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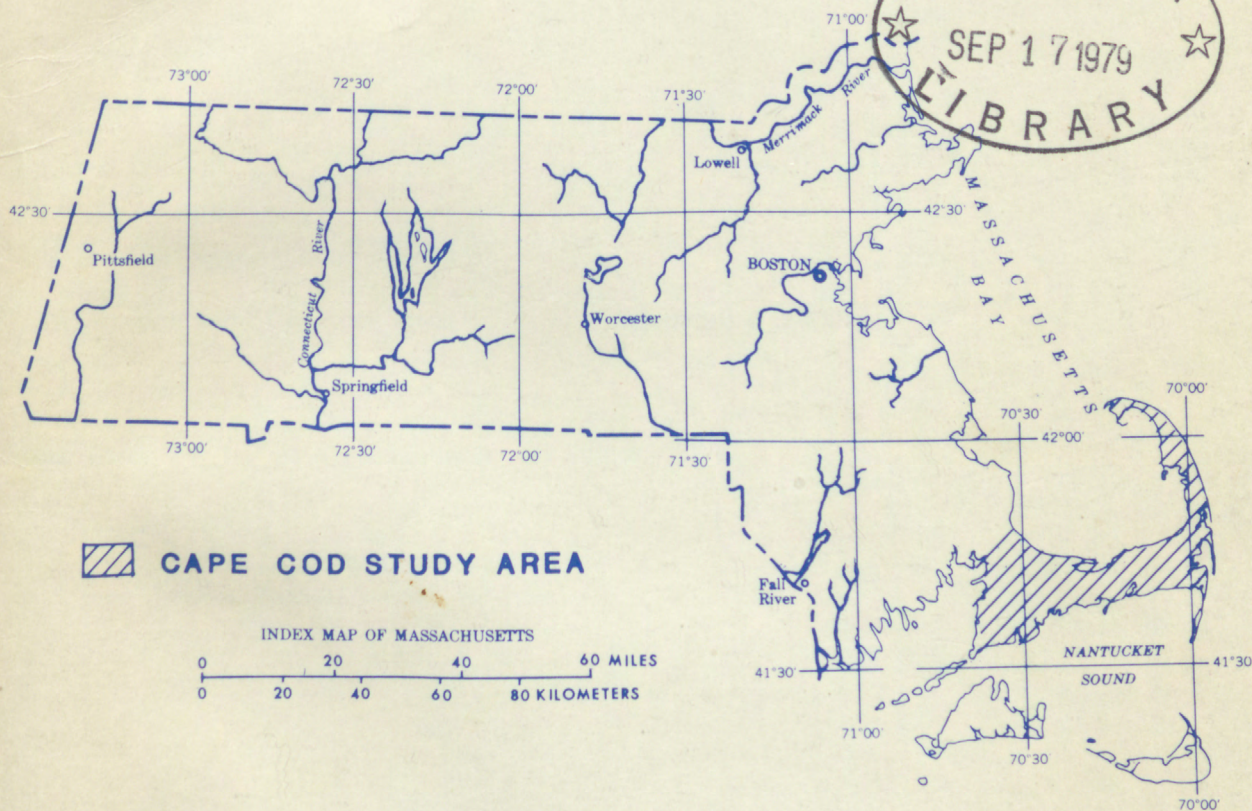
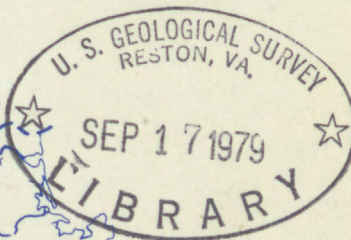
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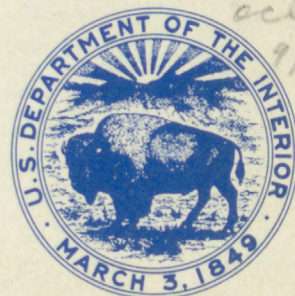
CHEMICAL QUALITY OF GROUND WATER ON CAPE COD, MASSACHUSETTS

U. S. GEOLOGICAL SURVEY

Water - Resources Investigations 79 - 65



Prepared in cooperation with the
COMMONWEALTH OF MASSACHUSETTS,
WATER RESOURCES COMMISSION
and the
NATIONAL PARK SERVICE



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By Michael H. Frimpter and Frederick B. Gay

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CONTENTS

	Page
Factors which can be used to convert inch-pound units to International System of Units (SI) with abbreviations -----	iv
Abstract -----	1
Introduction -----	1
Water quality -----	3
Physical properties and major constituents group-----	3
Metals -----	7
Ammonia and sulfide -----	9
Nutrients -----	9
Insecticides, herbicides, and industrial organic chemicals-----	10
Summary -----	11
Selected references -----	11

ILLUSTRATIONS

(Plates are in the pocket.)

- Plate 1. Ground-water quality and water table, upper and middle Cape Cod.
 2. Ground-water quality and water table, lower and middle Cape Cod.

	Page
Figure 1. Index map of the Cape Cod study area -----	2
2. Frequency distribution of major cations and anions -----	5
3. Increasing chloride concentrations from highway drainage -----	6
4. Relationship between dissolved oxygen and total iron -----	8
5. Increases in nitrate as nitrogen near Hyannis -----	9
6. Increases in nitrate as nitrogen at Camp Edwards -----	10

TABLES

	Page
Table 1. Physical properties and constituents in Cape Cod's ground water -----	4
2. Metals in Cape Cod's ground water -----	8

FACTORS WHICH CAN BE USED TO CONVERT INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI) WITH ABBREVIATIONS

Multiply inch-pound units	By	To obtain SI Units
<u>Length</u>		
inch (in)	2.540×10^1	millimeter (mm)
foot (ft)	3.048×10^{-1}	meter (m)
mile (mi)	1.609	kilometer (km)
<u>Area</u>		
square mile (mi ²)	2.590	square kilometer (km ²)
<u>Volume</u>		
gallon (gal)	3.785	liter (L)
cubic foot (ft ³)	2.832×10^2	cubic meter (m ³)
<u>Flow</u>		
gallon per minute (gal/min)	6.309×10^{-2}	liter per second (L/s)
<u>Weight</u>		
ton (short)	9.072×10^{-1}	megagram (mg)
part per million (ppm)	1.000	milligram per liter (mg/L)
part per billion (ppb)	1.000	microgram per liter (ug/L)
<u>Temperature</u>		
degree Fahrenheit (°F)	$5/9(°F-32)$	degree Celsius (°C)

CHEMICAL QUALITY OF GROUND WATER ON CAPE COD, MASSACHUSETTS

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ABSTRACT

Cape Cod is a 440 square mile hook-shaped peninsula which extends 40 miles into the Atlantic. Freshwater in Pleistocene sand and gravel deposits is the source of supply for nearly 100 municipal and thousands of private domestic wells. Most ground water on Cape Cod is of good chemical quality for drinking and other uses. It is characteristically low in dissolved solids and is soft. In 90 percent of the samples analyzed, dissolved solids were less than 100 milligrams per liter and pH was less than 7.0.

Highway deicing salt, sea-water flooding due to storms, and saltwater intrusion due to ground-water withdrawal are sources of sodium chloride contamination. Chloride concentrations have increased from 20 to 140 milligrams per liter, owing to saltwater intrusion at Provincetown's wells in Truro. In Yarmouth, contaminated ground water near a salt-storage area contained as much as 1,800 milligrams per liter chloride. Heavy metals, insecticides, and herbicides were not found at concentrations above the U.S. Environmental Protection Agency's recommended limits for public drinking-water supplies, but iron and manganese in some samples exceeded those limits. Ninety percent of 84 samples analyzed for nitrate reported as nitrogen contained less than 1.3 milligrams per liter and 80 percent contained 0.5 milligrams per liter or less of nitrate as nitrogen. Water containing nitrogen in excess of 0.5 milligrams per liter has probably been affected by municipal or domestic sewage or fertilizer, and water with less than this amount may have been affected by them.

Cape Cod's water-table aquifers are highly susceptible to seawater encroachment and to contamination from surface sources. Integrated water-supply, waste-disposal, and land-use planning and management, guided by results of vigilant monitoring and hydrologic analysis, are necessary to maintain the quality of the Cape's ground water.

INTRODUCTION

Cape Cod is a 440-mi² hook-shaped peninsula (fig. 1) that extends eastward 40 miles into the Atlantic from southern New England. The Cape is composed of unconsolidated sand and gravel, and some silt, clay, and till that overlie nearly impermeable crystalline bedrock 80 to 900 feet below the National Geodetic Vertical Datum of 1929. Freshwater in these porous and relatively permeable deposits form a lenslike fresh ground-water reservoir that is the source of supply for nearly 100 municipal wells and thousands of private domestic wells. This water source receives waste water and landfill leachates generated by an expanding Cape Cod population.

Adequate description and understanding of the occurrence, movement, and chemistry of ground water is needed for its effective development and management. This need led to a U.S. Geological Survey study of the ground water of Cape Cod in cooperation with Barnstable County; the Massachusetts Water Resources Commission, Divisions of Water Pollution Control and Water Resources; and the National Park Service. This report is one product of that study.

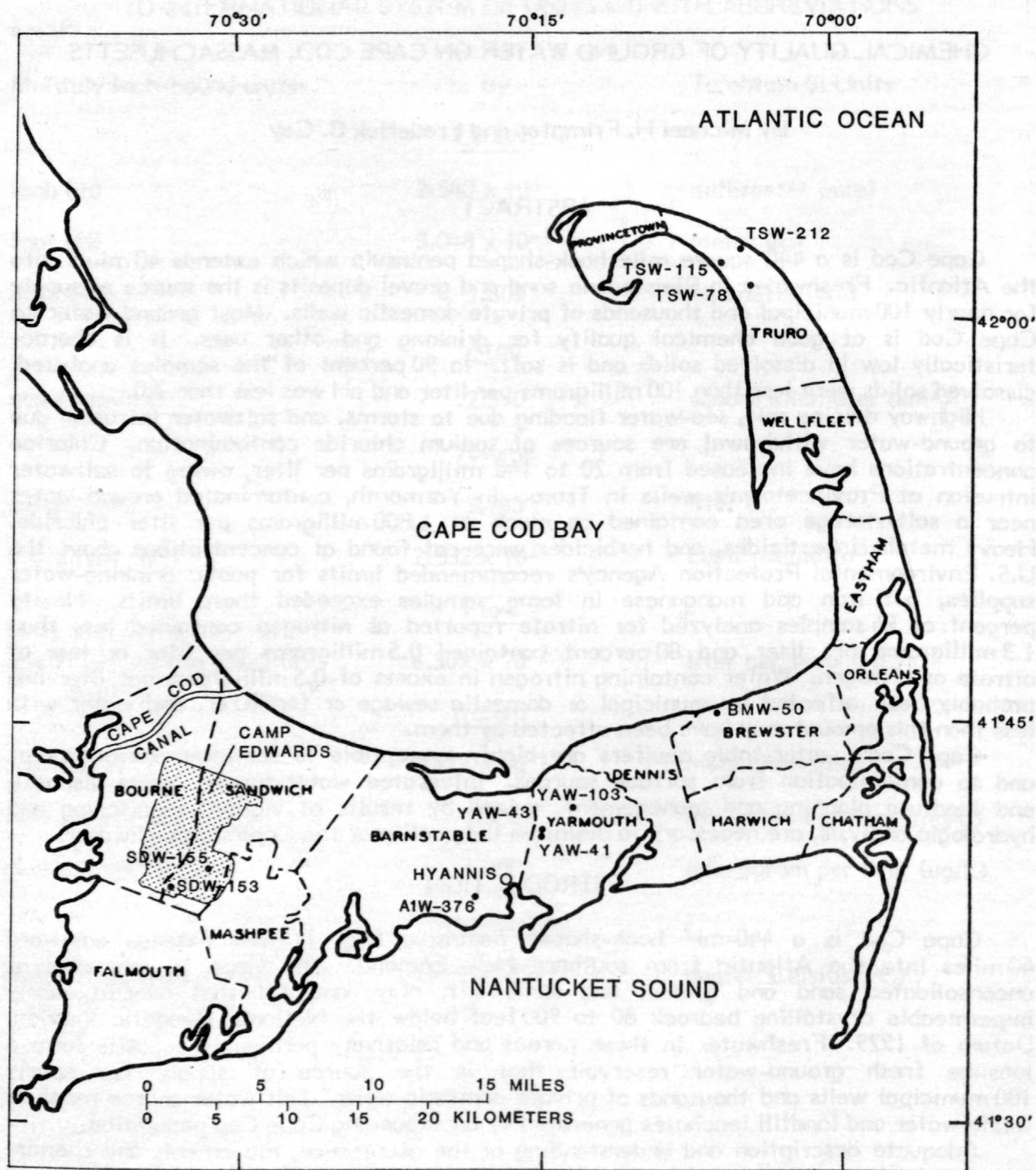


Figure 1.--Index map of the Cape Cod study area

The purpose of this report is to provide a base-line description of water quality for use in evaluating future changes and in formulating management plans for water quality. Samples were collected at 72 sites representative of many geologic, hydrologic, and land-use conditions. Analyses of the samples are supplemented by previous analyses of samples from 22 additional sites. Samples from 20 sites were analyzed for heavy metals, and samples from 10 sites were analyzed for common pesticides and industrial organic chemicals. Results of the analyses are available from the U.S. Geological Survey WATSTORE quality-of-water file.

WATER QUALITY

Most ground water on Cape Cod is of good chemical quality for drinking and other uses (plates 1 and 2 and tables 1 and 2). It is characteristically low in dissolved solids, soft, and virtually free of toxic heavy metals and organic compounds such as insecticides and herbicides. Constituents thought to be problems or threats to water supplies for drinking are salt (NaCl) from seawater intrusion, coastal flooding, and highway deicing salt, nitrogen from domestic and municipal sewage, and iron and manganese which occur naturally. Iron and manganese concentrations also can be increased locally by landfill leachates. Hydrogen sulfide gas and ammonia also occur naturally in organic sediments in a few areas.

Physical Properties and Major Constituents Group

The natural pH of the ground water was almost always below 7.0, making the water mildly to strongly corrosive to metal. Fifty percent of the pH values for 202 samples were less than 6.1, and 90 percent were less than 7.0. Acidic water results in solution of copper plumbing and subsequent deposition of copper compounds commonly causing blue-green stains on white porcelain fixtures. The median concentration of dissolved solids was 70 mg/L, and dissolved solids exceeded 100 mg/L in 10 percent of 196 samples. Sodium chloride was usually responsible for the high dissolved solids. Median sodium concentration from 112 samples was 13.2 mg/L, and median chloride concentration from 202 samples was 19 mg/L. Sulfate was well below the 250 mg/L recommended limit for drinking water (U.S. Environmental Protection Agency, 1977) in all samples. The median hardness (as CaCO_3) was 20 mg/L, well within the commonly described soft-water (0-60 mg/L) range (Durfor and Becker, 1964).

Specific conductance can be used as a general index of the concentration of dissolved solids in most waters. Specific conductance and dissolved solids from 191 samples were compared by linear regression and yields the following empirical formula:

Dissolved solids = $0.55 \times \text{specific conductance} + 4.5$ with a correlation coefficient of 0.97.

Correlation coefficient is an index measuring the closeness of fit of the observed points to the estimated line of regression. Correlations between various major constituents and specific conductance or dissolved solids did not yield relationships useful for estimation of chemical composition from specific conductance measurements.

The frequency distribution of the major cations; calcium, magnesium, and sodium, and the major anions; bicarbonate, sulfate, and chloride show that sodium chloride is the most common cause of high dissolved-solids concentrations (fig. 2). Calcium, magnesium, sulfate, and bicarbonate; however, occur most commonly only in low concentrations.

Table 1.—Physical properties and constituents in Cape Cod's ground water

(Data are in milligrams per liter except as indicated.
Dissolved solids less than 1000 milligrams per liter.)

Constituent	CONCENTRATION					Number of analyses
	Limit ¹	Maximum	Median	Minimum	90 percent of analyses contained less than value indicated	
Specific conductance (micromhos per centimeter at 25°C)	—	1760	123	46	173	202
pH (units)	—	7.6	6.1	4.2	7.0	202
Hardness (Ca + Mg as CaCO ₃)	60	185	20	5.0	38	202
Calcium	—	21	3.6	.5	7.4	202
Magnesium	—	34	2.4	.3	4.6	202
Sodium	—	264	13.2	3.5	23.8	112
Potassium	—	7.8	0.9	.2	1.6	112
Bicarbonate	—	100	11	.0	22	202
Carbon dioxide	—	41	5.7	.4	19	² 119
Sulfate	250	61	6.6	1.1	16.4	202
Chloride	250	480	19	5.8	38	202
Fluoride	2.2 at 57°F ³	.7	.0	.0	.2	202
Silica	—	41	9.1	3.2	12.8	200
Dissolved solids (sum of constituents)	—	877	70	29	100	196
Nitrate (N)	10	6.3	.12	.0	1.3	84
Ammonia (N)	—	.91	.01	.00	.07	73
Phosphorus	—	.5	.05	.01	.34	75
Total organic carbon	—	7.6	5.5	.07	—	10

¹Recommended limits for drinking water (U.S. Environmental Protection Agency, 1975 1977) except hardness for which soft is commonly described as 0-60 mg/L (Durfor and Becker, 1964).

²Limited to water samples with pH between 6 and 9; higher carbon dioxide values may be present in water with pH less than 6.

³Annual average of the maximum daily air temperature for Cape Cod, in degrees Fahrenheit.

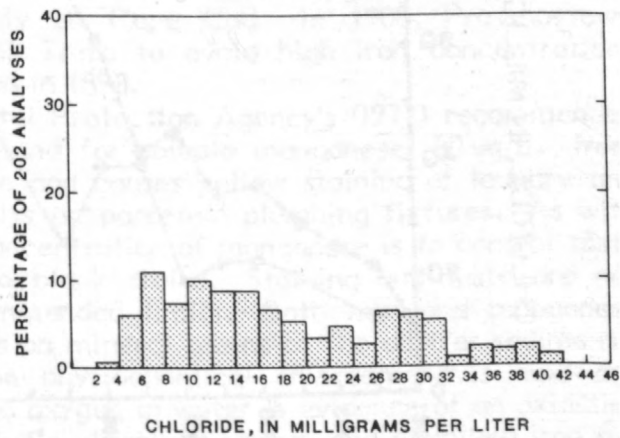
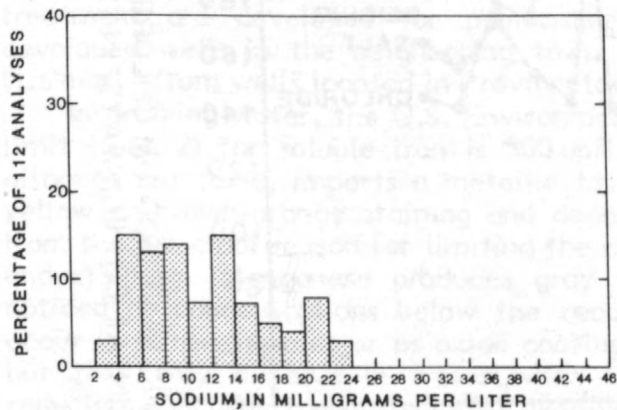
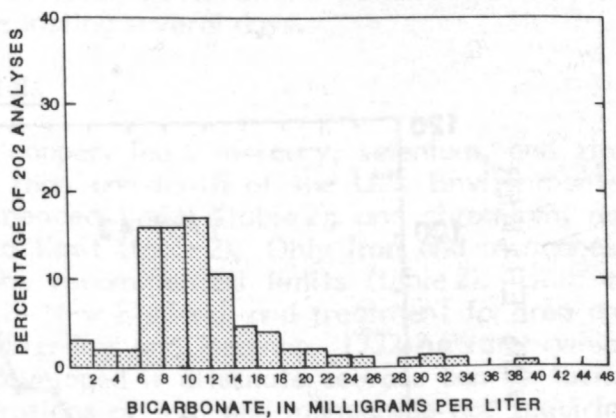
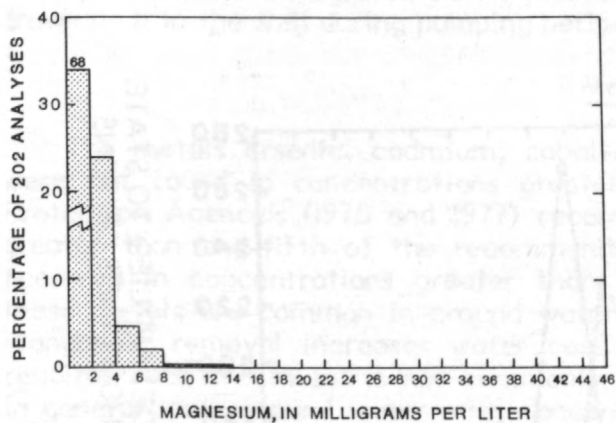
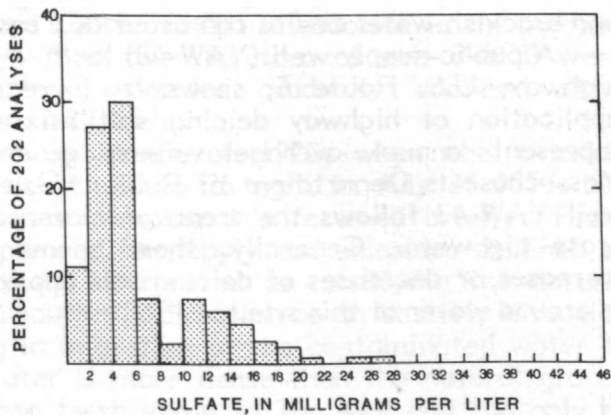
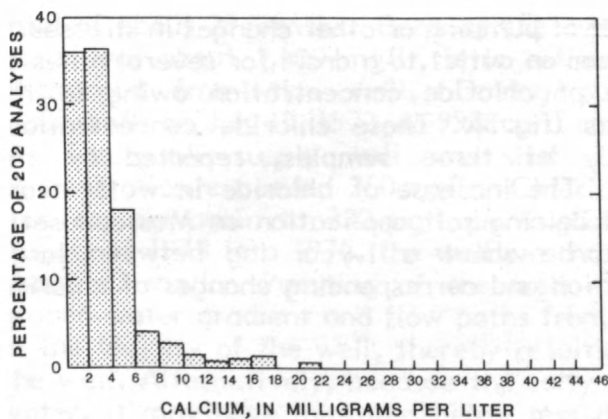


Figure 2.—Frequency distribution of major cations and anions

Saltwater intrusion, highway deicing salt, coastal flooding, sewage, and seawater spray from wind storms are commonly cited as sources of sodium and chloride. An example of seawater intrusion to a public supply is Provincetown's North Truro well field (TSW-115) west of U.S. Route 6, where heavy pumping during high demand causes an increase in sodium and chloride concentrations. At this well field, March 1975, sodium was 80 mg/L and chloride, 112 mg/L; but in July these constituents were 100 and 137 mg/L, respectively. Chloride concentrations at the North Truro well field rose from 20 mg/L in 1908 to 140 mg/L in 1919 (Kingsbury, 1936). Lateral intrusion from seawater and brackish-water bodies can occur as a result of pumping or other changes in stresses.

A public-supply well (YAW-43) located near an outlet to a drain for several miles of highway, U.S. Route 6, shows an increase of chloride concentration owing to the application of highway deicing salt mixtures (fig. 3). These chloride concentrations represent annual average values, generally of three samples, reported by the Massachusetts Department of Public Health. The increase of chloride in water from well YAW-43 follows the trend of increased deicing salt application on Massachusetts State highways. Generally, there seems to be about a 1-year lag between large increases or decreases of deicing salt application and corresponding changes of chloride in ground water at this site.

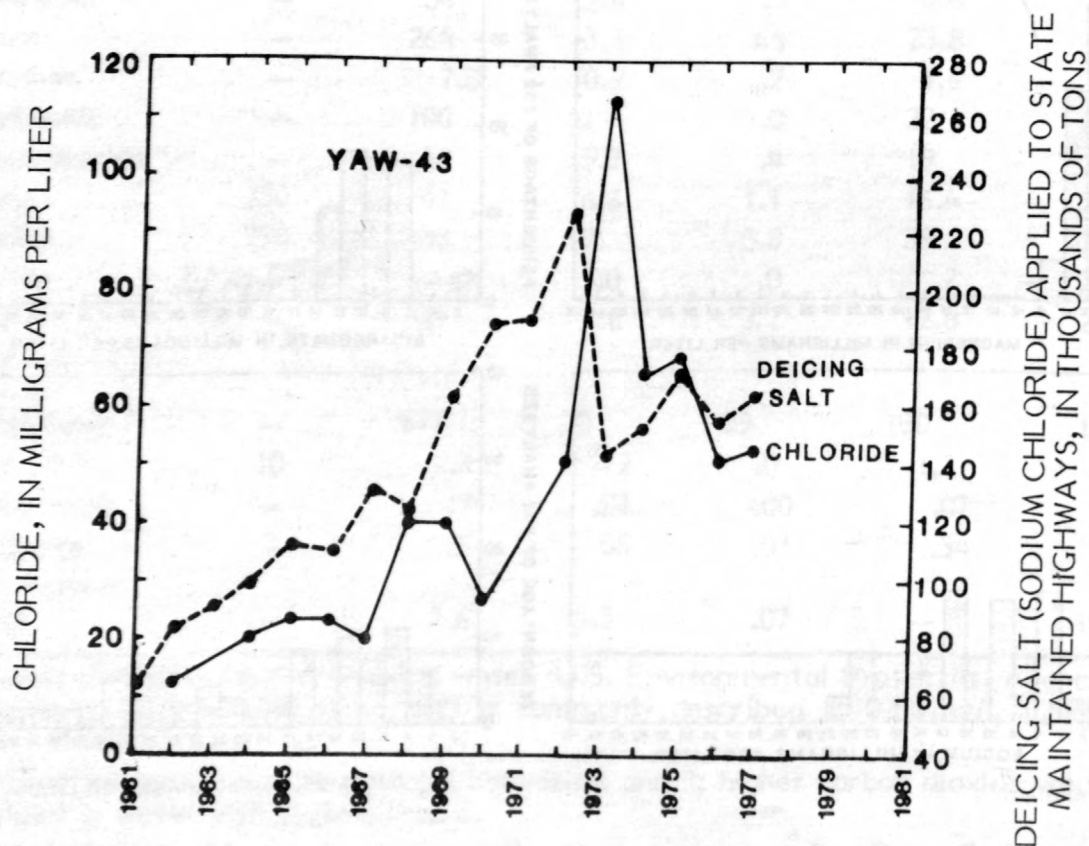


Figure 3.—Increasing chloride concentrations from highway drainage

Uncovered storage piles of highway deicing salt and sand-salt mixtures have been sources of salt (NaCl) contamination. From the winter of 1965-66 to the winter of 1974-75, an average annual quantity of about 1,400 tons of salt were purchased for storage and supply at a site 800 feet from public-supply well YAW-41. The salt was placed on bituminous concrete and stored in a shed constructed in 1971, and the sand-salt mixture was stored in a shed beginning in 1974. Chloride concentration in water from the well rose from 17 to 175 mg/L in 1972 and to 250 mg/L in 1973. A well was installed near the source in 1973 and pumped at an average rate of 70 gal/min for a total of about 29 months. Because the average concentration of chloride in the pumped water was about 1,400 mg/L, it is estimated that over 835 tons of salt (NaCl) were discharged from this well. During pumping, chlorides gradually declined from 1,800 mg/L on July 19, 1973, to 990 mg/L on April 29, 1976.

The public-supply well was shut down in March of 1973, when the chloride concentration exceeded 250 mg/L. Chlorides declined to 75 mg/L in July of 1973, but rose rapidly again to 230 mg/L in August when pumping was resumed briefly. From August of 1973 into 1974, the well was not pumped for supply and chlorides declined to about 20 mg/L. Pumping of the well may be interpreted as modifying the natural ground-water gradient and flow paths from a southerly direction to an easterly direction in the vicinity of the well, thereby resulting in migration of the contaminated water to the well. Alternatively, because the salty water is more dense than the natural ground water, it may have migrated below less dense fresh water at the well and can only be drawn up into the well during pumping periods lasting several days.

Metals

The metals arsenic, cadmium, cobalt, copper, lead, mercury, selenium, and zinc were not found in concentrations greater than one-tenth of the U.S. Environmental Protection Agency's (1975 and 1977) recommended limits (table 2); and chromium, not greater than one-fifth of the recommended limit (table 2). Only iron and manganese occurred in concentrations greater than the recommended limits (table 2). Both of these metals are common in ground water in New England, and treatment for iron and manganese removal increases water cost (Sterling and Belknap, 1932). Water which requires such treatment is not commonly developed if alternate sources can be found. In general, only ground water with concentrations of iron and manganese not requiring treatment are developed for public supply on Cape Cod. In 1908, Provincetown developed wells in the neighboring town of Truro to avoid high iron concentrations (1.6 mg/L) from wells located in Provincetown in 1893.

In drinking water, the U.S. Environmental Protection Agency's (1977) recommended limit (table 2) for soluble iron is 300 ug/L and for soluble manganese, 50 ug/L. Iron, although not toxic, imparts a metallic taste and causes yellow staining of laundry and yellow or brown-orange staining and deposits on porcelain plumbing fixtures. As with iron, the principal reason for limiting the concentration of manganese is to control taste and staining. Manganese produces gray to black stains. Staining and taste are not noticed at concentrations below the recommended limits. Both iron and manganese occur in mineral grains or as oxide coatings on mineral grains of the aquifer sediments, but they only dissolve in water when the physiochemical environment is acid and reducing. Because the presence of dissolved oxygen in water is evidence of an oxidizing environment in which iron is relatively insoluble, dissolved oxygen and dissolved iron are not expected to occur together in ground water (fig. 4). The small amounts of oxygen found in water containing iron during the study are due to brief sample exposure to air during oxygen analysis. The median dissolved oxygen of 48 samples was 7.0 mg/L. Although nearly all of the water on Cape Cod is acidic, it is reducing in limited areas

such as in organic sediments or in areas receiving leachate from landfills. For example, high iron contents of ground water in Provincetown are the result of reducing chemical conditions in buried marsh deposits. Organic layers were encountered in 1893 during the drilling of the first public-supply wells in Provincetown and the wells were soon abandoned because of high iron concentrations (Howard, 1942). Drillers and water-supply engineers have learned that wells placed in oxidized yellowish-brown colored sand rather than gray or black unoxidized sand have fewer iron and manganese problems.

Table 2.--Metals in Cape Cod's ground water
(Data are in micrograms per liter except as indicated.)

Constituent	Limit ¹	CONCENTRATION				75 percent of analyses contained less than value indicated	Number of analyses
		Maximum	Median	Minimum			
Arsenic	50	5	0	0	-	-	21
Cadmium	10	1	0	0	-	-	20
Chromium	50	10	(13 less than 10)		-	-	20
Cobalt	-	2	0	0	-	-	20
Copper	1000	30	10	0	-	-	20
Iron	300	8800	41	0	170	-	75
Lead	50	3	2.0	0	-	-	20
Manganese	50	950	19	0	87	-	83
Mercury	2	(all less than 0.5)				-	20
Selenium	10	1	0	0	-	-	20
Zinc	5000	210	0	0	-	-	20

¹Recommended primary and secondary limits for drinking water (U.S. Environmental Protection Agency, 1975 and 1977).

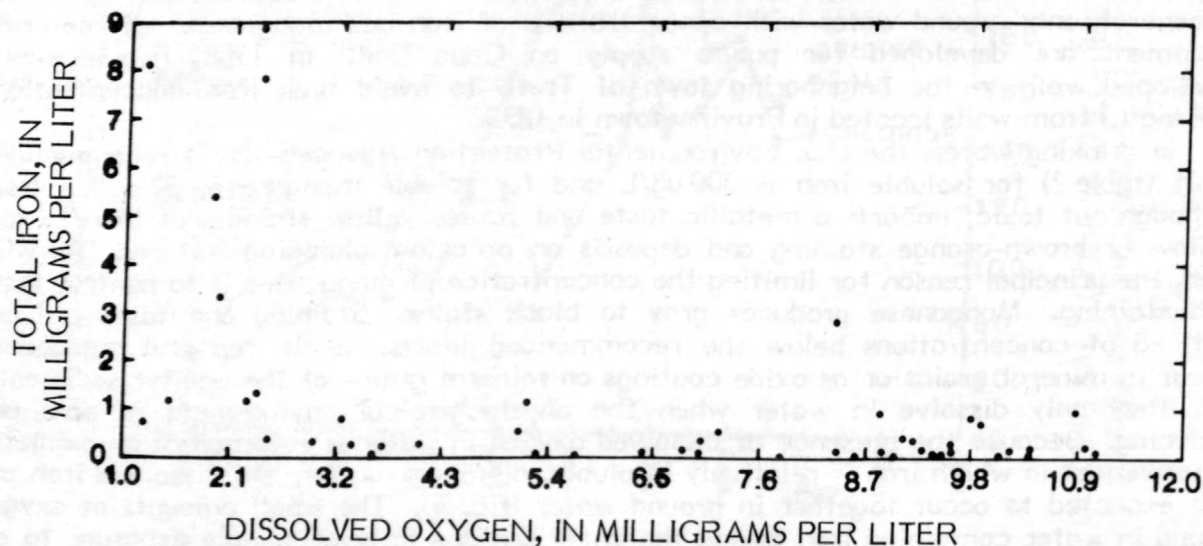


Figure 4.—Relationship between dissolved oxygen and total iron

Ammonia and Sulfide

Water with dissolved ammonia and hydrogen sulfide gases has a foul odor and commonly occurs in buried marsh deposits. A brackish water sample from a well (TSW-212) at the south end of Salt Meadow in Truro contained 4.2 mg/L sulfide, 9.3 mg/L total organic carbon, 2.3 mg/L ammonia, 600 ug/L iron, 140 ug/L manganese, and a pH of 6.5. A brackish water sample from a 9-foot-deep well (BMW-50) at Freemans Pond near Cape Cod Bay in Brewster contained 46 mg/L sulfide, 27 mg/L total organic carbon, 4.4 mg/L ammonia, 660 ug/L iron, 60 ug/L manganese, and a pH of 7.1. High concentrations of iron and manganese also commonly occur in sulfide-bearing water in the organic sediments.

Nutrients

Generally, the plant nutrients nitrogen, phosphorous, and potassium, were found only in low concentrations. Dissolved phosphorous is readily sorbed to sediment in both soil and aquifers and is removed from ground water within short distances of its source (Hem, 1970). Dissolved phosphorous (orthophosphate plus organic phosphorus) was found at a maximum concentration of 0.5 mg/L and a median concentration of 0.05 mg/L in samples from 75 sites. Dissolved potassium becomes chemically bound or sorbed to clay minerals (Hem, 1970), and was found at a maximum concentration of 7.8 mg/L and a median of 0.9 mg/L in samples from 112 sites. Only 10 percent of the samples had more than 1.6 mg/L, and greater than that amount probably indicated introduction of potassium from fertilizers, or perhaps sewage.

Nitrogen in the form of ammonia occurs in sewage and waste water effluents as well as the marsh deposits, but commonly becomes oxidized to nitrate over short distances from its source. Nitrate, unlike phosphorous and potassium, is a relatively conservative ion, less reactive with earth materials and, therefore, more persistent than phosphorous and potassium in ground water. Naturally occurring concentrations of nitrogen would appear to be very low except in the marsh deposits. The average concentration of nitrate as nitrogen from 84 sites was 0.5 mg/L; 90 percent were less than 1.3 mg/L, 75 percent were less than 0.36 mg/L, 50 percent were less than 0.12 mg/L, and the maximum concentration was 6.3 mg/L. Water containing concentrations of nitrate-nitrogen in excess of 0.5 mg/L may be affected by sewage or fertilizer. Eighty percent of the 84 samples contained less than 0.5 mg/L nitrate as nitrogen. The U.S. Environmental Protection Agency's recommended upper limit for nitrogen in drinking water is 10 mg/L. Increase of nitrogen in well A1W-376, probably the result of sewage disposal, is shown in figure 5.

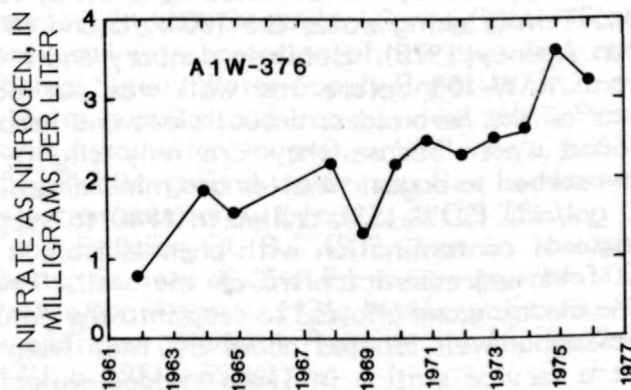


Figure 5.—Increases in nitrate as nitrogen near Hyannis

Increase of nitrogen in well SDW-155, which may be the result of fertilizer application or leaking sewer lines, or both, is shown in figure 6. Analysis of water from well SDW-155 in 1976 showed a nitrate-nitrogen concentration of 5.2 mg/L versus 4.3 mg/L observed in 1964.

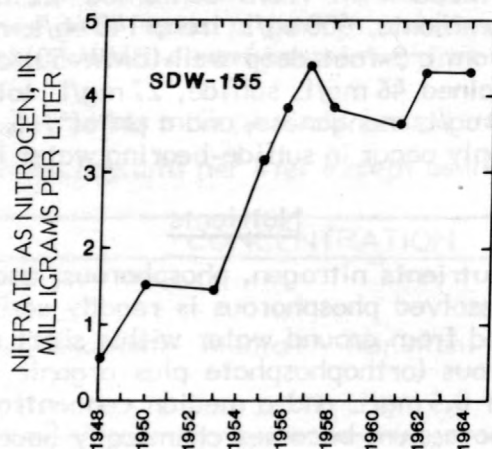


Figure 6.—Increases in nitrate as nitrogen at Camp Edwards

Insecticides, Herbicides, and Industrial Organic Chemicals

The following chlorinated hydrocarbon insecticides and herbicides were sought and not found in detectable amounts (0.01 ug/L) at nine sites: aldrin, lindane, DDD, DDE, DDT, dieldrin, endrin, heptachlor, heptachlor epoxide, 2,4-D, 2,4,5-T, and silvex. At one site discussed in the next paragraph, herbicide residues were detected. Also sought at 10 sites but not found in detectable amounts were polychlorinated naphthalenes (0.01 ug/L), chlordane and polychlorinated biphenyls (0.1 ug/L), and toxaphene (1 ug/L).

Most, but not all, toxic chemicals have an unpleasant or uncommon taste. An unpleasant taste and odor in a public water supply led to the discovery of a spill of perhaps as much as 110 gallons of herbicides at a public-supply well (YAW-103) in July 1975. The Massachusetts Department of Public Health measured 6 mg/L of 2,4-D soon after the discovery. The contaminated ground was removed. A scavenger well in a gravel-filled pit was pumped to a nearby stream at a rate of 60 to 100 gal/min for about 6 months. A sample collected from well YAW-103 in January of 1976 and analyzed by the U.S. Geological Survey contained 0.05 ug/L of 2,4-D and 0.02 ug/L of 2,4,5-T. The recommended limits for 2,4-D and 2,4,5-T in drinking water are 100 ug/L and 10 ug/L, respectively (U.S. Environmental Protection Agency, 1975). Between January and May of 1976, 7,800 ft³ of water were pumped from YAW-103 before the well was put back in service with no detectable concentrations of the herbicides. Insecticides and herbicides are not expected to be persistent in ground water because they are only slightly soluble in water and characteristically become sorbed to organic matter and mineral grains in the soil zone.

A well yielding 740 gal/min (SDW-153), drilled in 1940 to supply Camp Edwards, was abandoned in 1962 because of contamination with phenols from a waste-oil recovery and storage area about 1,200 feet upgradient (north) of the well. Phenolic compounds were reportedly used for engine cleaning and allowed to seep into the ground.

In 1977, a domestic-supply well located about 300 feet from a leaking underground gasoline storage tank at a service station in Truro yielded water with the odor of gasoline. The leaking tank 600 feet southwest of a well in Provincetown's South Hollow well field (TSW-78) was removed after an estimated 2,000 gallons of leakage, and the well field was temporarily shut down.

The modern chemical industry has developed and manufactured many complex and heavy weight molecular compounds, many of which are very stable (unreactive). Some of these compounds can be expected to be very persistent once introduced to ground water, and their chronic, long-term, or subtle effects on human health in trace quantities in drinking water are virtually unknown. Because of the uncertainty of the occurrence and effects of these compounds, the use of urban runoff, treated sewage, or industrial waste water for ground-water recharge might be undesirable.

SUMMARY

Ground water on Cape Cod is of good chemical quality for most uses. The water is soft, low in dissolved solids, mildly acidic, and the dominant ions are sodium and chloride. In 90 percent of the samples analyzed, dissolved solids were less than 100 mg/L. Iron and manganese were the only metals found in excess of limits for public drinking-water supplies (U.S. Environmental Protection Agency, 1975 and 1977). Naturally occurring iron, manganese, hydrogen sulfide, and salt are problems encountered in aquifers bearing organic sediment and are generally avoided by careful selection of well location. The ground water is susceptible to degradation from point sources such as; onland municipal sewage disposal, solid-waste sanitary landfills, septage and liquid waste-disposal sites (seepage pits or basins), dredgings dumps, deicing salt-storage facilities, oil- (hydrocarbon) storage areas and spills. Ground water is also susceptible to degradation from nonpoint sources such as septic systems, urban runoff, highway runoff, and agricultural and lawn fertilizers. On Cape Cod, control of ground-water quality degradation from point and nonpoint sources may be accomplished through vigilant monitoring, hydrologic analysis, and integrated water-supply, waste-disposal, and land-use planning and management.

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- NOTES -



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