

# CONTENTS

Abstract .....	1
Introduction .....	2
Geologic Setting and Bathymetry .....	4
Hydrology.....	7
Data-Collection Methods .....	7
Water-Table Configuration and Extent of the Ground-Water Contributing Area.....	7
Ground-Water and Lake-Stage Fluctuations .....	10
Water Balance.....	13
Precipitation and Evaporation .....	13
Ground-Water Inflow.....	13
Contributing-Area Approach.....	14
Isotope Mass-Balance Approach.....	14
Average Ground-Water Inflow .....	17
Water-Balance Results.....	17
Limnology .....	19
External Inputs .....	19
Ground-Water Nutrient Inputs.....	19
Sampling and Analytical Methods for Ground Water .....	19
Geochemical Conditions in the Aquifer .....	21
Ground-Water Point Sources.....	24
Ground-Water Background Source .....	29
Atmospheric Deposition Source.....	31
Swimmer Source .....	32
Other Nutrient Sources.....	32
Nutrient Limitation, Ratios, Source Size, Timing, and Disposal Strategies .....	32
Nutrient Loading Trophic Index.....	33
Plant Growth and Internal Cycling of Chemical Constituents .....	33
Methods of Sampling and Analysis of the Water Column .....	34
Temperature Stratification .....	34
Phytoplankton, <i>Nitella</i> , and Light .....	34
Dissolved Oxygen .....	40
Dissolved Oxygen in the Epilimnion .....	40
Dissolved Oxygen in the Metalimnion.....	43
Dissolved Oxygen in the Hypolimnion .....	44
Conductance, pH, Phosphorus, Nitrogen, Iron, Manganese, and Internal Nutrient Recycling.....	44
Historical, and Between-Lake Trophic Assessments .....	50
Trophic State from Water-Column Assessment .....	50
Historical Dissolved-Oxygen Profiles .....	51
Comparisons of Dissolved Oxygen Among Lakes.....	52
Trophic Stability .....	53
Trophic Ecology and Management Options.....	54
Summary and Conclusions.....	55
References Cited .....	56
Appendix A. Delta deuterium and delta oxygen-18 of lake water, ground-water inflow, and precipitation, Walden Pond.....	61

## FIGURES

1.	Map showing location and setting of Walden Pond, Concord, Massachusetts.....	3
2.	Generalized geologic cross section A-A' through Walden Pond and split-spoon interval, lithologic log, and natural-gamma log from monitoring well CTW214.....	5
3, 4.	Maps showing: 3. Bathymetry of Walden Pond .....	6
	4. Altitude and configuration of the water table on July 19, 1999, extent of the ground-water contributing area, and bathymetry, Walden Pond.....	8
5, 6.	Hydrographs showing: 5. Water levels at well CTW165 and Walden Pond, and annual precipitation amounts, Bedford and Framingham, 1953–99 .....	11
	6. Water levels at well CTW165 and Walden Pond, and monthly precipitation amounts, Bedford, 1995–99 .....	12
7, 8.	Graphs showing: 7. Temporal variation in delta oxygen-18 of precipitation, ground-water inflow, and lake water, Walden Pond, and monthly precipitation amounts, Bedford, June 1998 to September 1999 .....	15
	8. Relation between delta oxygen-18 and delta deuterium in precipitation, ground-water inflow, and lake water, Walden Pond, June 1998 to September 1999 .....	16
9.	Pie chart showing average annual water balance, Walden Pond.....	17
10.	Map showing specific conductance, nitrate concentrations, and estimated extent of the septic-system plume, in the area of the Walden Pond State Reservation septic leach field .....	20
11–15.	Graphs showing: 11. Relation between conductance and nitrate concentration in samples from ground-water wells away from the plume and within the plume from the Walden Reservation septic leach field, and samples from drive-point wells along the beach of Walden Pond.....	28
	12. Dryfall deposition of phosphorus from June 1, 1998, to September 1, 1999, collected on a water surface in a collector near Walden Pond .....	32
	13. Thermal stratification of Walden Pond: (A) Contour plot of temperature versus time and depth, from March 1997 to August 1999, and (B) Example temperature-depth profiles for 1998 .....	35
	14. Chlorophyll-a concentration-depth profiles from the deep-hole station of Walden Pond, June 1997–June 1998 .....	36
	15. <i>Nitella</i> biomass measured along transects in Walden Pond, 1998 .....	38
16.	Map showing bathymetry with sampling transects and zone of <i>Nitella</i> growth, Walden Pond, 1998.....	39
17–25.	Graphs showing: 17. Distribution of dissolved oxygen in Walden Pond, March 1997–August 1999 (A) Contour plot of dissolved oxygen in relation to depth and time, and (B) Dissolved oxygen in relation to depth on selected dates .....	41
	18. Dissolved oxygen profiles from the deep-hole station compared with those from the east-end station, Walden Pond (1997); and morning compared with afternoon profiles (September 17, 1997) .....	42
	19. Distribution of pH in Walden Pond, March 1997–August 1999 .....	46
	20. Total organic-plus-ammonia nitrogen, and dissolved nitrate-plus-nitrite nitrogen concentration-depth profiles in Walden Pond, March–September 1998 .....	47
	21. Total phosphorus and total dissolved phosphorus concentration-depth profiles in Walden Pond, 1997–1998 .....	48
	22. Depth distribution of nitrogen, phosphorus, dissolved oxygen, and temperature from September 23, 1998; and iron, sulfate, and manganese from September 10, 1997, in Walden Pond .....	49
	23. Dissolved oxygen content of the hypolimnion of Walden Pond, during summers of 1997, 1998, and 1999; dissolved oxygen content from single profiles in 1939, 1992, 1994 and 1996; and lines projecting dissolved oxygen content for summer 1939.....	51
	24. Historical dissolved oxygen profiles for Walden Pond .....	52
	25. Comparison dissolved oxygen profiles for eastern Massachusetts kettle-hole lakes: Ashumet Pond, Falmouth and Mashpee; Walden Pond, Concord; White Pond, Concord; and Gull Pond, Wellfleet .....	53

## TABLES

1. Bathymetric surveys of Walden Pond .....	4
2. Monthly average values used to calculate the delta oxygen-18 of evaporated water, Walden Pond .....	18
3. Ground-water quality constituents that indicate geochemical conditions in the aquifer of Walden Pond .....	22
4. Ground-water concentrations of nutrients and specific conductance from water monitoring wells in the aquifer of Walden Pond.....	25
5. Ground-water concentrations of nutrients and specific conductance in the beach-depth wells from temporary drive-points .....	28
6. Annual and summer nutrient budgets for Walden Pond based on 1995–99 average ground-water and precipitation inflows and 1998–99 average nutrient concentration data.....	30
7. Surface area and volume data at 1-meter increments for Walden Pond.....	37

## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

### CONVERSION FACTORS

Multiply	By	To obtain
cubic meter ( $m^3$ )	35.31	cubic foot
cubic meter per year ( $m^3/yr$ )	35.31	cubic foot per year
gram (g)	0.03527	ounce, avoirdupois
gram per square meter ( $g/m^2$ )	0.003278	ounce, avoirdupois per square foot
hectare (ha)	0.003861	square mile
kilogram (kg)	2.205	pound
kilogram per year (kg/yr)	2.205	pound per year
kilometer (km)	0.6214	mile
liter per minute (L/min)	0.2642	gallon per minute
meter (m)	3.281	foot
meter per year (m/yr)	3.281	foot per year
micrometer ( $\mu m$ )	0.00003937	inch
millimeter (mm)	0.03937	inch
square centimeter per second ( $cm^2/s$ )	0.1550	square inch per second
square kilometer ( $km^2$ )	0.3861	square mile
square meter ( $m^2$ )	10.76	square foot
Temperature is given in degrees Celsius ( $^{\circ}C$ ), which can be converted to degrees Fahrenheit ( $^{\circ}F$ ) by use of the following equation:		
$^{\circ}F = 1.8 (^{\circ}C) + 32$		

### VERTICAL DATUM

**Sea level:** In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

### ABBREVIATIONS

**Abbreviated water-quality units used in this report:** Chemical concentration in water solution is given in grams per liter (g/L), milligrams per liter (mg/L), micrograms per liter ( $\mu g/L$ ), or nanograms per liter (ng/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand milligrams per liter is equivalent to one gram per liter. One thousand micrograms per liter is equivalent to one milligram per liter. One thousand nanograms per liter is equivalent to one microgram per liter. Specific conductance is given in microsiemens per centimeter ( $\mu S/cm$ ). One microsiemen is equivalent to one millionth of siemen.