UNITED STATES

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GEOLOGICAL SURVEY

MAJOR SOURCES OF GROUND-WATER CONTAMINATION IN CONNECTICUT

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GLOSSARY

Adsorption: The adhesion of an extremely thin layer of molecules (as of gases, solutes, or liquids), to surfaces of solids or liquids.

Aerobic: Living, active, or occurring only in the presence of oxygen.

Anaerobic: Living or active in the absence of free oxygen.

Aquifer: A geologic formation or unit that can yield usable quantities of water.

Bedrock: Solid rock, commonly called "ledge", that forms the earth's crust. It is locally exposed at the land surface in Connecticut but more commonly is buried beneath a few inches to more than 300 feet of unconsolidated materials.

Brackish water: Water intermediate in salinity between salt water and fresh water.

Carbonate rock: Rock composed primarily of calcium and magnesium carbonate minerals.

Coliform bacteria, total: A particular group of bacteria that are used as indicators of possible sewage pollution. They are characterized as aerobic or facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C. In the laboratory, these bacteria are defined as the organisms which produce colonies within 24 hours when incubated at 35°C ± 1.0°C on M-Endo medium (nutrient medium for bacterial growth). Their concentrations are expressed as numbers of colonies per 100 mL of sample.

Cone of depression: A depression produced in the water table or other potentiometric surface by the withdrawal of water from an aquifer; it is shaped like an inverted cone with its apex at the pumping well.

Contamination: The degradation of natural water quality, as a result of human activities, to the extent that its usefulness is impaired (Miller and others, 1974, p. 319). (See section titled "Contamination - definition and criteria".)

Crystalline rock: Pertaining to igneous and metamorphic rocks; the most common types in the State are schist, gneiss, and granite.

Degradation of water quality: Adverse change in quality of water.

Dissolved solids: The residue from a filtered sample of water after evaporation and drying for one hour at 180°C; consist primarily of dissolved mineral constituents, but may also contain organic matter and water of crystallization.

Drainage basin, drainage area: The whole area or entire land surface that gathers water and contributes it ultimately to a particular stream channel, lake, reservoir, or other body of water.

Drawdown: The lowering of the ground-water level or potentiometric surface by pumping. It is equal to the difference between the static level and the pumping level.

Estuarine: Pertaining to or deposited in an estuary.

Estuary: A body of water or zone at the river's mouth in which river water mixes with, and measurably dilutes, salt water.

Evapotranspiration: Loss of water to the atmosphere by direct evaporation from water surfaces and moist soil combined with transpiration from living plants.

Filtration: The passage of a gas or liquid through porous material to separate out particles.

Fracture: A structural break or opening in bedrock along which water may move.

Ground water: Water in the saturated zone.

Ground-water discharge: The discharge of water from the saturated zone by 1) natural processes such as ground-water runoff and ground-water evapotranspiration and 2) artificial discharge through wells and other manmade structures.

Ground-water recharge: The addition of water to the saturated zone by 1) natural processes such as infiltration of precipitation or surface water and 2) artificial recharge through basins, sumps and other manmade structures.

Hardness, of water: The physical-chemical characteristic of water that is commonly recognized by the increase of quantity of soap required to produce lather. It is attributable to the presence of alkaline earths (principally calcium and magnesium) and is expressed as equivalent calcium carbonate ($CaCO_3$).

Head, static: The height of the surface of a water column above a standard datum that can be supported by the static pressure at a given point.

Hydraulic conductivity (K): A measure of the ability of a porous medium to transmit a fluid. The material has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of water at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head over unit length of flow path.

Hydraulic gradient: The change in static head per unit of distance in a given direction. If not specified, the direction is generally understood to be that of the maximum rate of decrease in head.

Impairment (of water quality): Change in water quality, to the extent that concentrations of certain constituents exceed background levels. (See section titled "Contamination - definition and criteria".)

Inches of water: Water volume expressed as the depth, in inches, to which it would accumulate if spread evenly over a particular area.

Induced infiltration: The process by which water in a stream or lake moves into an aquifer by the establishment of a hydraulic gradient from the surface-water body toward a pumping well or wells.

Induced recharge: The amount of water entering an aquifer from an adjacent surface-water body by the process of induced infiltration.

Infiltration: Passage of a gas or liquid into or through soil or rock by penetrating pores or small openings.

Ion: An atom or group of atoms that carries an electric charge as a result of having lost or gained electrons.

Leachate: Water that has filtered or percolated through porous or soluble material, such as refuse in a landfill, and contains dissolved and suspended solids leached from the material.

Leaching system: A structure, excavation or other facility designed to allow liquid to percolate into and filter through the underlying soil without overflow.

Major aquifer; favorable aquifer: In this report, the terms "major aquifer" and "favorable aquifer" refer to stratified-drift deposits known or inferred to be capable of yielding moderate to very large amounts of water (50-2,000 gallons per minute) to individual wells.

Methylene blue active substance (MBAS): A measure of apparent detergents, as indicated by the formation of a blue color when methylene blue dye reacts with synthetic detergent compounds.

Micrograms per liter (ug/L): A unit for expressing the concentration of chemical constituents in solution by weight per unit volume of water. One thousand micrograms is equivalent to 1 milligram.

Milligrams per liter (mg/L): A unit for expressing the concentration of chemical constituents in solution by weight per unit volume of water.

Nonpoint source: A source of contamination that does not emanate from a discernible, confined, and discrete conveyance, such as a pipe, ditch, or channel.

Nutrients: Compounds of nitrogen, phosphorous, and other elements essential for plant growth.

Permeability, coefficient of: The rate of flow of water, in gallons per day, through a cross sectional area of 1 sq ft of a saturated material under a hydraulic gradient of 1 foot per foot at a temperature of 16°C. Replaced by the U.S. Geological Survey with a new term-hydraulic conductivity (in this Glossary).

pH: The negative logarithm of the hydrogen-ion concentration. A pH of 7.0 indicates neutrality; values below 7.0 denote acidity, those above 7.0 denote alkalinity.

Point source: Any discernible, confined, and discrete conveyance, such as a pipe, ditch, or channel, from which pollutants are or may be discharged (Public Law 92-500, Section 502).

Precipitation: The discharge of water from the atmosphere, in either a liquid or solid state.

Runoff, total: That part of the precipitation that appears in streams; it includes ground-water and surface-water components. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Salt water: Water containing about 35,000 mg/L of dissolved solids, including about 19,000 mg/L of chloride (Cl).

Salt-water intrusion: The movement of salt water or brackish water into a nearby aquifer can result from the pumping of fresh water near the sea.

Sanitary landfill: Method of solid-waste disposal in which refuse is deposited, compacted, and covered with at least 6 inches of soil daily.

Saturated thickness: Thickness of an aquifer below the water table.

Saturated zone: The subsurface zone in which all open spaces are filled with water under pressure greater than atmospheric.

Sedimentary rock: Rock formed of sediment. The most common types in the State are sandstone, siltstone, and shale.

Septage: Liquid and solid material (sludge) pumped from a septic tank or cesspool during cleaning (New England Interstate Water Pollution Control Commission, 1976, p. 2).

Septic tank: A water-tight receptacle used for the treatment of sewage and designed and constructed to permit settling of solids, digestion of organic matter by detention, and discharge of the liquid part to a leaching system.

Sewage: Human excretions, all liquid domestic wastes, and such liquid agricultural, commercial, or manufacturing wastes as may tend to the detriment of the public health.

Solid waste; refuse: Garbage, rubbish, trash and other solid materials from domestic, commerical and other sources. Commonly requires transport to a disposal site.

Specific conductance, of water: A measure of the ability of water to conduct an electric current, expressed in micromhos per centimeter at 25°C. It is related to the dissolved-solids content and serves as an approximate measure thereof.

Storage coefficient: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield.

Stratified drift: A sorted sediment laid down by or in meltwater from a glacier; includes sand, gravel, silt, and clay deposited in layers.

Susceptible coastal zone: The area along the coast and along estuaries that is susceptible to salt-water intrusion.

Till: A nonsorted, nonstratified sediment deposited directly by a glacier and composed of boulders, gravel, sand, silt, and clay mixed in various proportions.

Transmissivity: The rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient. Equal to the average hydraulic conductivity times the saturated thickness.

Transpiration: The process whereby plants release water vapor to the atmosphere.

Unconsolidated: Loose, not firmly cemented or interlocked; for example, sand in contrast to sandstone.

Unsaturated zone: The subsurface zone above the water table.

Water table: The surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. In wells penetrating to greater depths, the water level will stand above or below the water table if an upward or downward component of ground-water flow exists.

Water year: A continuous 12-month period, October 1 through September 30, during which a complete streamflow cycle takes place from low to high flow and back to low flow. It is designated by the calendar year in which it ends, and that includes 9 of its 12 months.

FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

U.S. customary units	Multiplied by	Are converted to SI units
Length		
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	2.590	square kilometer (km^2)
Flow		
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
gallon per minute (gal/min)	.06309	liter per second (L/s)
million gallons per day (Mgal/d)	43.81	liter per second (L/s)
gallon per day per foot (gal/d/ft)	.00014	liter per second per meter (L/s/m)
Hydraulic Units		
transmissivity, foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
hydraulic conductivity, foot per day (ft/d)	.3048	meter per day (m/d)
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)

Maps produced by the U.S. Geological Survey
as part of the Connecticut 208 study

(Published separately in the Miscellaneous Field Studies Map Series

of Geological Survey publications and available from:

Distribution Section
U.S. Geological Survey
1200 South Eads Street
Arlington, VA 22202)

MF 981 A - Road salt-storage and road network in Connecticut

(Includes favorable aquifers and salt use by town).

MF 981 B - Disposal of solid wastes in Connecticut

(Includes favorable aquifers).

MF 981 C - Surface-water quality and built-up areas in Connecticut

(Includes favorable aquifers, sampling sites, sewage treatment facilities and industrial discharge sites).

MF 981 D - Industrial areas and ground disposal of industrial wastes in Connecticut

(Includes favorable aquifers and generalized geologic map).

MF 981 E - Nonsewered built-up areas and septage disposal sites in Connecticut

(Includes favorable aquifers and distribution of wells and septic tanks).

MF 981 F - Proximity of agricultural areas to major aquifers in Connecticut

(Includes manure-storage areas, milk-waste lagoons, and livestock, crop, fertilizer, and pesticide distribution, by County).

MF 981 G - Places in Connecticut where ground water is known to have deteriorated in quality

(Includes major aquifers, wells that yield impaired or contaminated water, and areas susceptible to salt-water intrusion).

MF 981 H - Proximity of pipelines and storage facilities for gas and oil to major aquifers in Connecticut

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ABSTRACT

Connecticut is underlain nearly everywhere by aquifers of one type or another. The most favorable for large-scale development are areally extensive, thick, saturated deposits of coarse-grained stratified drift. These aquifers are commonly in hydraulic connection with adjacent surface-water bodies, and many are in or near urban areas. These factors, together with the relatively shallow depth to the saturated zone, make water in stratified-drift aquifers susceptible to degradation.

Although the overall quality of Connecticut's ground water is good to excellent, the introduction of many types of contaminants has altered the quality at numerous locations within the State. Waste disposal sites, storage and transmission facilities for fuels or other chemicals, and land application of chemicals are the most common sources. The contaminants are generally transported vertically through the unsaturated zone, although some are emplaced below the water table or enter aquifers by induced infiltration from surface-water bodies.

Individual on-site septic systems are common nonpoint sources, but their impact on ground-water quality is localized. Septic systems in urban areas and in some rural areas where bedrock is shallow are contributing to an increase in the sodium, nitrate, and chloride concentrations in the adjacent ground water. Septage lagoons that serve as regional sites of septic-waste disposal also contribute sodium and chloride to the saturated zone. The extent and magnitude of quality changes resulting from septage disposal are not known.

Leachate from 24 out of 185 active landfills listed by the Connecticut Department of Environmental Protection has degraded ground-water quality, as documented by chemical analysis, and all other landfills are suspected of causing contamination, according to the Department. The locations of many abandoned private and municipal disposal areas are unknown, but they may still be generating leachate and affecting water quality.

Leached wastes from 30 out of 335 reported sites of industrial-waste disposal on or into the ground are known to have caused ground-water contamination; these wastes include metals, solvents, and organic chemicals. The leachate traveling downgradient from the disposal site

has contaminated wells more than 2,000 feet away. Reported sites constitute about one-third of the estimated total number of active industrial disposal sites throughout the State.

More than 50 out of 554 incidents of spillage and seepage of fuel oil, gasoline, and other hazardous liquids reported in a 1-year perod (July 1976 - June 1977) resulted in more than 44,000 gallons of these substances reaching the saturated zone. Most cases involved leaky storage tanks, and at least 1,000 gallons were lost in 9 of the incidents.

Storage of deicing chemicals is widespread, and the types of facilities vary considerably. Of 126 storage sties for road salt maintained by the Connecticut Department of Transportation, 13 are known to have caused ground-water contamination. Many additional town and private stockpiles exist throughout the State, but information on contamination from these sources is scarce. Where salt piles have been eliminated, moved, or covered, the residual salt-impregnated soil can still affect water quality.

Animal wastes, fertilizers, road salt, and pesticides that are applied over large areas also alter ground-water quality. In some areas, high nitrate concentrations are attributed to agricultural practices and high sodium and chloride concentrations to road-salt application. In addition, improper handling and storage of agricultural chemicals occasionally cause contamination.

Induced infiltration of poor-quality surface water can adversely affect ground-water quality. Streams that have impaired quality, at least occasionally in some reaches, include the Pequabuck, Park, Hockanum, Quinnipiac, Still, Naugatuck, and Norwalk Rivers. Salt-water intrusion of aquifers adjacent to the coast and estuaries has resulted from overpumping. This condition was historically more severe and significantly affected New Haven and Bridgeport.

The incidents of ground-water contamination identified during this investigation probably represent only a small part of the total. Detailed site studies and well-designed monitoring systems would be needed to adequately assess problems of ground-water quality in Connecticut.

PURPOSE AND SCOPE

One of the functions of the U.S. Geological Survey is to assess the availability and utility of water. Such an appraisal requires information on quality as well as quantity because water unfit for its intended use is of little value. This report covers the first two phases of a three part study to assess ground-water contamination from nonpoint sources in Connecticut. The investigation is intended to provide an overview of the extent of the problem and is part of Connecticut's "208" program under Public Law 92-500. The technical information on ground-water quality and availability provided by this study is to be used in preparing "208" programs for water-resources management in Connecticut.

The three objectives of this study, the first two of which are covered herein, are:

(1) Identify and classify the categories of subsurface contaminants and their sources. The most significant contaminants and sources with respect to size, potential hazard, and proximity to major aquifers are emphasized.

(2) Determine the location of known or probable sites of ground-water contamination with the aid of available data on ground-water quality, waste disposal, land application of fertilizers, deicing agents, and pesticides, and storage of liquids and soluble solids. Display information on ground-water availability and contamination on a series of maps.

(3) Evaluate the impact of selected nonpoint sources on water quality in major aquifers (see Glossary) by test drilling and water sampling. Determine, where possible, the source of contamination; its volume, history, areal extent, and thickness; significant characteristics of the affected aquifer or aquifers, the probable direction of ground-water movement, and the inferred sites of ground-water discharge.

A series of maps showing areas favorable for developing moderate to large ground-water supplies (with respect to probable well yields), areas where ground water is or has been contaminated, and areas where past or present land use has led or may lead to contamination has been published separately. (See list on back cover.)

USE OF THE REPORT

This report describes the hydrogeologic environment and identifies the major sources of ground-water contamination in Connecticut. It can be used separately or in conjunction with the series of maps listed on the back cover. All the companion maps show the distribution of stratified-drift aquifers that potentially are capable of yielding moderate to large amounts of water (50 to 2,000 gallons per minute) to individual wells. These aquifers are referred to as "major aquifers" and "favorable aquifers" on the maps and in this report.

The first part of this report discusses the hydrogeologic system and natural factors affecting the quality of water in Connecticut. Subsequent parts deal with the impact of known and potential contaminant sources on ground-water quality and are keyed to the maps listed on the back cover.

This report and the maps cannot substitute for detailed site investigations because of the small scale of the maps, incomplete data, and the generalized nature of much of the information.

ACKNOWLEDGMENTS

The U.S. Geological Survey in fiscal cooperation with the State of Connecticut, Department of Environmental Protection, collected and analyzed the data on which this report is based. Considerable information was obtained from State agencies, including the Departments of Environmental Protection, Health, Transportation, and the Office of Policy and Management.

Daniel B. Meade of the Connecticut Department of Environmental Protection compiled a map showing ground-water availability in the State (Meade, 1978). Walter J. Gancarz, of the 208 Industrial Sludge study, provided much useful information on industrial waste-disposal practices. Numerous town personnel supplied data on municipal storage and use of road salt. The efforts of these individuals are sincerely appreciated.

THE HYDROLOGIC CYCLE

The hydrologic cycle is the continuous circulation of water through the atmosphere, the land, and the oceans. Water vapor in the atmosphere condenses to form clouds from which precipitation falls on the land and ocean surface. Some water from precipitation travels over the land into streams and lakes, some seeps into the ground, and some evaporates. Water moves continuously from place to place so that the amounts stored in the atmosphere, on land, underground, and in glaciers and oceans, are always changing. The worldwide total, however, remains virtually constant.

Quality of Water in the Hydrologic Cycle

As water moves through the hydrologic cycle, various chemical, physical, and biological processes interact to change its quality. Precipitation incorporates particles and gases from the atmosphere, and water quality is further modified by reaction with soils, rocks, and organic matter on the ground.

The chemistry of water depends largely on the composition and physical properties of the materials it contacts and on the duration of the contact. Thus, slower moving ground water is generally more mineralized than surface water. During high flow, much of the water in streams comes directly from surface runoff, and its composition may approximate that of precipitation. During low flow, however, the main source of streamflow is ground-water discharge, and the solute content is consequently greater than at high flow. The quality of water in the diverse environments of the hydrologic cycle is shown in figure 1. Water quality is further modified by the activities of man at all stages of the hydrologic cycle. For example, soot and fuel exhaust affect the composition of precipitation; animal wastes, fertilizers, and petroleum residue degrade surface runoff; leachate from landfills and septic-tank effluent alter ground-water quality; and sewage and industrial waste affect streams. Figure 2 shows the effects of human activities on water quality.

Changes in physical, chemical, or biological properties of water in one environment can affect water quality in other environments. Sulfur dioxide in the air from smokestacks makes rainfall more acidic (Likens and Bormann, 1974), which, in turn, can accelerate leaching of waste materials from landfills. The leachate consequently degrades ground water moving toward a stream and eventually can contaminate the stream. Wells pumping water of good quality from an aquifer downstream may subsequently be affected by induced recharge of contaminated surface water.

HYDROGEOLOGIC SETTING

Connecticut is a 5009-square-mile area drained primarily by the Connecticut River and its tributaries and by several smaller rivers; most of the drainage ultimately discharges into Long Island Sound. (See fig. 3.) Drainage generally follows a north-south trend of topographic highlands. Topography, stream pattern, and ground-water flow are controlled by major stratigraphic and structural features of the bedrock, modified by glaciation and man.

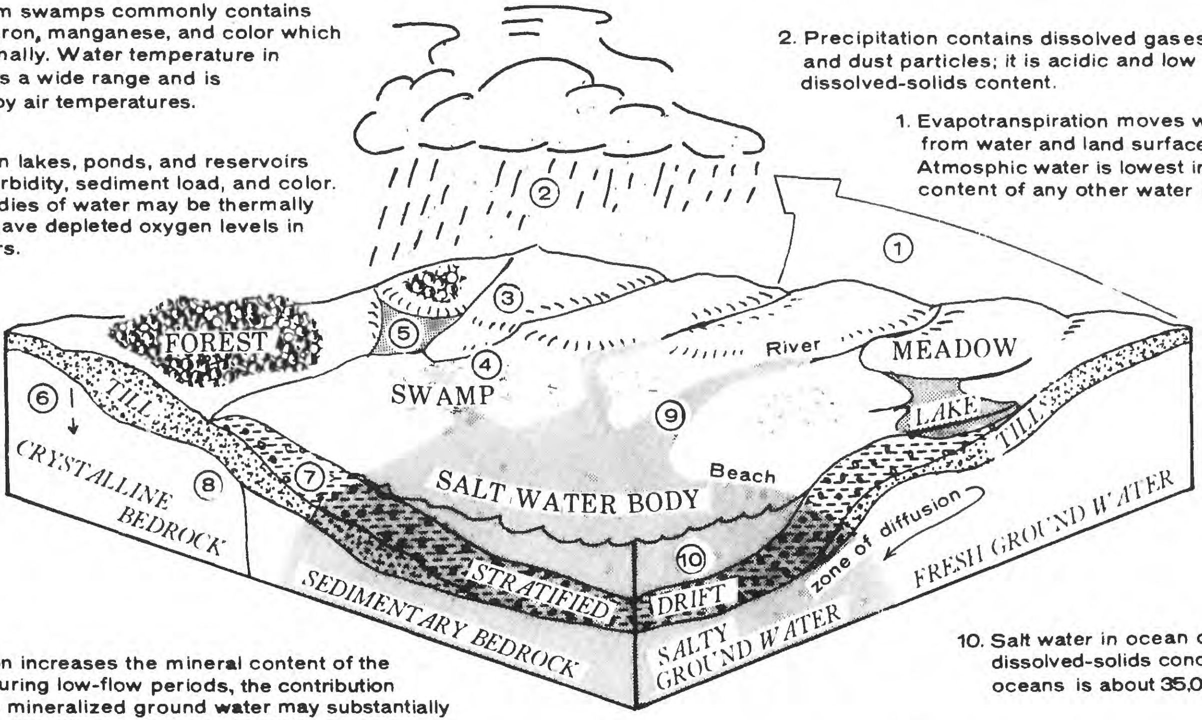
3. Surface runoff erodes soils and organic materials, which increase turbidity and sediment concentrations. Temperatures follow seasonal air temperatures but are less extreme.

4. Runoff from swamps commonly contains excessive iron, manganese, and color which vary seasonally. Water temperature in swamps has a wide range and is controlled by air temperatures.

2. Precipitation contains dissolved gases and dust particles; it is acidic and low in dissolved-solids content.

1. Evapotranspiration moves water in vapor form from water and land surface to the atmosphere. Atmosphic water is lowest in dissolved-solids content of any other water in the cycle.

5. Water stored in lakes, ponds, and reservoirs has reduced turbidity, sediment load, and color. The deeper bodies of water may be thermally stratified and have depleted oxygen levels in the lower layers.



6. Infiltration increases the mineral content of the water. During low-flow periods, the contribution of highly mineralized ground water may substantially increase the mineral content of smaller streams.

10. Salt water in ocean or sound. Highest dissolved-solids concentration of open oceans is about 35,000 mg/L.

7. Water in unconsolidated materials (stratified drift and till) is influenced by the composition of the materials. Dissolved carbonate minerals increase hardness. Water moving from bedrock also influences the quality of water in surficial deposits.

9. Estuarine water is mixture of salty and fresh water.

8. Water in bedrock is influenced by the composition of the bedrock and surficial materials through which the water moves.

FIGURE 1--QUALITY OF WATER IN THE HYDROLOGIC CYCLE UNDER NATURAL CONDITIONS
(Water becomes progressively more mineralized as it moves through the cycle)

1. **Gaseous liquid, and solid materials produced by man's activities are dissolved and absorbed by precipitation and returned to earth. Sulfer, lead, unburned hydrocarbons, dust, soot, and fly ash all contribute to** mineralization of precipitation **before it reaches land surface.**

2. Petroleum residue from paved areas, leachate from wastes, and fertilizers from lawns and gardens are all carried by runoff from populated areas . Construction in developing areas increases turbidity. Salt used in winter road maintenance enters both surface-water and ground-water bodies.

3. **Animal wastes and fertilizers are carried by runoff from agricultural and stock areas.**

4. **Lakes and ponds that receive nutrients (nitrate and phosphate ions) and sediments are prematurely aged. Continuation results in unsightly algal blooms in summer.**

5. **Heavily pumped wells near coast may lead to** salt-water intrusion.

6. Sewage-treatment plants bring sewage back to acceptable quality but the nutrient value of the treated water may be high. Nutrient-rich water hastens eutrophication and stimulates **algal** bloom downstream.

7. Intensive development can cause ground-water contamination because of waste disposal and intensive use; close spacing of wells may lead to salt-water intrusion.

8 Fossil fuel plants contribute large amounts of materials to the air, some of which precipitation eventually returns to earth. Water used to cool the generators of these plants is returned to the stream at a higher temperature.

9. Reservoirs and other impoundments improve water quality by trapping sediments. Turbidity and color of the water improve with storage. Excessive sediments will gradually fill reservoirs, reducing capacity, and eventually end their usefulness.

10. Housing developments remote from urban areas lack central water-supply and sewage-treatment facilities. Improper design and placement of individual wells and septic tanks may lead to large scale aquifer contamination and health problems.

11. Industry contributes waste to the air, water, and ground. Many industrial wastes are difficult and expensive to treat. Where direct discharge to streams is the disposal method employed, miles of downstream reach can be contaminated. Burial of solid waste may merely delay the eventual discharge of the noxious material into nearby water ways or the ground-water reservoir.

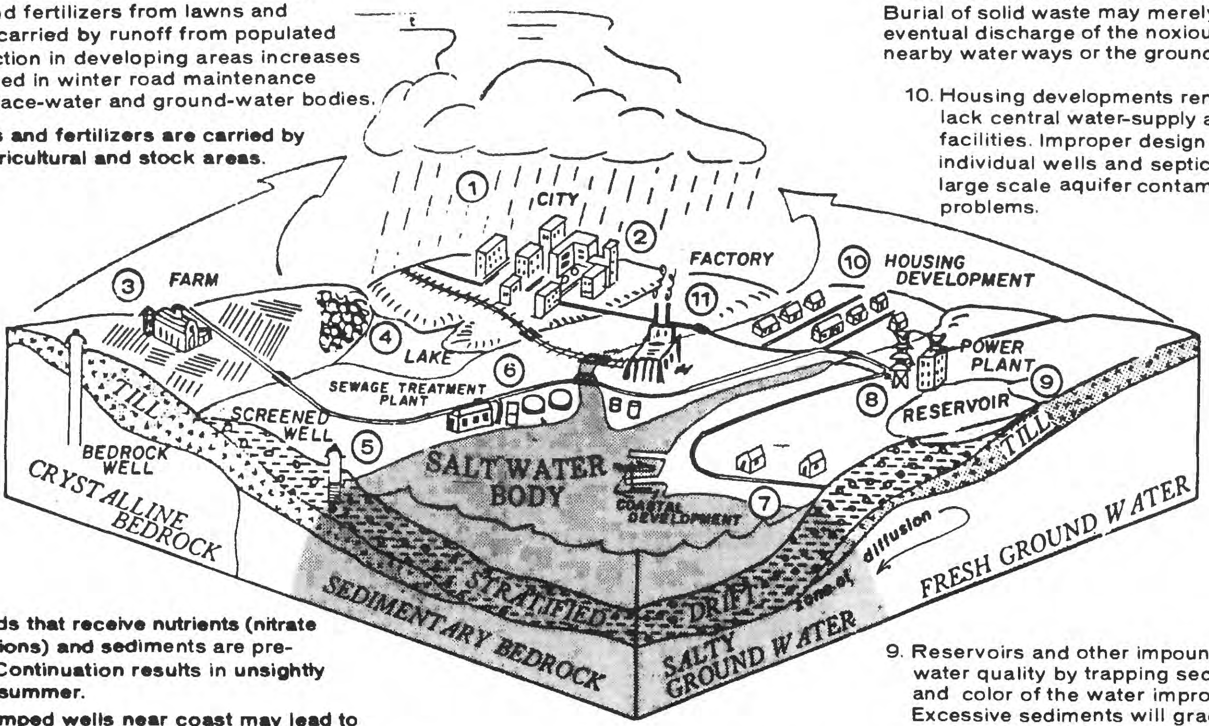


FIGURE 2--EFFECTS OF HUMAN ACTIVITIES ON WATER QUALITY

(The chemical and physical properties are affected usually resulting in deterioration in quality)

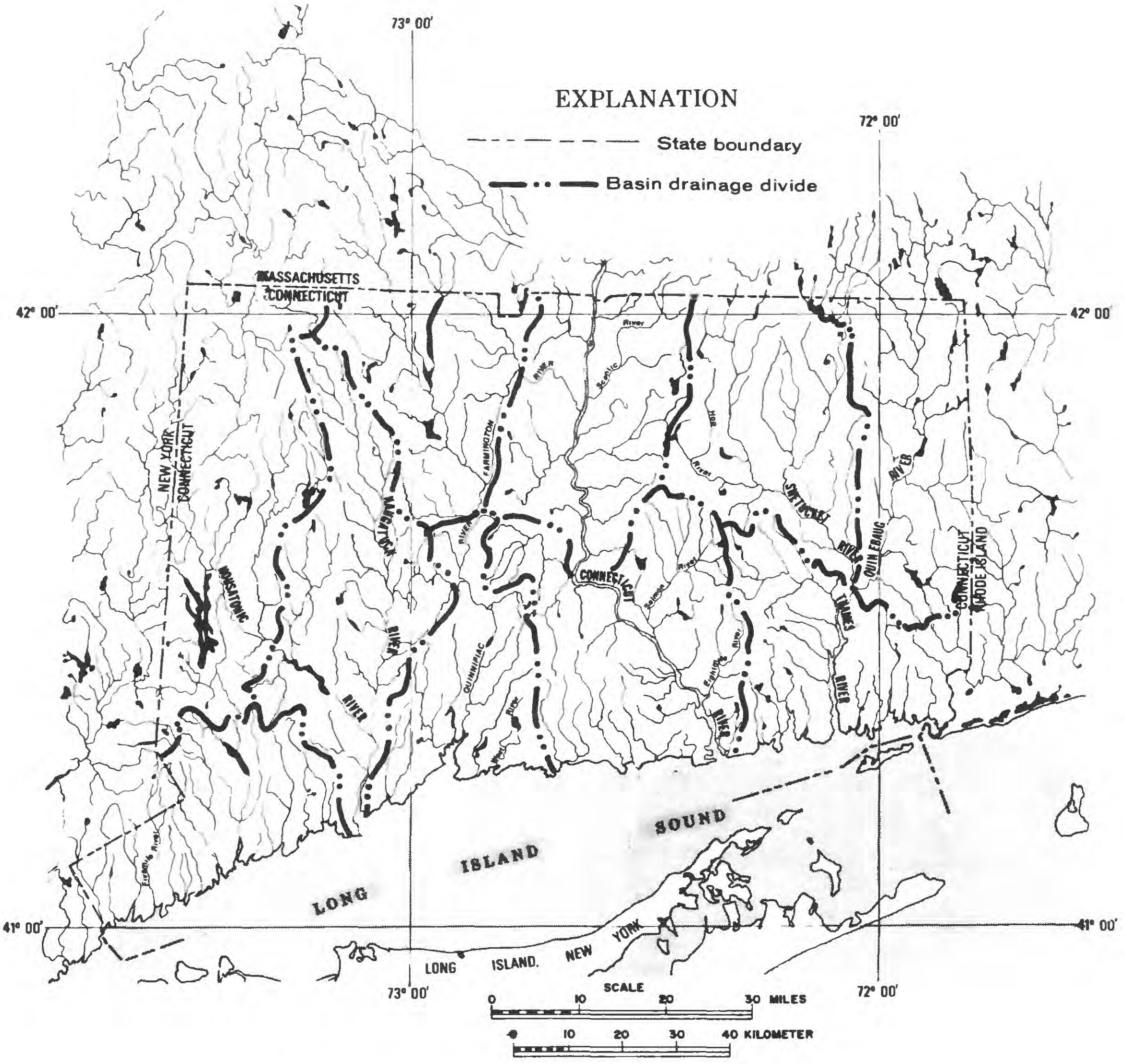


FIGURE 3--MAJOR STREAMS OF CONNECTICUT.

Precipitation is the major source of ground-water recharge in Connecticut. Annual precipitation averages from 44 to 48 inches over most of the State, or almost 4 inches per month, distributed almost evenly throughout the year (Brumbach, 1965). This is equivalent to about 70 million gallons of water falling on every square mile each month. Nearly half of the precipitation evaporates or transpires, mainly during the growing season. The rest infiltrates and moves downward to the water table or flows overland directly into streams.

The water that infiltrates moves downward to the water table and becomes ground water. Ground water moves downgradient through the saturated zone toward low points in the flow system: streams, ponds, springs, and centers of pumping. These low points are the sites of ground-water discharge.

Ground-Water Use and Development

The U.S. Water Resources Council (1968) projects that total water requirements for the North Atlantic region will quadruple during 1980-2020. Connecticut population and per capita water use are expected to increase during this period (Connecticut Office of Policy and Management, 1978). Historically, streams and reservoirs have supplied most of the State's needs, but ground-water use in Connecticut has been increasing. Except in rural areas, where it is the source of almost all domestic supply, ground water now accounts for only a small percentage of the total amount used. The estimated use of ground water is shown in table 1. Land available for additional surface-water impoundments is scarce, the cost of transporting water to new or expanding urban and industrial areas is high, and State policy favors development of future supplies from aquifers. Therefore, local ground-water sources will be an important part of the future water supply.

Table 1.--Ground water use, 1975[1/]

Category (Use)	Ground water (1,000 gallons per day)	Total water (1,000 gallons per day)	Percent ground water
Public supply	34,200	322,000	10.6
Rural:			
domestic	49,842	49,847	100.0
livestock	475	3,045	15.6
irrigation	410	4,310	9.5
Thermoelectric:			
cooling	0	719,000	0
other	300	4,940	6.1
Industrial	30,800	317,600	9.7
All uses, total	116,030	1,417,430	8.2

[1/] For additional water-use data see Murray and Reeves (1977). Figures do not include saline water.

To insure that ground-water quality will be acceptable for its intended use, protection and management plans are being reviewed, and new or modified plans will be proposed as part of the State's "208" program. These plans will be more effective if they are based on the availability, quantity, and quality of potential supplies, information on probable sources of contamination, and an understanding of the hydrogeologic system.

Aquifers

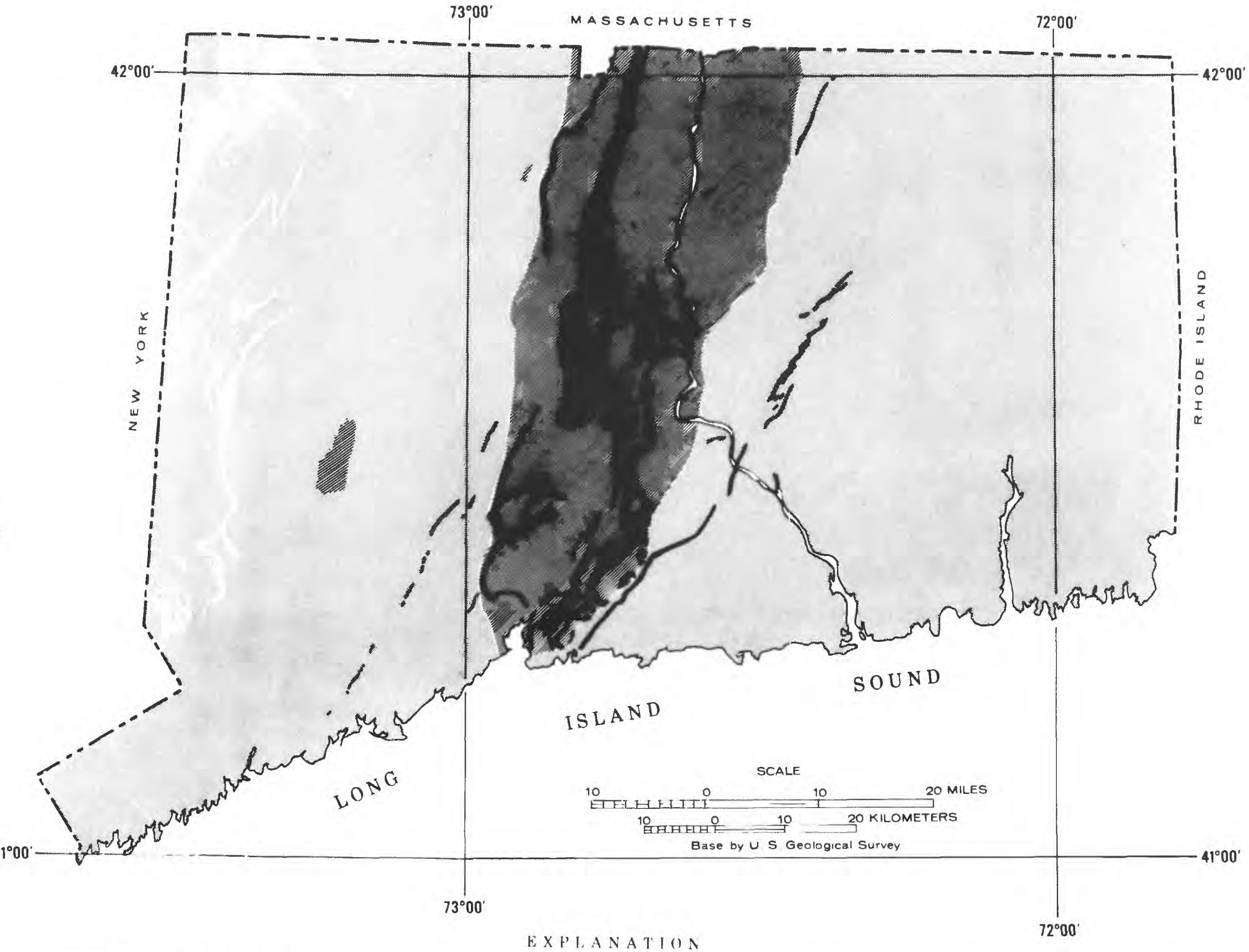
Water in Connecticut is extracted from aquifers composed of unconsolidated sediments and bedrock. Unconsolidated sediments overlie bedrock and store and transmit water through interconnected pore spaces between the sediment particles. Water in bedrock is stored in and flows primarily through fracture networks.

The two major types of unconsolidated sediments are stratified drift and till. Both are of glacial origin and are commonly similar in mineral composition to the underlying or adjacent bedrock from which they are predominantly derived. Stratified-drift aquifers are the most productive sources of ground water in the State. The largest well yields are generally obtained from coarse-grained deposits near major streams. Other important criteria for developing large supplies are saturated thickness and areal extent. Coarse-grained stratified-drift deposits that have a water-saturated thickness of 10 feet or more (termed "major aquifers" and "favorable aquifers"), are delineated on each of the maps referred to in this report. (See list on back cover.)

Till, popularly called "hardpan", provides small supplies of water for domestic use. It forms a widespread, discontinuous cover over bedrock in most upland areas and extends beneath stratified drift in valleys and lowlands. Till has been largely supplanted by bedrock as a domestic-supply source because of inadequate well yields and susceptibility to pollution.

Bedrock is subdivided into three general types: (1) crystalline rocks (noncarbonate), (2) sedimentary and associated igneous rocks, and (3) carbonate rocks. Yields from these rock types differ, depending on the number and size of fractures or other openings intercepted by a well. Bedrock aquifers are the principal source of water for those domestic and commercial users not served by public water supplies.

The distribution of bedrock aquifers is shown in figure 4. The crystalline bedrock aquifer includes rocks of diverse origins but with similar water-yielding properties. It is the most extensive aquifer in the State and underlies unconsolidated sediments in the eastern and western highlands and sedimentary and associated igneous rocks in a northeast-southwest band through the center of the State (Connecticut



EXPLANATION

- ░ CRYSTALLINE ROCKS -metamorphic and igneous rocks such as gneiss, schist, and granite, that contain and transmit water in open fractures.
- ▨ SEDIMENTARY ROCKS - such as sandstone, siltstone, and shale, that contain and transmit water in open fractures, pore spaces, and bedding planes. The area of sedimentary rocks in western Connecticut includes some interlayered basaltic rocks.
- ■ IGNEOUS ROCKS - such as basalt (trap rock) and diabase that contain and transmit water in open fractures and joint systems. Associated with sedimentary rocks.
- □ CARBONATE ROCKS - such as marble that contain and transmit water in open fractures.

FIGURE 4--GENERALIZED BEDROCK GEOLOGY OF CONNECTICUT (after Meade, 1978)

lowland). The sedimentary and igneous rocks are layered; wells may have different yields and water-quality characteristics, depending on the composition and physical properties of the layers tapped. The carbonate bedrock aquifer is principally restricted to valleys in the western highlands. Statistically, wells tapping this aquifer have higher yields than those tapping crystalline bedrock (Cervione and others, 1972, fig. 46), probably a result of topographic position as well as structural properties.

Well yields also depend on the amount of recharge. Ground-water recharge from precipitation is much greater in stratified-drift areas (estimated average 22 inches per year, Cervione and others, 1972, p. 48), than in till areas (about 7 inches per year; Holzer, 1975, table I) because the surficial materials are more permeable and slopes are gentler. Table 2 summarizes the hydrogeologic characteristics of principal aquifers

Table 2.--Principal hydrogeologic units: properties, water quality, and susceptibility to contamination

Hydrogeologic unit		Physical characteristics and distribution	Water-bearing properties	Background quality of ground water[1]	Susceptibility to contamination
Unconsolidated sediments	Stratified drift (coarse)[2]	Fine to coarse sand with some silt and gravel; deposits well sorted and stratified. Occur in stream valleys and lowlands. Commonly interbedded with finer layers. Overlie till and bedrock.	Most productive aquifers in State, especially where thick, coarse grained, and hydraulically connected to large streams or lakes. Provide large yields for public-supply and industrial uses.	Low dissolved-solids concentration. Generally moderately hard, especially where constituent fragments or underlying bedrock consist of carbonate rocks. Local high concentrations of iron and manganese.	Highly susceptible because of high hydraulic conductivity, proximity of water table to land surface, extensive cones of depression in heavily pumped areas, use of abandoned sand and gravel pits as dumps, and because of location in larger valleys, many of which are urbanized and industrialized.
	Stratified drift (fine)	Predominantly clay, silt, and very fine to fine sand; deposits well sorted and stratified. Occur in stream valleys and lowlands. Commonly interbedded with coarser layers. Overlie till and bedrock.	Poor aquifers, particularly where very fine grained and not interbedded with coarse layers.	Same as coarse-grained stratified drift.	Less susceptible than coarse-grained stratified drift becuase of its lower hydraulic conductivity.
	Till	Heterogeneous mixture of unstratified materials ranging in size from clay to boulders; generally compact; commonly called "hardpan". Overlies bedrock in most of the State.	Poor aquifers, especially where hydraulic conductivity is low and saturated section is thin. Can provide small supplies to dug wells of large diameter.	Low dissolved-solids concentration. Generally soft to moderately hard. Local high concentration of iron and manganese.	Less susceptible than stratified drift because of its low hydraulic conductivity, but dug wells are subject to contamination from local sources.
Bedrock[3]	Sedimentary (and associated igneous) rocks	Sedimentary aquifers are fine-to-coarse-grained bedded rocks (shale, sandstone, siltstone, and conglomerate); joints well defined. Underlie most of central Connecticut. Associated igneous rocks are basalt and diabase (trap rock) flows separated by sedimentary rocks; joints well defined. Form ridges in central Connecticut.	Yields adequate supplies for domestic and small-scale municipal and industrial purposes from openings along bedding planes and joints.	Moderate dissolved-solids concentration, generally moderately hard to hard. High dissolved sulfate, chloride, and sodium concentrations locally. Significant chemical quality differences, both areally and with depth.	Contaminants can enter along joints and bedding surfaces, especially where covering of till or other unconsolidated deposits is thin. Sedimentary rocks in lowlands susceptible because of urban and industrial land use.
	Carbonate rocks	Calcium and magnesium carbonate (limestone, dolostone and marble). Underlie a few valleys in western part of State.	Provide adequate supplies for domestic and small-scale municipal and industrial purposes.	Moderate dissolved-solids concentration, generally hard; most supplies require softening. Commonly alkaline and low in iron and manganese.	Susceptible where intensively and deeply weathered, as in parts of southwestern Connecticut and where covering of till or other unconsolidated materials is thin. Solution channels facilitating movement of contaminants are rare.
	Crystalline (noncarbonate) rocks	Predominantly metamorphic rocks (schist and gneiss), highly folded, numerous joints. Underlie most of eastern and western Connecticut; overlain by thin till in most places.	Yield adequate supplies for domestic use to drilled wells, from openings along joints.	Low dissolved-solids concentration, soft to moderately hard, locally hard, local high concentrations of iron and manganese.	Contaminants can enter along joints and other fractures, especially where covering of till or other unconsolidated deposits is thin.

[1] For source, significance, and range of dissolved constituents, see table 3. For hardness classification, see table 4.

[2] Shown on maps listed on back cover

[3] For distribution of different bedrock types, see figure 4

in Connecticut. More detailed information on specific parts of the State is contained in the series of Connecticut Water Resources Bulletins referenced in this report.

Aquifer Protection

Although most domestic wells are drilled in bedrock, coarse-grained stratified-drift aquifers are the most capable of yielding the large amounts of water needed for public supply and industrial use. Consequently, State and local aquifer-protection and management programs generally focus on stratified-drift areas. Stratified-drift aquifers are susceptible to contamination as they can receive recharge in three ways: (1) from precipitation directly on the land overlying the aquifer, (2) from ground-water that flows downgradient into the aquifer from adjacent upland areas, and (3) from induced infiltration of water from adjacent streams or lakes. To prevent contamination of stratified-drift aquifers, it may be necessary to consider the effects of land use not only over the aquifer, but also in adjacent upland areas, and in the entire upstream drainage areas of traversing streams. This, of course, would be difficult or impractical, especially where streams are large. The Connecticut River, for example, drains about 11,000 square miles upstream from Middletown, where a municipal well field derives much of its yield from induced recharge of river water. The town could conceivably regulate land use over the aquifer and adjacent uplands but could not control activities within the entire upstream drainage area supplying water to the Connecticut River.

GROUND-WATER QUALITY

Background Quality

Water quality is measured by the kinds and amounts of dissolved and suspended matter, physical characteristics, and chemical properties with respect to a particular use. The overall quality of Connecticut's ground water is good to excellent. Calcium and bicarbonate are the principal ions in most samples, and other major inorganic constituents include sodium, sulfate, chloride, and silica. These components are dissolved in various combinations and proportions depending on climate, chemistry of precipitation, physical and chemical composition of soil and aquifer materials, biologic processes, and subsurface flow patterns. Table 3 shows the major sources, significance, and range in concentration of constituents in water from major aquifers.

Table 3.--Source and significance of common constituents of water in Connecticut

			Range in ground water[2] (concentrations of chemical constituents in milligrams per liter)			
Chemical constituent or physical property	Principal sources	Significance and maximum limit for drinking water[1]	Aquifer type[3]	Median	Range	No. of samples
Silica (SiO_2)	Dissolved from practically all rocks and soils.	High concentrations precipitate as hard scale in boilers, water heaters, and pipes. Inhibits deterioration of zeolite-type water softeners and corrosion of iron pipes.	SD	12	3.0-30	236
			T	11	4.2-34	27
			SR	15	3.9-36	164
			Cb	9	2.3-22	32
			Cx	16	3.8-34	422
Iron (Fe)	Dissolved from minerals that contain oxides, sulfides, and carbonates of iron. Decaying vegetation, iron objects that are in contact with water, sewage, and industrial waste are also major sources.	On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate. More than about 0.3 mg/L stains laundry and utensils, causes unpleasant odors, and favors growth of iron bacteria. Iron in water is objectionable for food and textile processing. Most iron-bearing waters, when treated by aeration and filtration, are satisfactory for domestic use.	SD	.10	.00-40	317
			T	.08	.00-8.1	28
			SR	.27	.00-4.3	242
			Cb	.08	.00-3.4	32
			Cx	.10	.00-8.6	571
Manganese (Mn)	Dissolved from many rocks and soils. Commonly associated with but less common than iron.	More than 0.05 mg/L oxidizes on exposure to air to a black precipate. Manganese has the same undesirable characteristics as iron but is more difficult to remove.	SD	.02	.00-5.9	307
			T	.03	.00-.27	26
			SR	.01	.00-6.4	232
			Cb	.01	.00-.23	32
			Cx	.02	.00-.95	554
Calcium (Ca)	Dissolved from rocks and soils, expecially those containing calcium silicates, and carbonate and clay minerals.	Hardness and scale-forming properties of water are caused principally by dissolved bicarbonates and sulfates of calcium and magnesium. (See hardness.) Hard water is objectionable for electroplating, tanning, dyeing and textile processing. It also causes scale formation in steam boilers, water heaters, and pipes.	SD	23	.7-180	289
			T	13	2.8-72	27
			SR	35	.1-1,080	228
			Cb	49	16-92	32
			Cx	19	1.4-416	493
Magnesium (Mg)	Dissolved from rocks and soils, especially those containing magnesium silicates, clay minerals, and carbonate lenses.	See Calcium.	SD	6.4	.1-50	289
			T	3.0	.8-11	26
			SR	6.7	.0-460	228
			Cb	23	1.4-39	32
			Cx	5.8	.2-62	483
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Sewage, industrial wastes, road salt, and sea water are also major sources. Most home water softeners increase the amount of sodium in water by exchanging it for calcium and magnesium.	Because the concentration of potassium is usually low, sodium and potassium are sometimes calculated together and reported as sodium. Quantities found in the fresh water of the report area have little effect upon the usefulness of water for most purposes; however, more than 50 mg/L may cause foaming in steam boilers. Twenty mg/L of sodium is the maximum permitted for people limited to a very restricted sodium diet. Recommended maximum 20 mg/L for finished water.	SD	8.6	.9-314	191
			T	6.9	2.8-47	21
			SR	13	.9-3,800	223
			Cb	6.1	.7-21	32
			Cx	8.6	1.6-76	399
Carbonate (CO_3) and bicarbonate (HCO_3)	Dissolved from carbonate and calcium silicate minerals by reaction with carbon dioxide in water. Decaying vegetation, sewage, and industrial wastes are also important sources.	Carbonates of calcium and magnesium cause hardness, form scale in boilers and pipes, and release corrosive carbon dioxide. (See hardness.) Water of low mineral content and low bicarbonate content in proportion to carbon dioxide is acidic and corrosive.	SD	60	3-525	299
			T	33	1-93	26
			SR	103	14-470	233
			Cb	225	82-342	32
			Cx	58	0-292	484
Sulfate (SO_4)	Dissolved from rocks and soils containing sulfur compounds, especially iron sulfide; also from sulfur compounds dissolved in precipitation, and sewage and industrial wastes.	Sulfates of calcium and magnesium cause permanent hardness and form hard scale in boilers and hot water pipes.	SD	20	.2-292	296
			T	15	4.4-41	21
			SR	30	3.4-1,600	233
			Cb	21	8.0-74	32
			Cx	17	1.6-1,040	443
Chloride (Cl)	Dissolved from rocks and soils in small amounts. Other sources are animal wastes, sewage, road salt, industrial wastes, and sea water. Chloride concentration of most fresh water in the State is less than 20 mg/L.	Large amounts in combination with calcium will result in a corrosive solution and in combination with sodium will give water a salty taste. Maximum 250 mg/L.	SD	12	.0-607	305
			T	7.9	1.0-16	14
			SR	10	1.1-830	235
			Cb	7.5	.9-72	32
			Cx	7.8	.0-362	396

[1] Standards for drinking water, Connecticut Department of Health (Conn. General Assembly, 1975).

[2] Summary of analyses by U.S. Geological Survey up to 1977. For individual analyses, see U.S. Geological Survey Water-Data reports, published annually.

[3] SD = Stratified drift, T = Till, SR = Sedimentary rock, Cb = Carbonate rock, Cx = Crystalline rock

Table 3.--Source and significance of common constituents of water in Connecticut--Continued

Chemical constituent or physical property	Principal sources	Significance and maximum limit for drinking water[1]	Range in ground water[2] (concentrations of chemical constituents in milligrams per liter)			
			Aquifer type[3]	Median	Range	No. of samples
Fluoride (F)	Dissolved from minerals. Naturally mineralized water in the State has measured concentrations as high as 6.1 mg/L. Added to public water supplies by fluoridation.	About 1.0 mg/L of flouride reportedly reduces the incidence of tooth decay in young children; larger amounts may cause mottling of tooth enamel, depending on average water intake and climate (Lohr and Love, 1954, p. 39). Limits: 0.8 to 1.2 mg/L for artificially fluoridated water; maximum 2.0 mg/L for naturally fluoridated water.	SD	.1	.0-2.0	134
			T	.1	.0-.2	4
			SR	.2	.0-6.1	67
			Cb	.1	.1-.2	3
			Cx	.1	.0-1.6	160
Nitrate (NO_3; expressed as N)	Sewage, industrial wastes, fertilizers, and decaying vegetation are major sources. Lesser amounts are derived from precipitation and solution processes.	Small amounts have no effect on usefulness of water. A concentration greater than 2.3 mg/L (as N) generally indicates impairment. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors. Water containing more than 10 mg/L (as N) reportedly caused methemoglobinemia, which can be fatal to infants (Comly, 1945). Maximum 10 mg/L of nitrate expressed as N, which is equivalent to 44 mg/L nitrate expressed as NO_3.	SD	1.2	.0-24	288
			T	1.5	.0-12	23
			SR	1.0	.0-39	228
			Cb	.9	.0-3.6	32
			Cx	.2	.0-14	473
Specific conductance	Specific conductance, or the capacity of water to conduct an electric current, is an index of dissolved mineral content.	A specific conductance of 800 micromhos at 25°C is approximately equivalent to a dissolved-solids concentration of 500 mg/L.	SD	[4] 211	[4] 39-2,170	292
			T	124	34-1,190	29
			SR	305	74-21,900	232
			Cb	435	154-779	32
			Cx	174	33-1,860	556
Dissolved solids	Includes all dissolved mineral constituents derived from solution of rocks and soils; locally augmented by mineral matter in sewage and industrial wastes. Measured as residue on evaporation at 180°C or calculated as numerical sum of amounts of individual constituents. Ground water generally has a higher concentration of dissolved solids than surface water.	Water containing more than 1,000 mg/L dissolved solids is undesirable for public and private supplies and most industrial purposes.	SD	135	31-1,270	314
			T	89	40-678	28
			SR	196	47-16,800	231
			Cb	250	84-496	32
			Cx	113	20-1,590	527
Hardness (as $CaCO_3$)	Primarily due to calcium and magnesium and to a lesser extent to iron, manganese, aluminum, barium, and strontium. There are two classes of hardness, carbonate (temporary) and noncarbonate (permanent). Carbonate hardness refers to the hardness balanced by equivalents of carbonate and bicarbonate ions; noncarbonate refers to the remainder of the hardness. Most water in the State is classified as soft to moderately hard.	Hard water uses more soap to lather and deposits soap curds on bathtubs. Water having a hardness of more than 120 mg/L is commonly softened for domestic use. Hardness forms scale in boilers, water heaters, radiators and pipes, causing a decrease in rate of heat transfer and restricted flow of water. In contrast, water having a very low hardness may be corrosive. A classification of hardness appears in table 4.	SD	80	2-581	319
			T	39	10-211	27
			SR	122	0-4,590	247
			Cb	209	76-378	32
			Cx	62	3-1,120	544
Hydrogen ion (pH)	Water having high concentrations of acids, acid-generating salts, and free carbon dioxide has a low pH. Where carbonates, bicarbonates, hydroxides, phosphates, and silicates are dominant, the pH is high. Most natural waters range between 6 and 8.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline characteristics; values lower than 7.0 indicate acid characteristics. Acid waters and excessively alkaline waters corrode metals. Limits 6.4 to 8.5 for finished water.	SD	7.2	4.8-9.3	321
			T	6.8	5.0-7.7	29
			SR	7.7	5.8-9.4	226
			Cb	7.7	7.1-8.1	32
			Cx	7.3	4.4-8.6	540
Detergents as methylene blue active substance (MBAS)	MBAS is a measure of the concentrations of detergents in water. Primary sources of alkyl benzene sulfonate (ABS) and linear alkyl sulfonate (LAS) are synthetic household detergent residues in sewage and waste waters.	High concentration of ABS causes undesirable taste, foaming, and odors. Indicates presence of sewage or industrial waste. In mid-1965 ABS gradually replaced by LAS, which is more degradable. Maximum for MBAS 0.5 mg/L.	SD	.05	.01-.10	23
			SR	.03	.00-.25	87
Color	May be imparted by iron and manganese compounds, algae, weeds, and humus. May also be caused by inorganic or organic wastes from industry. True color of water is considered to be only that remaining in solution after the suspended material has been removed.	Water for domestic and some industrial uses should be free of perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes. Usually expressed in units of color (platinum-cobalt method) rather than in milligrams per liter. Recommended maximum 20 standard units for raw water, 15 units for finished water.	(Not measured or not related to aquifer type.)			
Dissolved oxygen (D.O.)	Derived from the atmosphere and from photosynthesis by aquatic vegetation. Amount varies with temperature and pressure and decreases during breakdown of waste material. Concentration can be expressed in mg/L or as a percentage of saturation.	Dissolved oxygen in surface water is necessary for support of fish and other aquatic life. It causes precipitation of iron and manganese in well water and can cause corrosion of metals. Standards for streams and lakes in the State are given in "Proposed water quality standards" (Connecticut Department of Environmental Protection, 1977b).	(Not measured or not related to aquifer type.)			
Temperature	Fluctuates seasonally in streams and shallow aquifers. At depths of 30 to 60 feet, ground-water temperature remains within 2°C or 3°C of mean annual air temperature (7°C to 11°C for the State) and increases gradually with depth. May fluctuate where affected by induced infiltration. Disposal of water used for cooling or industrial processing may cause local temperature anomalies.	Affects the usefulness of water for many purposed. For most uses, especially cooling, water of uniformly low temperatures is desired. A rise of a few degrees in the temperature of a stream may limit its capacity to support aquatic life. Warm water carries less oxygen in solution and is more corrosive than cold water.	(Not measured or not related to aquifer type.)			

[1] Standards for drinking water, Connecticut Department of Health (Conn. General Assembly, 1975).

[2] Summary of analyses by U.S. Geological Survey up to 1977. For individual analyses, see U.S. Geological Survey Water-Data reports, published annually.

[3] SD = Stratified drift, T = Till, SR = Sedimentary rock, Cb = Carbonate rock, Cx = Crystalline rock

[4] In micromhos per cm at 25°C.

Table 3.--Source and significance of common constituents of water in Connecticut--Continued

Chemical constituent or physical property	Principal sources	Significance and maximum limit for drinking water[1]	Range in ground water[2] (concentrations of chemical constituents in milligrams per liter)			
			Aquifer type[3]	Median	Range	No. of samples
Turbidity	An optical property of water attributed to suspended or colloidal matter which inhibits light penetration. May be caused by microorganisms, algae, suspended mineral substances including iron and manganese compounds, clay, silt, sawdust, fibers, or other materials in surface water. May result from natural processes of erosion or from the addition of domestic sewage, wastes from industries such as pulp and paper manufacturing, or sediment from construction activities.	Excessive concentrations are harmful or lethal to fish and other aquatic life. Turbidity is also undesirable in waters used by most industries, especially in process water. Turbidity can modify water temperature. Expressed either in standard units or in milligrams per liter silica. Maximum 5 units for raw water, 1 unit for finished water.	(Not measured or not related to aquifer type.)			
Coliform bacteria	A particular group of bacteria that are used as indicators of possible sewage pollution. Fecal coliform bacteria are present in the intestines or feces of warm-blooded animals and are often used as indicators of the sanitary quality of water. Fecal streptococcal bacteria are found also in the intestines of warm-blooded animals; their presence in water is considered to verify fecal pollution.	Concentrations can be eliminated or reduced by chlorination. Maximum concentration 1 colony per 100 milliliters for finished water, based on monthly average of periodic samples.	(Not measured or not related to aquifer type.)			

[1] Standards for drinking water, Connecticut Department of Health (Conn. General Assembly, 1975).

[2] Summary of analyses by U.S. Geological Survey up to 1977. For individual analyses, see U.S. Geological Survey Water-Data report, published annually.

[3] SD = Stratified drift, T = Till, SR = Sedimentary rock, Cb = Carbonate rock, Cy = Crystalline rock

Table 4.--Hardness classification and water suitability [1]

Descriptive rating	Hardness range as $CaCO_3$, in mg/L	Suitability
Soft	0-60	Suitable for many uses without softening
Moderately hard	61-120	Usable without softening except for some industrial applications
Hard	121-180	Softening required by laundries and for most domestic uses
Very hard	181 or more	Softening required for most purposes

[1] Modified from Durfor and Becker (1964, p. 27).

High concentrations of calcium and magnesium cause hard water. Ground water in the State is generally soft to moderately hard except in carbonate areas (see figure 4), where it may be hard or very hard. Some units of sedimentary bedrock and unconsolidated sediments derived from these units or from carbonate bedrock also yield hard water. Hardness classification is given in table 4.

Sodium and bicarbonate or sulfate ions predominate in some water samples from deep wells in sedimentary bedrock, whereas sodium and chloride predominate in some areas near the coast and along estuaries. High sodium concentration makes water unsuitable for drinking by people limited to a "very restricted sodium diet" (maximum 20 mg/L) (National Academy of Sciences, National Academy of Engineering, 1972, p. 88). High sulfate concentrations (greater than 250 mg/L), found locally in water from the sedimentary rocks in central Connecticut and crystalline rocks in eastern Connecticut, affects the taste of water. Sulfate also has a cathartic affect on occasional users, but is not considered a health hazard.

The most common problem constituents of natural ground water in Connecticut are dissolved iron and manganese. These elements are not considered harmful to health, but even in low concentrations they stain fixtures and laundry and preclude the use of untreated water for many industrial purposes. Objectionable amounts occur locally in surface water and ground water in all parts of the State, particularly in swamps, in some crystalline rocks rich in iron- and manganese-bearing minerals, and in unconsolidated sediments derived from these rocks.

Table 2 summarizes the quality of water from principal aquifers and their susceptibility to contamination. Detailed descriptions and published records of water quality in different parts of Connecticut are contained in the hydrologic data and inventory reports for specific areas listed under "References".

Contamination - Definition and Criteria

Ground-water contamination may be defined as the degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impaired (Miller, and others, 1974). Water-quality requirements for public supply, industrial use, and agricultural use differ widely. Because most ground water in Connecticut is used for public or private domestic supply, its use as drinking water is of primary importance and interest.

In some parts of the State, ground water unaffected by human activities, contains undesirably high concentrations of iron, manganese, sodium, sulfate, or other ions, or is so hard that its usefulness for many purposes is restricted.

For the purposes of this study, water is considered contaminated if, as a result of human activities, its physical properties or concentrations of chemical, biological, or radiological constituents:

(1) exceed limits for public drinking water set by the Connecticut Department of Health (Connecticut General Assembly, 1975), or,

(2) exceed recommended limits for drinking water set by the Federal government (U.S. Environmental Protection Agency, 1975; 1976), or

(3) otherwise indicate impairment of the usefulness of the water for human consumption. For example, if it contains toxic chemicals for which standards have not been set or for which concentrations were not determined.

Water quality is considered to be impaired, but not contaminated, if:

(1) its physical properties or concentrations of chemical, biological, or radiological constituents exceed the background levels reported in prior U.S. Geological Survey studies (Water Resources Inventory of Connecticut, parts 1-10, listed separately under "References"), but do not exceed State or Federal drinking water limits, or,

(2) it contains measurable quantities of man-made chemicals or their breakdown products for which standards for drinking water have not been established.

Ground water can be considered to be threatened with contamination where aquifers or parts of aquifers are in proximity to, or in hydrologic connection with, contaminated surface water, contaminated ground water, or potential sources of contamination such as landfills, septage-disposal pits, or chemical stockpiles.

Standards used in this report for contaminated and impaired ground water are summarized in table 5. Principal sources of contamination and contaminants are given in table 6.

Degraded Quality

Although most wells yield water of good quality, areas of degraded (contaminated or impaired) water exist in all parts of the State. Rolston, Grossman, Potterton, and Handman (1979) show locations of wells that yield or have yielded impaired or contaminated water as defined in table 5. Their map also indicates which aquifer is tapped at each site and shows the areal distribution of major aquifers. As shown on the map, ground-water quality has been affected in many areas overlying major aquifers.

Table 5.--Standards used in this report to classify ground-water as contaminated and impaired. (Concentrations of chemical constituents in milligrams per liter)

Contaminant	Contamination limits[a]	Impairment limits[b]
CHEMICAL, INORGANIC		
Arsenic	0.05	-
Barium	1.	-
Cadmium	.01	-
Chloride	250.	20.
Chromium	.05	-
Copper	1.	-
Cyanide	.2	c
Lead	.05	-
MBAS	.5	c
Mercury	.002	-
Nitrate(N)	10.[d]	2.3[e]
Nitrate(N)	1.	-
Nitrite + Nitrate(N)	10.[d]	2.3[e]
Selinium	.01	-
Silver	.05	-
Sodium	20.	-
CHEMICAL, ORGANIC		
Gross hydrocarbons, oil base	.001	c
Chlorinated hydrocarbons (pesticides)		
Endrin	.0002	c
Lindane	.004	c
Methoxychlor	.1	c
Toxaphene	.005	c
Chlorophenoxys (herbicides)		
2,4-D	.1	c
2,4,5-TP Silvex	.01	c
BIOLOGICAL		
Bacteriological		
Coliform organisms	4[f]	1[f]
Fecal coliform	g	c
Streptococci	g	c
Amoeba, protozoa	g	-
Viral	g	-
Hepatitis	g	c
RADIOACTIVITY		
Beta particles	50[h]	
Tritium	20,000[h]	-
Strontium -90	2[h]	-

[a] Water is considered contaminated if these limits are exceeded; based on standards for drinking water set by the Connecticut Department of Health (Connecticut General Assembly, 1975) and the U.S. Environmental Protection Agency (1975; 1976).

[b] Water quality is considered impaired if concentrations of any constituent exceeds background levels. (For discussion, see text.) Background levels have not been established for many constituents because of inadequate data.

[c] Presence indicates impairment.

[d] Equivalent to 44 milligrams per liter NO_3.

[e] Equivalent to 10 milligrams per liter NO_3.

[f] Colonies per 100 milliliters, for finished water; based on monthly average of periodic samples (see Connecticut General Assembly, 1975).

[g] No standards set as of 1979.

[h] Picocuries per liter.

Table 6.--Nonpoint sources and probable contaminants

	Contaminants										
Sources	Chloride	Metals	Detergents (MBAS)	Nitrate	Sodium	Gross hydro-carbons (oil)	Chlorinated hydro-carbons (pesticides)	Chloro-phenoxys (herbicides)	Other organic materials (solvents)	Bacteria	Viruses
Agriculture	X			X			X	X		X	X
Built-up areas[1]	X	X			X	X				X	X
Golf courses and lawns				X			X	X			
Industry		X				X			X		
Landfills	X	X			X	X			X	X	X
Petroleum storage						X					
Roads and airports	X	X			X	X					
Septic systems	X		X	X	X						X
Water softeners	X				X						

[1] Urban and industrial

The data used for this map include wells sampled during a series of water resources inventories of the State by the U.S. Geological Survey, in cooperation with the Connecticut Department of Environmental Protection, and water from public-supply wells analyzed periodically and reported by the Connecticut Department of Health (1971, 1976b). Water quality changes with time, and the map does not necessarily represent present conditions, but, rather, the worst quality detected during the sampling period. The water quality may have improved or worsened. The map also includes a few naturally mineralized sources and wells affected by salt-water intrusion.

NONPOINT SOURCES

Salt-Water Intrusion

Salt-water and brackish-water bodies border coastal Connecticut from the New York State line eastward to Rhode Island and also extend northward from Long Island Sound along estuarine reaches of most streams. Pumping of ground water from areas near salt water or brackish water has resulted in salt-water intrusion in many places, as a result of salt water or brackish water moving into nearby aquifers because of a reduction or reversal of the seaward hydraulic gradient.

The map by Rolston, Grossman, Potterton, and Handman (1979) shows the approximate extent of brackish water in estuaries and the area estimated to be susceptible to salt-water intrusion. It is derived in part from a compilation by Melvin and Haeni (1974) of information on the inland extent of surface water having a high dissolved-solids or high chloride concentration and, in part, on the dissolved-solids concentration in samples from coastal zone wells. Additional information is available from other studies (Brown, 1925; Mazzaferro and others, 1979; Thomas and others, 1968; Wilson and others, 1974; Ryder and others, 1970).

Susceptibility of Coastal Aquifers

Early studies by Brown (1925, 1928) in New Haven and contiguous parts of coastal Connecticut showed that salt-water intrusion is unlikely more than 250 feet inland from mean high water in shallow wells tapping unconsolidated deposits and more than 500 feet inland in deep bedrock wells. The subsequent development of more powerful pumps, the construction of large-capacity screened wells, and expanded water demands make it necessary to revise Brown's figures. Table 7 contains the geohydrologic guidelines used in delineating the potential width of the coastal zone considered susceptible to salt-water intrusion.

The inland extent of this "susceptible coastal zone", shown on the previously cited map, is only approximate because of the space distribution and incomplete nature of the data collected at different times under differing conditions. The map depicts the susceptibility of only the major coastal aquifers; minor aquifers at the same sites are omitted.

Table 7.--Estimated horizontal extent of zone susceptible to salt-water intrusion in principal hydrogeologic units along the Connecticut coastline[1]

Hydrogeologic unit	Distribution and thickness	Maximum landward extent (in feet)		Remarks
		Assumed	Reported	
Stratified drift (coarse-grained)	Chiefly in valleys; up to 300 ft thick	4,000	3,000	Pumping usually results in wide but shallow cone of depression. Stratification affects vertical movement.
Stratified drift (fine-grained)	Chiefly in valleys; up to 300 ft thick	2,600	Not differentiated	Lower hydraulic conductivity than coarse-grained unit results in smaller but deeper cone of depression. Stratification affects vertical movement.
Till	Generally occurs as a thin layer mantling bedrock; less than 20 ft thick	1,300	1,600	Saline water may infiltrate from underlying bedrock or overlying stratified drift.
Estuarine deposits, clay, or peat	Underlie tidal flats and some areas of artificial fill; commonly less than 30 ft thick	650	Not differentiated	Ground-water movement very slow. May retard salt-water intrusion to some wells.
Bedrock	Underlies entire coastline at depths as much as 300 ft	2,600	3,000	Small quantities of salt water may move rapidly to pumping wells through fissures or joints near the bedrock surface.

[1] For delineation of susceptible coastal zone see Rolston, Grossman, Potterton, and Handman (1979).

It also reflects the hydrologic conditions prevailing when salt-water intrusion was reported or measured. The construction of closely spaced wells pumping large amounts of fresh water would disturb the equilibrium and increase the extent of the vulnerable zone or accelerate the rate of salt-water intrusion.

Construction of a well within the susceptible coastal zone will not necessarily result in pumping salt water or brackish water. Records collected throughout coastal Connecticut show that many wells close to Long Island Sound or to estuaries yield fresh water. However, proximity to these salt-water bodies may impose limits on the spacing and individual pumping rates in these wells, apart from other hydrologic constraints.

Aquifer tests under favorable and controlled conditions provide useful data, such as aquifer transmissivity and storage coefficient and the location of hydrologic boundaries. These data, together with information on the altitude of the water table or potentiometric surface relative to that of nearby salt-water or brackish-water bodies, enable prediction of the degree of salt-water intrusion resulting from various pumping regimes. Water-management decisions can be based on such predictions, and the construction of observation wells to monitor the quality of ground water can give early warning of salt-water intrusion.

The following example illustrates the variability of salt-water intrusion of a stratified-drift aquifer in response to differing conditions. Two industrial wells in Ledyard alternately pumped water of satisfactory quality at 75 gal/min for more than a decade, although they are situated only about 215 feet from the Thames River estuary. In 1965, after 3 years of drought, brackish water intruded the aquifer, the chloride concentration of the ground water rose to a maximum of 360 mg/L (reported as parts per million on November 22, 1965, in Thomas and others, 1968, p. 72) and the wells were shut down. On resumption of pumping in 1966, less than a year later, the wells yielded water of satisfactory chemical quality. The rapid flushing of the brackish water is attributed partly to the high transmissivity of the stratified-drift aquifer and partly to the small areal extent of salt-water intrusion. Change in balance between recharge and discharge also contributed to restored natural equilibrium.

In general, more time is required to flush salt water from aquifers of low transmissivity, including sedimentary bedrock, crystalline bedrock, and till, than from aquifers of high transmissivity. Sedimentary bedrock and other aquifers in the New Haven area were intruded by salt water as far back as 1919 (Brown, 1928) and were pumped heavily during the 1940's. Although pumping has since decreased, recent analyses in the same area (Mazzaferro, 1973, table 5; U.S. Geological Survey, 1977) show that some wells still contain water that has a high chloride content. Generally, heavy and prolonged pumping from fine-grained stratified drift or bedrock aquifers may cause extensive salt-water intrusion that would require long periods to flush out.

Transmissivity is only one index for estimating the rate of recovery from salt-water intrusion. High-transmissivity aquifers may be expected to recover more rapidly than low-transmissivity aquifers, other aspects being equal. Conversely, highly transmissive aquifers, shown as "major aquifers" on the companion map, have broader zones of susceptibility. As previously indicated, however, recovery time also depends on the rates of recharge and discharge, number and relative location of pumping wells, and duration and rate of pumping.

Induced Recharge of Surface Water

Impaired surface water can be considered a nonpoint source of ground-water degradation where it can be induced into an aquifer. Induced recharge commonly provides a considerable part of the yield of large public and industrial wells tapping stratified-drift aquifers.

The quality of surface water in Connecticut is generally very good, but it has been impaired in some parts of the State. Table 8 of this report, and the companion map by Rolston, Banach, and Handman (1978), show the quality of streams at 47 sites sampled monthly by the U.S. Geological Survey. At 12 of these sites, most samples collected in the 1976 water year contained dissolved chloride, nitrate, copper, or zinc in concentrations above background levels, or contained detergents (MBAS), cyanide, or oil and grease. Salty water in estuaries and harbors is also shown on the companion map but is discussed separately in the section on salt-water intrusion. Suspended sediment and bacterial concentrations are not considered to affect ground-water quality, as they are normally filtered out during movement of water through riverbed and aquifer materials. Some conditions however, can allow bacteria to move to a well. These include increased infiltration after excavation or scarifying of the streambed and greater hydraulic gradients between the surface-water body and well caused by floods or by increased pumping and reduced dilution of sewage during prolonged low streamflow (Randall, 1970).

Discharge of Waste Water

The Connecticut Department of Environmental Protection has adopted standards for stream quality and issued river basin plans (1977b; 1976a-g), in compliance with the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), to improve substandard waters and to prevent degradation of high quality waters. The Department regulates the amount of waste water that can be discharged to any water body and the degree of treatment required, with regard to present and proposed stream quality. The map by Rolston, Banach, and Handman (1978) shows locations of permitted waste-water discharges to streams from industries and from private,

Table 8.--Overall quality of surface water at U.S. Geological Survey monitoring sites, 1976 water year[1]

U.S.G.S. station no.	Site description	Water quality[2]
01118525	Pawcatuck River near Pawcatuck	S
01119375	Willimantic River at Merrow	N
01122001	Natchaug River, at U.S. Highway 6, at Willimantic	M
01122610	Shetucket River at South Windham	M
01125150	French River at Mechanicsville	M
01125200	Quinebaug River at Putnam	M
01125720	Quinebaug River at Pomfret Landing	M
01127000	Quinebaug River at Jewett City	M
01127500	Yantic River at Yantic	M
01127701	Thames River near Mohegan	S
01184000	Connecticut River at Thompsonville	M
01186800	Still River at Riverton	M
01188000	Burlington Brook near Burlington	N
01188085	Farmington River at Unionville	M
01189030	Pequabuck River at Farmington	I
01189120	Farmington River at Avon	M
01189995	Farmington River at Tariffville	M
01190015	Farmington River at Windsor	M
01190045	Podunk River at South Windsor	I
01190069	Connecticut River, at railroad bridge, at Hartford	M
01191510	Park River at Hartford	I
01192370	Porter Brook near Manchester	M
01192516	Hockanum River at East Hartford	I
01192911	Connecticut River at Middletown	M
01193050	Connecticut River at Middle Haddam	M
01193500	Salmon River near East Hampton	N
01193750	Connecticut River at East Haddam	M
01196222	Quinnipiac River near Meriden	I
01196500	Quinnipiac River at Wallingford	I
01196530	Quinnipiac River at North Haven	I
01196656	New Haven Harbor near New Haven	S
01198550	Housatonic River near Canaan	M
01200600	Housatonic River near New Milford	M
01201485	Still River at Brookfield Junction	I
01201700	Lake Lillinonah near Brookfield Center	M
01203000	Shepaug River near Roxbury	N
01204510	Lake Zoar at Riverside	M
01205500	Housatonic River at Stevenson	M
01205551	Housatonic River at Shelton	M
01208500	Naugatuck River at Beacon Falls	I
01208736	Naugatuck River at Ansonia	I
01208828	Housatonic River at Stratford	S
01208890	Saugatuck River near Redding	N
01209570	Norwalk River at Georgetown	I
01209600	Comstock Brook at North Wilton	N
01209910	Stamford Harbor at Stamford	S

[1] October 1975 to September 1976. For locations and complete analyses, see Water Resources Data for Connecticut (U.S. Geological Survey, 1977).

[2] Classification:
(For criteria, see discussion in text in section titled "Induced recharge of surface water".)

N = fresh water; chiefly unaffected by human activities.
M = fresh water; quality moderately affected by human activities. Not likely to have an adverse affect on ground-water quality if induced into aquifers.
I = fresh water; quality significantly impaired by human activities. May adversely affect ground-water quality if induced into aquifers.
S = salty water. Will adversely affect ground water quality if induced into aquifers.

municipal, and State sewage-treatment plants. Treatment-plant discharges into the ground are also shown. No discharges are permitted to streams feeding reservoirs for drinking water, but many streams that traverse potentially high-yield aquifers (termed "favorable aquifers" on the map), receive effluent discharges.

Urban Runoff

Urban storm-water runoff is a source of stream contamination that is difficult to control. It commonly contains litter, animal wastes, and chemicals used to melt snow and ice or to control vegetation and insects. Urban areas are shown on the previously cited map. Sartor and Boyd (1972) determined that runoff from such areas can contribute more pollution load during the first hour of a moderate to heavy storm than raw sanitary sewage from the same area could during an equal period. Urban storm water also contains more lead and other dissolved solids than average domestic waste water (Bryan, 1974).

Combined sanitary and storm sewers were common in the past and still exist in 17 Connecticut communities. The volume of storm water may be so great that the contents of the combined sewers overflow into rivers without treatment. The Connecticut, Naugatuck, and Thames Rivers, for example, receive discharges from combined sewer overflows. To prevent this, separate sanitary- and storm-sewer systems are commonly constructed, so that all sanitary waste is treated. Storm water, however, is not treated.

Street sweeping, storage and later treatment of the runoff from the first one-third to 1 inch of precipitation, and diversion of early storm runoff to treatment plants are methods that can be used to reduce contamination of surface water by urban runoff. It may be more beneficial to water quality to treat urban runoff than to provide tertiary treatment for sewage, according to Cordery (1977). In addition, inspecting, cleaning, and sealing sewers to prevent leakage of waste water can directly reduce ground-water contamination.

Subsurface Sewage Disposal

Subsurface discharge of sewage is a source of ground-water degradation in many parts of Connecticut. Ground water is most susceptible to contamination from sewage where the water table is high, bedrock is near land surface, and housing is dense -- common conditions in many parts of the State. Developed areas served by on-site sewage disposal systems, including residential urban and suburban areas housing one or more families per acre, and some industrial, commercial and institutional lands are shown on the companion map by Rolston and Bingham (1978).

Many of these unsewered areas overlie stratified-drift aquifers potentially favorable for large water supply.

Septic Systems

In Connecticut, 22 percent of urban and 89 percent of rural households have private subsurface sewage-disposal systems, more than 350,000 in total (table 9). Some are abandoned each year after sewer connection, but 3 to 5 thousand new systems are installed each year (Connecticut Department of Health, 1977, oral communication). In unsewered areas, much of the average 40 to 80 gallons of water used per person per day is discharged from septic tanks into the ground through drain fields. Domestic use of water adds as much as 300 mg/L of dissolved solids and millions of coliform bacteria per 100 milliliters (mL) of water (Miller and others, 1974). The waste water is most commonly treated by means of septic systems that consist of two parts: a watertight concrete tank and a distribution system (trench, pit, bed, or gallery) in a soil-leaching or absorption field. The tank, designed to retain effluent for

Table 9.--Domestic sewage-disposal in Connecticut, 1970[1]

	Number of year-round housing units		
Disposal Method	Urban	Rural	Total
Public sewer	589,103	19,500	608,603
Septic tank or cesspool	170,488	184,097	354,585
Other[2]	2,323	3,310	5,633
Total	761,914	206,907	968,821

[1] Based on data from U.S. Bureau of the Census, 1972, p. 98.
[2] Not defined.

at least 24 hours, allows 30 to 80 percent of the solids to settle out and some bacterial digestion (Patterson and others, 1971). Liquid containing the remaining dissolved and suspended solids and bacteria overflows into the leaching field. The leaching system is designed on the basis of daily sewage flow and soil seepage rate to distribute waste over a large area. The Connecticut Public Health Code requires an equal area to be reserved for future expansion or replacement of the leaching field (Connecticut Department of Health, 1976a). The design life of a septic system has been given as 15 to 20 years (Patterson and others, 1971, p. 5), although, based on a study in Glastonbury (Hill, 1974), the median life expectancy of a properly installed septic system in Connecticut may be 22 to 38 years, depending on soil type.

Waste water disposed of through septic systems percolates downward to the saturated zone, mixes with ground water, and moves downgradient to streams and other discharge points. The dissolved-solids load in streams that receive such discharge is increased by an amount related to housing density in the drainage area (Morrill and Toler, 1973). Twelve pounds of nitrogen per person is estimated to be added to lake water each year from septic tanks adjacent to lakes and their tributary streams (Patterson, and others, 1971).

Percolation through unsaturated soil removes much organic matter, bacteria, and viruses by filtration, adsorption, and biochemical reactions. Most dissolved inorganic ions, such as chloride, nitrate, and sodium, however, pass through to the saturated zone without attenuation. As a result, in some places, concentrations of these constituents in ground water exceed Connecticut Department of Health standards for drinking water.

Soil processes may be less efficient in removing constituents where tile fields are located below the biologically active zone of the soil (U.S. Environmental Protection Agency, 1973a). Fine-grained or poorly sorted sediments, where seepage is slow, provide better filtration of waste water, but the system may fail if waste volume is great, and fine-grained soils may eventually clog with solids. On the other hand, coarse-grained deposits perform well in seepage tests, but are generally less effective in removing bacteria, viruses, and nutrients (Miller and others, 1974). In bedrock, water moves through fractures and other large openings and is renovated little, if at all (Allen and Morrison, 1973). Bacteria and viruses can travel significant distances if they reach the saturated zone in a fractured bedrock aquifer.

Biodegradation of detergents is also retarded by the anaerobic conditions common below the water table (Hughes, 1975). Detergents in water can disperse normally insoluble organic compounds and mobilize bacteria, viruses, and other pollutants so that they travel farther than they would otherwise.

In a crystalline bedrock aquifer overlain by thin till in unsewered areas, a large part of the net ground-water recharge may be from septic-tank wastes. Holzer (1973) estimated that on a 1-acre lot in crystalline-bedrock areas, 50 percent of the net recharge is from septic waste and concluded that domestic wells may become contaminated if they are improperly sited or in a high-density development (more than one housing unit per acre). In stratified-drift areas, where 20 percent of ground-water recharge over a 1-acre lot is estimated to be derived from septic wastes, higher density development may not contaminate domestic wells (Holzer, 1973). However, where sediments are coarse grained and infiltration is rapid, water quality may be affected.

To ensure adequate filtration and reduce the possibility of well contamination, the Connecticut Public Health Code requires a minimum of 4 feet between the bottom of the leaching field and the bedrock surface and a minimum of 18 inches between the bottom of the leaching field and the maximum ground-water level. Septic systems must also be at least 75 feet from any well, and they may not receive commercial and industrial wastes, toxic chemicals, oils, greases, or discharges from water softeners. Nevertheless, analyses of well water by the Connecticut Department of Health show high nitrate and bacterial concentrations that may be attibutable to septic wastes in many places in the State (Connecticut Department of Health 1977). Salts used for regeneration of home water softeners have also contributed to contamination, as reported in Vernon and in North Stamford, although road salt was probably an additional factor (Miller and others, 1974; Henderson and Waters, 1971). Where the physical situation precludes individual septic-tank installation, sewering is an alternative for waste disposal.

Septage Disposal

Periodically, depending on waste composition and septic-tank capacity and design, accumulated solids are removed from the tank. These solids, termed "sludge", or "septage", are removed by contractors and trucked to 39 private and municipal disposal areas authorized by the Connecticut Department of Environmental Protection or to sewage-treatment plants. The locations of authorized disposal sites for septic-tank sludge are shown on one of the maps compiled for this study (Rolston and Bingham, 1978). The Water Compliance Unit of the Department of Environmental Protection regulates these areas, permitting only septic wastes to be discharged into the sludge digestion cells. Bottoms of cells are lined with at least 1 foot of sand and are at least 4 feet above the estimated maximum height of the water table. Cells are designed to hold one tenth of the estimated yearly volume of sludge received (Connecticut Department of Environmental Protection, 1976h). None of the present sites have been systematically monitored; consequently, their effect on water quality is not known.

Hydrocarbon Storage and Transfer Facilities

Leaks and spills of fuels and other chemicals have contaminated ground water in Connecticut. Major pipelines and bulk storage facilities shown on the companion map by Rolston, Bingham, and Handman (1979) are potential sources of leaks and spills. The Institute of Gas Technology (1975, p. 72-73) reports 546 miles of gas transmission mains and 5,406 miles of gas distribution mains in use in the State in 1973. These figures include 475 miles of interstate pipeline facilities. Many pipelines and storage tanks are located on stratified-drift aquifers or adjacent to large streams. The map does not show small installations, such as gasoline storage at service stations and fuel-oil tanks for homes and businesses. It does, however, show the distribution of licensed gasoline dealers, by town. More than 3,200 gasoline retailers are registered in Connecticut (Connecticut Department of Motor Vehicles, 1977), and many industries have large underground fuel tanks. Although individual leaks from these sources are generally small, they constitute a problem because they are numerous and difficult to detect. Further, small installations may not be properly inspected and maintained. Areas adjacent to roads, of course, are also susceptible to contamination from accidental spills of materials in transport.

State laws regulating the storage, transport, and use of hazardous materials are designed principally to prevent and control fires; they are not directly concerned with protecting surface water or ground water from contamination. (See Connecticut General Statutes, 1975.) Safety barriers around bulk storage areas, for example, will contain spilled fluid, but it may percolate to the saturated zone if the surface is permeable. Sometimes actions taken to prevent fires and explosions, such as washing down spills after accidents, inadvertently lead to contamination of water bodies.

Spills, seepages, and discharges, however, are reported to and investigated by the Special Waste Handling Unit of the Water Compliance Section of the Connecticut Department of Environmental Protection. This Unit prescribes procedures to prevent or reduce contamination, such as immediate removal of contaminated soil, use of sorbent materials to aid in containment and removal, and biological or chemical treatment. Once soluble or floating materials reach the water table they may be removed by pumping or intercepted by ditches and drains. Widespread contamination may require installation of numerous pumping wells for alleviation. These procedures are costly and often difficult. In many places, restoration of ground-water quality is not feasible, and contaminated wells are abandoned. Furthermore, the contaminated water removed from an aquifer commonly requires treatment before disposal.

The Special Waste Handling Unit investigated 554 incidents of spillage, seepage, and discharge of oil, chemicals, and other hazardous substances, totalling more than 290,000 gallons, during July 1976-June 1977 (Connecticut Department of Environmental Protection, 1977a).

In more than 50 of these incidents, hydrocarbons reached the saturated zone; the total loss exceeded 44,000 gallons. Most involved leaky tanks and pipes. The nine largest leaks and spills, each of which resulted in loss of more than 1,000 gallons beneath land surface, are given in table 10.

Surface spills are usually visible and sometimes can be recovered if prompt action is taken. Subsurface leaks, however, especially if slow, may not be detected until hydrocarbons are seen, smelled, or tasted in water. Once the organic materials reach the water table, they may persist for years. For example, industrial fuel oil from a 15,000

Table 10.--Reported spills and discharges of petroleum products reaching the saturated zone (July 1976 through June 1977)[1]

Date	Town	Source	Type	Estimated Amount (gal)	Cause	Correction
10-25-76	Ansonia	Private oil co.	Gasoline	5,000	Plumbing failure	Repaired
11-1-76	Sherman	Private co.	#2 oil	1,000	Line fracture	Repaired
11-1-76	Norwalk	Private oil co.	Gasoline	3,000	Tank fracture	--
11-8-76	Branford	DOT[2]	Gasoline	5,000	Tank fracture	Partial removal
2-4-77	Meriden	Private oil co.	Gasoline	1,900	Leaking storage tank	Partial removal
2-8-77	Avon	Private school	#2 oil	14,000	Line fracture	Contained
2-22-77	Darien	DOT[2]	Gasoline	5,900	Tank failure	Removed
4-29-77	Killingly	Private co.	Diesel fuel	3,000	Tank fracture	Removed
5-13-77	Norwalk	Private oil co.	Gasoline	2,000	Tank fracture	Partial removal

1/ Includes losses equal to or greater than 1,000 gallons; data from Connecticut Department of Environmental Protection (1977).

2/ Connecticut Department of Transportation gallon tank started leaking into the Pawcatuck River in 1973. The tank was removed in 1974, but an undetermined amount of oil remains in the saturated zone and continues to discharge into the river 4 years later. The oil reaching the river is restricted by containment booms and is periodically removed.

In the Stafford Hollow section of Stafford, ground-water contamination from abandoned and leaking fuel tanks at the town garage has affected about a dozen houses and businesses. In another area, the Uncasville section of Montville, several wells within an 8-acre area were contaminated after a break in a gasoline transfer line at a service station. The gasoline is being removed by pumping.

The U.S. Environmental Protection Agency (1973a) lists corrosion, equipment failure, and line rupture by earth moving equipment as the major causes of leaks. Steel storage tanks of 3,000 to 5,000 gallon capacity generally last about 15 years (Connecticut Department of Environmental Protection, 1977, oral communication). Many of those installed in service stations during the last 25 years are probably corroding. To retard corrosion, new tanks can be coated with tar or plastic, lined with fiberglass, constructed of corrosion-resistant materials, or installed in vaults.

To contain losses and facilitate recovery, excavations for tanks and pipelines can be lined with an impermeable material, such as clay, or sealed concrete. Losses from pipeline breaks are generally large, but they can be reduced by installation of automatic shut-off valves, as required by Connecticut General Statutes (1975).

Information on the local ground-water flow system is an aid in locating the source of contamination and predicting movement in the saturated zone. For example, Holzer (1976) used hydrogeologic data and appropriate flow equations to determine the source area of a widespread oil leak from storage tanks in stratified drift near the Connecticut River in Hartford and to select an appropriate clean-up system. Oil and gasoline are relatively insoluble and tend to remain near the water table rather than mix with ground water. Fluctuations of the water table can disperse these contaminants vertically in the upper part of the saturated zone. Movement is generally downgradient at a rate slower than that of ground water, but, under certain conditions, oil and gasoline may move upgradient (Osgood, 1974). Concentrations of hydrocarbons are reduced by processes such as evaporation, decomposition, and dilution, and they eventually discharge from the saturated zone.

The total magnitude of ground-water contamination from leaks and spills is difficult to assess as many leaks are probably not detected. Dispersion of oil and gas in ground water is complex, and recovery systems are commonly expensive, timeconsuming, and often inadequate. Therefore, preventive measures, including high standards of inspection and maintenance, prompt replacement of corroded and faulty equipment, and quick remedial action to clean up leaks and spills are considered the most feasible way to reduce the impact of leaks and spills on the quality of ground water (U.S. Environmental Protection Agency, 1973c).

Road Salt - Application and Storage

Since the early 1960's, sodium and chloride concentrations in Connecticut's waters have risen (Mazzaferro and others, 1977). Background concentrations for both ions in Connecticut's waters are generally less than 20 mg/L, but urbanization, industrialization, and increased automobile and truck-based transportation systems have contributed to the increase. Road salt is the most common source. Locations of salt stockpiles and the State's road network, part of the data on nonpoint sources compiled for this study, are shown on map MF 981-A (Bingham and Rolston, 1978). Stockpiles associated with known cases of ground-water contamination are indicated on this map, as are the locations of former storage areas.

The concentration of sodium in drinking water is of concern because sodium intake correlates with the incidence of hypertension and related diseases (Terry, 1974, p. 38-43). The Connecticut Department of Health has set a maximum desirable standard of 20 mg/L of sodium for drinking water, and this is not to be exceeded when water of better quality can be obtained (Connecticut General Assembly, 1975). Analyses of public water supplies reported by the Department of Health (1976b) show that 134 supplies had sodium concentrations greater than 20 mg/L during 1971 - 1975.

Chloride in drinking water does not directly affect health. The maximum concentration, 250 mg/L, was chosen partly on the basis of taste. Water containing greater than 250 mg/L chloride might be rejected by consumers because of taste, and those affected might turn to unsanitary sources of drinking water (Terry, 1974, p. 36).

Chloride also increases the corrosiveness of water and corrosive water may dissolve toxic metals that are present in trace amounts from iron pipes, thereby affecting water quality. Certain industries, such as dairy processing and photographic operations, require water low in chloride (American Water Works Association, 1951), and are unable to use water with high salt concentrations unless it is treated. Industries that require water of low specific conductance would be affected, as dissolved salts raise the conductivity of water.

Sources of Sodium and Chloride

Natural sources of salt in Connecticut's ground water are salt spray along the coast, salt-water intrusion, and minor amounts from the solution of minerals. Salt spray is carried inland by wind and deposited on the land surface by precipitation; it contributes 1 to 6 mg/L chloride to waters (Jackson, 1905), and is fairly constant over extended periods. The increase in salt observed in Connecticut's water cannot be attributed to natural sources alone; water softeners, septic-tank leachate, and storage and use of road salts all contribute. The first two have local effects, whereas, the third has had a Statewide impact.

Application and Storage

Since the 1940's, keeping Connecticut's roads and highways open yearround has resulted in an increasing reliance on salt to complement abrasives and snow plowing. Granular sodium chloride, and in some restricted watersheds a mixture of calcium chloride and sodium chloride is spread on the snow and ice. Records of the Connecticut Department of Transportation show that road-salt use was highest during the 1969-70 winter, when 160,000 tons were applied to State-maintained roads. This was reduced, partly for economic reasons, to an average of 92,000 tons per year from 1971-77. Table 11 summarizes the Department's snow and ice control policy for State-maintained roads.

Connecticut's 169 towns have individual programs for snow and ice control on town roads; no Statewide regulations apply. The total amount of salt used and the amount used per road mile by each town for the 1976-77 winter is shown on one of the maps produced for this study (Bingham and Rolston, 1978). Salt use during the 1976-77 winter, as reported by the towns, ranged from 0.6 tons per mile in Guilford and Goshen to 23.1 tons per mile in Norwich. A total of more than 102,000 tons of salt was reported to have been used by the towns, ranging from 40 tons in Franklin to 7,000 tons in Stamford. These figures do not include salt used by the Connecticut Department of Transportation, institutions, industries, businesses, and individuals during this period. Differences in salt use by towns result, in part, from differences in the amount of snow accumulation, number of snow and ice storms, and road characteristics such as hills, curves, and intersections, as well as variations in the ratio of salt to sand used and application rates.

Ground-water quality is affected when salt is either plowed, splashed, or washed off the road, percolates into the adjacent soil, and reaches the water table. Contamination can occur where salt applications are high and runoff reaches the water table. In North Stamford, road-salt applications were found to contribute to contamination of several domestic wells (Henderson and Waters, 1971).

Table 11.--Snow and ice removal from Connecticut highways

(Materials and usage recommended by the State Department of Transportation[1])

Material	Ratio (salt to sand)	Type of road	Application rate (lb per 2-lane mi)	Use[2]
Salt	1:0	Multi-lane	432	All multi-lane highways
		Two-lane	Up to 300	Selective, in place of mixture
		Ramp	Up to 300	Selective, in place of mixture
Sand	1:16[3]	Multi-lane	1328	Following salt application, freezing rain conditions
		Two-lane	Variable	Freezing rain conditions
		Ramp	Variable	Freezing rain conditions
Salt-sand mixture	2:7	Two-lane	1482	All two-lane roads
		Ramp	1977	All ramps
Salt-sand mixture	1:8	Two-lane	Variable	Freezing rain conditions
		Ramp	Variable	Freezing rain conditions
Special mixtures	--	All	Variable	Experiments, special areas[4]

[1] Summarized from Connecticut Department of Transportation (undated, 1976?)

[2] Applied as soon as sufficient snow accumulates to prevent material from being swept away

[3] Salt added to prevent freezing of storage pile

[4] Cal-salt used in designated watersheds

Improperly stored road salt can affect ground-water quality because every rainfall dissolves some salt from uncovered piles. Salt spilled during loading and transfer operations, and washed from trucks and other equipment may also reach the saturated zone under favorable conditions. Contamination in the vicinity of salt stockpiles has resulted in abandonment of several wells and relocation of wells and storage facilities. Of the 126 storage sites maintained by the Connecticut Department of Transportation, 13 are reported to have caused ground-water contamination. Some have been eliminated, moved, or covered, but residual salt may still be present.

For example, ground-water contamination from a salt-storage site in southeastern Connecticut is reported by Miller and others (1974). Test wells were installed in a stratified-drift aquifer at the site of a proposed municipal well field. Road salt had been stored at a site about 1,000 feet from the wells and during 1955-65 all runoff and truck washings had drained into nearby dry wells. In 1968, chloride concentrations in water from the test wells ranged from 12 to 36 mg/L. When the water was retested in 1970, because of a nearby oil spill, chloride concentrations exceeded 400 mg/L. The same year, water from a bedrock well at the salt-storage facility had a chloride concentration of 1,100 mg/L. The municipal well-field site, estimated to be capable of supplying several million gallons of water per day, was consequently abandoned.

Another case of contamination resulted from improper salt storage in the Tylerville section of Haddam. Water from a 187-foot deep, 8-inch diameter industrial well yielding 18 gal/min had low chloride concentrations until 1974. The following year, the chloride concentration increased to more than 245 mg/L (reported as parts per million). The apparent direction of ground-water flow is northeastward, and a road-salt storage stockpile was located southwest of the well until it was moved in 1974.

The Connecticut Department of Transportation at present covers its salt stockpiles and places them on pavement. Runoff from the paved area is either collected and directed into retention basins to prevent it from reaching ground water, or is discharged into streams considered to have sufficient flow to adequately dilute it (Connecticut Department of Transportation, 1976?). Many towns also cover their salt piles and locate them in bins and on pavement. Some, however, continue to store salt, either separately or mixed with sand, in the open and directly on the land surface.

Road Salt in Ground Water

Salt applied to roads or leached from stockpiles enters the saturated zone as a solution containing chloride and sodium or other ions. Chloride ions move through the ground-water system unattenuated by adsorption, making chloride a good indicator of the rate and extent of movement. Sodium ions, on the other hand, may be exchanged for other ions by clay minerals in the soil. Although some attenuation of sodium is possible, it is limited by the mineralogy of the soils and aquifer materials. In Connecticut, minerals in the saturated zone adsorb few ions; decreases in concentration result primarily from dilution.

Alternatives to Present Practices

Accepting some snow on pavement during the winter, driving slower, and using chains or studded snow tires, are some of the ways to reduce the present use of road salt. Another alternative is to salt only major roads, hills, curves, and intersections. Secondary roads and level straight roads could be plowed but not salted. Salted and unsalted stretches of road could be designated and marked to minimize danger and inconvenience. Salt use can also be reduced by early and frequent plowing during a storm and by application under optimum conditions of relatively high temperatures and moderate to high flow of traffic (Connecticut Department of Transportation, 1978, oral communication).

Economical and environmentally safe chemical replacements for sodium chloride have also been considered by transportation agencies. Cal-salt, a mixture of calcium chloride and sodium chloride, is used in selected watershed areas and urea is used on runways at some airports in Connecticut. Sodium formate, tetra-potassium pyrophosphate, lithium chloride, and other substances were tried, but found unacceptable (Button and Kasinskas, 1975), because they are prohibitively expensive or do more environmental damage than sodium chloride. An alternative to the use of granular sodium chloride is being tested by the Connecticut Department of Transportation (Button and Kasinskas, 1975). A brine solution is sprayed under extremely high pressure on the snow and ice. The salt is already in solution and can begin to melt the snow immediately. Preliminary results indicate that this method could substantially reduce the amount of salt needed to keep roads free of snow.

Table 12.--Composition of typical municipal refuse in Connecticut[1/]

Category	Description	Percent by Weight
Glass	Primarily bottles	8.8
Metal	Cans, wire, foil	8.7
Paper	Various types, some with fillers	38.2
Plastics	From packaging, housewares, furniture, tags, and nonwoven synthetics	1.1
Leather, rubber	Shoes, tires, toys, etc.	1.5
Textiles	Cellulosic, protein, woven synthetics	2.0
Wood	Wood packaging, furniture, logs, twigs	2.7
Food wastes	Garbage	21.1
Miscellaneous	Inorganic ash, stone, dust	1.8
Yard wastes	Grass, brush, shrub trimmings	14.1

[1/] From Niessen and Chansky (1970)

Solid-Waste Disposal

Disposal of municipal solid wastes in Connecticut is primarily the responsibility of the individual towns. Landfills are the primary means of solid-waste disposal; they receive a variety of materials from domestic, commercial, institutional, power utility, and industrial sources. The average composition of typical domestic refuse collected in the State is given in table 12. Licensing and regulation of landfills is done through the Solid Waste Management Unit of the Connecticut Department of Environmental Protection. The Solid Waste Unit has authorized about 185 active landfills, and has issued permits for 91 of them to date (1978). Permits for landfills are issued only after completion of engineering site studies.

Per capita generation of solid waste is increasing as is the State's population, but the number of sites considered suitable for landfill disposal is decreasing. Locations of 250 current and former solid-waste disposal facilities and their proximity to favorable aquifers and to surface-water bodies are shown on a map produced for this study by Rolston, Pregman, and Handman (1978). The type of waste received, water-quality monitoring sites, and locations of known ground-water contamination are also shown. These landfill sites, located throughout the State, are all probable contamination sources, and 24 are reported by the Solid Waste Management Unit to have degraded ground-water quality, as documented by chemical analysis.

Landfill facilities can generally be classified as mixed waste, bulky waste and demolition debris (from buildings), and industrial-waste sites. About 185 sites are actively in use (Connecticut Department of Environmental Protection, 1978). Mixed-waste sites are primarily municipal or regional landfills and 67 out of 127 active in the State in 1978 are permitted by the Department of Environmental Protection. These wastes are required to be compacted and covered daily with a compacted layer of natural earth materials to reduce blowing litter, fires, and insects and animals. Upon completion, the landfill is covered with soil, graded to prevent erosion and ponding, and planted with an appropriate cover of vegetation. Vegetation further aids in erosion control and increases evapotranspiration, thereby reducing the amount of water reaching the refuse.

Bulky-waste and demolition-debris sites are designed for non-putrescible wastes from the demolition of buildings and other structures, debris from new construction projects, and wastes too large for disposal at mixed-waste sites. The Connecticut Department of Environmental Protection has permitted 23 bulky waste and demolition areas out of 38 authorized sites active in 1978. These wastes can not be considered "clean" fill, as ground-water quality has been affected at several sites, including those in Cromwell and Newtown.

Industrial landfills are operated by individual industries and are located both on and off the plant sites. As of 1978, the State has issued a permit for only one industrial site, in New Milford. For further discussion of industrial waste disposal practices, see the section of this report titled "Industrial storage and disposal".

The solid-waste facilities map (Rolston, Pregman, and Handman, 1978) also includes transfer stations and incinerators. Transfer stations are central points at which solid wastes are collected, reduced in volume by compaction, and transferred to a vehicle for removal to a landfill or incinerator. In 1978, 15 of the 18 in active use have State permits. Solid wastes are stored at these stations up to 48 hours.

Incinerators burn the combustible part of the solid wastes under controlled conditions. The residue, consisting mostly of ash, glass, and metals, has 5 to 25 percent of the original volume. It is commonly buried either on-site or at a nearby landfill. Most municipal incinerators in Connecticut have been closed and replaced with transfer stations.

Leachate that is produced when water comes in contact with refuse originates from the initial moisture in the solid wastes, from precipitation that infiltrates the cover material and percolates through the wastes, or from ground water where refuse has been deposited below the water table. Ground-water quality is affected when leachate from a disposal site reaches the water table, or is produced directly in the saturated zone. Leachate is produced at all Connecticut disposal areas, as none are lined or covered with impermeable material.

The composition of leachate differs depending on the composition of the wastes, the nature of the cover materials, the landfill design, the amount and source of water, and length of time it is in contact with the wastes. The range in concentration of constituents in leachates from several areas is shown in table 13.

The primary inorganic constituents of leachate can be divided into six major groups (Clark and Piskin, 1977). In descending order of concentration they are:

1. bicarbonate plus carbonate (total alkalinity)
2. sulfate
3. sodium plus potassium
4. calcium plus magnesium
5. chloride
6. iron plus manganese

Table 13.--Composition of leachate from landfills[1]
(Concentrations of chemical constituents in milligrams per liter)

Constituent	Range
Alkalinity (as $CaCO_3$)	0 - 20,850
Ammonia (NH_3, as N)	0 - 1,106
Biological oxygen demand (BOD)	9 - 54,610
Calcium (Ca)	5 - 4,080
Chemical oxygen demand (COD)	0 - 89,520
Chloride (Cl)	34 - 2,800
Cadmium (Cd)	0 - 9.9
Hardness (as $CaCO_3$)	0 - 22,800
Iron (Fe)	0.2 - 5,500
Lead (Pb)	0 - 5.0
Magnesium (Mg)	16.5 - 15,600
Manganese (Mn)	0.06 - 1,400
pH (units)	3.7 - 8.5
Phosphate (PO_4)	0 - 154
Potassium (K)	2.8 - 3,770
Sodium (Na)	0 - 7,700
Sulfate (SO_4)	1 - 1,826
Total dissolved solids	0 - 42,276
Total suspended solids	6 - 2,685
Zinc (Zn)	0 - 1,000

[1] Summary of compositions reported in literature, by U.S. Environmental Protection Agency (1973b).

Renovation (purification) of leachate before it reaches wells or discharges into surface-water bodies is desirable. To allow for maximum renovation, solid wastes are generally emplaced in the unsaturated zone where leachate movement is relatively slow. The Connecticut Department of Environmental Protection requires a minimum distance of 60 inches between the base of the solid wastes and both the estimated highest position of the water table and the bedrock surface. This enables the leachate to pass downward, under the influence of gravity, through a stipulated minimum thickness of unsaturated earth materials before it reaches the water table or bedrock. A site in which the solid waste is directly in contact with ground water has a much greater potential for contamination than one in the unsaturated zone.

Renovation occurs in the unsaturated zone primarily by aerobic biodegradation, filtration, adsorption, ion exchange, and precipitation and complexing of the organic and inorganic chemicals in the leachate. The effectiveness of these renovation processes depends on the amount and composition of the leachate and the thickness, physical properties, and mineralogy of the unconsolidated materials beneath the landfill. Biodegradation of organic materials and bacteria is common in the unsaturated zone. Removal of dissolved inorganic constituents is less complete because the materials beneath landfills have scant capacity for adsorbtion. In the saturated zone, where oxygen content is small, and under anaerobic conditions elsewhere, the degradation of organic compounds is less complete. Anaerobic conditions may also lead to solution of iron and manganese from sediments, and concentrations of these metals are generally high in landfill leachate.

In the saturated zone, the soluble constituents of leachate mix with ground water and are transported in directions governed largely by the hydraulic gradients. Dispersion, dilution, adsorption, and chemical reactions also control the concentrations of constituents in ground water. An irregular plume of leachate-contaminated ground water extends downgradient from the disposal site and moves slowly toward points of ground-water discharge. The plume may affect a considerable part of an aquifer if the discharge sites are distant. Furthermore, transport may be so slow that the full impact on water quality may not be realized for many years. When leachate is detected in a well or in surface waters to which the ground water is discharging, a substantial volume of contaminated or impaired ground water may exist.

Fine-grained stratified drift (predominantly very fine sand, silt, and clay) and till have low hydraulic conductivities and, under conditions of similar hydraulic gradient and moisture content, transmit water more slowly through the unsaturated zone than coarse-grained stratified drift (predominantly sand and gravel). The low rate of flow through fine-grained and poorly sorted materials allows more time for renovation before the leachate reaches the water table. Coarse-grained stratified drift, on the other hand, is a much less effective medium for leachate renovation. Leachate will pass through this material at higher rates and with less improvement in quality. Stratified-drift aquifers suitable for large-scale ground-water development are generally coarse grained, and, consequently, they are susceptible to contamination by leachate from landfills. Of about 185 active disposal sites, 80 are on stratified-drift and 20 are in public water-supply watersheds.

Ground water may become contaminated regardless of the material in which the landfill is constructed. Miller and others (1974), for example, discuss conditions at a 30-year-old landfill in southern Connecticut that covers 90 acres. The site is a wetland adjacent to Long Island Sound underlain by 40 to 60 feet of till overlying crystalline bedrock. The water table has risen as high as 8 feet into the bottom of the refuse, and approximately 80,000 gallons of leachate is produced each day. Several hundred million gallons of leachate-contaminated ground water exists in the vicinity of the landfill in an area at least 3,500 feet by 3,000 feet and to a depth of more than 60 feet. Chestnut and Holzer (1973) studied a landfill in eastern Connecticut on fine-grained stratified drift. Contamination of the upper part of the saturated zone was found in the vicinity of the landfill, and chloride concentrations exceeded background levels 2,100 feet downgradient.

Bedrock aquifers in Connecticut are also subject to contamination by leachate from landfills. Water is stored in and transmitted through fracture systems in the bedrock. These fractures are oriented in many directions and are generally larger and more numerous near the land surface. Ground-water movement through fractures is fairly rapid, decreasing opportunity for water-quality renovation. As a result, bedrock aquifers are highly susceptible to contamination if solid waste is emplaced near the bedrock surface. Many bedrock wells in the vicinity of the Weston town landfill, for example, have been contaminated by landfill leachate (Geraghty and Miller, 1973).

In a study of leachate movement beneath a landfill in Ohio, G. R. Kunkle and J. W. Shade (1976) state that:

"There appears to be no reliable method to predict the degree of leachate renovation. Therefore, it becomes imperative to implement a water-quality monitoring program in order to document base line conditions as a measure against any future degradation of water quality."

Accordingly, monitoring wells have been installed at all new and expanded landfill sites in Connecticut since 1975. A coordinated program of monitoring, begun in the fall of 1977 by the Connecticut Department of Environmental Protection, is planned to eventually include comprehensive and regular monitoring of ground-water quality in the vicinity of landfills. Landfills at which surface-water monitoring sites and wells have already been installed are indicated on the map by Rolston, Pregman, and Handman (1978), prepared for this study.

Engineering techniques have been used in Connecticut and elsewhere to control or reduce the effect of leachate on ground-water quality. For example, leachate production may be reduced at a site by use of cover materials that restrict infiltration of precipitation and impermeable liners that prevent or restrict leachate movement from the landfill area. Contaminated water can be removed from the saturated zone by pumping wells downgradient from a landfill. The water may then be treated before discharge, as is done in Enfield (Martin Associates, 1976). Such recovery and treatment systems can be costly and may not be fully effective (Miller and others, 1974, p. 218).

Industrial Storage and Disposal

Industrial chemicals are used and stored in many parts of Connecticut; unwanted byproducts of industrial production may also be stored temporarily or disposed of on company property. Planned discharge or inadvertent leakage from such storage sites constitute a nonpoint source of ground-water contamination.

Much of Connecticut's industry is concentrated in valleys areas along major streams and their tributaries. The map by Rolston, Handman, and Grossman (1978) shows that these valleys are also the sites of most known industrial-waste storage and disposal. For example, many sites are near the Housatonic River and its tributary, the Naugatuck, in the western part of the State; the Connecticut River and its tributary, the Farmington, in the central part; and the Thames River estuary and its two principal tributaries, the Quinebaug and Shetucket, in the east. The major streams generally flow southward and discharge to Long Island Sound. Smaller streams, such as the Quinnipiac River, have additional clusters of adjacent storage and disposal sites.

The major river valleys in the State are also the sites of the largest and thickest stratified-drift aquifers, the principal sources of large, sustained supplies of ground water. (See section titled "Aquifers".) These aquifers are susceptible to contamination not only because of their proximity to industry but also because of natural conditions, such as the generally shallow depths to the water table and the restricted areal extent, high transmissivity, and high infiltration rates of aquifers. The problem is compounded by improper industrial storage and waste disposal.

The industrial disposal sites shown on the map (Rolston, Handman, and Grossman, 1978) and summarized in tables 14 and 15 of this report are based largely upon information obtained from the Water Compliance Unit of the Connecticut Department of Environmental Protection. They represent primarily those sites that have come to the attention of the Water Compliance Unit since its establishment in 1973; most older abandoned sites are not documented.

The completeness of the tabulated information may be inferred by comparing it with detailed information collected in the Bridgeport, Hartford, and Waterbury areas in an ongoing "208" study of industrial sludge (Connecticut Areawide Waste Treatment Management Planning Board, 1977?). If the proportion of industrial disposal sites found in this study compared to the total number of sludge-producing industries in these areas is representative, about 1,000 industrial disposal sites exist Statewide. As previously indicated, this larger figure is itself incomplete because it largely excludes older disposal sites abandoned for more than 8 or 10 years.

Table 14.--Industrial disposal sites in Connecticut[1]

	Metals	Metals and solvents	Metals and others[2]	Solvents (only)	Solvents and others[3]	Others (no metals or solvents)	Metals, solvents and others	Unknown	Total
Number	90	17	27	25	7	94	11	64	335
Percent of total	27	5	8	7	2	28	3	19	99[4]

[1] Summary of known sites.

[2] Includes organic materials other than solvents.

[3] Other than metals.

[4] Percentages do not total 100 because of rounding.

Table 14 shows that 35 percent of the industrial disposal sites (cols. 1 and 3) contain metals (generally metal hydroxides) or metals and organic wastes (excluding solvents). About 28 percent (col. 6) contain neither metals nor solvents, and 9 percent consist of solvents or solvents mixed with other nonmetals (cols. 4 and 5). The solvents are largely, if not entirely, liquid organic chemicals.

The susceptibility of ground water to contamination from industrial disposal differs in the various hydrogeologic units, as discussed in table 2. Table 15 groups 335 industrial disposal sites on the basis of regional bedrock geology. Generalized bedrock geology is shown in figure 4 and on the map by Rolston, Handman, and Grossman (1978). The limey carbonate rocks in the western part of the State are small in areal extent but are significant because of their capacity to neutralize or buffer acid solutions. Some of the sedimentary rocks in the central part of the State contain a limey carbonate cement, which is also capable of neutralizing acid solutions. In contrast, most of the sedimentary rocks and igneous rocks interbedded with them contain few or no carbonate minerals. The crystalline rocks in the eastern and western parts of the State are similar in their mineralogy. They generally lack carbonate minerals and have little capacity to neutralize acid wastes.

In most of Connecticut, the bedrock is covered by glacial deposits of varying composition and thickness. The mineralogy and chemical properties of these deposits are similar to the underlying rocks from which they are largely derived. The unconsolidated deposits overlying the carbonate bedrock in western Connecticut and the sedimentary bedrock in the central part of the State contain carbonate minerals and probably

Table 15.--Distribution of industrial disposal and storage sites, in relation to regional bedrock geology[1]

Disposal sites	Type of bedrock					Total
	Carbonate rocks (marble, limestone and dolomite)	Crystalline rocks (noncarbonate)	Sedimentary and associated rocks	Crystalline rocks (noncarbonate)	Unknown or uncertain	
Location in State	Extreme west	Western highland	Central lowland	Eastern highland	Statewide	Statewide
Number	19	76	96	136	8	335
Percent of total[2]	5.5	22.5	28.5	40.5	2.5	99.5

[1] See figure 4 for distribution of geologic units

[2] Rounded to nearest 0.5 percent

Table 16.--Selected occurrences of industrial contamination of ground water in Connecticut

Location[1] (Town)	Contaminant	Hydrogeologic units at site	Approximate horizontal distance travelled (ft)	Affected locality or facility	Date detected (year)	Reference	Remarks
Bethel	Phenols, chemicals, salts	Stratified drift overlies carbonate bedrock	--	Three industrial wells	1964	DEP[2]	Also affected water in a public supply well field.
Bristol	Acid waste from brass fabrication	Stratified drift overlies sedimentary bedrock	--	Four wells	--	LaSala (1964, p. 54)	Analyses show high copper, zinc and iron content of ground water and low pH. Corrective measures taken to protect wells from further contamination.
Bristol	Metallic wastes and sewage	Stratified drift overlies sedimentary bedrock	--	Group of wells	--	LaSala (1964, p. 55)	Analyses of water from two wells of a larger group indicate possible contamination. High iron and manganese reported.
Canterbury	Solvents and other organic materials	Stratified drift overlies crystalline bedrock	--	Local ground water	1978	DEP[2]	No wells affected.
Canton	Trichloroethylene, methylethylketone, and other solvents	Stratified drift overlies crystalline bedrock	--	Wells	1973	DEP[2]	Possible contamination of wells resulting from accidental spill of chemicals.
Durham	Chlorinated hydrocarbons (waste solvents)	Till overlies sedimentary bedrock	500	School well	1969	Miller and others(1974, p. 155)	Reference augmented by field data. Foul taste and odor reported. Exact location of contamination source unknown.
East Granby	Chlorinated hydrocarbons (solvents)	Stratified drift overlies sedimentary bedrock	--	Well	--	DEP[2]	Contamination from chemical waste storage area.
East Granby	Chlorinated hydrocarbons (solvents)	Stratified drift overlies sedimentary bedrock	--	Well	--	DEP[2]	Contamination from a spill.
Essex	Mixed solvent	--	--	Local ground water	1976	Connecticut Department of Environmental Protection (1977)	Industrial discharge. Exact location not reported.
Essex	Solvents	Stratified drift overlies crystalline bedrock	--	Local ground water	--	DEP[2]	Detected during excavation for a septic system. Source unknown.
Franklin	Organic waste	Till overlies crystalline bedrock	--	Domestic well	--	DEP[2]	Chicken manure and egg processing waste.
Ledyard	Styrene	Till overlies crystalline bedrock	110	Six wells	1961-64	Grossman (1970, p. B203)	Styrene, aromatic hydrocarbon, weathered in part to polystyrene. Obnoxious odor reported.

Table 16.--Selected occurrences of industrial contamination of ground water in Connecticut--Continued

Location[1] (Town)	Contaminant	Hydrogeologic units at site	Approximate horizontal distance travelled (ft)	Affected locality or facility	Date detected (year)	Reference	Remarks
Ledyard	Hydrocarbons (See remarks)	Stratified drift overlies crystalline bedrock	9,000 (?)	About ten wells	1965	Letter to State Water Resources Commission (Nov. 22, 1965), and company official (1977, oral communication)	Contaminants reportedly hydrocarbon and other unknown biochemical waste products. Discoloration reported. Public supply well replaced contaminated wells.
Manchester	Chlorinated hydrocarbons (solvents)	Stratified drift overlies sedimentary bedrock	100	Wells	--	DEP[2]	Solvent storage area located about 100 ft from well.
Newtown	Cyanide	Till (?) overlies crystalline bedrock	1,500	Four wells	--	DEP[2]	Cyanide spill; probably from tank truck.
Plainfield	Organohalides: trichloroethane, trichloromethane, trichloroethelyne, chlorobutane, carbon tetrachloride, toluene, methylene chloride, and tetrachloroethylene	Stratified drift overlies faulted crystalline bedrock	1,200 -2,000	Public-supply well and a few industrial wells	1975-76	Duplicated memorandum from Connecticut Department of Environmental Protection (1976)	Odor complaints reported. For details on supply well PL 33, see Thomas and others (1966, p. 24, 30). Public supply well and industrial wells are in bedrock.
Plainfield	Solvents and other organic materials	Stratified drift overlies crystalline bedrock	1,000	Local ground water	1978	DEP[2]	Industrial disposal site. No wells affected.
Plainville	Metallic industrial wastes	Stratified drift (?) overlies sedimentary bedrock	--	Industrial water supply	--	LaSala (1964, p. 54)	Contamination from sludge pits among factors causing six-well supply to be abandoned.
Plainville	Detergents	Stratified drift overlies sedimentary bedrock	1,400	Two public-supply wells	1958	LaSala (1964, p. 55)	Foaming reported. One public-supply well temporarily shut down.
Plainville	Organohalides: carbon tetrachloride, trichloromethane, tetrachloroethylene, trichloroethylene, acetone, trichloroethane, methylene chloride, chlorobutane and toluene	Stratified drift overlies sedimentary bedrock	1,000	Two public-supply and four industrial wells	1975	Duplicated memorandum from Connecticut Department of Environmental Protection (June 24, 1976)	No noticeable odors or discoloration reported. For details on public-supply wells, see Mazzaferro (1973, p. 12). Public supply wells tap stratified drift.
Prospect	Solvent	Stratified drift (?) overlies crystalline bedrock	100	Well	1976	DEP[2]	Solvent released by rupture of underground tank.
Somers	Heavy metals	Stratified drift overlies sedimentary bedrock	--	Well	--	DEP[2]	Contamination from disposal of metal finishing wastes in lagoons.
South Windsor	Solvents	Stratified drift overlies sedimentary bedrock	--	Wells	--	DEP[2]	Contamination from spills on sandy ground.
Southington	Chromates	Stratified drift overlies sedimentary bedrock	1,000	Industrial wells	1969	Miller and others (1974, p. 155)	Analysis showed water contained as much as 26 mg/L of chromate. Yellow color reported. Source was metal plating wastes in waste lagoon.
Southington	Solvents	Stratified drift overlies sedimentary bedrock	2,000	Public-supply and test wells	1976	DEP[2]	Disposal lagoon abandoned.
Southington	Waste oil	Stratified drift overlies sedimentary bedrock	500	Public-supply well	1978	DEP[2]	Well abandoned.
Waterford	Industrial waste	Stratified drift overlies crystalline bedrock	--	Local ground water	1976	Connecticut Department of Environmental Protection (1977)	Dumping in gravel pit stopped. Exact location not reported.
Watertown	Metals, cyanide	Stratified drift (?) overlies crystalline bedrock	--	Spring	--	DEP[2]	Contamination from lagoon.
Weston	Hydrocarbon wastes	Till overlies crystalline bedrock	500	School well	--	Oral communication, consultant, October, 1977	Wastes dumped on neighboring property.
Windsor Locks	Enamel solvents, kerosene, glue	Stratified drift overlies sedimentary bedrock	600	Well	1966-71 (?)	DEP[2]	Methyl isobutyl ketone reported.

[1] Location of known disposal sites is shown by Rolston, Handman, and Grossman (1978).

[2] Unpublished data from files of Connecticut Department of Environmental Protection, Water Compliance Unit.

have a greater potential for neutralizing acid wastes than similar deposits elsewhere.

The on-site storage or disposal of industrial wastes in Connecticut has resulted in at least 30 reported cases of ground-water contamination from 1955 through 1978. The way in which these wastes reach the saturated zone, the processes of renovation, and the mechanisms of transport in flowing ground water are generally the same as outlined for leachate in the previous section. Of the 169 towns in Connecticut, only 21 are known to have documented cases of ground-water contamination from these sources. Table 16 lists the locations by town, of each case together with other relevant data. Many (8) are in the Bristol-Plainville-Southington area. Few cases have been reported in the major heavily industrialized areas served by public supplies, probably because most use surface-water sources that are comparatively far away. The general abandonment and destruction of wells in many metropolitan areas also result in less frequent sampling of ground water. Where urban pumping is heavy, the water is commonly used for cooling and dewatering and it is less likely to be analyzed. These conditions may explain why most of the cases documented in table 16 are in rural areas or small to intermediate-sized industrial areas.

Agricultural Wastes and Chemicals

The quality of ground water can be adversely affected by agricultural practices under some conditions. Runoff and infiltration at sites of application or storage of manure, fertilizers, pesticides, and herbicides may introduce chemicals into water bodies. The transport of agricultural contaminants to the water table and within the saturated zone are illustrated in many reports, for example, LeGrand (1970), Runnells (1976), and Garrett and others (1975). The concentration of these substances in the saturated zone depends on many factors, including the initial concentration and volume; solubility and rate of degradation under prevailing conditions; specific gravity and adsorption characteristics; amount, rate, and origin of recharge; physical properties and composition of soil and unconsolidated deposits; slope of the land surface; depth to water table; and characteristics of the ground-water flow system. The susceptibility of various hydrogeologic units to contamination is discussed in table 2.

Contaminants observed at any sampling point (well, spring, or stream) may originate from local or distant sources. Usually local sources, such as storage sites, are easier and less costly to identify than distant ones or where a chemical is applied over a wide area of a basin. Several sources may each contribute and create a complex problem. For example, some areas in the upper Connecticut River Valley have high nitrate concentrations in the ground water and surface water (U.S. Geological Survey, 1969; 1970). Several possible sources have been identified, including dairy farms, tobacco fields, chicken farms, landfills, and septic systems in residential developments. All probably have contributed to some degree, and the additive effect is widespread.

A map prepared by Bingham and Todd (1979) is intended as a guide to assessing areas where nonpoint source contamination from agriculture is most likely. Ground-water contamination may originate from the distribution, storage in stockpiles, accidental spilling, or application of manure, chemical fertilizers, herbicides, and pesticides. These activities are not restricted to cropland. Consequently, all farmland, including farm yards, barn yards, and pastures, as well as cropland, is combined on the map.

Stockpiles or spills of manure, fertilizers, or pesticides are localized; any resulting contamination can usually be detected by analyzing ground-water samples collected from downgradient sites. "Intentional spills", where users of agricultural chemicals dump excess mixtures or wash their equipment, may cause more problems than accidental spills. After repeated discharges at the same sites, enough chemicals may accumulate to degrade the underlying soil and ground-water quality.

Livestock and poultry manure affects water quality primarily at storage sites where runoff and infiltration are uncontrolled. The U.S. Department of Agriculture (1974) reports nearly 5 million livestock and poultry in the State. Table 17 shows distribution of livestock, by county. Dairy and poultry farms produce the most manure; each dairy cow produces about 90 pounds per day. In the past, farmers stockpiled

Table 17.--Agricultural land use, livestock, and use of agricultural chemicals in Connecticut during 1974
(Data from U.S. Dept. of Agriculture, 1974)

	Fairfield County	Hartford County	Litchfield County	Middlesex County	New Haven County	New London County	Tolland County	Windham County	State
Acres of:									
Farmland	18,213	77,112	100,085	19,899	34,373	79,382	42,086	68,906	440,056
Harvested cropland	6,677	33,664	34,507	7,268	13,831	23,557	14,374	25,279	159,157
Irrigated cropland	194	5,752	122	241	755	65	314	31	7,474
Acres of crops:									
Corn	1,256	6,595	9,988	1,608	3,013	8,433	6,986	12,883	50,762
Tobacco	0	4,715	0	157	0	0	84	0	4,956
Vegetable (including potatoes)	814	5,419	451	217	1,738	937	664	227	10,467
Fruit (including berries)	380	2,098	530	443	1,526	442	280	494	6,193
Other (including hay)	4,391	15,395	25,125	5,023	8,093	14,534	6,581	12,880	92,022
Livestock (number)									
Cattle	2,844	12,299	22,796	3,562	7,599	17,114	11,814	20,912	98,940
Horses	445	431	689	459	361	322	180	283	3,170
Sheep	208	465	900	172	699	551	479	785	4,259
Hogs	190	1,572	361	302	1,240	2,208	592	1,056	7,521
Poultry	55,155	249,603	129,805	427,767	219,783	1,715,409	333,858	1,792,681	4,924,061
Agricultural Chemicals:									
Commercial fertilizer									
Acres	3,080	26,958	18,281	3,688	8,197	13,933	11,167	18,636	103,940
Tons	924	18,707	4,323	1,342	2,972	3,622	3,923	4,814	40,627
Tons/acre	0.30	0.69	0.24	0.36	0.36	0.26	0.35	0.26	0.39
Sprays (insecticides, fungicides, and herbicides)									
Acres	2,735	29,023	8,740	3,433	7,233	8,904	7,395	13,254	80,725

manure in the barnyard without controlling runoff or limiting infiltration. As a result, nutrients and bacteria entered streams and aquifers. In recent years, a Federal and State program has encouraged and assisted farmers in constructing lined manure-storage pits or lagoons. The U.S. Agricultural Stabliization and Conservation Service and the Connecticut Cooperative Extension Service estimate that 52 percent of Connecticut dairy farms and 19 percent of other livestock farms (poultry, hog, beef, sheep, and horse) need pollution abatement structures (Wadsworth, 1976?). Those installed as of 1978 are shown on the companion map (Bingham and Todd, 1979). The pits and lagoons are designed to prevent or retard runoff and infiltration, thus retaining the nutrients for distribution on cultivated fields. These practices could also be used at holding yards for packing plants, where the volumes of manure are smaller but potentially detrimental to water quality.

Another source of water contamination on farms is the application of fertilizers and pesticides. Table 17 shows amounts of these chemicals used, by county. Insets on the map prepared for this study (Bingham and Todd, 1979) show the acres used for various crops, the acres of cropland receiving commercial fertilizers and pesticides, and the number of pounds of restricted-use pesticides sold by county in 1976. The information on restricted-use pesticides is from files of the Water Compliance Unit of the Connecticut Department of Environmental Protection. It includes 90 types sold to private applicators (excluding exterminators). Individual strength, toxicity, and place of application of each pesticide have not been documented.

Many types of organic and inorganic crop fertilizers are used in Connecticut. The organic fertilizers include manure, cover crops, and meals (such as cotton seed and fish meals). Manure reportedly causes few water-quality problems after being spread on fields because the nitrogen tends to be chemically attached to organic materials and leaches into the ground slowly. Similarly, the cover crops (principally legumes such as alfalfa, vetch, and rye grasses) and meals provide nitrogen and mulch for crops, but the nitrogen, in general, is not readily dissolved by precipitation. Consequently, cover crops and meals may not be major sources of high nitrogen concentrations in ground water (de Roo, 1958). On most farms, organic fertilizers supply less than half the nitrogen the crops require. Inorganic fertilizers, which supply most of the nitrogen needs, are more commonly associated with ground-water contamination.

Tobacco, a major crop in the Connecticut River Valley, requires high rates of fertilizer application that have contributed to increased nitrate concentrations in ground water in the Thompsonville and Hazardville sections of Enfield and in parts of East Windsor and western Glastonbury (L. A. Weiss, U.S. Geological Survey, 1978, written communication). Table 17 shows that fertilizer use, in tons per acre, is about twice as high in Hartford County, where most of the tobacco is grown, than in other parts of the State.

Excessive application rates and poor timing of application of fertilizers with regard to crop needs can affect water quality (Baier and Rykbost, 1976). When liquid nitrogen or high nitrate compounds are applied to fields before seeding and in quantities large enough to supply the total crop needs for the season, most of the nitrogen may be leached before the crop can use it. Overfertilization of suburban lawns and golf courses may have similar results, but leaching of nitrate under grassland is small compared to that under croplands, even at higher levels of fertilization (Steenvoorden, 1976, p. 54). To prevent leaching of nitrate before it is taken up by crops, new application practices have been recommended, including supplying crop nitrogen demands at intervals during the growing cycle in addition to planting time, and preferably by side dressing (Baier and Rykbost, 1976). This makes the nitrogen available for plant use at the proper time and reduces the period in which the nitrogen is susceptible to leaching and transport below the root zone.

Thousands of kinds of pesticides are used, and the fate of most of these compounds after distribution is unknown or difficult to predict. The persistence of such compounds is discussed by Garrett and others (1975). They report that some pesticides, such as DDT, maintain their potency for more than 20 years, whereas others may decay in hours to months, depending on the environment. Pesticides may not be harmful by the time they reach the saturated zone because they generally have low solubilities, and change in strength by dilution and dispersion, filtration, adsorption, and chemical reactions in the unsaturated zone (Garrett and others, 1975). However, some persistent compounds reach the water table virtually unchanged in composition. In such cases, the concentrations of the contaminants in ground water depend on the local environment within the saturated zone. An example of pesticide contamination of a domestic well and a school well in Middlefield in 1966 was reported by Miller and others (1974, p. 283). Thallium, probably applied as an insecticide, seeped into a sedimentary bedrock aquifer at shallow depths and moved downgradient through the fractures and joints. Wells as far as 2,000 feet away were affected.

CONCLUSIONS

The information on nonpoint sources of ground-water contamination and their locations discussed in this report provide a broad overview of the extent of the problem in Connecticut. It is intended to aid State and local agencies in developing "208" water-quality management plans.

Although the overall quality of Connecticut's ground water is good, human activities have changed this quality locally in all parts of the State. In most reported cases of contamination, only small areas are apparently affected. If present waste-management and chemical storage and application practices continue, however, and as population and development increase, the number of occurrences, the areal extent, and the severity of ground-water impairment will also increase. The sites of known and potential contamination identified in the course of this study and shown on the companion maps are probably a small part of the total.

Most of the changes in ground-water quality in Connecticut are produced by the following nonpoint sources: individual septic systems in areas of high population density, leaks and spills of petroleum products, storage and application of road salts, disposal of solid wastes and industrial sludges, infiltration of contaminated or salty surface water, and improper storage or use of agricultural chemicals. These sources are all known to have adversely affected ground-water quality in aquifers within the State. The number of occurrences and the severity of contamination vary from one nonpoint source to another and within each category.

Stratified-drift aquifers that have favorable hydrologic characteristics are the most likely sources of future public and industrial water supplies, but are highly susceptible to contamination from nonpoint sources. These aquifers underlie valleys that are commonly extensively developed; ground water in many has already been degraded.

Contaminated ground water is commonly slow to improve in quality through natural processes, such as dilution, adsorption, and dispersion, and discharge from the saturated zone may take a long time. Consequently, water of poor quality may persist for years, often undetected but potentially harmful. Further, the affected ground water may be physically or economically impossible to remove or improve in a reasonable period of time. Predicting future concentrations of contaminants within an aquifer may be costly and technically difficult or infeasible. A well-designed surveillance system for these and other aquifers would futher define the scope of water-quality problems and facilitate action to prevent additional impairment. Appropriate management programs for ground-water development and compatible waste disposal, based on hydrologic data, can help to reduce or prevent undesirable impacts on water quality.

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