



# TECHNICAL BRIEF: BASIC GEOCHEMICAL WATER QUALITY SAMPLING AND TESTING

Guidance for field practitioners on the sampling,  
testing and validation of geochemical water  
quality.

## ABSTRACT

Where groundwater is being used by a humanitarian organization to supply medical facilities and/or populations, the sampling, measuring, and testing of its quality is important for several reasons, not least the organization's responsibility to its patients and the public health of the populations it works with. Basic water quality assessments are an important first step in the determination of potential risks from a water source and should be conducted prior to any further, more in-depth, investigations.

This document details a set of minimum standards for the sampling and testing of water quality under field conditions and presents several methods to evaluate laboratory reports. Two one-page technical briefs are presented for the sampling and validation of water quality analyses with accompanying explanation notes.

Standard groundwater source and water quality measurement and reporting forms are added as appendices to ensure that quality data is available for further analysis, interpretation and record keeping.

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*Cover photo: Measuring the electrical conductivity of water at a groundwater source in Palorinya, Northern Uganda (MSF, 2017)*

## Document SCOPE

This technical brief gives guidance on the sampling and testing of the chemical water quality of groundwater sources<sup>1</sup> in humanitarian settings and is intended to describe a set of minimum standards with the understanding that other water quality testing scenarios will require further specific and appropriate guidance<sup>2</sup>.

## Why test groundwater quality?

- To ensure water is safe, acceptable and in compliance with standards applicable to its use<sup>3</sup>.
- To answer questions or concerns that people might have about the water they are consuming.
- As a baseline for a recently constructed, rehabilitated, or commissioned source.
- As part of a longer-term monitoring strategy.
- To establish what treatment or pre-treatment methods might be required to reduce or eliminate some or all the constituents in water.
- To provide a characterisation of the geological and hydrogeological environment to determine the provenance of a dissolved constituent and/or provide an assessment of the suitability and potential sustainability of a source or others in the area.

## When?

All groundwater sources supplying medical facilities in humanitarian response or being used for public supply must be tested after construction (during pumping tests), rehabilitation and/or commissioning, serving as a baseline for future monitoring. Groundwater sources should be tested if there are notable, observable and/or measurable changes in water quality – these might be organoleptic<sup>4</sup> issues or changes in routinely measured bulk parameters such as pH, turbidity, or conductivity. The monitoring of groundwater sources must include routine water quality testing according to a schedule appropriate for the usage and programme and is a critical part of evaluating the longer-term sustainability of a source.

## What?

The key bulk, master, and indicator parameters<sup>5</sup> must be measured when water is sampled in the field and all major dissolved ions<sup>6</sup> reported with every laboratory analysis. There are several reasons for this:

- They provide key information about the hydrogeological and geochemical context,
- They provide baseline data for future reference,
- They dominate the water chemistry (usually >99% of the dissolved content) and have an important relationship with the transport and fate of some toxic dissolved chemicals,
- Quality assessments can be made of the testing laboratory.

In addition, details of the groundwater source must be recorded alongside the samples, this includes the location, construction details (depth, diameter, position of screens etc.) and water level.

Water samples must always be taken as close to the source as possible and prior to any treatment processes or distribution. Similar sampling and treatment can be carried out post treatment or distribution but will not represent natural chemical water quality and so is not within the scope of this guidance document.

## How?

### *Authorisation and permissions*

All field teams have the responsibility of ensuring that they have permission to access a site and carry out water sampling and testing. The results of all tests must be made available to the relevant national regulatory body if requested.

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<sup>1</sup> This includes large diameter wells, drilled boreholes (tubewells) and springs.

<sup>2</sup> This includes testing for trace elements, sometimes referred to as 'heavy metals', organic chemicals (such as pesticides and herbicides) and radionuclides (such as radon).

<sup>3</sup> Standards may vary considerably dependent on usage.

<sup>4</sup> Taste, odour and appearance.

<sup>5</sup> See the table on page 7 for an overview of these parameters.

<sup>6</sup> A major dissolved constituent is, for this document, any chemical with a concentration that generally exceeds 5mg/L.

### Health and safety

The health and safety of all staff and other people working at, or living near to, the groundwater source is of paramount importance. A full risk assessment should be made by the project responsible prior to any water quality sampling activities. The risk assessment should account for security, access and permission to the site, work in confined and restricted spaces, fumes from generators, electrical hazards, movement of vehicles around the site and all other potential hazards, not least the perception of members of the community towards the activity.

### Units of measurement

Several units are used for the expression of the concentration of a solute in water, the following are the most important, alongside their most commonly used units of measurement<sup>7</sup>:

- Mass concentrations – *mg/L* and *µg/L*, which can be considered equivalent to *ppm* and *ppb*.
- Molarity – *mols/L* or *mmols/L*. Divide the concentration in *g/L* or *mg/L* by the molar mass (MM) of the chemical.
- Molality – *mols/kg* or *mmols/kg*. Molarity is more commonly used in basic chemical water quality analyses, but it can be assumed that most natural waters have a mass  $\approx 1\text{kg/L}$ .
- Equivalence – *eq/L* or *meq/L*. Multiply the *mols* or *mmols/L* by the *valence* (charge) of the ion.

Care must always be taken with concentration units as there are different conventions. For example, it is common in Europe to express the concentration of nitrate as *mg/L as NO<sub>3</sub>*, whereas in the U.S. the concentration is normally expressed as *mg/L as N*, or *NO<sub>3</sub>-N*. To convert between the two a factor is calculated from their relative molar masses – 62g/mol for NO<sub>3</sub> and 14g/mol for N. Thus, a concentration of 50mg/L as NO<sub>3</sub> = 50 x (14/62) = 11.3 mg/L as N – the water quality standard for nitrate in both regions.

### Total and dissolved analysis

*A total analysis* – gives the concentration of all dissolved and colloidal or precipitated chemical species in a water sample.

*A dissolved content analysis* – gives the concentration of the dissolved content.

*Filtration and acidification* are required for a dissolved content analysis - this removes any colloidal or precipitated minerals; this is usually carried out at the time of sampling using a 0.45µm cellulose acetate membrane filter. Acidification to a pH <2, by adding around 0.5 and 2ml of acid per 100ml sample, preserves dissolved metals in solution and helps prevent adsorption to the container wall. This process is termed '*sample conservation*'.

The standard protocol for sample conservation is as follows [1]:

Chemical(s)	Treatment/conservation method	Container	Transport conditions
Cations and metallic elements	Filtration with 0.45 µm filter, acidified to $\leq \text{pH } 2$	Polyethene (PE/HDPE) - min. 100ml	Dark environment, cold chain (2-8°C)
Anions	No filtration required unless turbidity >5 NTU.	Polyethene (PE/HDPE) - min. 100ml	Dark environment, cold chain (2-8°C)
Nitrate	No filtration (unless turbidity >5 NTU), preserved with ultrapure nitric acid (HNO <sub>3</sub> ) to $\leq 2 \text{ pH}$	Translucent or brown polyethene or analytical grade glass, >125ml	Dark environment, cold chain (2-8°C)
Ammonium	No filtration (unless turbidity >5 NTU), preserved with ultrapure sulphuric acid (H <sub>2</sub> SO <sub>4</sub> ) to $\leq 2 \text{ pH}$	Translucent or brown polyethene or analytical grade glass, >125ml	Dark environment, cold chain (2-8°C)

Table 1: Standard protocols for sample conservation

<sup>7</sup> The most commonly used units are not always from the International System of Units (SI) of measurements – e.g. the SI unit for molarity is moles/m<sup>3</sup> but moles or millimoles/L (mmol/L) are more commonly used for natural and groundwaters.

These techniques are not practical for most field settings - specialist ultra-pure acids are needed and too many samples are required, increasing the risk of mixing up test results. A total analysis gives the best representation of what is going to be ingested by users, avoiding the need for sample conservation beyond maintaining a dark environment under cold chain conditions. This is the approach described in this technical brief with the proviso that, under certain conditions, this can lead to slight errors in analyses.

### *Laboratories*

Potential testing laboratories (labs) should be contacted prior to sampling to establish both the humanitarian organization's and the lab's requirements. In many countries the national water ministry has testing capacity, often these labs will be more than capable of carrying out basic water quality analyses. Other institutions, such as universities and teaching hospitals might also provide the service. In all instances, if a choice has been made to carry out a total analysis, then the lab should be informed of this and that the sample has not been filtered or acidified.

Potential testing laboratories should be able to provide the following information:

1. The type of measurement techniques and equipment available – see [Table 4: Water quality measurement techniques](#) for guidance on the different methods most commonly used,
2. Their requirements for sample size,
3. Their requirements for sample conservation, although the organization should insist on a total analysis with minimum conservation techniques, as described above,
4. The turnaround time between receiving a sample and providing results,
5. An example analysis, preferably with an error check as validation, see [Validating test results](#) below.

Most laboratories have a standard reporting format, the following are some key requirements:

1. All samples must be referenced using the ID provided by the organization - if the lab needs to maintain their own sampling identification, then this must be cross referenced in their final report,
2. Report on how they carried out the testing – how samples were processed and what equipment and method was used for each analyte and parameter,
3. Note accurately the time and date of receiving and testing each sample,
4. Provide the name and signature of a responsible person with an official validation stamp,
5. Present all results in a tabulated format with clear units of measurement for each result,
6. Include a column with any national standards, with units, for comparison with the test results.

All labs should be able to carry out an ion-balance error calculation on a set of results, if so, they must present this with the final report. For analyses that are more complex, for example for trace metals that might require speciation (such as chromium and arsenic), additional advice must be sought prior to sending samples for testing.

### *Equipment*

A basic list of all the equipment required for sampling and testing of groundwater sources is included for guidance in [Appendix 1: Water sampling and testing equipment](#).

### *Field measurement and testing*

The following parameters must be measured and recorded in the field at the time of sampling:

- Electrical conductivity (EC), pH, temperature, turbidity, and alkalinity.

The following parameters might also be measured in the field:

- Total hardness, nitrate (or total nitrogen), colour (true and apparent), oxidation-reduction potential (ORP), dissolved oxygen (DO).

For all these tests there are well established methods of field testing using digital probe meters, titration techniques, colourimetric test kits or (spectro-)photometers. All digital probe meters must be recently calibrated, properly handled and stored and all reagents pre-expiry and in good condition.

Refer to the [Table of groundwater water quality analytes and parameters](#) below for more details on sampling and testing these parameters.

### *Sampling, preservation, packaging, and labelling*

The following procedure should be followed when sampling a groundwater source after first obtaining permission and following all other guidance that has been given. Sampling should always be done at the head of the source:

1. Note all the details of the source and fill the form in [Appendix 2: Groundwater Source FORM](#),
2. Record the resting (static) water level,
3. Purge the source prior to sampling by removing >3 volumes of water unless a decision has been made to test water quality at start-up<sup>8</sup> or it is not possible to remove that volume of water<sup>9</sup>,
4. Purge and flush the sample tap or line,
5. Take three clean, sterile, polyethylene polyethylene (PE/HDPE) sample containers with a minimum volume of 250ml each<sup>10</sup>,
6. Before taking each sample, make any field measurements<sup>11</sup>,
7. Take one sample immediately after purging, another when the water level has started to stabilise during pumping, and the last towards the end of the pumping cycle,
8. Each sample container must be flushed at least 3 times with the water to be sampled,
9. The containers must be filled to the top whilst avoiding contact with the inside of the container and lid,
10. All samples must be clearly marked using an indelible marker pen using an identification code or number that can be referenced and used by the lab,
11. Record the time, water level, flow, the results of all field measurements and other observations and measurements on the form in [Appendix 2: Groundwater Source FORM](#), alongside the sample ID,
12. Samples should be placed into cold chain (2-8°C) in a dark environment as soon as possible,
13. Fill out all fields in the form in [Appendix 3: Water quality chain of custody FORM](#),
14. Transport to the lab for testing in a dark environment, under cold chain conditions (2-8°C) and, ideally, within 48 hours.

No specific guidance is given here on labelling as this information can be found in the two forms in Appendix 2 and 3.

### *Validating test results*

Water quality analyses can be evaluated for their accuracy using several techniques within two broad categories:

1. Testing the lab by sending water of a known quality with field samples,
2. Analysis of the lab results for error.

It is important to be clear about what is being tested with the first method and there are several different approaches that can be taken. The most relevant for the purposes of this guidance are:

1. *Replicate samples* – several samples taken from the same source and sent together. This should be standard practice.
2. *Field blanks* – samples of de-ionised water taken into the field and then packaged and labelled as all other samples.
3. *Method or equipment blanks* – samples of de-ionised water passed through all the same preparation techniques as other samples. If sample conservation is used, then this will test whether there is contamination from these practices.

Reporting which technique is used is critical - a failure to properly label these or other samples will not be a test of the lab's capacity, only of basic logistical competence.

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<sup>8</sup> This might be done if information about the impact of the casing or rising main material on water quality is required.

<sup>9</sup> This might be the case if an open well is being sampled and tested.

<sup>10</sup> Contact with the testing lab will confirm the volume of sample required as they might need to split into separate aliquots for analysis.

<sup>11</sup> At an absolute minimum this would include pH, temperature, conductivity and turbidity.

There are several methods that can be used to validate test results within the second category - each of them relies on all the major cations and anions being tested by the lab:

1. An ion-balance error calculation.
2. Estimation or calculation of total concentration from electrical conductivity,
3. Calculation of electrical conductivity from analysis results (to compare with field or lab measurements).

### 1. Ion balance error calculations

A sample of water must be electrically neutral, otherwise it would give an electric shock on contact. This principal of electro-neutrality can be expressed in terms of chemical composition and concentration:

$$\sum \text{anions (meq/L)} = \sum \text{cations (meq/L)}$$

To evaluate a water quality analysis according to this relationship, all measurements must be expressed in equivalents – usually milliequivalents (meq/L) are used. The conversion is done in two steps:

Step 1 - divide the concentration expressed in mg/L, or ppm, by the molar mass of the dissolved ion to obtain the molarity (mmol/L).

Step 2 – multiply the molar mass by the valence (charge) on the dissolved ion.

#### Worked Example

A WQ analysis reports a concentration of calcium (Ca<sup>2+</sup>) of 120 mg/L.

There are, thus; 120/40.078 g/mol = 2.99 ≈ 3 mmol/L of Ca<sup>2+</sup> ions in solution.

And, therefore; 3 mmol/L x 2 = **6 milliequivalents/L (meq/L)**

20	2
<b>Ca</b>	20.0802
Calcium	
40.078	

The valence and the molar mass of all the major ions, and some others, can be found in the [Table of groundwater water quality analytes and parameters](#) (see red circle in the worked example below).

The sum of all the positively charged ions (cations) and negatively charged ions (anions) in an analysis, which must include measurement of all the major dissolved ions, can now be evaluated and the error expressed according to:

$$\text{Ion balance error (+/-\%)} = \left( \sum \text{cations} + \sum \text{anions} \right) / \left( \sum \text{cations} - \sum \text{anions} \right) \times 100$$

An error of <+/-5% is deemed acceptable, anything greater than this and there might be one or several issues, including the lab itself. Where the problem lies requires further investigation but consistent errors outside this limit and from the same lab indicate that there is a problem with their equipment, procedures or reporting and they should be expected to explain this. See [Appendix 5: Diagnosis table – water quality analyses](#) for the diagnosis of some common problems with water quality analyses.

### 2. Estimating and calculating total concentration from electrical conductivity

There is a direct relationship between electrical conductivity and total dissolved solids, this forms the basis of this and the next method and is explained in the section [Electrical conductivity and total dissolved solids](#).

An estimate of the total anions and cations can be made from an EC measurement according to this formula:

$$\sum \text{anions (meq/L)} = \sum \text{cations (meq/L)} \approx EC/100 (\mu S/cm)$$

This is not a precise relationship but for waters with low total dissolved solids it gives a first pass means to evaluate an analysis [2].

### 3. Calculation of electrical conductivity from analysis results

Historically there have been several methods proposed to calculate the EC of a water sample from analysis results and these often served to either estimate a missing, or hard to measure, analyte, or to validate an analysis. Rossum presented one such method, often referred to as the 'modified Rossum method' [3]. This involved the calculation of a preliminary estimation of EC ( $EC'$ ) from the product of analyte concentration, expressed as meq/L, and various factors with the units  $\mu\text{S}/\text{cm}/\text{meq}/\text{L}$ :

$$EC' = 52.0 [Ca] + 46.6 [Mg] + 49.6 [Na] + 72.0 [K] + 84.6 [CO_3] + 43.6 [HCO_3] + 75.9 [Cl] + 71.0 [NO_3] + 73.9 [SO_4]$$

Depending on the overall TDS and the water type (see Water type (geochemical facies)), another formula must then be applied to  $EC'$  to achieve a final estimation of EC ( $\mu\text{S}/\text{cm}$ ), where T is the concentration in equivalents (meq/L) of either the anions or cations;

- i) If  $T < 10$  meq/L, or  $T > 10$  meq/L and  $\text{HCO}_3^-$  is the predominant anion, then;  $EC = EC' - (EC'^{1.447}/157)$
- ii) If  $T > 10$  meq/L and chloride ( $\text{Cl}^-$ ) is the dominant anion, then;  $EC = EC' - (EC'^{1.38}/178)$
- iii) If  $T > 10$  meq/L and if sulphate ( $\text{SO}_4^{2-}$ ) is the dominant anion, then;  $EC = EC' - (EC'^{1.436}/116)$

The factors used to calculate  $EC'$  were determined by empirical analysis of hundreds of water quality test results and can be referred to as *conductivity factors*. Determination of the water type is generally achieved by calculating and plotting the relative percentage of anions in a water sample<sup>12</sup>.

[Appendix 4: Water quality test result sheet](#) includes all the formulae above in order to be able to carry out this calculation and compare field measured EC with the lab measured result. The relative error can then be calculated according to;

$$\text{Relative error} = \frac{(\text{measured value} - \text{calculated value})}{\text{measured value}}$$

Any major errors from laboratory results should be investigated as described for previous validation methods and [Appendix 5: Diagnosis table – water quality analyses](#) can help explain some common reasons for these errors and differences.

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<sup>12</sup> Groundwater tends, with depth and residency time, towards an Na-Cl type, passing first from a bicarbonate ( $\text{HCO}_3^-$ ) type to a sulphate ( $\text{SO}_4^{2-}$ ) type [4].

Table of groundwater water quality analytes and parameters

Designation	Analyte/parameter	Ion(s)	Units	MM (g/mol)	Valence (charge)	Measuring and reporting priority	When to test	Comments
Physical and bulk parameters	Total dissolved solids (TDS)	All	mg/L	-	-	Must be reported.	<b>Lab must measure and report.</b>	Will be calculated from lab analysis. Estimation possible from electrical conductivity.
	Electrical conductivity (EC)	All	µS/cm	-	-	<b>Must be measured.</b>	In the field at time of sampling and in the lab.	Meters must be recently calibrated.
	Colour (true and apparent)	-	Pt-Co or Hazen	-	-	Not critical for basic analysis, good to know.	In the field at time of sampling.	Provides, with other WQ results information on colour determinants in sample, e.g. precipitated minerals.
	Turbidity	-	NTU	-	-	<b>Must be measured.</b>	In the field at time of sampling.	Photometer or turbidity tube.
	Total suspended solids (TSS)	-	mg/L	-	-	Not often measured.	Lab might measure and report.	Measure of particles >2 microns in size.
	Alkalinity	HCO <sub>3</sub> <sup>-</sup> / CO <sub>3</sub> <sup>2-</sup>	mg/L as CaCO <sub>3</sub>	-	-	<b>Must be measured.</b>	<b>In the field at time of sampling. Lab must measure and report.</b>	Simple titration and speciation kits available for field tests.
	Hardness	Ca <sup>2+</sup> + Mg <sup>2+</sup>	mg/L as CaCO <sub>3</sub>	CaCO <sub>3</sub> = 100	-	Must be reported from calculation.	<b>Lab must measure and report.</b>	Indicator of mineral scaling issues. Important parameter for water treatment technologies that use sensitive membranes.
Master parameter	pH	H <sup>+</sup>	-	-	-	<b>Must be measured.</b>	<b>In the field at time of sampling and in the lab.</b>	Probes sensitive, must be recently calibrated.
	Temperature	-	°C/°F	-	-	<b>Must be measured.</b>	<b>In the field at time of sampling and in the lab.</b>	All pH and EC probes measure temperature for correction of these parameters to a standard.
	Oxidation-reduction potential (ORP)	-	mV	-	-	Not critical for basic analysis.	Measure if carrying out environmental assessment. Not a basic WQ parameter.	Probes sensitive, must be recently calibrated. Readings can take time to stabilise, and advice should be sought regarding interpretation of results.
	Dissolved oxygen (DO)	-	mg/L as O <sub>2</sub>	-	-	Not critical for basic analysis.	Measure if carrying out environmental assessment. Not a basic WQ parameter.	Probes sensitive, care must be taken.
Major cation	Calcium	Ca <sup>2+</sup>	mg/L	40.08	+2	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	Can be measured in field as part of total hardness using a titration kit.
	Magnesium	Mg <sup>2+</sup>	mg/L	24.31	+2	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	
	Sodium	Na <sup>+</sup>	mg/L	22.9	+1	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	Some handheld meters available – can be expensive and sensitive if they are ion-selective. Others make calculation from other parameters.

	Potassium	K <sup>+</sup>	mg/L	39.1	+1	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	-
Minor cation	Ammonium	NH <sub>4</sub> <sup>+</sup>	mg/L	18.01	+1	Often measured to determine total nitrogen in sample.	Lab might measure and report.	Forms part of total nitrogen content of sample.
	(Total) iron	Fe <sup>2+</sup> /Fe <sup>3+</sup>	mg/L or µg/L	55.85	+2	Should be measured in areas with known problems.	In the field at time of sampling and in the lab.	Indicators of problem are low pH and complaints of red/brown mineral precipitate and turbidity. Important parameter for water treatment technologies that use sensitive membranes.
	Manganese	Mn <sup>2+</sup>	mg/L or µg/L	54.94	+2	Should be measured in areas with known problems.	In the field at time of sampling and in the lab.	Indicators of problem are low pH and complaints of brown/black mineral precipitate and turbidity. Important parameter for water treatment technologies that use sensitive membranes.
Major anion	Bicarbonate	HCO <sub>3</sub> <sup>-</sup>	mg/L	61	-1	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	Forms part of total alkalinity.
	Carbonate	CO <sub>3</sub> <sup>2-</sup>	mg/L	60	-2	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	
	Chloride	Cl <sup>-</sup>	mg/L	35.45	-1	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	-
	Sulphate	SO <sub>4</sub> <sup>2-</sup>	mg/L	96.06	-2	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	Forms part of total sulphur, see note below.
Minor anion	Nitrate	NO <sub>3</sub> <sup>-</sup>	mg/L	62.01	-1	<b>Must be measured.</b>	<b>Lab must measure and report, can be measured in the field.</b>	Colourimetric kits available for measurement of nitrate/nitrite in the field.
	Nitrite	NO <sub>2</sub> <sup>-</sup>	mg/L	46.01	-1	Should be measured with nitrate.	Lab might measure and report.	
	Fluoride	F <sup>-</sup>	mg/L	19	-1	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	Can be measured in the field using a spectrophotometer.
	Bromide	Br <sup>-</sup>	mg/L	79.9	-1	Often measured.	Lab might measure and report.	Bromide can be an indication of seawater intrusion.
	Orthophosphate	PO <sub>4</sub> <sup>3-</sup>	mg/L	94.97	-3	Often measured.	Lab might measure and report.	Will make up the most of total phosphate concentration in groundwater. Indication of agricultural and industrial pollution.
non-ionic	Silica	SiO <sub>2</sub>	mg/L	64.07	-	<b>Must be measured.</b>	<b>Lab must measure and report.</b>	Important parameter for water treatment technologies that use sensitive membranes.

Table 2: Basic groundwater quality analytes and parameters

Note: The measurement of **hydrogen sulphide (H<sub>2</sub>S)** and its dissolved ion (HS<sup>-</sup>) as part of total sulphur in a sample is complicated by the fact that the former is a gas, and the latter requires complex preservation techniques using zinc acetate solution. The presence of hydrogen sulphide in water is usually an acceptability issue before a health one given the 'rotten egg' odour. The presence of hydrogen sulphide gas is usually an indicator of sulphate related bacteria in the groundwater and can be accompanied by elevated iron levels, staining around outlets and black bio-masses growing on pumps, filters and related infrastructure.

## [Explanation notes](#)

### [Introduction](#)

Carrying out a basic water quality analysis is not complex, but several terms, concepts and measurement parameters need to be explained in order to help with their interpretation and ensure that results are accurately presented. Geochemistry is a vast field and this section can only touch on some of most important and general aspects - many additional resources are available for a deeper exploration of the subject

### [Major, minor and trace constituents](#)

The constituents of water can be classified according to the following groups<sup>13</sup>:

- Major constituents: 7 constituents<sup>14</sup> make up 99% of TDS and their concentrations exceed 5 mg/L.
- Minor constituents: 0.01 – 10 mg/L.
- Trace constituents: < 0.1 mg/L.

### [Classification of water quality parameters](#)

The following table gives the commonly accepted classifications of different water quality parameters<sup>15</sup>:

Parameter sub-type	Examples
Physical, indicator	Colour, odour, taste, turbidity, electrical conductivity, pH, total dissolved solids, temperature, total suspended solids.
Inorganic or chemical	Calcium, magnesium, potassium, sodium, bicarbonate, carbonate, chloride, sulphate, fluoride, alkalinity, nitrate, nitrite, phosphate, bromide.
Bulk inorganic chemical	Hardness, alkalinity.
Toxic metals and trace elements <sup>16</sup>	Copper, chromium, cadmium, zinc, (inorganic) mercury, iron, manganese, arsenic, lead, antimony, aluminium, cobalt, selenium, nickel.
Organic	BOD, COD, carbon containing compounds – hydrocarbons and petrochemicals, pesticides, methyl-mercury, pharmaceuticals, food, explosives, paints, and cosmetics.
Nutrient demand	Biological and chemical oxygen demand (BOD & COD).
Bacteriological	Total coliform, faecal coliform, <i>E-coli</i> , iron, and sulphate reducing/related bacteria (IRB and SRB).
Biological	Phytoplankton, zooplankton.
Radio-nuclide	Gross alpha emitters, beta particle and photon (gamma) radioactivity, radium 226 and radium 228 (combined) and uranium <sup>17</sup> .
Isotope	Oxygen, tritium (hydrogen), carbon-14 (often used for groundwater dating and carbon dating respectively).

Table 3: Classification of water quality parameters

### [Water type \(geochemical facies\)](#)

Hydrogeologists and geochemists like to present water quality analyses and use various graphical techniques which describe the *water type* or *geochemical facies*. These methods, which include *Piper* and *Stiff diagrams*, usually present the relative concentrations of major anions and cations. Several models of geochemical evolution can then be applied to these representations to evaluate the geochemistry along a flow path, over time, at different depths or according to the impact of abstraction. The relative concentrations, expressed in meq/L, of the major anions ( $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^{2-}$ ) in groundwater is significant to the model that describes evolution

<sup>13</sup> Adapted from reference [11].

<sup>14</sup> Calcium, magnesium, potassium, sodium, chloride, sulphate, carbonate and bicarbonate. Note that carbonate and bicarbonate make up carbonate alkalinity and that in most natural waters the majority (>80%) of this will be present as the bicarbonate ion ( $\text{HCO}_3^-$ ).

<sup>15</sup> Adapted from reference [12]. Complete agreement on these classifications is unlikely.

<sup>16</sup> Some of these are often referred to as 'heavy metals', although this is a somewhat misleading and inaccurate term.

<sup>17</sup> See; <http://wellowner.org/water-quality/radionuclides/>

of water with increasing time and depth and to defining the relationship between electrical conductivity and total dissolved solids [5].

For the purposes of this guideline and for the application of the modified Rossum method to the calculation of electrical conductivity (see [Validating test results](#)), the water type represented by an analysis is determined according to the dominant anion expressed as a percentage of the total anion concentration in meq/L.

### Water quality measurement techniques

A water sample is typically analysed for chemical constituents using one or more of the following methods<sup>18</sup>:

Table 4: Water quality measurement techniques

Method	Analyte/parameter	Level of detection	Abbreviation
Inductively coupled plasma – atomic emission spectroscopy	Major and minor constituents	ppm, mg/L	ICP-AES
Atomic absorption spectroscopy	Trace element	ppb, µg/L	AAS
Inductively coupled plasma – mass spectroscopy	Trace element constituents, some speciation when combined with some chromatographic method	ppb, µg/L	ICP-MS
Gas chromatography – mass spectroscopy	Most useful for organic compounds. Involves separation prior to analysis.	ppb, µg/L	GC-MS
Colorimetry/ spectrophotometry	Rapid. Major constituents.	ppm, mg/L	<i>None commonly used</i>
Classical wet chemical methods (titrimetric)	Major constituents; relatively inexpensive; enables speciation	ppm, mg/L	<i>None commonly used</i>

The abbreviations given above should be used in WQ analysis reports to indicate the type of test used to measure an analyte.

### Electrical conductivity and total dissolved solids

There is a direct relationship between electrical conductivity (EC) and total dissolved solids (TDS)<sup>19</sup>. However, the relationship varies according to the water type and the overall concentration, or *activities*, of the solutes. It is typical to express the relationship using the following formula:

$$TDS (mg/L) = f \cdot EC(\mu S/cm)$$

Where, *f* represents a *conversion factor* and varies in natural waters between a value of 0.5 and 0.8.

Most handheld, field portable, EC meters are programmed to calculate and output a TDS value and typically use a value ≈0.67 by default. Adjustments can normally be made to this value within the range of 0.5 and 1.0 - this must be done following a comprehensive water quality analysis if longer term monitoring is to be carried out.<sup>20</sup>

### Turbidity, total suspended solids, and colour (true and apparent)

Confusion surrounds these terms as they are, in some way, related.

**Turbidity** is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms. It gives water a muddy or milky appearance due to the

<sup>18</sup> Adapted from reference [13].

<sup>19</sup> Note that the term TDS, as used here, is sometimes referred to as total dissolved salts, given that dissolved solids such as sugars will not impart conductivity to a sample as their dissolved products are non-ionic. However, there should not be much sugar, or any other organic compound, in natural groundwater.

<sup>20</sup> See; <http://www.hannacan.com/PDF/manHI98311.pdf>

scattering of light by the suspended material. The measurement of turbidity compares the intensity of light scattered by a sample and that of a reference suspension. This can be done using several low technology solutions, such as *Secchi discs* or turbidity tubes, or by (spectro-)photometric methods. The most common unit of turbidity is the logarithmic *Nephelometric Turbidity Unit* (NTU), although other units might also be used [6]. Excessive turbidity is considered an acceptability issue and can cause problems with chlorination.

**Suspended solids** - are defined as the portion of total solids in a water sample retained by a glass fibre (GF/C) filter of pore size >2 µm, all other constituents are considered to be dissolved or in gaseous form [6]. In practice it is common to use a 0.45 µm filter, which is the same that would be used during bacteriological analysis. Lab methods of measurement filter, dry, and weigh the residue, and the result is termed *total suspended solids* (TSS) and is usually expressed in mg/L. The size of filter must always be reported with this measurement.

Turbidity and total suspended solids are not the same thing, but they are related. Some researchers have tried to establish empirical relationships for water quality monitoring [7] and some equipment manufacturers have developed probes which measure both parameters simultaneously.<sup>21</sup>

**Apparent colour** is a measure of the direct, physically observable colour of water without turbidity removal.

**True colour** in water samples can result from the presence of natural metallic ions (iron and manganese), humus and peat materials, plankton, weeds, and industrial wastes. It is the colour of water with all suspended particles removed by filtration to achieve a turbidity free sample.

There are many units of colour and True Colour Units (TCU), 'APHA', 'Pt-Co' and 'Hazen' are commonly used, all referencing the same colour scale<sup>22</sup>. Colour is commonly measured using a (spectro)photometer.

For the purpose of groundwater quality testing and monitoring, turbidity is important as it can easily be measured in the field. Groundwater turbidity is often related to mineral precipitates or, sometimes, to the suspended products of corrosion. In some situations, it might be valuable to measure the true colour of groundwater, especially at shallow sources which might be affected by contamination with organic matter from nearby surface water or soil overburden.

These measurements, when made, should be made in the field as close as possible to the source and at the same time as sampling for lab testing - these properties can easily change during transport to a laboratory.

Most national water guidelines quote figures or limits for turbidity and colour. Typically, a limit of 5 NTU is set by most regulatory bodies for turbidity and 15 TCU/Hazen Units for true colour.

## pH

pH is probably the most important parameter in aqueous chemistry, determining the *dissolution, speciation, mobility and fate* of minerals, elements, and compounds. It is the measure of the activity of the hydrogen ion (H<sup>+</sup>) in a solution arising from the dissociation of the water molecule according to the simplified relationship:



And, is expressed on a unitless (dimensionless) logarithmic scale:

$$pH = -\log[a_{H^+}] \approx -\log[H^+]$$

Where, [a<sub>H<sup>+</sup></sub>] is the activity of the hydrogen ion and [H<sup>+</sup>] is the concentration.

The range of pH is commonly considered to be 0 to 14, with a lower number indicating a more acidic solution and a higher a more alkaline one, but it is possible to have pHs well outside of this range<sup>23</sup>.

pH must always be measured in the field at the time of sampling using a recently calibrated electrode and again during a lab analysis. Various colourimetric methods are available using reagents, but these do not usually provide an adequate range or accuracy and can give misleading results in poorly buffered (low alkalinity waters). Field measurements ensure the sample has not been affected by de-gassing and can be compared later with lab

<sup>21</sup> See: <https://www.hach.com/asset-get.download.jsa?id=10929896654>

<sup>22</sup> See: <https://www.hunterlab.com/blog/color-and-appearance-theory/apha-pt-co-hazen-color/>

<sup>23</sup> concentrated HCl has a pH of about -1.1

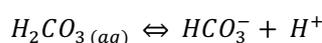
results. At a minimum both pH and conductivity should be monitored at all groundwater sources and significant changes require follow up with a more comprehensive analysis to compare with previous or baseline analyses.

Water quality standards and guidelines from several national and supra-national sources quote values for pH, generally as an *indicator parameter* within the range of 6.5 to 8.5. Values outside of this range can be good indicators of serious water quality and contamination issues. Elevated dissolved iron levels tend to be associated with pHs below 7 and, in extreme cases, much lower than this. Low pHs can also indicate poorly buffered waters with little or no dissolved carbonate, which might cause issues with corrosion and the release and mobilisation of metals from distribution pipework and storage containers. Waters with pH above 8 are often rich in dissolved carbonate minerals and present a risk of mineral scaling and cause issues for effective chlorination. Levels above 8.5 can indicate serious contamination issues, possibly from industry and agriculture.

### Alkalinity

Alkalinity is a measure of all *bases* in solution which have the capacity to neutralise or *buffer* acids and is an important, field measurable, parameter which has implications for the overall chemistry of a water sample. It should not be confused with pH, although the two are somewhat related, one is not a measure of the other. Bicarbonate ( $\text{HCO}_3^-$ ), carbonate ( $\text{CO}_3^{2-}$ ) and hydroxide ( $\text{OH}^-$ ) ions are the principal contributors to water alkalinity - borates, silicates, and phosphates can also contribute, although to a far lesser extent in natural waters unaffected by contamination or treatment. Alkalinity is sometimes used as a surrogate measure of the *total inorganic carbon* in a sample<sup>24</sup>, and, in geochemistry, the term generally refers to what is, technically speaking, *carbonate alkalinity*. For the purposes of this section, the term 'alkalinity' will be used according to this convention.

One of the most important chemical reactions in geochemistry is the atmospheric dissolution of carbon dioxide ( $\text{CO}_2$ ) in precipitation, forming carbonic acid ( $\text{H}_2\text{CO}_3$ )<sup>25</sup>. The *dissociation* of  $\text{H}_2\text{CO}_3$  is the first step in the formation of carbonate alkalinity in waters destined to recharge groundwaters:



Note that these reactions release two protons ( $\text{H}^+$ ) into solution, decreasing the pH. Bicarbonate and carbonate ions are also released, providing some buffering capacity. The relative concentrations of the different species arising from the dissociation of  $\text{CO}_2$  in water is determined by the pH and is often represented using a *speciation* diagram (see above). At around pH 10.3 there is one *equivalence point*, where the concentrations of  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  are equal, at pH 8.3  $\text{HCO}_3^-$  dominates, then there is another equivalence point for  $\text{HCO}_3^-$  and  $\text{H}_2\text{CO}_3$  at around pH 6. At around pH 4.5 there is no  $\text{CO}_3^{2-}$  or  $\text{HCO}_3^-$  present, only  $\text{H}_2\text{CO}_3$  - this is the *end point of alkalinity*. The measurement of alkalinity requires acid titration (usually with sulphuric acid,  $\text{H}_2\text{SO}_4$ ), first to pH 8.3 and then to a pH between 4.3 and 4.9, depending on the nature of the sample, its total alkalinity, and ionic strength. Two reagents are used during this titration – Phenolphthalein, which changes from pink to colourless at pH 8.3, and Bromcresol Green-Methyl Red, which changes from green to pink at pH 4.5. Some analyses report *Phenolphthalein alkalinity* as a measure of  $\text{CO}_3^{2-}$  concentration, although there is unlikely to be a significant concentration given that most natural, uncontaminated, waters have a pH of between 6.5 and 8.5, whereby far the most prevalent carbonate species is the bicarbonate ion. The main sources of natural alkalinity are rocks which contain carbonate-based minerals, such as calcium carbonate ( $\text{CaCO}_3$ ) and dolomite ( $\text{Ca.Mg}(\text{CO}_3)_2$ ). Carbonic acid dissolves these minerals, releasing carbonate and bicarbonate ions into solution. The following equation describes the dissolution of calcite:

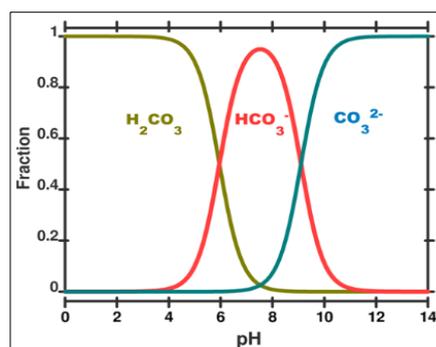
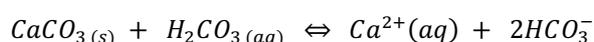


Figure 1: Carbonate speciation and pH

<sup>24</sup> See: [https://support.hach.com/app/answers/answer\\_view/a\\_id/1000033](https://support.hach.com/app/answers/answer_view/a_id/1000033)

<sup>25</sup> Carbonic acid is considered a *weak acid* as it is only partially dissociated, with both the undissociated acid and its dissociation product(s) being present in solution.

This reaction results in an increase in pH and alkalinity in *closed systems*, where availability of CO<sub>2</sub> is finite. In *open systems*, such as shallow groundwater environments, more CO<sub>2</sub> can dissolve in the water, maintaining the pH, increasing alkalinity, and leading to further mineral dissolution which will be limited by the saturation point or availability of the mineral. As with most mineral dissolution, the dissolution of carbonate is reversible and temperature dependent. Increases in temperature and/or pH, as well as the dissolution of other minerals, will cause the *remineralisation* or *precipitation* of calcite out of solution, which explains the grey-white solid found on the heating elements of kettles and the increase in suspended solids in water samples where CO<sub>2</sub> has degassed out of solution, increasing the pH.

Alkalinity is usually expressed, by convention, in units of *mg/L as CaCO<sub>3</sub>*, standardising reporting, and ensuring comparative analyses are possible. This does not imply that the source of alkalinity is, necessarily, carbonate in nature, although this will often be the case in natural groundwater samples. Both hardness (see below) and alkalinity are expressed in mg/L as CaCO<sub>3</sub> for the convenience of using a single unit to represent the concentration of multiple chemicals and for ease in calculating a solution's carbonate and non-carbonate hardness (see below)<sup>26</sup>. Typical values of alkalinity are as follows:

Source	Alkalinity (mg/L as CaCO <sub>3</sub> )	Dependency
Rainwater	<10	Carbon dioxide dissolution
Surface water	20-500	Soil type and contamination
Groundwater	50-1000	Geology and mineral dissolution, possibly contamination
Seawater	100-500	Mineral dissolution, carbon dioxide levels, surface, and groundwater inputs

Lab results should report the concentration of bicarbonate, carbonate, and total alkalinity as standard. This is not always the case, and it is important to know how to convert between units:

Converting Carbonate Alkalinity from mg/L as CaCO<sub>3</sub> to mg/L as CO<sub>3</sub><sup>2-</sup>

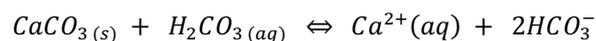
CaCO<sub>3</sub> has a molecular weight of 100 g/mol and the CO<sub>3</sub><sup>2-</sup> anion has a molecular weight of 60 g/mol.

Therefore, each milligram of CaCO<sub>3</sub> contains 60/100 = 0.6 mg of CO<sub>3</sub><sup>2-</sup> and the conversion is as follows:

**Carbonate Alkalinity as CO<sub>3</sub><sup>2-</sup> (mg/L) = 0.6 \* Carbonate Alkalinity as CaCO<sub>3</sub> (mg/L)**

Converting Bicarbonate Alkalinity from mg/L as CaCO<sub>3</sub> to mg/L as HCO<sub>3</sub><sup>-</sup>

Consider the following reaction:



CaCO<sub>3</sub> has a molecular weight of 100 g/mol and the HCO<sub>3</sub><sup>-</sup> anion has a molecular weight of 61 g/mol.

Therefore, each mol of HCO<sub>3</sub><sup>-</sup> corresponds to one mol of CaCO<sub>3</sub> (100 g) and contains 2 x 61 g = 122 g of HCO<sub>3</sub><sup>-</sup> and the conversion is as follows:

**Bicarbonate Alkalinity as HCO<sub>3</sub><sup>-</sup> (mg/L) = 1.22 \* Bicarbonate Alkalinity as CaCO<sub>3</sub> (mg/L)**

Calculating alkalinity from bicarbonate and carbonate concentrations

Considering the above conversions and their factors, the calculation of total alkalinity from expressions of bicarbonate and carbonate ion concentrations in lab reports can be made according to the following formula:

$$(Carbonate) Alkalinity = 0.8[HCO_3^-] + 1.67[CO_3^{2-}]$$

Where, [...] is the concentration expressed in mg/L.

National and international water quality guidelines do not usually quote a figure for alkalinity, but water treatment plants usually ensure some buffering capacity in finished water to prevent issues with pH fluctuations and corrosion of pipework. Some authors recommend demineralised water is dosed, or *conditioned*, to achieve a minimum alkalinity of 30mg/L as HCO<sub>3</sub><sup>-</sup> [8].

<sup>26</sup> See; [https://support.hach.com/app/answers/answer\\_view/a\\_id/1000214/~what-is-the-difference-between-hardness-and-alkalinity%3F-](https://support.hach.com/app/answers/answer_view/a_id/1000214/~what-is-the-difference-between-hardness-and-alkalinity%3F-)

## Hardness

*Total hardness* is defined as the concentration of all multi-valent cations in water, which might include calcium, magnesium, iron, manganese, aluminium, strontium, and barium, although for most natural groundwaters it is the expression of total calcium and magnesium concentration<sup>27</sup>. This is an important water quality parameter which indicates, at elevated levels, a risk of mineral precipitation in hot water piping systems and on the membranes of water treatment filters. It is often defined as the capacity for water to consume or precipitate non-synthetic soaps, failing to make them lather properly - multi-valent cations other than calcium and magnesium have been found to have this property as well [6].

Many different units are used to express the concentration of hardness in water, an indication of the importance that it has been afforded to water quality in the past. These include German degrees, general hardness, grains per gallon, English degrees, French degrees. It is most common nowadays to express the concentration in mg/L as CaCO<sub>3</sub>. This convention is a convenient means to express the concentration of two ions with a single unit of measurement and facilitates the comparison of measurements with other analyses. Finding conversion factors between different units is easy, there are many sources that can be found using a simple online search.

Hardness can easily be calculated from a water quality analysis or measured using simple and cheap titration kits in the field. To calculate and express the concentration in the standard manner, the following formula is used:

$$\text{Total water hardness (mg/L as CaCO}_3\text{)} = 2.5[\text{Ca}] + 4.1[\text{Mg}]$$

Where, [...] denotes the concentration in mg/L (or ppm).

Hardness is often divided into *permanent* and *temporary* components;

**Permanent hardness** – calcium and magnesium derived from the dissolution of sulphate and chloride base minerals, e.g. *ionic halides* such as calcium and magnesium chloride (CaCl<sub>2</sub> and MgCl<sub>2</sub>), gypsum (Ca.SO<sub>4</sub>.2H<sub>2</sub>O), anhydrite (Ca.SO<sub>4</sub>).

**Temporary hardness** – calcium and magnesium derived from the dissolution of carbonate minerals, e.g., calcite (CaCO<sub>3</sub>) and dolomite (Ca.Mg(CO<sub>3</sub>)<sub>2</sub>).

Temporary hardness is often termed *carbonate hardness*, its concentration, expressed in equivalents, being equal to alkalinity, or, strictly speaking, carbonate alkalinity. Total hardness (TH), temporary, or carbonate, hardness (CH), permanent, or non-carbonate hardness (NCH), and (carbonate) alkalinity (Alk) are related according to the following relationships:

- If Alk < TH, then CH = Alk
- If Alk >= TH, then CH = TH

To satisfy the above equations, and, in general, it is held that TH = CH + NCH. However, if CH > TH, then the difference is sometimes termed *pseudo hardness* (PsH) or *apparent hardness*. This is the portion of carbonate hardness that is associated with monovalent cations such as potassium, sodium and ammonium derived from the dissolution of minerals such as natron (NaCO<sub>3</sub> and NaHCO<sub>3</sub>) – these are most common in spring waters.

The standard classification of water hardness is as follows (in units mg/L)<sup>28</sup>;

- 0-60: soft
- 61-120: moderately hard
- 121 – 180: hard
- >180: very hard

This parameter is important given the sensitivity of some water treatment technologies and hot water systems to hardness and mineral precipitates. It should be calculated with all water quality analyses and is included in [Appendix 4: Water quality test result sheet](#) and most suppliers of reverse osmosis membrane treatment units

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<sup>27</sup> See; <http://www.aqion.de/site/140>

<sup>28</sup> See; <https://water.usgs.gov/edu/hardness.html>

will require its quantification prior to selection of (pre-)treatment options. The removal of calcium and magnesium from water is referred to as *water softening*, a process that often uses *ion exchange* technologies that replace these divalent cations with the monovalent cation sodium. Most national, regulatory authorities do not set health-based guidelines for calcium, magnesium, or total hardness. The EU sets a range of 80-100 mg/L as CaCO<sub>3</sub> for hardness, considering this to be an acceptable balance between corrosion resistance and the risk of mineral precipitation.

Other measures of the capacity of water to precipitate carbonate minerals are also used and expressed in some water quality analyses. They include the Langelier Saturation Index (LSI), Ryznar Stability Index (RSI) and the Puckorius Scaling Index (PSI). It is becoming more common to analyse water quality data according to mineral saturation indices - this information can help quantify certain risks associated with using a source and help understand better the geochemical environment and provenance of dissolved constituents.

### Oxidation-reduction potential (ORP)

Oxidation-reduction potential (ORP) or reduction-oxidation (redox) potential is a measure of the equilibrium potential of water and is usually expressed relative to the standard hydrogen electrode (SHE), and, thus, often referred to as  $E_h$ . The units of ORP, if expressed as  $E_h$ , are millivolts (mV), although other units are sometimes used to express ORP, the most common is *pe*, a unitless value<sup>29</sup>. Whichever system is used, the more positive a value, the more *oxidising* a water is - its constituents having a greater capacity to lose electrons - and the lower the value, the more *reduced* a water is - its constituents having a greater the capacity to gain electrons. Measurements of ORP, in conjunction with the measurement of pH, are used to evaluate *geochemical speciation models* and can provide insights on the evolution of geochemical water quality[9]. The figure above shows the stability diagram for various arsenic species according to  $E_h$  and pH values as an example<sup>30</sup>. It is a particularly important measurement in environmental and contamination assessments and in the treatment and management of wastewater, with some researchers determining that *Escherichia coli* (*E.coli*) kill rates in chlorinated water were more strongly correlated with ORP measurements than with chlorine residual measurements [10].

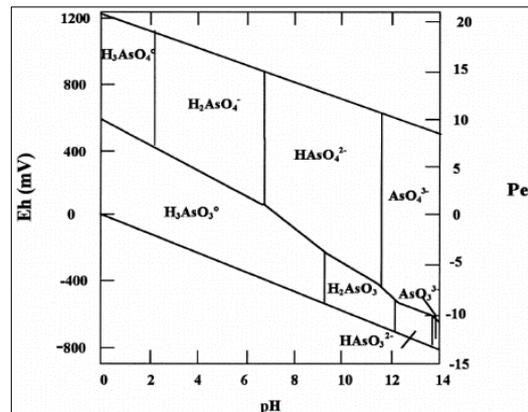


Figure 3:  $E_h$ -pH stability diagram for arsenic species

Maintenance, care, and calibration of ORP electrodes are critical in making meaningful ORP measurements, which must always be taken in the field at the time of sampling, and the interpretation of results necessitates more than a passing understanding of geochemistry - all reasons that preclude their applicability for basic water quality analyses in most circumstances. Advice should be sought by field practitioners needing to measure this parameter to ensure that meaningful results are measured and reported prior to interpretation.

<sup>29</sup>  $E_h = 0.059 pe$

<sup>30</sup> Source; [https://www.researchgate.net/figure/Redox-potential-Eh-pH-diagram-for-aqueous-arsenic-species-in-the-system-AsO-2-H-2-O-at\\_fig2\\_7946075](https://www.researchgate.net/figure/Redox-potential-Eh-pH-diagram-for-aqueous-arsenic-species-in-the-system-AsO-2-H-2-O-at_fig2_7946075)

## Bibliography and References

- [1] B. Misstear, D. Banks, and L. Clark, *Water Wells and Boreholes (Google eBook)*. 2006.
- [2] D. Appelo, C., Postma, *Geochemistry, Groundwater and Pollution*. London: CRC Press. 2005.
- [3] J. Logan, "Estimation of electrical conductivity from chemical analyses of natural waters," *J. Geophys. Res.*, vol. 66, no. 8, p. 2479, 1961.
- [4] I. I. Chebotarev, "Metamorphism of natural waters in the crust of weathering-3," *Geochim. Cosmochim. Acta*, vol. 8, no. 4, pp. 198–212, Sep. 1955.
- [5] I. I. Chebotarev, "Metamorphism of natural waters in the crust of weathering-1," *Geochim. Cosmochim. Acta*, vol. 8, no. 4, pp. 198–212, 1955.
- [6] B. Sundaram *et al.*, *Groundwater Sampling and Analysis-A Field Guide*. 2010.
- [7] S. Rahman and M. Clarke, "ESTABLISHING A RELATIONSHIP BETWEEN TURBIDITY AND TOTAL SUSPENDED SOLIDS – A Student Project," 2011.
- [8] F. Kozisek, "Health Risks From Drinking Demineralised Water," *Nutr. Drink. Water*, pp. 148–163, 2005.
- [9] D. K. Nordstrom and F. D. Wilde, "Reduction-Oxidation Potential," 2005.
- [10] A. Copeland and D. A. Lytle, "Measuring the oxidation-reduction potential of important oxidants in drinking water," *J. Am. Water Works Assoc.*, vol. 106, no. 1, pp. E10–E20, 2014.
- [11] P. Domenico and F. Schwartz, "Physical and chemical hydrogeology, 1990," 2001.
- [12] L. Deshpande, "Water Quality Analysis Laboratory Methods," *Counc. Sci. Ind. Res. New Delhi, Govt. India*, p. 68, 2012.
- [13] J. I. Drever, "The geochemistry of natural waters: surface and groundwater," p. 417, 2002.

*Appendix 1: Water sampling and testing equipment CHECKLIST*

<i>The following CHECKLIST is for guidance only and other equipment might be necessary depending on the context. All equipment must be calibrated and functioning properly and permission to access site is ALWAYS a prerequisite.</i>			
<b>Basic groundwater survey</b>	CHECK	<b>Documentation</b>	CHECK
GPS unit, handheld w/batteries		Groundwater Source FORM	
Water level probe ('dipmeter') and batteries		Field notebook and pens	
Flow measurement container (check volume first, <u>do not make assumptions or estimations</u> . Volume ≈ 1-minute yield)		Borehole records (if available)	
Calculator		Permanent marker or chinagraph pencil	
Digital camera		Relevant authorisation letter, if required	
Pump kit, genset and associated equipment if required		Site plans and map if required	
<b>Basic water quality measuring equipment</b>		<b>Safety equipment</b>	
Conductivity meter		First aid kit	
pH meter (and temperature)		Drinking water	
Turbidity		Gloves – leather heavy duty and examination type	
Alkalinity titration test kit, w/reagents		Sunscreen or shade	
Hardness titration test kit, w/reagents		Appropriate footwear and clothing	
Nitrate test kit, w/reagents		Phone, radio, or other communication device	
(True/apparent) colour/turbidity photometer		<b>Tools and sundries</b>	
Other meters as required (ORP, DO etc.)		Basic toolkit, including electrical meter	
Calibration fluids as required		Bucket(s)	
Cold-chain equipment (check capacity)		Handwashing equipment and consumables	
<b>Basic water quality measuring consumables</b>		Disinfection wipes	
Sample containers – min. 3 for one source		'Gaffer' or 'duct' tape, one roll	
Ziplock bags		Measuring tape	
Sample labels		Rope	
Demineralised water (if sending blanks)			
<b>Other equipment not included above</b>			
<b>Notes:</b>			

**Appendix 2: Groundwater Source FORM**

Project/Location:  Date:  Source ID:

GPS Location: X/E/W :  Y/N/S :  Z/elev. :  UTM zone :

Date of completion(dd/mm/yyyy):  Type of source:

Constructed by:  Owner-operator:

Report the current operational use and condition of the source and site:

Depth of borehole/well(m):  Yield (w/units):  Casing material and dia.(mm):

Water levels (mbgl) – Static:  Dynamic:

**Abstraction infrastructure** – note if this is spring source then complete only relevant information:

Pump installed (y/n):  Type:  Depth (mbgl):

Rising main type, dia. & length:  Delivery material, dia. & length:

Enter any other comments about the installation:

**Water Quality** Is there water quality information available for this site? (y/n):  If yes, the date:

Key comments on water quality, including any complaints from users:

**Sampling details** (field measurements should be made as close to the time of sampling as possible)

Date:		Time of starting pump:					Name of tester:			
Time (hh:mm)	Flow Units:	Water level (mbgl)	pH	EC (µS/cm)	Turbidity (NTU)	Temp (deg.C)	Alkalinity (mg/L)	ORP/Redox (mV)	DO (mg/L)	WQ sample ID

Any other comments/observations – volumes of samples, shipping date, problems with sampling etc.:

*All source and sample IDs used in this form must correspond with others used in all other forms, records, and reports.*

Appendix 3: Water quality chain of custody FORM

FORM no.:	<i>(number of form if more than one required)</i>	Laboratory name:	
Project & cost-centre:		Laboratory contact person:	
Contact person:		Phone:	
Phone:		Email:	
Email:		Contract/job number:	
Other information:			

Sample ID	Source ID	Location	Date sampled (dd/mm/yyyy)	Preservation method (if any)	Requested analysis	Comments
Sampled by (name and position):				Signature:		

Sample relinquished by:		Signature:		Date:		Time:	
Sample received by (lab):		Signature:					

*This form must be completed in conjunction with the Groundwater Source FORM and all sample IDs correspond with those used in all other forms, records, and reports.*

Appendix 4: Water quality test result sheet

Water quality test reporting and calculation sheet									
1	A	B	C	D	E	F	G	H	I
2	Analyte	MM (g/mol)	Valence (+/-)	Cond. Factor [ $\mu\text{S}/\text{cm}/(\text{meq}/\text{L})$ ]	Conc (mg/L)	Molarity (mmol/L)	Equivalence (meq/L)	%tot	EC' ( $\mu\text{S}/\text{cm}$ )
3	<b>Calcium - Ca<sup>2+</sup></b>	40.08	2	52					
4	<b>Magnesium - Mg<sup>2+</sup></b>	24.31	2	46.6					
5	<b>Sodium - Na<sup>+</sup></b>	22.9	1	49.6					
6	<b>Potassium - K<sup>+</sup></b>	39.1	1	72					
7	Ammonium - NH <sub>4</sub> <sup>+</sup>	18.01	1	-					-
8	Iron - Fe <sup>2+</sup>	55.85	2	-					-
9	Manganese - Mn <sup>2+</sup>	54.94	2	-					-
10	Aluminium - Al <sup>3+</sup>	26.98	3	-					-
11				Total '+':					
12	<b>Bicarbonate - HCO<sub>3</sub><sup>-</sup></b>	61	-1	43.6					
13	<b>Carbonate - CO<sub>3</sub><sup>2-</sup></b>	60	-2	84.6					
14	<b>Chloride - Cl<sup>-</sup></b>	35.45	-1	75.9					
15	<b>Sulphate - SO<sub>4</sub><sup>2-</sup></b>	96.06	-2	73.9					
16	<b>Nitrate - NO<sub>3</sub><sup>-</sup></b>	62.01	-1	71					
17	<b>Fluoride - F<sup>-</sup></b>	19	-1	-					-
18	Nitrite - NO <sub>2</sub> <sup>-</sup>	46.01	-1	-					-
19	Bromine - Br <sup>-</sup>	79.9	-1	-					-
20	Orthophosphate - PO <sub>4</sub> <sup>3-</sup>	94.97	-3	-					-
21	<b>Silica - SiO<sub>2</sub></b>	60.08	n/a						
22				Total '-'					
23				<b>Total '+ &amp; '-'</b>				<b>EC':</b>	
24	<b>Calculated EC (check water type)</b>	<b><math>\mu\text{S}/\text{cm}</math></b>		Use the formula relevant to the water type, where T=meq/L (+ or -), {cell G11 or G22}					
25	EC (T<10 meq/L, or T>10 and HCO <sub>3</sub> type)			$EC = EC' - (EC' ^{1.44}/157)$					
26	EC (T>10 meq/L, Cl type)			$EC = EC' - (EC' ^{1.38}/178)$					
27	EC (T>10 meq/L, SO <sub>4</sub> type)			$EC = EC' - (EC' ^{1.436}/116)$					
28	<b>Calculated parameters</b>	<b>mg/L</b>	<b>mmol/L</b>	<b>meq/L</b>					
29	TDS (mg/L):		-	-	TDS = Sum of mg/L {cell E23}				
30	Alkalinity as CaCO <sub>3</sub> :				Alkalinity as mg/L CaCO <sub>3</sub> = [HCO <sub>3</sub> ]/1.22 + [CO <sub>3</sub> ]/0.6, where [...] = mg/L				
31	Hardness as CaCO <sub>3</sub> (Ca+Mg):				Hardness = 4.1 [Mg] + 2.5[Ca], where [ ] = mg/L. Mmol/L = mg/L x 100. Meq/L = mmol/L x 2				
33	<b>Ion balance error (%)</b> :			$Ion\ balance\ error = (G11+G22)/(G11-G22) \times 100$					

Note: Analytes in bold must be measured. Others make little contribution to the overall TDS of a sample, and thus are not critical for an ion balance analysis. It is normal practice to measure nitrite (NO<sub>2</sub><sup>-</sup>), ammonium (NH<sub>4</sub><sup>+</sup>) and silica (SiO<sub>2</sub>) - the former two for a total nitrogen analysis and the latter as a risk assessment for membrane treatment and plumbing systems.

Appendix 5: Diagnosis table – water quality analyses

#	Observation	Diagnosis/probably cause	Action
1	$\sum \text{anions (meq/L)} \neq \sum \text{cations (meq/L)}$ , with possible ion-balance error >5%	<ul style="list-style-type: none"> <li>▪ Poor lab practice or faulty, uncalibrated equipment – this might apply to any of the below issues.</li> <li>▪ Poor calculation, titration, or conversion/expression of results for bicarbonate concentration (a major anion).</li> <li>▪ Sample separation at the lab, or preparation of two separate samples in the field might account for errors if filtration removes suspended solids at one stage.</li> <li>▪ Presence of a significant concentration of ionisable inorganics that are not measured during sampling or lab analysis, e.g. fluoride, iron, silicates, boron. Note, however, that these would have to be present at very elevated levels to make a major contribution to overall TDS.</li> <li>▪ Presence of ionisable organic chemicals at (very) significant concentrations – this would only be an issue here with the most polluted of sources.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Compare other WQ analyses from the same source or lab.</li> <li>▪ Contact the lab to try and diagnose the problem. However, care should be taken – there can be a perfectly good reasons for these errors.</li> </ul>
2	$\text{EC}/100 (\mu\text{S}/\text{cm}) \neq \sum \text{anions (meq/L)} \text{ or } \sum \text{cations (meq/L)}$ , and/or Estimated/calculated EC $\neq$ measured EC.	<ul style="list-style-type: none"> <li>▪ The EC/100 relationship is an estimation that will not hold true for many natural waters with elevated TDS, especially those with high sulphate concentrations.</li> <li>▪ Sulphate complexes well with Ca and Mg ions to form uncharged species, e.g. <math>\text{CaSO}_4^0</math> - a measurement of EC cannot account for these species, but their constituents will be measured in an analysis. Calculated EC would thus overestimate measured EC.</li> <li>▪ Possible lab error if the conditions above are not met - care should be taken before reaching this conclusion as this estimation is rarely precise.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Ascertain if high sulphate concentration accounts for the issue.</li> <li>▪ Compare other similar WQ analysis results from the same lab.</li> <li>▪ Carry out theoretical calculation of EC using modified Rossum method and compare with field and lab results.</li> </ul>
3	$\sum \text{anions (meq/L)} \gg \sum \text{cations (meq/L)}$	<ul style="list-style-type: none"> <li>▪ Adsorption of cations onto suspended particles, or sample container wall, which are then filtered out of solution, or remain adsorbed to container, prior to analysis.</li> <li>▪ Presence of cations that are not measured or expressed in report, although these should form a small % of TDS.</li> <li>▪ Presence of suspended solids that are dissolved during alkalinity titration with acid, leading to higher bicarbonate (major anion) result whilst filtration removes solids prior to cation analysis.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Results from samples with high suspended particle content should be interpreted accordingly.</li> <li>▪ Compare field measurements of turbidity and</li> <li>▪ Ask lab to report all pre-testing treatment/filtration methods.</li> </ul>
4	$\sum \text{anions (meq/L)} \ll \sum \text{cations (meq/L)}$	<ul style="list-style-type: none"> <li>▪ Presence of anions that are not measured in the analysis, see 1 above.</li> <li>▪ Poor alkalinity titration or incorrect calculation/expression, leading to error in bicarbonate (or carbonate) concentration.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Compare field and lab alkalinity measurements.</li> <li>▪ Consider unmeasured anions, e.g. fluoride.</li> </ul>

5	$EC_{\text{field}} \neq EC_{\text{lab}}$	<ul style="list-style-type: none"> <li>▪ Degassing, perhaps of <math>CO_2</math>, from the sample results in pH change and precipitation of minerals out of solution – <math>EC_{\text{field}}</math> would thus be expected to be <math>&gt; EC_{\text{lab}}</math>.</li> <li>▪ Poorly calibrated field or lab equipment.</li> <li>▪ Different, or poorly adjusted, temperature compensation in field or lab equipment. Usually this is performed by the unit itself.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Check equipment.</li> <li>▪ Carry out theoretical calculation of EC using modified Rossum method and compare with field and lab results.</li> </ul>
6	$pH_{\text{field}} \neq pH_{\text{lab}}$	<ul style="list-style-type: none"> <li>▪ Degassing (perhaps <math>CO_2</math>) from the sample.</li> <li>▪ Oxidation of iron (<math>Fe^{2+}</math>) or other metal species, leading to increase or decrease in pH (both might occur depending on other constituents and pH start-point).</li> <li>▪ Poorly calibrated equipment used, either in field or lab.</li> <li>▪ Different, or poorly adjusted, temperature compensation in field or lab equipment. Usually this is performed by the unit itself.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Check field equipment is calibrated.</li> <li>▪ Establish if handling or preparation of samples might have caused degassing.</li> <li>▪ Check iron levels – high iron levels are common in low pH waters and can often be associated with turbidity, see 9 below.</li> </ul>
7	$Alkalinity_{\text{field}} \neq alkalinity_{\text{lab}}$	<ul style="list-style-type: none"> <li>▪ Lab or field equipment issues.</li> <li>▪ Poor titration technique.</li> <li>▪ Poor calculation, expression/conversion of concentrations, missing carbonate (<math>CO_3^{2-}</math>) measurement.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Compare field and lab measurements.</li> <li>▪ Check calculations.</li> <li>▪ Check carbonate concentration if pH high.</li> </ul>
8	$Nitrate_{\text{field}} < nitrate_{\text{lab}}$	<ul style="list-style-type: none"> <li>▪ Presence of nitrate related bacteria reducing nitrate in sample.</li> <li>▪ Poor cold-chain and extended (<math>&gt;48\text{hrs}</math>) between sampling and lab analysis.</li> </ul>	Ensure good cold-chain and limit time between sampling and testing to $<48\text{hrs}$ , if possible.
9	$Turbidity_{\text{field}} < turbidity_{\text{lab}}$	<ul style="list-style-type: none"> <li>▪ Precipitation of minerals during transport, e.g. calcite or iron (hydr-)oxides.</li> <li>▪ Difference in measurement technique or units of expression.</li> </ul>	Ensure good cold-chain and limit time between sampling and testing to $<48\text{hrs}$ , if possible.
10	$Colour_{\text{field}} \neq colour_{\text{lab}}$	<ul style="list-style-type: none"> <li>▪ Precipitation of minerals during transport.</li> <li>▪ Difference in measurement technique or units of expression.</li> </ul>	Ensure good cold-chain and limit time between sampling and testing to $<48\text{hrs}$ , if possible.



Appendix 7: Overview of various (supra-)national water quality guidelines

Classification	Name	Common Dissolved form(s)	Usual Expression (units)	WHO Guideline (2017)	EC Guideline (2011)	Canadian DW Guidelines (2017)	USEPA MCL (or other) Guideline (2013)	Yemen (2008)	Kenya (2006)	Uganda/ East Africa (2014)	Nigeria (2011)	Ethiopia (2013)	Bangladesh (2017)	USEPA Guideline (ACUTE - 1 Day, 10kg Onal)	US EPA Guideline (ACUTE - 10 Day, 10kg Child)	USEPA RID (mg/kg/day) - Lifetime	Kidney dialysis Guideline (ANUS/ANM)	
Physical/ Organoleptic	Temperature	n/a	deg C/deg F	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	Appearance/Colour	n/a	True Colour Unit (TCU), Hazen	No health based guidance	Acceptable to consumers	<=15 TCU	n/a	15	15	15	15	n/a	15	n/a	n/a	n/a	n/a	
	Odour or Odor(US)	n/a	Threshold Odour Number (TON) or ppm ammonia concentration	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	3 threshold odour numbers as SDWR (2018)	n/a	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	n/a	Acceptable to consumers	n/a	n/a	n/a	n/a	
	Taste	n/a	Taste threshold	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	Acceptable to consumers	n/a	n/a	n/a	n/a	
	Turbidity	n/a	NTU	Ideally <1 NTU pre chlorination and UV, if not possible then <3 NTU	1 NTU	1 NTU, although some lower guidelines for specific treatment methods	5 NTU	5	5	5	5	n/a	10	n/a	n/a	n/a	n/a	
Master parameter	TSS (total) / Non-filtrable residue (NFR)	n/a	mg/L	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	pH at 25deg.C	H <sup>+</sup>	Dimensionless	6.5-8.5 (not health)	>6.5 and <9.5	7.0-10.5	6.5 - 8.5	6.5-9	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	n/a	n/a	n/a	n/a	Usually buffered to 6.9-7.6	
Bulk Parameters	ORP / Redox Potential	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	Salts/Salinity	n/a	mg/L as NaCl	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	see TDS	n/a	
	Electrical Conductivity (EC at 25 deg.C)	n/a	µsiemens/cm (µS/cm) at 25°C	none, see TDS	2,500 at 20°C	none, see TDS	none, see TDS	2500	n/a	1500	n/a	1400	n/a	n/a	n/a	n/a	Equipment dependent must be within v.50k	
	Total Dissolved Solids (TDS)	n/a	mg/L	No HRG	see EC, above.	500 (AO)	500 (SDWR)	1500	1500	700	900	1000	1000	n/a	n/a	n/a	n/a	
	Sodium Absorption Ratio (SAR)	Na <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup>	ratio	This is not a parameter used for drinking water but for irrigation water. Some governments likely to have standards for this.														
	(Total) Alkalinity or Acid neutralizing capacity (ANC)	n/a	mg/L as CaCO <sub>3</sub>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	(Total) Acidity or Titration Acidity	n/a	Expressed as various acids depending on industry	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other parameters	(Total) Hardness	n/a	mg/L as CaCO <sub>3</sub> but many others also used: General Hardness, German/English/French/Degress, grains per Gallon (US)	Not of health concern at levels found in drinking water (2017)	between 80 and 100 mg/L	n/a	n/a	500	500	300	n/a	300	200-500	n/a	n/a	n/a	n/a	
	Dissolved Oxygen	O <sub>2</sub>	mg/L or as a % air saturation (partial pressure, pO <sub>2</sub> )	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
Major Cation (+)	(Total) Silica	SiO <sub>2</sub>	mg/L SiO <sub>2</sub>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
	Calcium	Ca <sup>2+</sup>	mg/L	200 (AO)	none	none	none	200	250	150	none	75	75	none	none	none	2mg/L	
	Magnesium	Mg <sup>2+</sup>	mg/L	none	none	none	none	80-150	100	100	0.2	50	80-85	none	none	none	4mg/L	
	Sodium	Na <sup>+</sup>	mg/L	200 (AO)	200mg/L as an indicator parameter	none	30 mg/L for individuals on a 500 mg/day restricted sodium diet (2016)	400	200	200	200	n/a	200	none	none	none	70mg/L	
	Potassium	K <sup>+</sup>	mg/L	none	none	none	none	12	n/a	n/a	n/a	1.5	12	none	none	none	8mg/L	
Major Anion (-)	Sulphate	SO <sub>4</sub> <sup>2-</sup>	mg/L	No health affect at concentrations normally found in natural waters.	250, (surface and recreational waters are 200mg/L)	500	400mg/L proposed as an MCL to protect infants in 1985 but not finalized. 2018 HRV states 500mg/L	400	400	400	100	250	400	none	none	none	100mg/L	
	Chloride	Cl <sup>-</sup>	mg/L	none - taste threshold of 250mg/L	250mg/L as an indicator parameter	250 (AO)	250 (SDWR)	600	250	250	250	250	150-600	none	none	none	n/a	
	Bicarbonate	HCO <sub>3</sub> <sup>-</sup>	as CaCO <sub>3</sub>	n/a	n/a	n/a	n/a	500	n/a	n/a	n/a	n/a	n/a	none	none	none	n/a	
	Carbonate	CO <sub>3</sub> <sup>2-</sup>	as CaCO <sub>3</sub>	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	none	none	none	n/a	
Nitrogen	Nitrate	NO <sub>3</sub> <sup>-</sup>	mg/L as NO <sub>3</sub> N, mg/L as NO <sub>3</sub>	50mg/L as NO <sub>3</sub>	50mg/L and (nitrate)/3 + 1, where {} = conc. in mg/L	10mg/L as N + 45mg/L as NO <sub>3</sub>	10mg/L as N + 45mg/L as NO <sub>3</sub>	10-50 (imples as NO <sub>3</sub> and as N)	30 as NO <sub>3</sub>	45 as NO <sub>3</sub>	50 as NO <sub>3</sub>	50 as NO <sub>3</sub>	50 as NO <sub>3</sub>	10mg/L as N	10mg/L as N	1.6	2mg/L (as N) = 8.8mg/L as NO <sub>3</sub>	
	Nitrite	NO <sub>2</sub> <sup>-</sup>	mg/L	3mg/L and the sum of the nitrate and nitrite to its guideline value should not exceed 1	0.10 mg/L for nitrite ex water treatment works	1mg/L as N or, 3mg/L as NO <sub>2</sub>	1mg/L as N + 4.5mg/L as NO <sub>2</sub>	2	n/a	3	0.2	3 as NO <sub>2</sub>	<1	1mg/L as N	1mg/L as N	0.16	n/a	
	Ammonia/Ammonium	NH <sub>3</sub> /NH <sub>4</sub> <sup>+</sup>	mg/L	n/a	0.3mg/L NH <sub>3</sub>	0.05mg/L - 1.0mg/L to prevent formation of nitrate/nitrite by nitrification	30mg/L (life time) - NH <sub>3</sub>	0.3-0.05 (NH <sub>3</sub> )	0.5 as N	0.5 as NH <sub>3</sub>	n/a	1.5	0.5	none	none	none	n/a	
Minor Anion	Cyanide	CN <sup>-</sup>	mg/L	0.07	0.05	0.2	0.2	0.1	n/a	n/a	n/a	n/a	n/a	0.2mg/L	0.2mg/L	0.0006	n/a	
	Fluoride	F <sup>-</sup>	mg/L	1.5	0.5mg/L for fluoridated supplies, 1.5mg/L for naturally occurring	1.5	4mg/L	1.5-0.5	1.5	1.5	1.5	1.5	1	none	none	0.06	0.2mg/L	
	Phosphate/P/Phosphate	PO <sub>4</sub> <sup>3-</sup>	mg/L	none	none	none	0.0001mg/L (lifetime) for 'white phosphorus'	0.5	30	2.2	n/a	n/a	6	none	none	0.00002	n/a	
	Hydrogen Sulphide	HS <sup>-</sup>	mg/L	Not of health concern at levels found in drinking water	none	none	n/a	n/a	0.1	n/a	0.05	n/a	0	none	none	none	n/a	
Baron	H <sub>2</sub> BO <sub>3</sub> (aq) or B(OH) <sub>3</sub> (aq)	mg/L	2.4	1 as B	5	no MCL	n/a	1 as B, 10 as compounds	2.4 as Boric Acid	n/a	0.5 as B	1	3mg/L	3mg/L	0.2	n/a		

Category	Name	Common Dissolved form(s)	Usual Expression (units)	WHO Guideline	EC Guideline	Canadian DW Guidelines	USEPA MCL (or other Guideline)	Yemen	Kenya	Uganda/ East Africa	Nigeria	Ethiopia	Bangladesh	USEPA Guideline (ACUTE - 1 Day, 10kg Child)	US EPA Guideline (ACUTE - 10 Day, 10kg Child)	USEPA RID (mg/kg/day) - lifetime	Dialysis Guideline (ANS/AAMM)	
Minor Cation	Barium	Ba <sup>2+</sup>	mg/L	0.7mg/L n/a	No EC guidance 0.2	1mg/L 0.3(AO)	2mg/L 0.3 (SDWR)	0.3-0.1 1	1 as Ba 0.3	0.7 0.3	0.7 0.3	0.7 0.3	0.01 0.3-1.0	0.7 none	0.7 none	0.2 none	0.1mg/L n/a	
	Iron	Fe <sup>2+</sup> , Fe <sup>3+</sup>	mg/L															
	Manganese	Mn <sup>2+</sup>	mg/L	HBV of 0.4mg/L, previously had a provisional 0.5mg/L standard.	0.05mg/L	0.05 (AO)	0.05 (SDWR)	0.2	0.1	0.1	0.2	0.5	0.1	1mg/L	1mg/L	0.14	n/a	
	Aluminium	Al <sup>3+</sup> , Al <sup>2+</sup>	mg/L	0.1-0.2mg/L, primarily for surface water treatment facilities.	0.2mg/L	<0.1 (conventional treatment); <0.2 (other treatment types)	0.05 to 0.2 mg/L (SDWR)	0.2	0.1	0.2	0.2	0.2	0.2	none	none	none	0.01mg/L	
Treatment Chemicals and By-Products of Treatment	Chlorine	HOCl(aq), HCl, OCl <sub>2</sub>	mg/L (ppm)	5	n/a	n/a	4	n/a	0.2-0.5 as FRC	0.2-0.5 as FRC	0.2-0.25 as FRC	n/a	0.2	3	3	0.1	0.5mg/L (FRC)	
	Chloramine	NH <sub>2</sub> Cl (mono), NHCl <sub>2</sub> (di), NCl <sub>3</sub> (tri-)	mg/L	3	n/a	3	4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.1	n/a	
	Chlorine Dioxide	ClO <sub>2</sub>	mg/L	see chlorite and chlorate	n/a	n/a	0.8	n/a	n/a	n/a	n/a	n/a	n/a	0.8	0.8	0.03	0.03	
	- Chlorite	NaClO <sub>2</sub>	mg/L	0.7	n/a	1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.8	0.8	0.03
	- Chlorate	NaClO <sub>3</sub>	mg/L	0.7	n/a	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Cyanuric Acid	C <sub>3</sub> H <sub>3</sub> N <sub>3</sub> O <sub>3</sub>	mg/L	50 mg/litre (as NaDCC) 40 mg/litre (as cyanuric acid)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	THMs	Many chemicals - bonds of halogens and chlorine	µg/L															
Other elements	Antimony	Sb(s), Sb(OH) <sub>3</sub>	µg/L	20	50	6	6	5	n/a	n/a	n/a	n/a	n/a	0.01mg/L	0.01mg/L	0.0004	0.006mg/L	
	Arsenic	HAsO <sub>4</sub> <sup>3-</sup> in more oxidised waters, As(s) in more reduced waters.	mg/L	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.01	0.05	none	none	0.0003	0.005mg/L	
	Beryllium	Be(OH) <sub>2</sub> (s) - relatively insoluble	mg/L	Not of health concern at levels found in drinking water	n/a	n/a	0.004	n/a	n/a	n/a	n/a	n/a	n/a	30	30	0.002	0.0004mg/L	
	Cadmium	Cd <sup>2+</sup>	mg/L	0.003	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.005	0.04	0.04	0.0005	0.001mg/L	
	Chromium	Cr <sup>3+</sup> , Cr(VI)O <sub>4</sub> <sup>2-</sup>	mg/L	0.05	0.05	0.05	0.1	0.05	0.05	0.05	0.05	0.05	0.05	1mg/L (total)	1mg/L (total)	0.003	0.014mg/L	
	Cobalt	Co <sup>2+</sup>	mg/L	n/a	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Copper	Cu <sup>2+</sup>	mg/L	2	2	1	1.3	1	0.1	1	1	1	n/a	1	n/a	n/a	n/a	0.1mg/L
	Lead	Pb <sup>2+</sup>	mg/L	0.01	0.01	0.01	0	0.05	0.01	0.01	0.01	0.01	0.05	n/a	n/a	n/a	0.005mg/L	
	Mercury (inorganic)	Hg	µg/L	6	1	1	2	1	50(l)	1	1	1	1	2	2	0.3	0.0002mg/L	
	Molybdenum	Mo (relatively insoluble)	µg/L	Not of health concern at levels found in drinking water	n/a	n/a	n/a	n/a	n/a	n/a	0.07	n/a	n/a	n/a	0.08	0.08	0.005	n/a
	Nickel	Ni(H <sub>2</sub> O) <sub>6</sub> <sup>2+</sup>	µg/L	70	20	n/a	n/a	n/a	20	300(l)	20	20	n/a	10	1	1	0.002	n/a
	Perchlorate	ClO <sub>4</sub> <sup>-</sup>	µg/L	70	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.007	n/a
	Selenate (SeO <sub>4</sub> <sup>2-</sup> ) selenite (HSeO <sub>3</sub> <sup>-</sup> ) selenite (SeO <sub>3</sub> <sup>2-</sup> )	mg/L	0.04	0.01	0.05	0.05	0.05	0.01	0.01	0.01	n/a	0.01	0.01	n/a	n/a	0.005	0.09mg/L	
	Silver	Ag	mg/L	Inadequate data to set standard	n/a	n/a	0.1 (SDWR)	0.01-0.1	n/a	n/a	n/a	n/a	n/a	0.02	n/a	n/a	n/a	0.005mg/L
	Thallium	Tl	µg/L	n/a	n/a	n/a	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7	7	n/a	0.002mg/L
	Tin	Sn		n/a	n/a	n/a	3	n/a	n/a	n/a	n/a	n/a	n/a	n/a				n/a
	Titanium	Ti		n/a	n/a	n/a	4	n/a	n/a	n/a	n/a	n/a	n/a	n/a				n/a
	Uranium			n/a	n/a	n/a	5	n/a	n/a	n/a	n/a	n/a	n/a	n/a				n/a
	Vanadium			n/a	n/a	n/a	6	n/a	n/a	n/a	n/a	n/a	n/a	n/a				n/a
Zinc	Zn <sup>2+</sup>	µg/L	Not of health concern at levels found in drinking water	none but 3.0mg/L for A1 waters	5mg/L	none	15	5	5	5	3	5	5	6	6	0.3	0.1mg/L	

Key: DWA = drinking water advisory, SDWR = secondary drinking water regulation (non-enforceable USEPA level), AO = aesthetic objective (Health Canada), HBG = health based guideline (WHO), MCL = maximum contaminant level (USEPA)