MONITORING OF FRESH AND BRACKISH WATER RESOURCES

D. Banks
Holymoor Consultancy, Chesterfield, UK

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Contents

Summary

In summary, the author wishes to leave the reader with the following ideas and concepts:

- Monitoring may be carried out at several levels, with several aims. The design, density and frequency of sampling of the network will depend on its purpose.
- There is a place for national speculative monitoring networks, to provide a baseline against which future (hitherto unknowable) environmental trends may be assessed. Short term economic and management goals should not be allowed

to terminate or constrain the existence of these networks.

- The utility of a monitoring data series often increases disproportionately to its duration. Keep long monitoring data series active !
- The choice of monitoring equipment will depend on many factors, also economic and social. Mechanical monitoring methods are not necessarily inferior to electronic.
- Monitoring data should always be interpreted in the light of, and used to refine, a conceptual model of the hydrological system. The model may be used to refine and redesign the network to ensure the optimal data collection distribution.
- A good conceptual model should be able to be formalised as a mathematical or numerical model.
- Metadata, concerning the collection of primary data, are important. Be aware of the likely quality of your data, which may be affected by sampling and analytical practice. Attempt to quantify uncertainty in data.
- Become interested in analytical chemistry. Cultivate good relationships with staff at your laboratory.
- Choose appropriate data interpretation and presentation techniques. Be wary of over-interpreting data (e.g. by contouring or averaging). Retain accessibility to raw unprocessed data.
- There is a tendency towards more integrated, holistic monitoring methods, due to both ideological / philosophical and purely economic reasons.

1. Introduction

Estimates vary, but it is believed that only some 3 % of the world's water is non-saline, falling into the category of "fresh and brackish water resources". Of the total, over 2 % is locked up as ice in glaciers or polar ice caps, leaving less than 1 % as (mostly) groundwater, with a small proportion of surface water.

Although ice comprises the greatest proportion of non-marine water resources, its monitoring is dealt with elsewhere in the encyclopaedia. Monitoring of glaciers is regarded as crucial for evaluating possible climate change, as well as for identifying trends in the chemical composition of wet and dry atmospheric precipitation (whose chemical and isotopic signature is locked away in ice strata). Nevertheless, it should always be remembered, in addition to these concerns, that polar and glacial ice represent huge, potentially exploitable reservoirs of fresh water, whose capacity should be monitored.

This Topic will, however, focus on fresh and brackish surface- and groundwater reserves. It is interesting that those resources which are largest are not those that attract most public attention. Few of us spare much thought for the huge volumes of water locked up in ice-sheets or glaciers; slightly more of us are aware of the groundwater stored in the pores and fractures beneath our feet. When most of us think of water, however, we think of streams and rivers, despite their minimal contribution to the global fresh-water balance. This attitude has probably arisen because it is the visible streams and rivers which have traditionally supplied us with sustenance in the past: readily accessible water for drinking and irrigation, transport arteries, fish and wildfowl to eat. Anyone who has read about or visited the Nile Valley will realise the importance of that river for the culture which has thrived there from the time of the Ancient Egyptians to the present day.

Of course, groundwater has also played a historical role, particularly in arid regions. The references to wells and springs in the Pentateuch and Gospels are numerous, while desert oases have thrived as centres of culture and trade. The drive to access groundwater has also forced humans to develop new engineering techniques, from the qanats of the Armenian, Assyrian and Arabic cultures, the 99 m deep "Jacob's Well" in Cairo (dating from 1700 BC) to the vast hand-dug wells of Ethiopia. But it is only relatively recently (with the advent of motorised pumps and drilling rigs), that groundwater has been accessible on a large scale and from great depths. Until even more recently, groundwater was regarded as sterile and of little interest to ecologists, but now it is known that even the deep underground can host viable bacterial communities and can also support macrobiota such as crustaceans and worms in karstic aquifers. It has even been suggested that the deep groundwater environment may have been the cradle for the evolution of life.

Before proceeding, we should beware of sharp distinctions. Groundwater and surface-water are not wholly separate entities. Groundwater springs often feed our streams, while bank infiltration from rivers may feed some of our most important groundwater well-fields. Water quality and quantity are likewise inextricably linked. And finally, there is no sharp boundary between fresh and brackish water reserves: fresh groundwater may gradually become saline in coastal areas, in areas of evaporite minerals, or in arid areas of high evaporation. Likewise, surface waters grade from fresh to brackish in estuarine environments.

2. What is Monitoring?

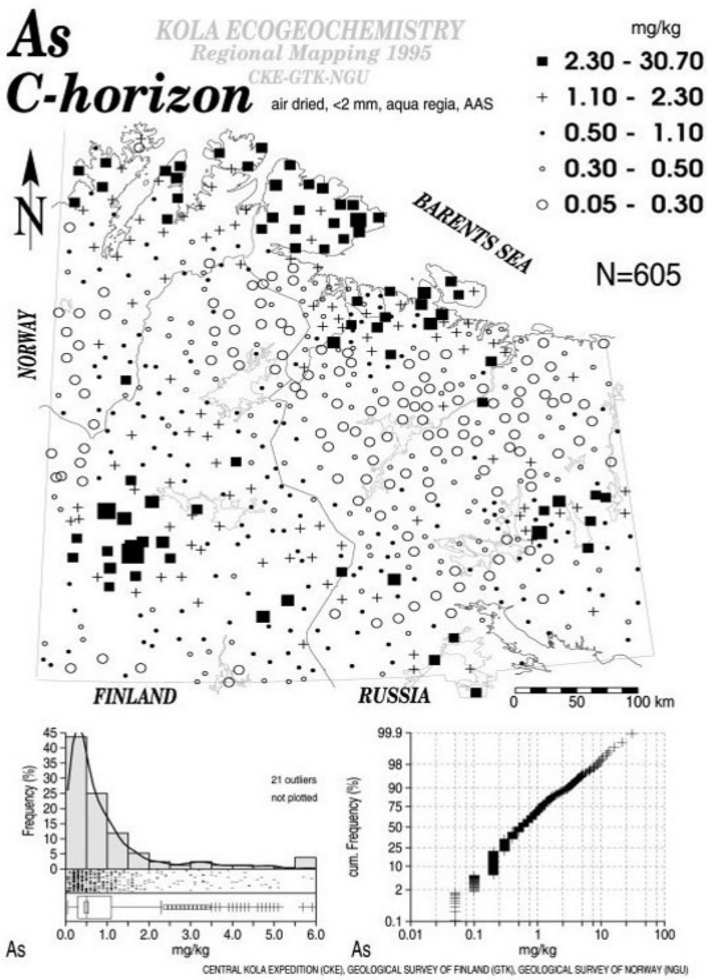
Hydrological monitoring may be defined as the systematic collection of hydrological data in order to characterise hydrological systems and to identify systematic change (often anthropogenic) in those systems.

Monitoring is typically taken to imply collection of time-series data. While this is often the case, it is not necessarily so: indeed data in all four dimensions (three spatial dimensions + time) may be required to characterise a system. Indeed, Clemens Reimann and his colleagues (see Bibliography) went a long way towards characterising the state of soil chemistry on the Kola Peninsula, Russia, and to identifying environmental impacts of reindeer herding and nickel smelting activities, with minimal collection of time series data. Thoughtful presentation of spatial data was effective at identifying natural variability of heavy metals due to underlying geology, and contamination of soils around Nikel town due to smelting activity (Figure 1a,b).

3. The History of Monitoring

It is unknown when the concept of water monitoring first arose. Crude forms of monitoring were practised by the ancient civilisations who engaged in water engineering. As early as 3000 BC nilometers were in use in Egypt to measure the stage (i.e. level) of the Nile (either marks on quay walls, flights of steps or graduated columns in stilling wells), and by 1800 BC nilometers had been installed at the 2nd Cataract. In fact, the longest existing record of river stage derives from a nilometer at Roda, stretching from 622 AD to 1926 AD. By 1050 BC crude water metering methods were employed at the Gadames Oasis in North Africa, where water clocks and floats were used to time the allotted periods for irrigation water to enter each farmer's fields.

Although stage measurements were rather widespread in ancient civilisations, the conversion of water level to flow rate was rather slow to be accomplished. Sometime between 150 BC and 250 AD, in the Roman Empire, Hero of Alexandria first enunciated the basic principle of flow calculations; that the discharge (Q) is equal to the cross sectional area of the channel (A) times the average velocity (V): Q = A x V. This forms the basis for the simplest technique of flow gauging, involving the estimation of a channel's water-filled cross-section and measuring the velocity by an impeller or by monitoring the speed of a floating object moving downstream (popularly known as the "Poohstick Method" after the description in A.A. Milne's "The House at Pooh Corner"). Hero's discovery was not widely recognised, however, and upon the fall of Rome, Europe was plunged into the Dark Ages. Hero's find was not rediscovered until 1628, when Benedetto Castelli re-proposed the formula.



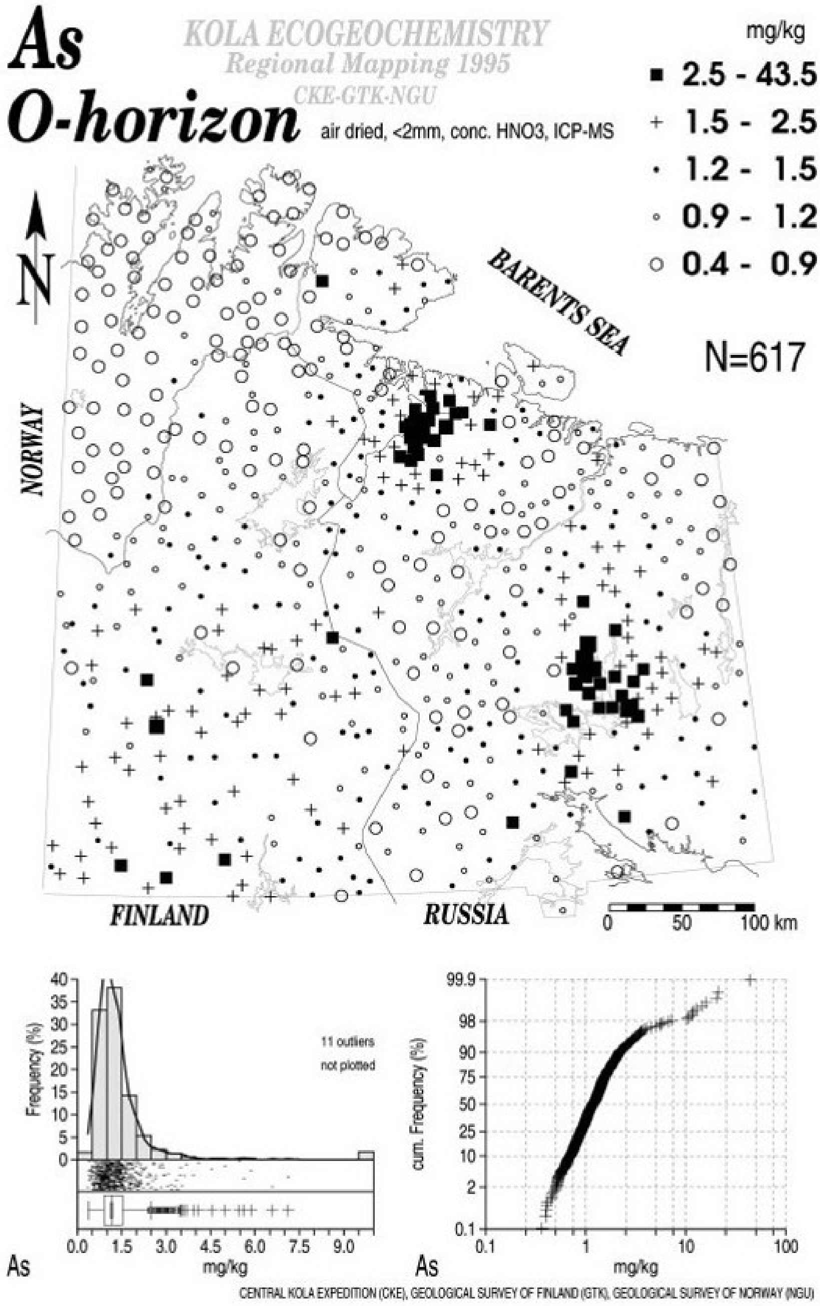


Figure 1. Maps showing distribution of arsenic in (a) the C-horizon (i.e. glacial deposits) and (b) O-horizon (humic topsoil) of the Kola peninsula, Russia. The C-horizon data effectively represents the background (geological) distribution of arsenic, whereas the humus shows gross anthropogenic contamination around metal smelting centres in Russia. © Geological Survey of Norway.

From the 16th Century, the science of hydrology proceeded rapidly. The Italian, Dr Santorio Santorio (1561-1630) proposed a current meter based on a pivoted plate, reacting to the impact of water velocity, while the Briton, Robert Hooke, proposed an impeller current meter in 1683.

Systematic monitoring of river stage commenced in Europe in the 18th Century, with readings for the Elbe at Magdeberg (from 1727), the Rhine at Emmerich (from 1770) and the Oder at Küstrin (from 1778) being published in 1837.

However, the concept of systematic river flow (discharge) monitoring did not commence until the 19th Century in Europe. The flow in the upper Rhine at Basle was monitored from 1809, the Tiber in Rome from 1825 and the French Garonne from 1837. In the USA, the Ohio in West Virginia was gauged from 1838, and a gauging network expanded rapidly with the formation of the United States Geological Survey (USGS). Regular flow monitoring in Britain did not commence until 1912 and by 1936 only 27 regular gauging stations existed. Groundwater level monitoring in Britain commenced in a well at Chilgrove, Sussex, in 1836, with data still being collected today.

As regards water quality, Henrik Ibsen's play "An Enemy of the People", from 1882, describes the fictional Dr. Stockmann attempting to close a public bath after discovering (via bacteriological analysis) that pollution from a tannery was seeping into the feeder springs. This fictional incident was doubtless based on real contemporary events in Norway. In 1854 Dr. Snow of London succeeded in getting a public water pump in Broad Street closed; in this case not through analytical monitoring, but by conducting an epidemiological study of the incidence of cholera amongst local inhabitants: a crude form of ecotoxicological monitoring (see below).

4. Why Monitor?

Both of these examples provide at least one very good reason for monitoring water resources, the safeguarding of human health from pollution. But this is not the sole reason for water monitoring:

- Monitoring of impact of *point-source* pollution on the environment and water resources.
- *Regional* monitoring of water volumes, fluxes and quality for the purposes of regional water management.
- Monitoring to be able to predict the impact of hydrological events (floods, rising groundwater levels) on structures.
- *National or global* monitoring to assess the state of health of our planet.
- Monitoring to develop and improve our conceptual models of how hydrological systems function

The different types of monitoring will require differing monitoring networks in terms of density, operational philosophy and parameters monitored. A *national* or *global* network will typically have a low density of carefully selected stations at which a number of parameters, not necessarily specific to a particular type of problem, but characterising a range of different responses, will be measured. A *local* network, designed to monitor a point pollution source, will have a small areal extent but high observational density, with the measurement of parameters specific to the pollution incident (e.g. chlorinated solvents). The networks may be integrated as a nested system, in which points for a *national* network may be selected from the greater number of points comprising a number of denser, *regional* or *local* networks.

When designing a monitoring network, it is important to ask, "What questions is the network designed to answer?". The answer to this query will be used to define the density, locations, observational frequency and monitored parameters of the network.

A *caveat* to this advice must be mentioned, however. For networks designed for national and global monitoring (type (4) above) and for developing conceptual models (type (5)) it may not be clear at the present time, exactly what environmental trends or issues the network will identify. Regrettably, because scientists are sometimes unable to pin down the exact purpose of such networks, there has been a tendency, in the so-called developed world, for governments not to fund such speculative monitoring. This is a grave error. Many of this decade's most pressing environmental issues, from global warming, through depletion of the ozone layer and acid rain to the rising groundwater levels below London, can only be identified and discussed sensibly in the light of observational data collected *before* the observers were aware of the issues at stake. The data we collect now will undoubtedly be important for the diagnosis of future problems of which we are currently unaware. We should invest in this future.

5. The Importance of Background Conditions

The Norwegian hydrogeologist Gaute Storrø has described the hydrological cycle as nature's bloodstream. Human blood brings nutrients (and in some cases, toxins or infectious agents) to the body's cells, and it removes waste products to the liver and kidneys for excretion. Illness can be diagnosed by testing the blood; either for its physical (pressure, flow, temperature), chemical (sugar and salt content or content of much more complex metabolites or toxins) or microbiological (bacteria, viruses) parameters.

Analogously, rainfall transports certain chemicals to the land from the sea or atmosphere, several of which are of importance for plant and animal health (iodine, sulphur, phosphorus, nitrogen, potassium); water containing dissolved oxygen or carbon dioxide percolates into the ground and weathers rocks, ultimately resulting in the formation of life-giving soils; groundwater flushes the waste products of this weathering (typically dissolved salts) to surface waters and to the sea. Sometimes, the water cycle also introduces environmental toxins to our soils or water resources. The monitoring of water resources can help us to diagnose the health of the hydrosphere and may take the form of measurement of physical (pressure, flow, temperature), chemical (concentrations of gases, salts or pollutants), biological (bacteria, viruses, otters) or even nuclear (stable or radioactive isotopes) parameters.

However, to be able to diagnose a problem, we need to know what the unperturbed, or "background" condition is. To diagnose influenza, we need to know that the average normal blood temperature is around 36.9°C. To diagnose diabetes, we need to know the blood's normal sugar content. To correctly and fully identify the cause of AIDS, we would need to know that the HIV virus does not occur in the blood of non-sufferers (in fact, a debatable hypothesis, as not all HIV carriers develop AIDS immediately). Similarly, to identify a drought, we need to know the normal rainfall and river flow condition; to diagnose arsenic contamination by human activity, we need to know how much arsenic occurs naturally in waters (Figure 2) and to be able to say that a hydrazine occurrence in soil water is due to a spillage of rocket fuel, we need to know that it does not occur naturally in non-polluted soils (also, in fact, debatable point, as hydrazines occur in some natural fungi).

This is not all, however. The background condition is not a single invariant figure. 36.9°C is only the *average* temperature of healthy human blood; amongst individuals there is a rather wide variation. Similarly, river flows and groundwater levels may fluctuate on a diurnal, rainfall-related and seasonal basis and may also reflect climatic trends over many years. The background concentration of all elements in natural waters (including arsenic) will vary widely, depending on local geology, pH and redox conditions, sometimes varying by over six or seven orders of magnitude for uranium in groundwaters (Figure 2).

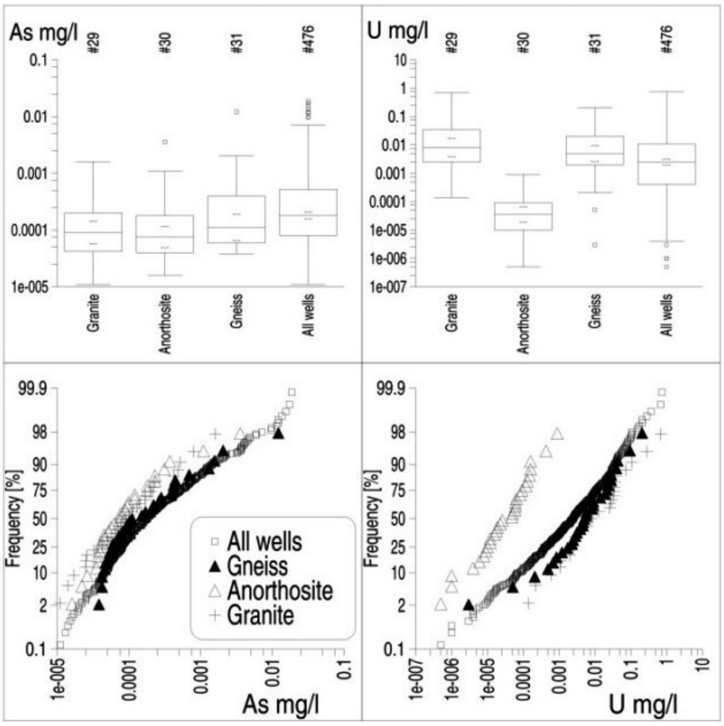


Figure 2. The distribution of arsenic and uranium in groundwater in different Norwegian Precambrian bedrock types. The upper diagrams show the data as boxplots (see Glossary). The lower diagrams show the data as cumulative frequency distribution curves: the median concentration is found at 50 % frequency. Data supplied by the Geological Survey of Norway. Note the log scale on the x-axis and the probability scale on the y-axis. © Geological Survey of Norway.

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Biographical Sketch

David Banks studied Natural Sciences at Cambridge University (U.K.) and went on to gain an MSc in Hydrogeology from Birmingham University in 1984. After a brief spell in voluntary work and as a kitchen assistant, he spent five years with Thames Water Authority (subsequently the National Rivers Authority) in Reading, gaining practical experience with test pumping, geophysical logging and dealing with customers' waterlogged cellars. Wanderlust then led Dave across the North Sea to Trondheim, Norway, in 1989, where he spent 6 years as a "Forskermann" (*Researcher*) in the Section for Geochemistry and Hydrogeology at the Geological Survey of Norway. During this Norwegian sojourn, Dave became involved in work in Eastern Europe, especially in Lithuania and Latvia. He made it his mission to find collaborative projects ever further eastwards until he discovered his all-time favourite city at Tomsk, Western Siberia, where he has spent a number of happy and fruitful visits as a guest of Tomsk State University (TGU).

After his return to the U.K., Dave was employed in a large commercial consultancy and then as a lecturer at the University of Sheffield, before deciding to "go it alone" as an independent consultant in hydrogeology and environmental geochemistry in Chesterfield, where he trades as "Holymoor Consultancy". Much of his work is related to minewater contamination issues and groundwater resources assessment. However, amongst other clients, he is contracted by Norwegian Church Aid to assist in emergency water supply and sanitation to some of the world's more interesting regions, including Afghanistan, Iraq, Chad, Kosovo and the Great Lakes area of Central Africa. Dave is also becoming increasingly interested in the promotion of the use of ground source heat pumps, a relatively little-known technology in the U.K. Dave has a daughter, Jenny, and enjoys songwriting and playing the guitar, occasionally as one half of the lo-fi folk duo *The Sedatives.*