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Standard Guide for
Displaying the Results of Chemical Analyses of Ground Water for Major Ions and Trace Elements—Use of Maps[1]

1. Scope

1.1 This guide offers a series of options but does not specify a course of action. It should not be used as the sole criterion or basis of comparison and does not replace or relieve professional judgment.

1.2 This guide covers methods that display, as mapped information, the chemical constituents of ground-water samples. Details required by the investigator to use fully the methods are found in the listed references.

1.2.1 The use of maps to display water-quality data are a common technique to assist in the interpretation of the chemistry of water in aquifers, as the areally distributed values can be easily related to the physical locality by the investigator.

1.2.2 The distribution in an aquifer of chemical constituents from two water sources or of liquids of different densities may be difficult to illustrate explicitly on a two-dimensional map because of stratification in the third dimension. Also, the addition of a vertical cross section may be required (see 4.4).

1.3 Many graphic techniques have been developed by investigators to assist in summarizing and interpreting related data sets. This guide is the fourth document to inform the hydrologists and geochemists about traditional methods for displaying ground-water chemical data.

1.3.1 The initial guide (Guide D 5738) described the category of water-analysis diagrams that use pattern and pictorial methods as a basis for displaying each of the individual chemical components determined from the analysis of a single sample of natural ground water.

1.3.2 The second guide (Guide D 5754) 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 analyses of natural ground water.

1.3.3 The third guide (Guide D 5877) presented methods that graphically display chemical analyses of multiple ground-water samples, discrete values, as well as those reduced to comprehensive summaries or parameters.

1.4 Notations have been incorporated within the illustrations of this guide to assist the user in understanding how the maps are constructed. These notations would not be required on a map designed for inclusion in a project document.

NOTE 1—Use of trade names 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 represent 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 Guide for Reporting Results of Analysis of Water[2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 1129 Terminology Relating to Water[2]

D 5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site[3]

D 5408 Guide for the Set of Data Elements to Describe a Ground-Water Site; Part One—Additional Identification Descriptors[3]

D 5409 Guide for the Set of Data Elements to Describe a Ground-Water Site; Part Two—Physical Descriptors[3]

D 5410 Guide for the Set of Data Elements to Describe a Ground-Water Site; Part Three—Usage Descriptors[3]

D 5474 Guide for Selection of Data Elements for Ground-Water Investigations[3]

D 5717 Guide forDesign of Ground-Water Monitoring Systems in Karst and Fractured Rock Aquifers[3]

D 5738 Guide for Displaying the Results of Chemical Analyses of Ground Water for Major Ions and Trace Elements—Diagrams for Single Analyses[3]

D 5754 Guide for Displaying the Displaying the Results of

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[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

Current edition approved Oct. 10, 1996. Published June 1997.

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

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

Chemical Analyses of Ground Water for Major Ions and Trace Elements—Trilinear Diagrams for Two or More Analyses[3]

D 5877 Guide for Displaying the Results of Chemical Analyses of Ground Water for Major Ions and Trace Elements—Diagrams Based on Data Analytical Calculations[4]

3. Terminology

3.1 *Definitions*—All definitions are in accordance with Terminology D 653. Additional definitions that relate to this guide can be found in Guide D 596, Terminology D 1129, and Guides D 5738, D 5754, and D 5877.

4. Significance and Use

4.1 Each year many thousands of water samples are collected and the chemical components are determined from natural and human-influenced ground-water sources.

4.2 The objective interpretation of the origin, composition, and interrelationships of water can be simplified by displaying the distribution of the constituents and related parameters on areal maps **(1,2)**.[5]

4.2.1 The origin of the chemical composition of the water may be postulated by the amount and the distribution of the constituents as shown on the maps.

4.2.2 The chemical composition of the water can be scrutinized for distinct characteristics and anomalies by use of the maps.

4.2.3 The interrelationships of the water chemistry from various sampling locations can be visualized on the maps.

4.3 This guide presents various mapping methods for showing distribution of chemical constituents using areal and time-related trends; maximum, minimum, or mean values; and relationships between chemical and associated parameters.

4.4 Exercise caution when interpreting the distribution of chemical constituents on two-dimensional (X and Y) maps as liquids of different densities tend to stratify in the third dimension (Z).

NOTE 2—Water (or other liquid) with a relatively low concentration of dissolved solids (or of a low relative density) normally will float on top of water with high dissolved solids or a liquid of higher density **(3–7)**. A naturally occurring example is an island surrounded and underlain by sea water where rain water falling on the island forms a fresh water lens above the underlying sea water. Where the presence of liquids of different densities are evident in a mapped area, cross sections of the aquifer assist in showing the vertical (Z) distribution of the chemical constituents or a pattern can be used on the map to delineate the extent of this water.

NOTE 3—Immiscible liquid contaminants, such as petroleum products, with a relative density less than that of the water will float on top of the water. Liquids that are more dense than water will flow to the bottom of the aquifer. Miscible liquids, such as sea water, mix with the fresher water creating a zone of dispersion at the interface of the two liquids.

4.5 Aquifers in fractured rock or karst areas may result in noncontinuum conditions for the chemical parameters in the water (Guide D 5717). This guide assumes the aquifer usually consists of an equivalent porous media.

4.6 This is not a guide for the selection of a map technique for a distinct purpose. That choice is program or project specific.

NOTE 4—For many hydrochemical research problems involving the scientific interpretation of ground water, the areal map is only one segment of several methods needed to interpret the data.

5. Selection and Preparation of Data for Plotting on Areal Maps

5.1 *Minimum Data Requirements*:

5.1.1 In order to position accurately the ground-water quality collection locations on two- and three-dimensional maps, a minimum set of data elements must be known for each site. Refer to Practice D 5254, and Guides D 5408, D 5409, D 5410, and D 5474 for guidance in selecting the appropriate assortment of information.

5.1.2 A basic requirement for the analytical methods described in this guide is that the samples be selected randomly or of a systematic sampling strategy, and of sufficient number and distribution to represent the sampled population to allow for the construction of a meaningful map.

NOTE 5—A truly random sample is impractical, as ground-water samples are from a subsurface population that only can be obtained from sources that intersect the water table, for example, wells, springs, tunnels, or caves. These sources are not likely to be distributed randomly in three-dimensions throughout an aquifer. A more refined picture of the entire population, however, is possible as the size of the random sample is increased **(8)**.

5.2 *Recommended Checks for Accuracy of Data Parameters*:

5.2.1 To avoid errors, all of the chemical analyses used for the mapping methods described in this guide must be verified properly.

5.2.1.1 Noncontinuum concentrations or possible erroneous values in a data set (sample) become more apparent when using mapping methods, as these appear as extreme values on the maps.

5.2.1.2 Erroneous values that fall in the same numerical range as a typical value in the data set are difficult to detect but are most likely found by a complete validation of the data set (sample) against the original data source.

NOTE 6—To reduce the chance of incorporating erroneous numbers on the map displays, the original chemical analyses and related data must be previewed carefully as to proper collection and analytical procedures. In addition, care must be taken to ensure that none of the numbers have been transposed during transcription of the data. Completely automated data collection and transcription procedures help to eliminate data errors.

5.2.2 For those analyses where all of the major chemical ions in the ground water are determined, a check of the chemical balance should be made to help in the detection of data errors (see Guides D 5738, D 5754, and D 5877).

6. Ground-Water Quality Maps

6.1 *Introduction*—This guide provides methods that furnish helpful map displays of the results of chemical analyses of water samples. These methods include procedures that display the distribution of a single constituent for a discrete period, the areal change of a constituent concentration over a period, and

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[4] *Annual Book of ASTM Standards*, Vol 04.09.

[5] The boldface numbers in parentheses refer to the list of references at the end of this guide.

the relationship of two or more parameters from each analysis for the map area.

6.2 *Maps of a Single Chemical Constituent for a Discrete Time*—These maps display the areal distribution of a single ion in an aquifer or within a project.

6.2.1 *Distribution of an Ion by Sized Symbols*—A simple map is valuable for showing collection sites for areas of limited data or a complex distribution of chemical constituents. Fig. 1 shows the values of the constituent symbolized by the size of a solid circle **(9)**.

6.2.2 *Distribution of a Compound by Equal Concentration Lines*—A two-dimensional map of a compound or ion in a homogeneous aquifer is shown by Fig. 2 where the value and distribution of the constituent is represented by equal lines. This map shows the distribution of volatile organic compounds (VOC) resulting from spills in a developed area **(10)**.

6.2.3 *Distribution of an Ion Emphasized by Shaded Concentration Areas*—Maps that use shaded concentration or colored areas visually point out areas of interest to the project (Fig. 3). The shaded area can be used to highlight either high or low concentrations, for example, the maximum chloride ion **(11)**.

6.2.4 *Distribution of an Ion in Waters from Multiple Sources*—The distribution of a constituent in water from two or more sources, for example, fresh water and sea water, and in a homogeneous aquifer, is shown by Fig. 4. This map shows the position of the saltwater-freshwater interface and the distribution of the chloride constituent. The saltwater wedge is moving north toward an area of withdrawal and into the area of the aquifer that contains freshwater. The north edge of the saltwater wedge is at the base of the freshwater **(12)**.

6.2.5 *Shaded or Colored Concentration Map and Matching Vertical Cross Section*—The addition of a cross section with the concentration map improves the understanding of the vertical distribution of a liquid containing the constituent (Fig. 5). Usually a liquid with a density significantly different than the natural water in the aquifer will stratify the level depending upon the density of the invading liquid (see 4.4) **(13)**.

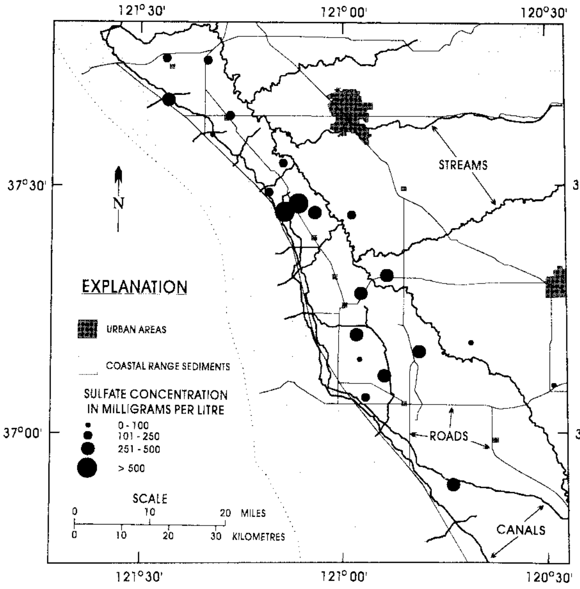

FIG. 1 Map Showing Data Values by Sized Symbols [Adapted from Ref (9)]

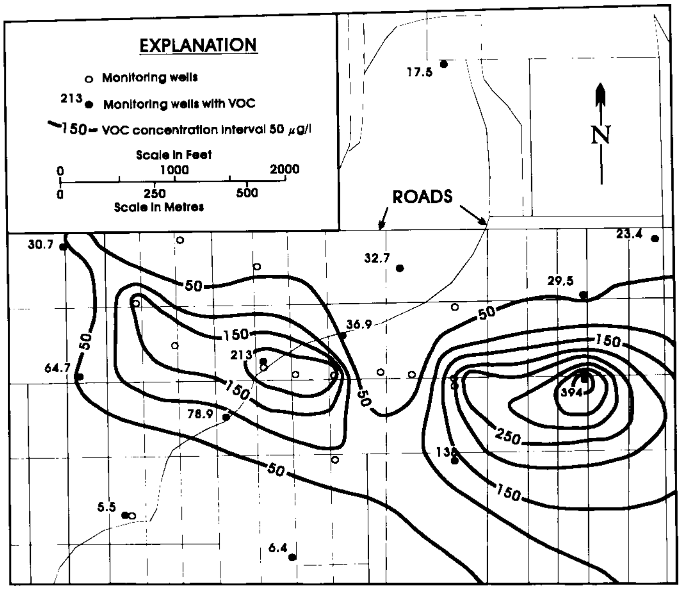

FIG. 2 Map Showing Lines of Equal Total VOC Concentration [Adapted from Ref (10)]

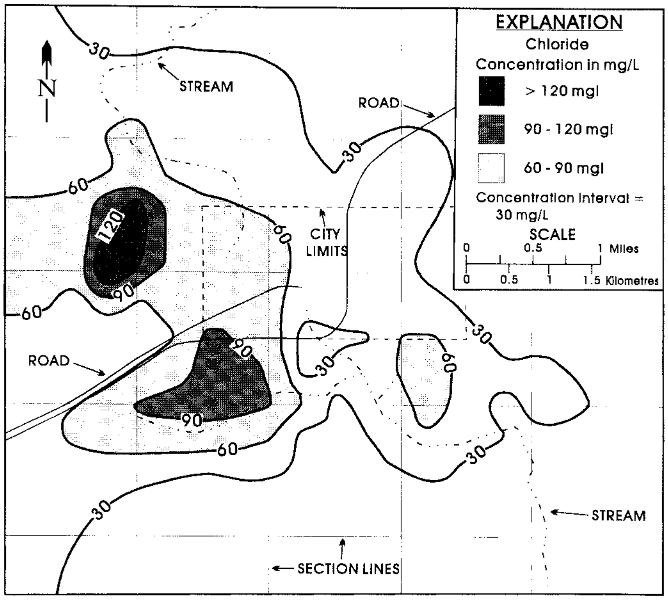

FIG. 3 Map of Shaded Areas of Chloride Concentration [Adapted from Ref (11)]

6.2.6 *Ion Distribution in Water Infiltrating from a Surface Source*—Other types of maps show the results of surface facilities, such as streams or constructed pits, intersecting the aquifer. Fig. 6 represents sulfate distribution in an aquifer as a result of water infiltrating through a land fill operation **(14)**.

6.3 *Change Maps of a Single Chemical Constituent for Two Discrete Times*—These maps display change or areal distribution of a single ion in an aquifer or within a project over a period of time.

6.3.1 *Multiple Maps Showing Ion Change for a Period of Time*—Maps can show a change in chemical parameters in an aquifer over a specific period. Fig. 7 uses two maps to show the increase in dissolved solids over a 17-year period as a result of large withdrawals at well fields in a coastal area **(15,16)**.

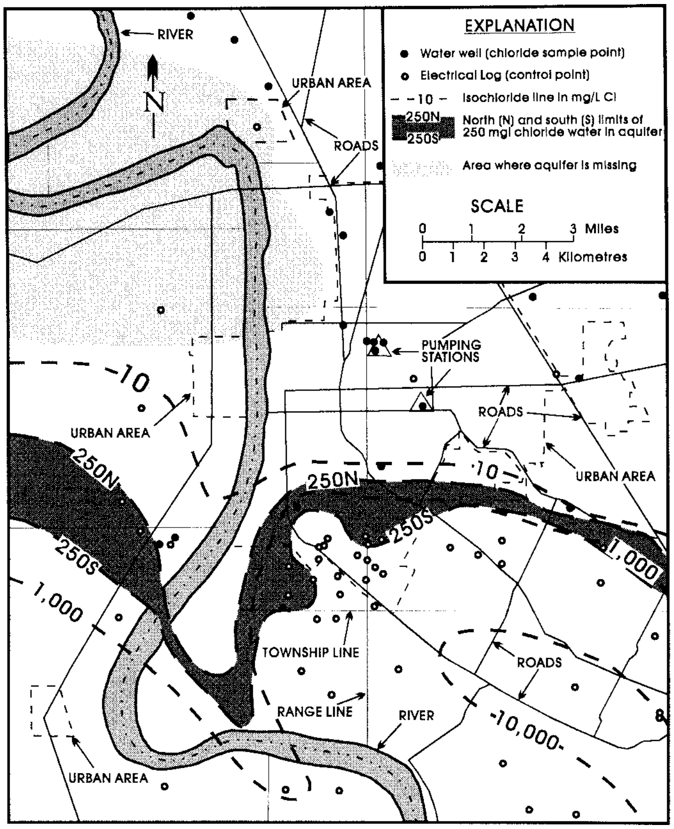

FIG. 4 Map Showing Fresh-Salt Water Interface in an Aquifer [Adapted from Ref (12)]

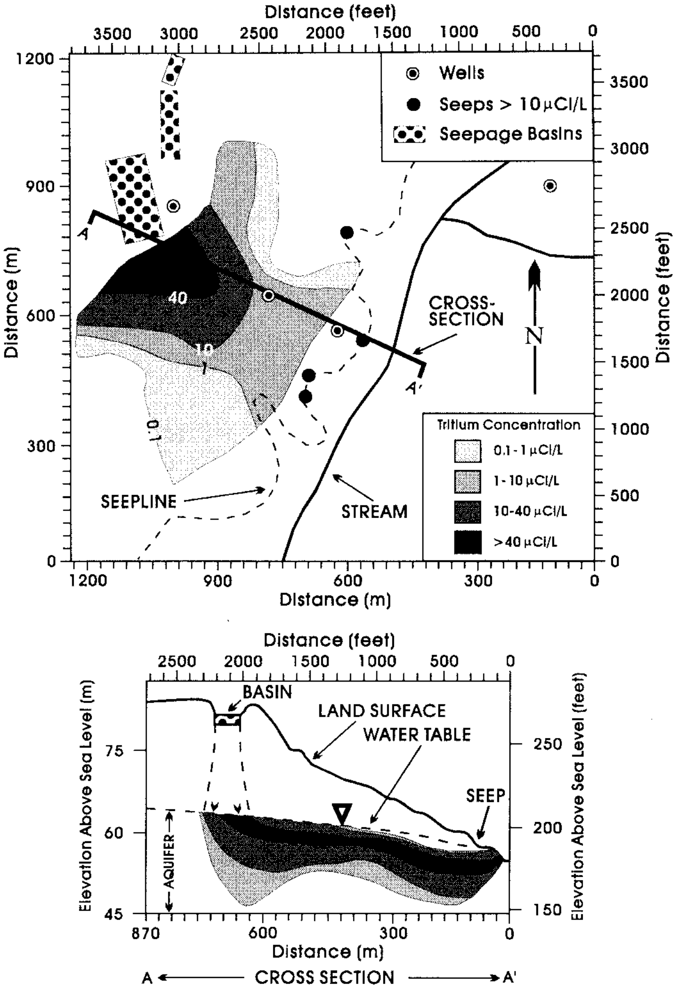

FIG. 5 Map and Cross Section of Tritium in an Aquifer [Adapted from Ref (13)]

6.3.2 *An Integrated Map Showing Ion Change for a Period of Time*—The map displayed by Fig. 8 employs isochemical lines of different intensities to show the increase of SO_4^{2-} over a specific period as a result of fertilization **(15)**.

6.4 *Other Ground-Water Quality Maps*—These maps display the areal distribution of the computed relationship of two or more chemical constituents, calculated values for a single constituent, the pseudo-three-dimensional placement of a parameter, and hydrochemical facies. Maps that display graphical plots at each representative ground-water site are described in Guide D 5738.

6.4.1 *Isochemical Ratios of Ions and Related Parameters*—A map showing the chemical ratio of NO_3/Kjeldahl *N* ions of water from wells in and down-gradient from a landfill is displayed by Fig. 9. The placement of this ratio indicates the location of the reducing fronts as the leachate migrates. Parameters other than chemical constituents can be used to compute the ratios, for example, dissolved solids and sample collection depth **(17)**.

6.4.2 *Isochemical Statistical Values*—A map showing the mean values for an ion requires multiple samples over a specific period from each collection site (see Fig. 10 for an example). This map shows lines of equal mean values of HCO_3 in water collected from a number of monitoring wells down-gradient from an old landfill **(18)**.

6.4.3 *Pseudo-Three-Dimensional Map of Ion Values*—A map showing the isometric surface (pseudo-three-dimensional distribution) of any of the chemical parameters, such as arsenic, is displayed by Fig. 11. This map is of a hazardous waste site that contained organic and inorganic contaminants **(19)**.

6.4.4 *Maps Showing Distribution of Anion and Cation Facies*—Maps showing the anion and cation characteristics of water in an aquifer are displayed by Fig. 12. These maps show the variation of the hydrochemical facies of water throughout an aquifer and assist in understanding the movement and chemical origin of the water **(20)**.

7. Automated Procedures for Water-Quality Maps and Cross Sections from Scientific Software Clearinghouses

7.1 Information concerning the availability of a number of computer software packages for displaying ground-water quality data as maps and cross sections can be obtained from the various clearinghouses.[6]

8. Keywords

8.1 chemical ions; cross sections; ground water; water-quality maps

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[6] Available from Rockware Scientific Software, 4251 Kipling Street, Suite 595, Wheat Ridge, CO 80033; Scientific Software Group, P.O. Box 23041, Washington, DC 20026-3041; International Ground Water Modeling Center, Colorado School of Mines, Golden, CO 80401-1887; and Donley Technology, Box 152, Colonial Beach, VA 22443.

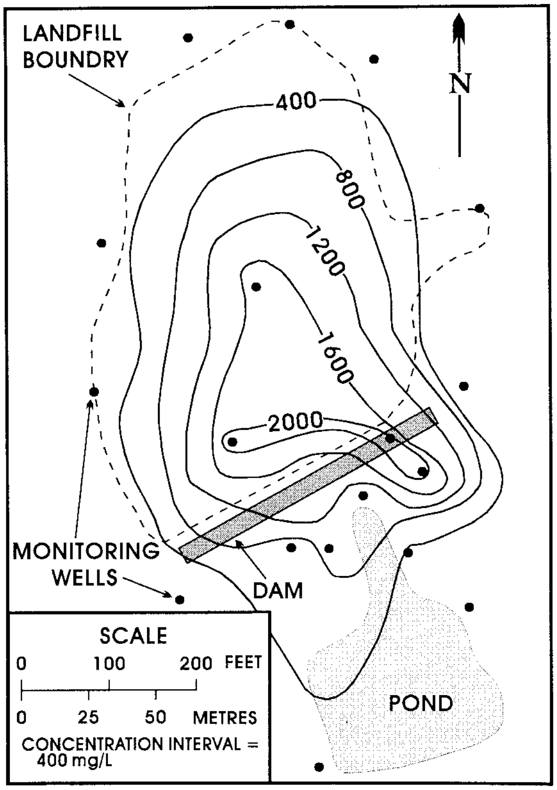

FIG. 6 Map of SO_4^{-2} Distribution in Aquifer Resulting from Landfill Operation [Adapted from Ref (14)]

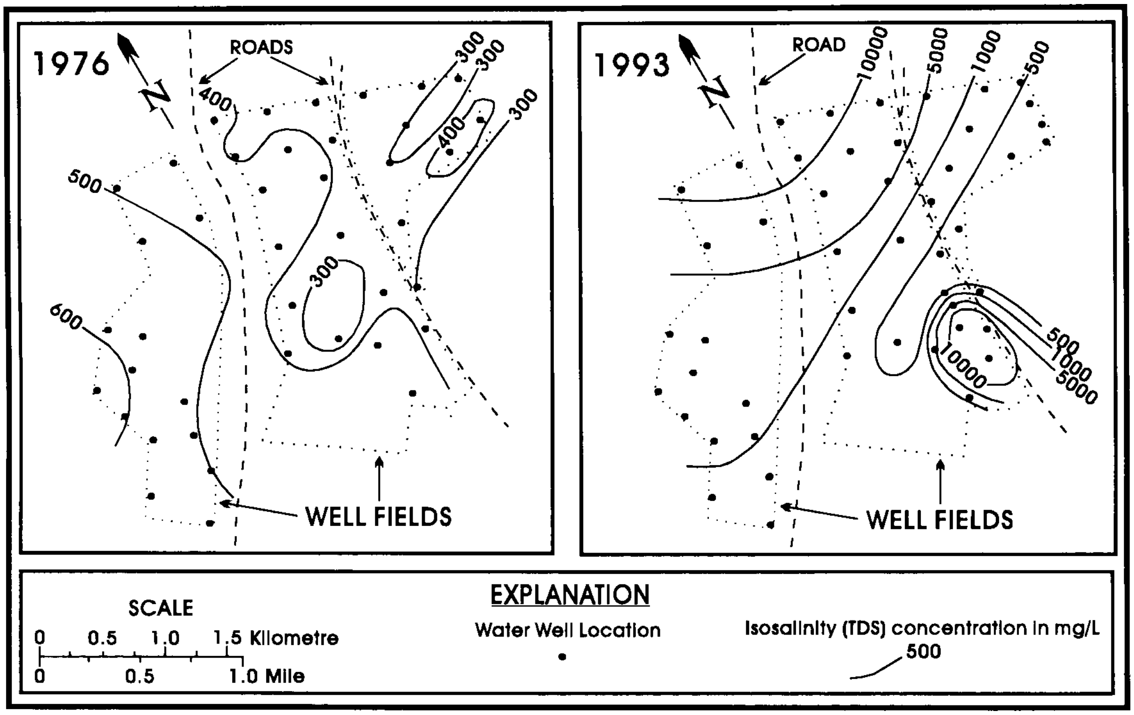

FIG. 7 Maps Showing Change in Total Dissolved Solids in a Ground-Water Aquifer Over a 17-year Period [Adapted from Ref (16)]

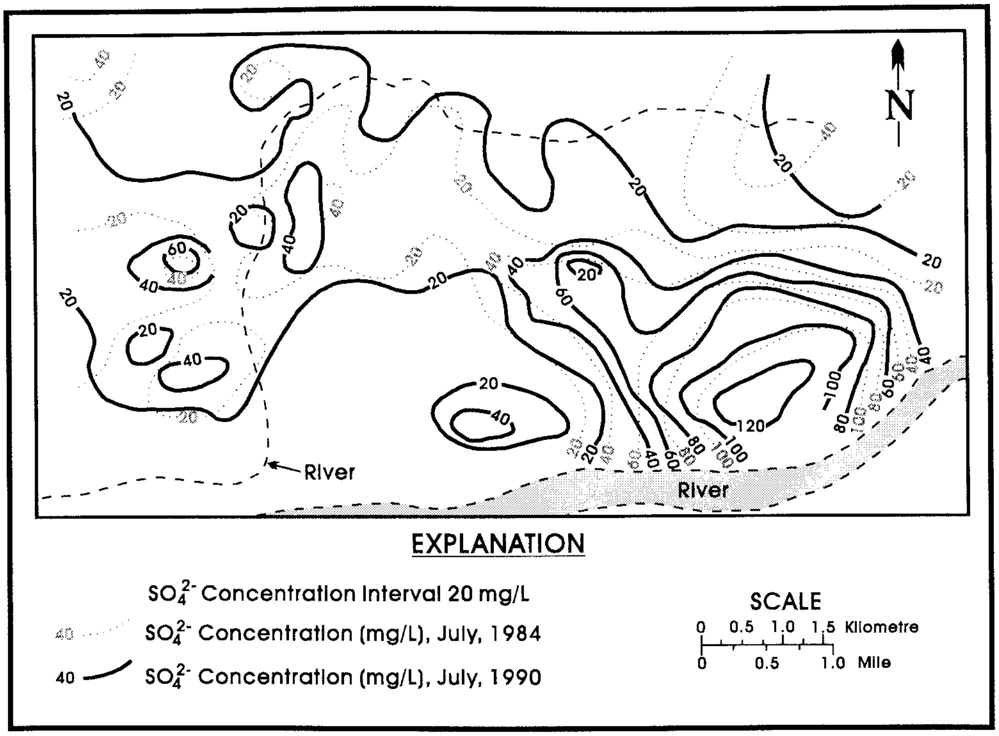

FIG. 8 Map Showing Change of SO_4^{2-} Concentration in a Ground Water Aquifer from July 1984 to July 1990 [Adapted from Ref (15)]

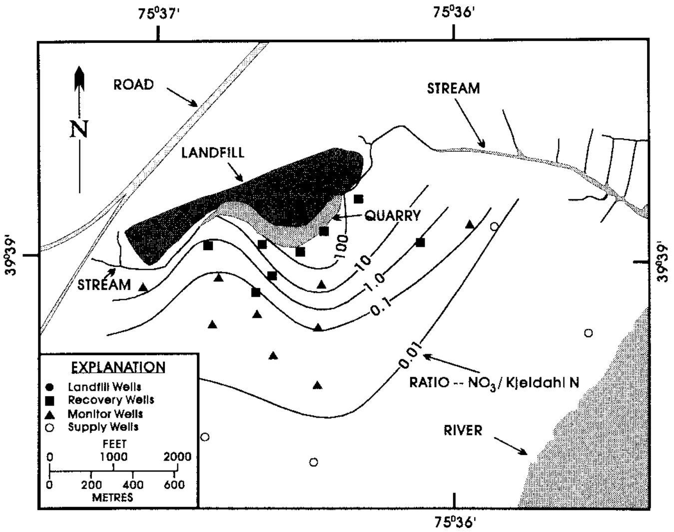

FIG. 9 Map of Ratio of Reduced Nitrogen Species to Oxidized Nitrogen [Adapted from Ref (17)]

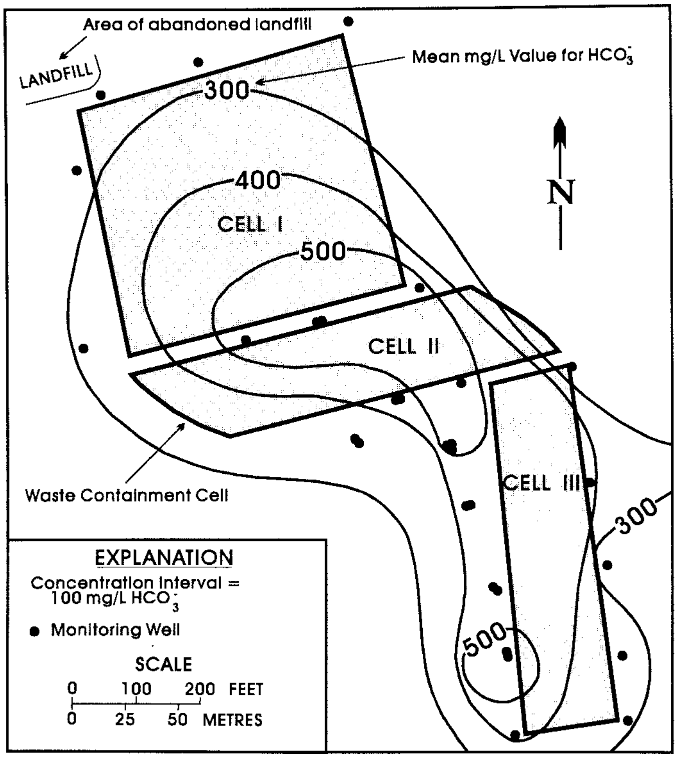

FIG. 10 Map of Mean HCO_3^- Values for Summer of 1985 in Aquifer Down-Gradient from an Old Landfill [Adapted from Ref (18)]

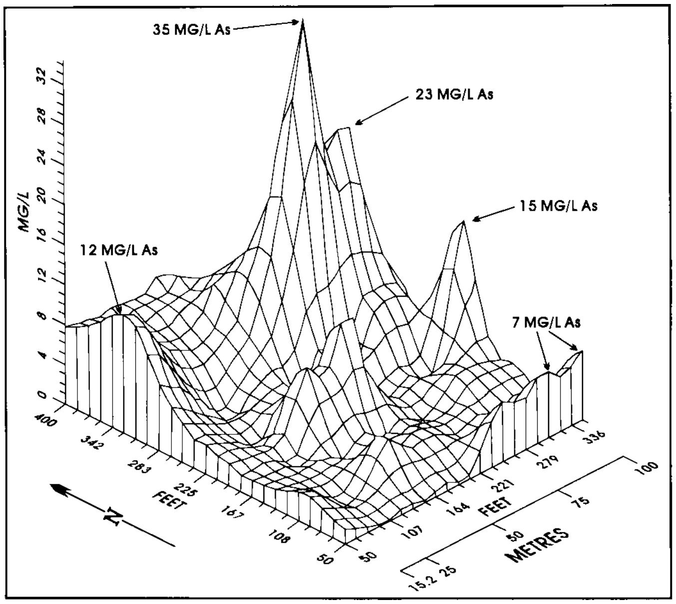

FIG. 11 Three-Dimensional Map of Arsenic Concentration in an Aquifer [Adapted from Ref (19)]

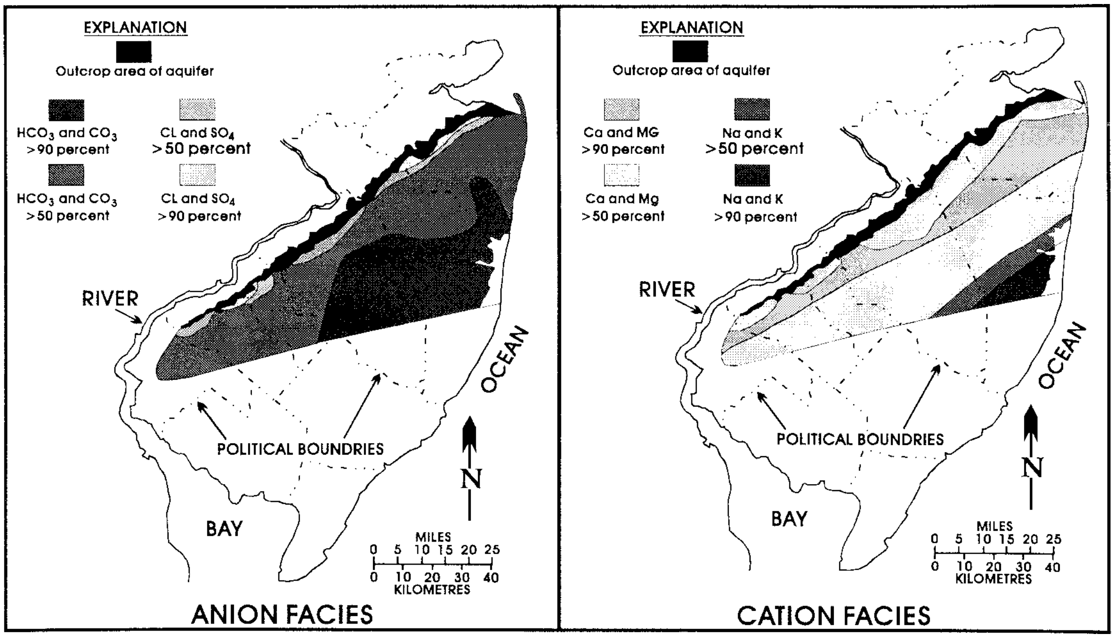

FIG. 12 Maps Showing Anion and Cation Facies in an Aquifer [Adapted from Ref (20)]

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