



Standard Guide for Displaying the Results of Chemical Analyses of Ground Water for Major Ions and Trace Elements—Diagrams for Single Analyses¹

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1. Scope

1.1 This guide covers the category of water-analysis diagrams that use pictorial or pattern methods (for example, bar, radiating vectors, pattern, and circular) as a basis for displaying each of the individual chemical components that were determined from the analysis of a single sample of natural ground water (see Terminology).

1.2 This guide on single-analysis diagrams is the second of several standards to inform the professionals in the field of hydrology with the traditional graphical methods available to display ground-water chemistry.

NOTE 1—The initial guide described the category of water-analysis diagrams that use two-dimensional trilinear graphs to display, on a single diagram, the common chemical components from two or more complete analyses of natural ground water.

1.2.1 A third guide will be for diagrams based on data analytical calculations that include those categories of water analysis graphs where multiple analyses are analyzed statistically and the results plotted on a diagram (for example, the box, and so forth).

1.3 Numerous methods have been developed to display, on single-analyses diagrams, the ions dissolved in water. These methods were developed by investigators to assist in the interpretation of the origin of the ions in the water and to simplify the comparison of analyses, one with another.

1.4 This guide presents a compilation of diagrams from a number of authors that allows for transformation of numerical data into visual, usable forms. It is not a guide to selection or use. That choice is program or project specific.

NOTE 2—Use of tradenames in this guide is for identification purposes only and does not constitute endorsement by ASTM.

1.5 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to repre-*

sent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

2. Referenced Documents

2.1 ASTM Standards:

D 596 Practice for Reporting Results of Analysis of Water²

D 653 Terminology Relating to Soil, Rock, and Contained Fluids³

D 1129 Terminology Relating to Water²

D 5754 Guide for Displaying the Results of Chemical Analyses of Ground Water for Major Ions and Trace Elements—Trilinear Diagrams for Two or More Analyses²

3. Terminology

3.1 *Definitions*—Except as listed as follows, all definitions are in accordance with Terminology D 653.

3.1.1 *anion*—an ion that moves or would move towards an anode; thus nearly always synonymous with negative ion.

3.1.2 *cation*—an ion that moves or would move towards a cathode; thus nearly always synonymous with positive ion.

3.1.3 *equivalent per million (epm)*—for water chemistry, an equivalent weight unit expressed in English terms, also expressed as milligram-equivalent per kilogram. When the concentration of an ion, expressed in parts per million (ppm), is multiplied by the equivalent weight (combining weight) factor (see explanation of equivalent weight factor) of that ion, the result is expressed in epm.

3.1.3.1 *Discussion*—For a completely determined chemical analysis of a water sample, the total epm value of the cations will equal the total epm value of the anions (chemically balanced). The plotted values on the water-analysis diagrams described in this guide can be expressed in percentages of the total epm (although all illustrations are in milliequivalent per litre) of the cations and anions of each water analysis. Therefore, in order to use the diagrams, analyses must be converted from ppm to epm by multiplying each ion by its

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² *Annual Book of ASTM Standards*, Vol 11.01.

³ *Annual Book of ASTM Standards*, Vol 04.08.

equivalent weight factor and determining the percent of each ion of the total cation or anion.

3.1.4 *equivalent weight factor*—the equivalent weight factor or combining weight factor, also called the reaction coefficient, is used for converting chemical constituents expressed in ppm to epm and mg/L to meq/L (see explanation of epm and meq/L). To determine the equivalent weight factor, divide the formula weight of the solute component into the valence of the solute component:

$$(\text{equivalent weight factor}) = \frac{(\text{valence solute component})}{(\text{formula weight solute component})} \quad (1)$$

Then to determine the equivalent weight (meq/L) of the solute component, multiply the mg/L value of the solute times the equivalent weight factor, as follows:

$$(\text{meq/L solute component}) = (\text{mg/L solute component}) \times (\text{equivalent weight factor}) \quad (2)$$

For example, the formula weight of Ca^{2+} is 40.10 and the ionic charge is two (as shown by the 2+), and for a value of 20 mg/L Ca, the equivalent weight value is computed to be 0.9975 meq/L;

$$(0.9975 \text{ meq/L Ca}) = (20 \text{ mg/L Ca}) \times \frac{(2)}{(40.10)} \quad (3)$$

3.1.4.1 *Discussion*—Many general geochemistry publications and water encyclopedias have a complete table of equivalent weight factors for the ions found in natural ground water (1, 2).⁴

3.1.5 *grains per U.S. gallon (gpg)*—for water chemistry, a weight-per-volume unit, also, for irrigation water, can be expressed in tons per acre-foot (ton/acre-ft). The weight (grains or tons) of solute within the volume (gallon or acre-foot) of solution and solute. A grain is commonly used to express the hardness of water where one grain is equal to 17.12 ppm CaCO_3 .

3.1.6 *milliequivalent per litre (meq/L)*—for water chemistry, an equivalent weight unit expressed in metric terms, also expressed as milligram-equivalent per litre. When the concentration of an ion, expressed in mg/L, is multiplied by the equivalent weight (combining weight) factor (see explanation of equivalent weight factor) of that ion, the result is expressed in meq/L.

3.1.6.1 *Discussion*—For a completely determined chemical analysis of a water sample, the total value of the cations will equal the total value of the anions (chemically balanced). The plotted values on the water-analysis diagrams described in this guide are expressed in percentages of the total meq/L of the cations and anions of each water analysis. Therefore, in order to use the diagrams, analyses must be converted from mg/L to meq/L by multiplying each ion by its equivalent weight factor and determining the percent of each ion of the total cation or anion.

3.1.7 *milligrams per kilogram (mg/kg)*—for water chemistry, a weight-per-weight unit expressed in metric terms. The number of milligrams of solute (for example, sodium (Na)) per

kilogram of solution (water) and solute. For example, a 10 000 mg/kg solute is the same as 1 % solute in the total 100% solute and solution. The mg/kg unit is equivalent to ppm according to Matthes (3).

3.1.8 *milligrams per litre (mg/L)*—for water chemistry, a weight-per-volume unit expressed in metric terms. The weight in milligrams (10^{-3} g) of the solute within the volume (litre) of solute and solution. The weight can be also expressed in micrograms (10^{-6} g). The use of the mg/L unit is the worldwide standard for the analysis and reporting of water chemistry.

3.1.8.1 *Discussion*—The ppm and mg/L values of the constituents in natural ground water are nearly equal (within anticipated analytical errors) until the concentration of the dissolved solids reaches about 7000 mg/L. For highly mineralized waters, a density correction should be used when computing ppm from mg/L (1).

3.1.9 *natural ground water*—as defined for this guide, is water positioned under the land's surface, that consists of the basic elements, hydrogen and oxygen (H_2O), and numerous major dissolved chemical constituents, such as calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), carbonate (CO_3), bicarbonate (HCO_3), chloride (Cl), and sulfate (SO_4), and has not been significantly influenced by human development.

3.1.9.1 *Discussion*—Other major constituents, in special cases, can include aluminum (Al), boron (B), fluoride (F), iron (Fe), nitrate (NO_3), and phosphorus (PO_4). Minor and trace elements that can occur in natural ground water vary widely, but can include arsenic (As), copper (Cu), lead (Pb), mercury (Hg), radium (Ra), and zinc (Zn). In addition, natural ground water may contain dissolved gases, such as hydrogen sulfide (H_2S), carbon dioxide (CO_2), oxygen (O_2), methane (CH_4), ammonia (NH_3), argon (Ar), helium (He), and radon (Rn). Also maybe included are neutrally charged mineral species, such as silicate (SiO_2), naturally occurring organics, such as tannic acids, colloidal materials, and particulates, such as bacteria viruses and naturally charged pollen spores.

3.1.9.2 *Discussion*—Most of the natural ground water is a part of the hydrologic cycle, that is the constant circulation of meteoric water as vapor in the atmosphere as a result of evaporation from the earth's surface (land and ocean), liquid and solid (ice) on and under the land as a result of precipitation from the atmosphere, and as liquid returned to the ocean from the land. A very small amount of the ground water may be magmatic water originating from rocks deep within the crust of the earth. Other ground water is connate in that it is trapped in sediments and has not actively moved in the hydrologic cycle for a period measured in geologic time.

3.1.9.3 *Discussion*—While moving through the hydrologic cycle, chemical elements in the water are exchanged with other ions and dissolved into and precipitated out of the water, depending upon reactions with air and other gases, rock minerals, biological agents, hydraulic pressure, and the ambient temperature. The chemical composition of natural ground water ranges from that similar to distilled water with a minor amount of dissolved solids to a brine with at least 100 000-mg/L dissolved solids (natural occurring brine have been

⁴ The boldface numbers in parentheses refer to a list of references at the end of the text.

analyzed with more than 300 000-mg/L dissolved chemical solids) (4).

3.1.10 *parts per million*—for water chemistry, a dimensionless ratio of unit-of-measurement per unit-of-measurement expressed in English terms. One part per million is equivalent to 1 mg of solute to 1 kg of solution. For example, if the total weight of the solution and solute (1 million ppm) has 99 % solution and 1 % solute, this is the same as 990 000 ppm solution and 10 000 ppm solute in the 1 million parts.

3.1.11 *water analysis*—a set of chemical ions as analyzed from a water sample. In this guide, the water analysis normally includes the common constituents as found in natural ground water (see 3.1.9; *natural ground water*).

3.1.12 *water-analysis diagram*—the phrase, as used in this guide, is for the graphical plotting methods used for displaying a single water-quality analysis. These systems use various types of graphical displays that form characteristic patterns of the plotted individual cations and anions of the analysis. The pattern of the one analysis is then compared with the patterns

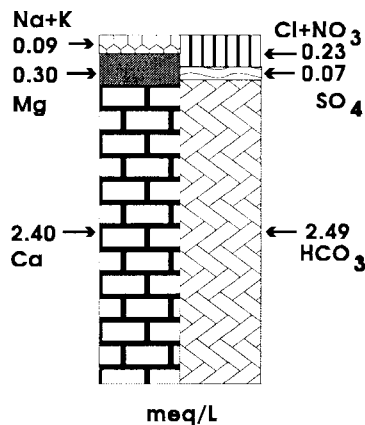
formed by the plotting of other analyses. This method can be utilized to assist in the scientific interpretation of occurrence of cations and anions in natural ground water, for example, the interrelationship of a number of water samples within the studied area. Simpler types of the diagrams (for example, bars) can be used to display single ion values, such as Cl^- or Na^+ .

4. Summary of Guide

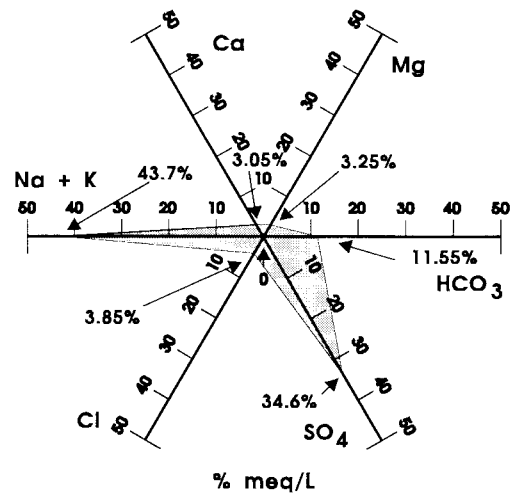
4.1 This guide includes descriptions of the water-analysis diagrams that pictorially display common chemical components of a single water analysis from a natural ground-water source.

4.1.1 The significance and use of the four distinct types of diagrams (bar, radiating, pattern, and circular) (see Fig. 1) are described.

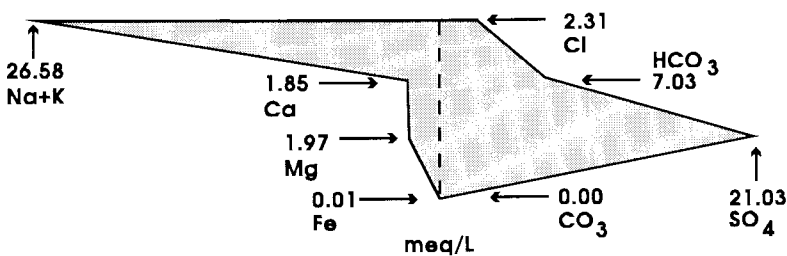
4.2 The minimum required chemical constituents from each water analysis for inclusion on the more commonly used diagrams are listed.



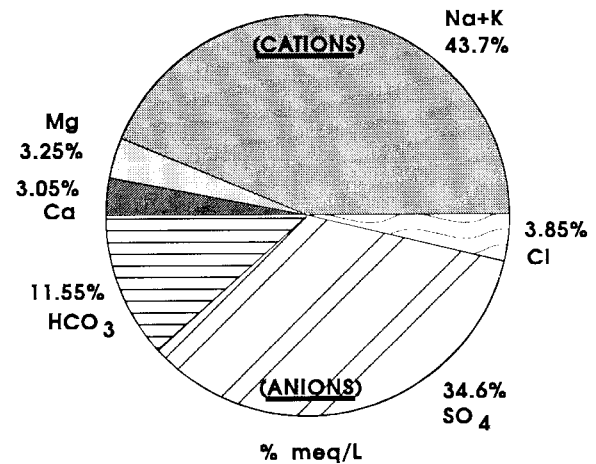
(a) Bar Diagram



(b) Radiating Vector Diagram



(c) Pattern Diagram



(d) Circle Diagram

FIG. 1 Examples of the Four Types of Single-Analysis Diagrams