

Metals Transport in the Sacramento River, California, 1996–1997

Volume 1: Methods and Data

Charles N. Alpers, Howard E. Taylor, *and*
Joseph L. Domagalski, editors

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 99-4286

In cooperation with the

Sacramento Regional County Sanitation District
California State Water Resources Control Board
U.S. Environmental Protection Agency
U.S. Department Of Commerce, National Marine Fisheries Service

6211-12

Sacramento, California
2000

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
Placer Hall
6000 J Street
Sacramento, California 95819-6129

Copies of this report can be purchased
from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.

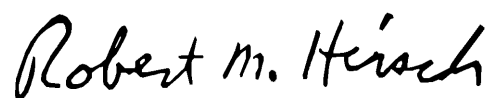
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Chief Hydrologist

CONTENTS

Executive Summary	1
Abstract	3
Introduction, <i>by</i> Charles N. Alpers.	4
Description of the Sacramento River Basin and Ongoing Studies, <i>by</i> Joseph L. Domagalski, Peter D. Dileanis, Donna L. Knifong, <i>and</i> Charles N. Alpers	7
Surface-Water Hydrology	8
Physiography	11
Land Use	11
Mining	11
Other Land Uses.	16
Ongoing Studies—NAWQA Program	16
Basic Fixed Sites	16
Streambed Sediment and Tissue Sites	19
Study Design: Field and Laboratory Methods, <i>by</i> Charles N. Alpers, Howard E. Taylor, David A. Roth, Daniel J. Cain, James W. Ball, Daniel M. Unruh, <i>and</i> Peter D. Dileanis.	19
Site Selection and Sampling Schedule.	19
Water Sampling	19
Sacramento River and Yolo Bypass Sites.	19
Tributary Sites	21
Streambed Sediment and Caddisfly Larvae Sampling	22
Methods for Sample Collection and Field Measurements.	22
Water Sampling	22
NAWQA Protocols.	22
USGS’s NRP Ultratrace Element Protocol	23
Streambed Sediment Sampling	24
Caddisfly Sampling	27
Sample Processing Methods	27
Water Sample Processing	27
NAWQA Protocols.	27
USGS’s NRP Ultratrace Element Protocol	28
Streambed Sediment Sample Preparation	34
Caddisfly Sample Preparation	34
Analytical Procedures	35
Major Cations and Trace Elements	35
Inductively Coupled Plasma Spectrometry	35
Atomic Fluorescence Spectrometry	35
Iron Redox Speciation	36
Lead Isotopic Analysis	36
Anions	36
Nutrients.	36
Organic Carbon	37
Particulate Size Distribution.	37
Colloids	37
Streambed Sediments.	38

Quality Assurance and Quality Control, <i>by</i> Howard E. Taylor, Ronald C. Antweiler, Charles N. Alpers, David A. Roth, Terry I. Brinton, Daniel J. Cain, James W. Ball, Daniel M. Unruh, <i>and</i> Peter D. Dileanis	38
Data Quality Objectives	38
Major Cations and Trace Elements	39
Accuracy	39
Standard Reference Materials	39
Spike Addition Recovery	42
Blanks	43
Precision	48
Trace Elements in Caddisfly Larvae	52
Standard Reference Materials	52
Spike Addition Recovery	52
Iron Redox	52
Lead Isotopes	56
Anions, Nutrients, and Organic Carbon	58
Particulate Size Determinations	59
Results, <i>by</i> Ronald C. Antweiler, Peter D. Dileanis, Charles N. Alpers, Howard E. Taylor, <i>and</i> Joseph L. Domagalski	62
Metal Concentrations in Water	62
Dissolved Constituents from Tangential-Flow Ultrafiltration	62
Isolated Colloidal Material	64
Total Digestions	64
Sequential Extractions	65
Equivalent Colloid Concentrations in Water	67
Total Recoverable Analyses of Whole-Water (Unfiltered) Samples	69
Conventional Membrane and Capsule Filtration	69
Metal Concentrations in Streambed Sediments	72
Metal Concentrations in Caddisfly Larvae	81
Lead Isotopes in Colloid Concentrates and Streambed Sediments	81
Anions, Nutrients, Organic Carbon, and Field Parameters	84
Particulate Size Distribution	86
Suspended Colloids	86
Streambed Sediments	87
Summary and Conclusions, <i>by</i> Charles N. Alpers, Howard E. Taylor, <i>and</i> Joseph L. Domagalski	98
References Cited	100
Glossary	105
Appendix 1. Quality Assurance Project Plan for the Data-Collection Activities of the Sacramento River Metals Transport Study	109
Appendix 2. Quality Assurance and Quality Control Data for Chemical Analyses	153
Appendix 3. Data for Field Parameters, Anions, Nutrients, Organic Carbon, and Sampling Sites	221
Appendix 4. Metal Concentrations in Water Samples	227
Appendix 5. Metal Concentrations in Sediment and Colloid Samples	363
Appendix 6. Particulate Size Distribution in Colloid and Sediment Samples	399
Appendix 7. Trace-Element Data in Caddisfly Larvae	409
Appendix 8. Plots of Dissolved and Colloidal Metal Concentrations	415

FIGURES

1. Map of the Sacramento River Basin, California	6
2. Hydrographs showing daily mean discharge for the period July 1, 1996, to June 30, 1997, for nine sites in the Sacramento River Basin, California	10

3. Histograms showing monthly precipitation for the period July 1996 to June 1997 and long-term monthly averages for three sites in the Sacramento River Basin, California	12
4. Map of physiographic provinces for the Sacramento River Basin, California.	13
5. Map showing historic copper, lead, and zinc mines in relation to other selected features in the Sacramento River Basin, California	14
6. Map of historic gold and mercury mines in relation to other selected features in the Sacramento River Basin, California	15
7. Map showing agricultural and other nonmining land uses in the Sacramento River Basin, California.	17
8. Map showing sampling sites in Sacramento River Basin, California	18
9. Diagram showing the procedure for the collection and processing of composite water samples in the Sacramento River Basin, California	31
10. Diagram showing the procedure for the collection and processing of grab water samples in the Sacramento River Basin, California	32
11. Diagram showing the procedure for the collection and processing of colloid samples in the Sacramento River Basin, California	33
12. Correlation plot of observed versus reported (certified or most probable value) dissolved concentration values of calcium, magnesium, sodium, and silica in standard reference materials	42
13. Correlation plot of observed versus reported (certified or most probable value) dissolved concentration values of aluminum, boron, barium, iron, strontium, and zinc in standard reference materials	43
14. Correlation plot of observed versus reported (certified or most probable value) dissolved concentration values of copper, lithium, manganese, molybdenum, and nickel in standard reference materials.	44
15. Correlation plot of observed versus reported (certified or most probable value) dissolved concentration values of arsenic, beryllium, chromium, antimony, and vanadium in standard reference materials	45
16. Correlation plot of observed versus reported (certified or most probable value) dissolved concentration values of silver, bismuth, cadmium, cobalt, lead, rubidium, selenium, thallium, and uranium in standard reference materials	46
17. Correlation plot of observed concentration values in total digestions and in the sum of sequential digestions versus certified concentrations of aluminum, calcium, iron, potassium, and silicon in standard reference material.	48
18. Correlation plot of observed concentration values in total digestions and in the sum of sequential digestions versus certified concentrations of chromium, magnesium, sodium, titanium, and zinc in standard reference material.	49
19. Correlation plot of observed concentration values in total digestions and in the sum of sequential digestions versus certified concentrations of barium, copper, manganese, nickel, and lead in standard reference material.	50
20. Correlation plot of observed concentration values in total digestions and in the sum of sequential digestions versus certified concentrations of cadmium, cobalt, lithium, antimony, and vanadium in standard reference material.	51
21. Correlation plot of observed concentration values in total digestions and in the sum of sequential digestions versus certified concentrations of mercury, thorium, thallium, and uranium in standard reference material	52
22. Distribution diagram of the percentage recovery of dissolved spike addition determinations for cadmium, copper, mercury, lead, and zinc versus the percentage of samples observed in the Sacramento River Basin, California	53
23. Box plots showing concentration ranges for aluminum in selected blank water samples and dissolved (ultrafiltrate) subsamples from the mainstem Sacramento River, California.	55
24. Box plots showing concentration ranges for cadmium in selected blank water samples and dissolved (ultrafiltrate) subsamples from the mainstem Sacramento River, California.	56
25. Box plots showing concentration ranges for copper in selected blank water samples and dissolved (ultrafiltrate) subsamples from the mainstem Sacramento River, California.	57
26. Box plots showing concentration ranges for iron in selected blank water samples and dissolved (ultrafiltrate) subsamples from the mainstem Sacramento River, California.	58
27. Box plots showing concentration ranges for lead in selected blank water samples and dissolved (ultrafiltrate) subsamples from the mainstem Sacramento River, California.	59

28. Box plots showing concentration ranges for zinc in selected blank water samples and dissolved (ultrafiltrate) subsamples from the mainstem Sacramento River, California.	60
29. Correlation plots of field replicates for dissolved aluminum, cadmium, copper, iron, lead, and zinc in the Sacramento River Basin, California	61
30. Plot of relative standard deviation for replicate determinations of aluminum versus dissolved (ultrafiltrate) concentration in the Sacramento River Basin, California.	62
31. Plot of relative standard deviation for replicate determinations of cadmium versus dissolved (ultrafiltrate) concentration in the Sacramento River Basin, California.	63
32. Plot of relative standard deviation for replicate determinations of copper versus dissolved (ultrafiltrate) concentration in the Sacramento River Basin, California.	64
33. Plot of relative standard deviation for replicate determinations of mercury versus dissolved (ultrafiltrate) concentration in the Sacramento River Basin, California.	65
34. Box plots showing range, mean, and median of dissolved (ultrafiltrate) concentrations in the Sacramento River Basin, California, for cadmium, copper, lead, and zinc	73
35. Box plots showing range, mean, and median of dissolved (ultrafiltrate) concentrations in the Sacramento River Basin, California, for aluminum, cerium, iron, and manganese.	74
36. Plots of aluminum concentration in relation to distance from Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	75
37. Plots of cadmium concentration in relation to distance from Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	76
38. Plots of copper concentration in relation to distance from Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	77
39. Plots of iron concentration in relation to distance from Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	78
40. Plots of lead concentration in relation to distance from Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	79
41. Plots of zinc concentration in relation to distance from Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	80
42. Plot of dissolved (ultrafiltrate) lead concentration in composite water samples compared with dissolved (ultrafiltrate) lead concentration in concurrent grab water samples in the Sacramento River Basin, California	81
43. Plot of equivalent colloid concentration in river water computed using aluminum data compared with colloid concentration in river water computed using iron data in the Sacramento River Basin, California	82
44. Plots of effective concentration (dissolved plus colloid) compared with total recoverable (whole-water) concentration in the Sacramento River Basin, California, for cadmium, copper, lead, magnesium, mercury, and zinc.	83
45. Box plots showing comparison of concentrations from three types of filtered samples at three sites in the upper Sacramento River Basin, California, for cerium, copper, and iron	85
46. Plot of cadmium concentrations in suspended colloids and streambed sediment in relation to distance from Sacramento River mouth, California	86
47. Plot of copper concentrations in suspended colloids and streambed sediment in relation to distance from Sacramento River mouth, California	87
48. Plot of iron concentrations in suspended colloids and streambed sediment in relation to distance from Sacramento River mouth, California	88
49. Plot of mercury concentrations in suspended colloids and streambed sediment in relation to distance from Sacramento River mouth, California.	89
50. Plot of lead concentrations in suspended colloids and streambed sediment in relation to distance from Sacramento River mouth, California.	90
51. Plot of zinc concentrations in suspended colloids and streambed sediment in relation to distance from Sacramento River mouth, California.	91
52. Plots of lead isotope ratios in relation to distance from the Sacramento River mouth, California, for streambed sediments and suspended colloids.	93
53. Plot of $^{206}\text{Pb}/^{204}\text{Pb}$ in relation to distance from the Sacramento River mouth, California, for streambed sediments and suspended colloids	94

54. Plot of $^{206}\text{Pb}/^{204}\text{Pb}$ versus $^{208}\text{Pb}/^{207}\text{Pb}$ for streambed sediments and suspended colloids in the Sacramento River Basin, California	95
55. Plot of lead concentration in streambed sediments and suspended colloids versus distance from the Sacramento River mouth, California	96
56. Plot of $^{206}\text{Pb}/^{204}\text{Pb}$ versus lead concentration for streambed sediments and suspended colloids in the Sacramento River Basin, California	97
57. Plot of particulate size distributions for colloid samples collected during September 1996 along the Sacramento River, California	98
Appendix 1:	
1. Location map showing sampling sites and site numbers	121
2. Location map showing sites in and below Keswick Reservoir	122
3. Depth-integrating sampler, D-77	130
4. The all-Teflon cone splitter and stand	135
Appendix 8:	
A8-1. Plots of calcium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	417
A8-2. Plots of cerium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	418
A8-3. Plots of cobalt concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	419
A8-4. Plots of chromium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	420
A8-5. Plots of gadolinium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	421
A8-6. Plots of potassium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	422
A8-7. Plots of manganese concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	423
A8-8. Plots of nickel concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations	424
A8-9. Plots of antimony concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	425
A8-10. Plots of uranium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	426
A8-11. Plots of vanadium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	427
A8-12. Plots of yttrium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	428
A8-13. Plots of ytterbium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	429
A8-14. Plots of zirconium concentration in relation to distance from the Sacramento River mouth, California, for equivalent colloid concentrations and dissolved (ultrafiltrate) concentrations.	430

TABLES

1. Sampling sites along the Sacramento River showing distance from river mouth and dates of sampling for various media	20
2. Sampling methods used for composite water samples	25
3. Sampling methods used for grab water samples	26
4. Sampling methods used for colloid samples	29
5. Subsamples of water and quality assurance protocols for sample preservation for various analyses	30
6. Operational settings for analysis of mercury with the cold vapor-atomic fluorescence spectrometer	35
7. Types of nutrient analyses and analytical methods	37
8. Instrumentation and calculation parameters used in the colloid particulate size-distribution analysis	38

9. Percentage of determinations for critical elements within the stated percentage recovery for the certified or most probable value for the National Institute of Standard and Technology’s standard reference materials (waters) or the U.S. Geological Survey’s standard reference water samples	40
10. Percentage of determinations of noncritical elements within the stated percentage recovery for the certified or most probable value for the National Institute of Standard and Technology’s standard reference materials (waters) or the U.S. Geological Survey’s standard reference water samples	41
11. Percentage of determinations for critical elements within the stated percentage recovery for the certified value for the National Institute of Standard and Technology’s standard reference material SRM 2704–Buffalo River Sediment.	47
12. Percentage of determinations of noncritical elements within the stated relative percentage recovery for the certified or “informational purposes” value for the National Institute of Standard and Technology’s standard reference material SRM 2704–Buffalo River Sediment	47
13. Percentage of determinations for each selected element that fell within the specified range of the percentage recovery for the calculated theoretical value of the spike addition in water samples	53
14. Percentage of determinations of critical elements within the stated percentage recovery for the certified or critical value compared with the sum of the sequential extraction phases of the National Institute of Standard and Technology’s standard reference material SRM 2704–Buffalo River Sediment.	54
15. Percentage of determinations of noncritical elements within the stated percentage recovery for the certified or “informational purposes” value compared with the sum of the sequential extraction phases of the National Institute of Standard and Technology’s standard reference material SRM 2704–Buffalo River Sediment	54
16. Percentage of field duplicate dissolved samples whose relative percentage difference was below specified values for critical elements	60
17. Percentage of replicate dissolved samples whose relative standard deviation fell below the specified values for all elements analyzed	66
18. Percentage of duplicate colloid samples whose relative percentage difference of total elemental analysis was below specified values for critical elements	67
19. Percentage of replicate colloid samples whose relative standard deviation fell below the specified values for all elements analyzed	68
20. Percentage of duplicate colloid samples whose relative percentage difference for the sum of sequential elemental analysis was below specified values for all critical elements	69
21. Percentage of duplicate colloid samples whose relative standard deviation for the sum of sequential elemental analysis was below specified values for all elements analyzed.	70
22. Comparison of metal concentrations determined in the study with certified values reported by the National Institute of Standards and Technology for standard reference materials SRM 1566a–Oyster tissue and SRM 50–Albacore tuna	71
23. Percentage of metal recovered from representative caddisfly samples spiked with a known quantity of metal.	71
24. Lead isotopic data for the National Institute of Standard and Technology’s standard reference material SRM-981 for filament temperatures of 1,191° to 1,300°C for the VG Sector 54 and VG 54R mass spectrometers.	72
25. Comparison of lead isotopic data obtained from the VG Sector 54 and VG 54R mass spectrometers for a Shasta Dam colloid sample (collected in December 1996).	72
26. Lead isotope data for suspended colloids and streambed sediments from the Sacramento River and some of its tributaries	92
Appendix 1:	
1. Quality assurance data objectives for chemical analyses of water samples	125
2. Quality assurance data objectives for chemical analyses of bed-sediment samples and colloid concentrates, including sequential extraction.	127
3. Quality assurance data objectives for field measurements of water quality.	128
4. Subsamples of water required for scheduled analyses	133
5. Subsamples of bed sediment required for scheduled analyses	139

Appendix 2:	
A2-1. Results of EPA's Performance Evaluations WP036 (A2-1a), WP037 (A2-1b), and WP038 (A2-1c) for the USGS's National Water Quality Laboratory.	154
A2-2. Results of laboratory and field blanks for water sample processing	157
A2-3. Observed metal concentrations and percentage recovery in biological reference materials processed using the same methods as caddisfly samples	198
A2-4. Procedural blanks for caddisfly samples collected from the Sacramento River and Cottonwood Creek, October 21–23, 1996.	199
A2-5. Concentration data for standard reference materials	200
Appendix 3:	
A3-1. Field measurements and concentrations of anions, nutrients, and organic carbon.	222
A3-2. Sampling site numbers, names, and locations	226
Appendix 4:	
A4-1. Concentrations of major cations and trace elements in filtered water samples	228
A4-2. Concentrations of major cations and trace elements in unfiltered (whole) water samples.	327
A4-3. Lead concentrations in filtered water samples collected at a single point in the stream cross section.	360
A4-4. Lead concentrations in unfiltered (whole) water samples collected at a single point in the stream cross section	362
Appendix 5:	
A5-1. Concentrations of selected elements in streambed sediment samples	364
A5-2. Concentrations of selected elements in suspended colloid samples	368
A5-3. Concentrations of selected elements in sequentially extracted suspended colloid samples	386
Appendix 6:	
A6-1. Particulate size distribution of Sacramento River colloid samples as determined by photon correlation spectrometry	400
A6-2. Particulate size distribution of streambed sediment samples	407
Appendix 7:	
A7-1. Dry tissue weight and metal concentration data for caddisfly larvae	410
A7-2. Dry tissue weight and metal concentration data for standard reference materials processed concurrently with caddisfly samples	413
A7-3. Metal mass balance of body fractions prepared from caddisfly samples collected from the Sacramento River and Cottonwood Creek	414

CONVERSION FACTORS, VERTICAL DATUM, ACRONYMS and ABBREVIATIONS, and CHEMICAL NOTATION

Conversion Factors

Multiply	By	Obtain
acre-foot (acre-ft)	1,233	kiloliter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft ³ /s)	28.32	cubic liter per second
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi ²)	2.590	square kilometer
cubic yard (yd ³)	0.7646	cubic meter

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{\circ}\text{F}=1.8(^{\circ}\text{C})+32.$$

Vertical Datum

Sea level: In this paper, “sea level refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Acronyms and Abbreviations

(Additional information given in parenthesis)

μg, microgram

μg/g, microgram per gram

μg/L, microgram per liter

μm, micrometer

μS/cm, microsiemens per centimeter at 25° Celsius

MΩ-cm, megohm centimeter

σ, sigma

cm, centimeter

cm², square centimeter

cP, centipoise

g, gram

g, gravitational constant

g/L, gram per liter

in./yr, inch per year

km, kilometer

km², square kilometer

L, liter

L/min, liter per minute

kHz, kilohertz

m, meter

mg, milligram

mg/g, milligram per gram
mg/L, milligram per liter
mL, milliliter
mm, millimeter
mW, milliwatt
ng, nanogram
ng/L, nanogram per liter
nm, nanometer

Ax, axial
BOR, Bureau of Reclamation
BTD&Q, Branch of Technical Development and Quality Systems
CDEC, California Data Exchange Center
CV-AFS, cold vapor-atomic fluorescence spectrometer
DIFF, diffraction
DL, detection limit
DOC, dissolved organic carbon
EPA, U.S. Environmental Protection Agency
F, fractionation factor
HDPE, high density polyethylene
IC, iron chromatography
ICP-AES, inductively coupled plasma-atomic emission spectrometry
ICP-MS, inductively coupled plasma-mass spectrometry
M, Molar
MPV, most probable value
n, number of observations, number of duplicate samples
N, Normal
NAWQA, National Water-Quality Assessment (Program)
NIST, National Institute of Standards and Technology
NMWL, nominal molecular weight limit
NRP, National Research Program
NWQL, National Water Quality Laboratory
PFA, perfluoroalkoxy
PTFE, polytetrafluoroethylene
PUB, published concentration value for standard reference material
PVC, polyvinyl chloride
QAPP, Quality Assurance Project Plan
QAQC, quality assurance and quality control
REC, percentage recovery
rms, root mean squared
RPD, relative percentage difference
RSD, Relative Standard Deviation
SCDD, Spring Creek Debris Dam
SCPP, Spring Creek Power Plant
SD, standard deviation
SOC, suspended organic carbon
SRM, standard reference material
SWRS, standard reference water sample
TDS, total dissolved solids
USGS, U.S. Geological Survey
UV-vis, ultraviolet-visible spectroscopy
WPPEs, Water Pollution Performance Evaluation Study
WSPES, Water Supply Performance Evaluation Study
wt, weight

Chemical Notation

Elements

Ag, silver
Al, aluminum
Ar, argon
As, arsenic
Au, gold
B, boron
Ba, barium
Be, beryllium
Bi, bismuth
Br, bromine
C, carbon
Ca, calcium
Cd, cadmium
Ce, cerium
Cl, chlorine
Co, cobalt
Cr, chromium
Cs, cesium
Cu, copper
Dy, dysprosium
Er, erbium
Eu, europium
F, fluorine
Fe, iron
Fe(II), ferrous iron
Fe(III), ferric iron
Gd, gadolinium
H, hydrogen
Hg, mercury
In, indium
Ir, iridium
Ho, holmium
K, potassium
La, lanthanum
Li, lithium
Lu, lutetium
Mg, magnesium
Mn, manganese
Mo, molybdenum
N, nitrogen
Na, sodium
Nd, neodymium
Ni, nickel
O, oxygen
P, phosphorous
Pb, lead
Pr, praseodymium
Rb, rubidium
Re, rhenium
Rh, rhodium

S, sulfur
Sb, antimony
Se, selenium
Si, silicon
Sm, samarium
Sn, tin
Sr, strontium
Tb, terbium
Te, tellurium
Th, thorium
Ti, titanium
Tl, thallium
Tm, thulium
U, uranium
V, vanadium
W, tungsten
Y, yttrium
Yb, ytterbium
Zn, zinc
Zr, zirconium

Compounds, Ions, and Minerals

Cl, chloride
CaCO₃, calcium carbonate; calcite (or aragonite)
CO₂, carbon dioxide
CuFeS₂, chalcopyrite
F⁻, fluoride
FeS₂, pyrite
HBr, hydrobromic acid
HCl, hydrochloric acid
HF, hydrofluoric acid
HgCl₂, mercuric chloride
HNO₃, nitric acid
H₂SO₄, sulfuric acid
K₂Cr₂O₇, potassium dichromate
MMHg, monomethylmercury (CH₃Hg⁺)
N₂, nitrogen gas
NaN₃, sodium azide
NH₂(CHOH)₃ HCl, tris hydrochloride
NH₃, ammonia
NO₂⁻, nitrite
NO₃⁻, nitrate
SiO₂, silica (or quartz)
SnCl₂, stannous chloride
SO₄²⁻, sulfate
(Zn,Fe,Cd)S, sphalerite