (UofA) in October of 2011 as the Bocock chair in agriculture and the environment. With the help of many expert and talented individuals and generous support from UofA, he designed and built the metal-free ultraclean SWAMP laboratory for the study of trace elements in soil, water, air, and plants. He has 290 publications to his credit, including 230 journal publications, and his work has been cited more than 17,500 times (Google Scholar). He was awarded the Philippe Duchaufour Medal for Soil System Science by the European Geoscience Union (2013) and elected a Fellow of the Royal Society of Canada (2018) and a Fellow of the Geochemical Society and the European Association of Geochemistry (2019). He is the founder and president of the Elmvale Foundation, a federally registered charity for environmental education (www.elmvale.org↗). Over the past 45 years, with the help of family and friends, he has planted more than 25,000 trees (more than 50 species) on his family farm property near Elmvale, Ontario.

**Beatriz Bicalho** was born in Brazil and became a biochemist by training (1995, University of Sao Paulo, Brazil). She received her MSc in chemistry in 1999 and PhD in chemistry in 2003 from Brazilian universities in the field of natural products. In 2008, she joined the Laboratory of Separation Sciences at the University of Ghent, Belgium, as a postdoctoral fellow. In 2014, she joined the SWAMP Laboratory at the UofA as a research associate responsible for High Resolution-ICP-MS. Dr. Bicalho has worked since 2018 as a research and development professional in the private sector.

**Chad Cuss** obtained his PhD at Trent University (Analytical Nanogeochemistry and Applied Chemometrics), Canada, after which he spent five years in the SWAMP laboratory at the University of Alberta before moving to a faculty position at Memorial University of Newfoundland, Grenfell campus. Dr. Cuss' research program focuses on analytical nanogeochemistry: the development and application of analytical methods to measure and better understand the properties and behavior of nanoscale particles in natural systems and how these are connected to their functionality at micro and macro scales.

**Muhammad Javed** is an environmental specialist/geochemist with project experience in industry and academia. His technical area of expertise focuses on identifying and characterizing anthropogenic contamination by applying state-of-the-art sampling and analytical techniques. Dr. Javed possesses strong quantitative skills and practical experience related to sampling, handling, analysis, and interpretation of data generated from environmental samples, particularly from the Athabasca oil sands region of northeastern Alberta. He has experience working with a wide range of sample media including river water, municipal wastewater, oil sands process-affected water, snow, dust in snow, soil, sediment, and suspended solids. Dr. Javed applies a multidisciplinary approach that includes geochemistry, statistics, and data analysis to understand environmental processes at the ecosystem scale.

**Iain Grant-Weaver** is a chemical analyst and researcher with several years of experience in both commercial and research laboratories with a focus on trace elemental analysis. He worked closely with other scientists and researchers in his role as a laboratory technologist at the University of Alberta SWAMP Lab from 2015 to 2022, during which time he was a listed coauthor of over 20 academic papers. He holds bachelor degrees in both biology and civil engineering from the University of Alberta. He currently resides in Edmonton.

**Michael Krachler** was born in Austria in 1967. He received his MSc in chemistry (1993) and PhD in analytical chemistry (1997) from the University of Graz, Austria. In 1998, he joined the Research Centre of Juelich, Germany, as a Marie Curie Fellow funded by the European Commission. In 2000, he became a staff member of William Shotyk´s research group at the University of Heidelberg, Germany, with responsibility for the state-of-the-art clean room infrastructure including the trace element and ICP-MS laboratories. His research interests centered on applications of High Resolution-ICP-MS for the determination of ultra-trace elements and lead isotopes in various environmental compartments such as Arctic ice and pristine groundwater. Since 2009, Dr. Krachler has been a senior researcher at the Joint Research Centre of the European Commission in Karlsruhe, Germany, currently focusing on analytical method development for nuclear forensics.

**Tommy Noernberg** is a mechanical engineering technologist at the SWAMP Laboratory, University of Alberta. He also holds an advanced drone pilot license and has experience in designing and manufacturing them. Mr. Noernberg has brought to the laboratory 25 years of experience from the Institute of Physics and Chemistry at the University of Southern Denmark (Odense). He is responsible for the dedicated support of the SWAMP laboratory infrastructure and equipment and the management of the gamma spectrometry facility. He assists scientists with their research through active collaboration, providing innovative equipment solutions involving original design, fabrication (with 3D printers), and machining of a broad range of specialized equipment for field and lab experiments. In addition to coauthoring 56 publications, he has extensive field experience in Europe (Denmark, Germany, Greenland, and Italy) as well as Canada (including southern Ontario, northern Quebec, Manitoba, the Yukon, and Nunavut). In the field, Mr. Noernberg is responsible for the safe operation, maintenance, and transportation of relevant equipment; ensuring the purity and integrity of samples; and supervision and safety of field personnel.

**Michael Powell** received his BSc and MSc in the USA and PhD in Canada (geology-geochemistry). His main interests include the soil-plant-water nexus, non-traditional methods of soil remineralization, and solid fossil fuel utilization. Most of his career has mingled the public, private, and civil society sectors through multicultural, multinational, and multidisciplinary research/projects. He has coauthored over 80 publications, five book chapters, 50 conference proceedings, and thousands of pages of government and private-sector reports. During the academic part of his career, he designed and implemented numerous international projects with budgets in excess of 1.5 million dollars per annum; the majority of his work has emphasized the importance of using natural sciences results to benefit society. As an international consultant, Dr. Powell worked mainly on degraded soil restoration and reforestation in India and developing new technologies for soil remineralization using waste materials (India, China, Colombia, and Ecuador). He acted as a consultant to the Department of Science, Technology and Higher Education in Ecuador from 2014 to 2017 with the objective of strengthening the country's research capacity. He presented over 60 workshops to more than 2,500 persons in academic and public sector research organizations, reviewed and evaluated the research infrastructure and capacity at most of the country's major universities, developed research plans for government research organizations, and evaluated all research funding applications.

**Jiancheng (James) Zheng** is a research scientist (cold regions chemistry) with the Geological Survey Canada, part of Natural Resources Canada in Ottawa, Ontario. Dr. Zheng is also an adjunct professor with the Department of Earth and Environmental Sciences at the University of Ottawa. His research interests include contamination control, methodology development for quantification of ultra-low concentrations of trace metals, climate change, and anthropogenic contaminants in snow/ice cores and water.

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