Sewage Plume in a Sand and Gravel Aquifer, Cape Cod, Massachusetts

United States Geological Survey Water-Supply Paper 2218

Prepared in cooperation with the Massachusetts Department of Environmental Quality Engineering Division of Water Pollution Control

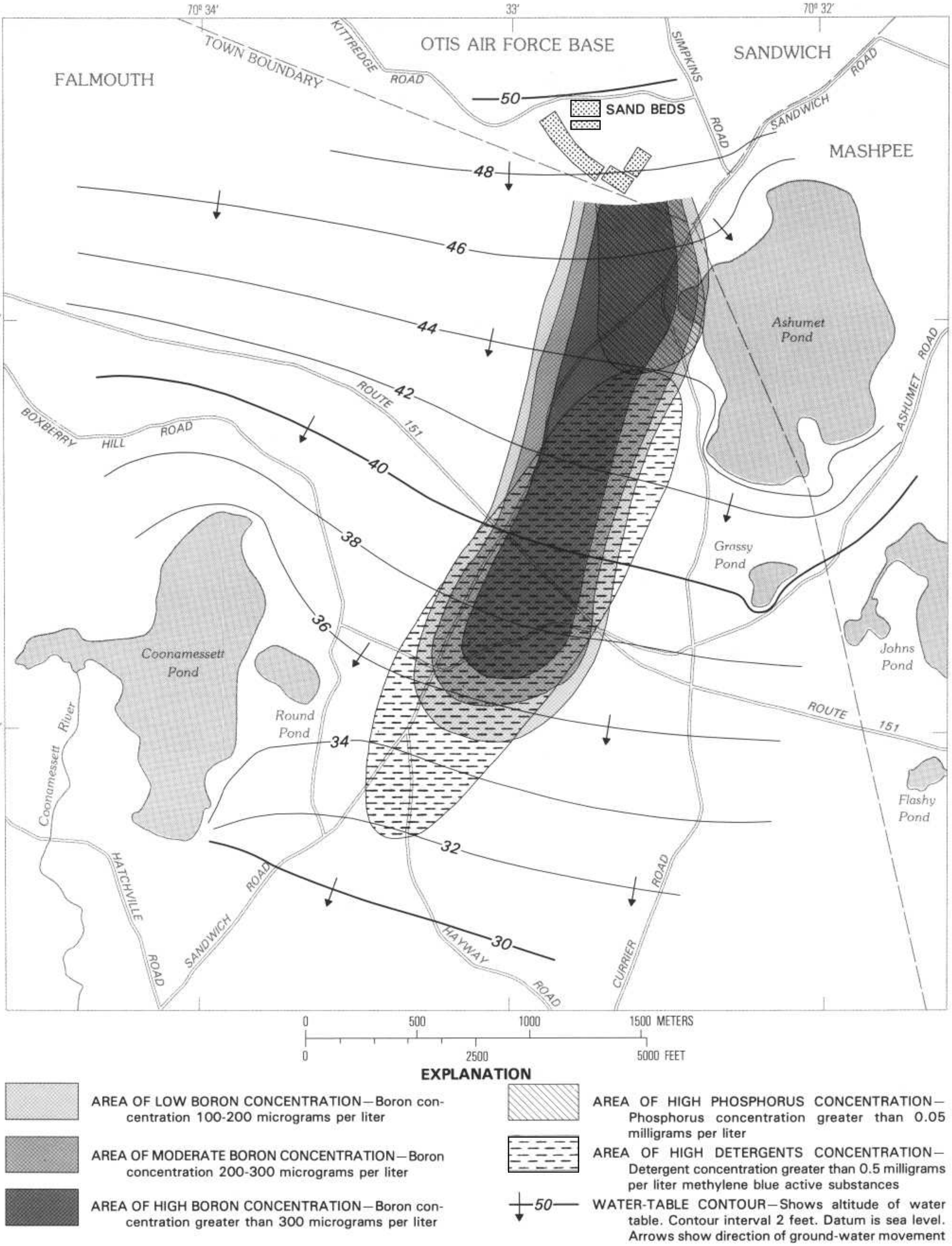

Figure 16. Relationship between the water table and the distributions of boron, phosphorus, and detergents in the plume.

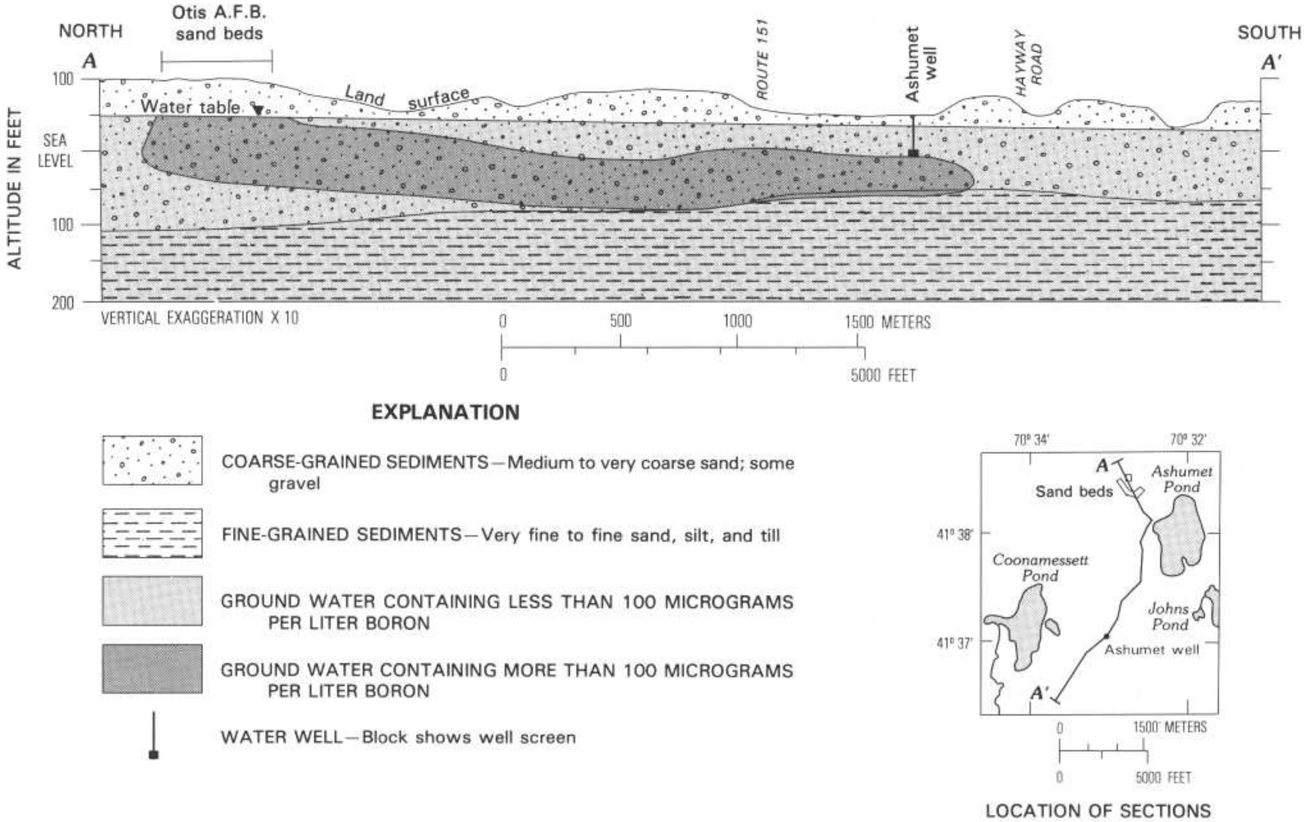

Figure 17. Vertical location of the plume as shown by the distribution of boron in ground water.

Vertical Location of the Plume

The plume is contained almost entirely in the sand and gravel (fig. 17). The bottom of the contaminated zone coincides with the boundary between the permeable sand and gravel and the less permeable fine-grained sediments. The nearly horizontal flow of ground water through the sand and gravel transports the contaminants by advection through this permeable zone of the aquifer.

The plume is overlain by 20 to 50 feet of uncontaminated ground water (fig. 17). The depth to the top of the plume below the water table generally increases with increasing distance from the sand beds, especially within 5,000 feet of the beds. The primary source of the uncontaminated ground water above the plume is the addition of recharge from precipitation along the path of the plume. The ground water above the plume contains as much as 11 mg/L dissolved oxygen, which suggests that it is derived from precipitation that has recently recharged the aquifer. Downward displacement of the contaminated zone also may be caused in part by vertical movement of contaminated ground water at the disposal site and by a small density difference between the contaminated and uncontaminated ground water which would cause the plume to sink into the aquifer (Kimmel and Braids, 1980, p. 31–32). The contribution of these two factors to the observed depression of the plume cannot be determined from available data.

The impact of the plume on the quality of ground water discharging to wells and surface-water bodies is related in part to the vertical location of the contaminated zone. Some domestic-supply wells are located directly over the plume. These wells usually do not penetrate more than 15 feet below the water table, however, and they generally are pumped at low rates (100 to 600 gal/d). Therefore, these wells, although located along the path of the plume, tap the uncontaminated ground water overlying the plume (fig. 17). Because most domestic-supply wells are screened above the plume, the collection and analysis of water samples from private wells performed in phase 2 of the study (table 1) did not detect the contaminated zone. Domestic wells drilled deeper into the aquifer, however, may tap the plume.

Wells screened above the plume that are pumped for sustained durations at higher rates may induce vertical movement of the contaminated water up and into the well. This process is affected by the distance between the well screen and the plume and by the duration and rate of pumping. For example, a large-capacity well is located 8,000 feet from the sand beds along the path of the plume. The well, known as the Ashumet Well (fig. 17), is part of the public water-supply system of the town of Falmouth. The screen of the well is 10 feet long and is set above the center of the plume. In January 1979, water from the well contained 0.9 mg/L detergents after the well had been pumped continuously at 0.75 Mgal/d during most of the previous summer, fall, and early winter. The well was shut down on June 10, 1979, due to the detergents in the water; the U.S. Environmental Protection Agency recommended concentration limit for detergents (foaming agents) in drinking water is 0.5 mg/L MBAS (U.S. Environmental Protection Agency, 1979, p. 42198). The detergent concentration of the water subsequently decreased to 0.6 mg/L after 45 days, 0.4 mg/L after 291 days, and 0.3 mg/L after 451 days from the shutdown. Although this decrease could have been caused by other reasons, the plume probably was drawn up into the well during the prolonged pumping and returned to its original position after pumping ceased.

Several ponds along the path of the plume (fig. 8) are connected hydraulically to the aquifer and receive ground-water discharge during all or part of the year (R. S. McVoy, Massachusetts Division of Water Pollution Control, written commun., 1981). Ashumet Pond, for example, is located 1,700 feet from the sand beds. Field evidence indicates that ground water discharges into the pond along its northwestern shore. The specific conductance of ground water (fig. 8) shows that the path of the plume intercepts the pond along this part of the shore. However, chemical analyses of water samples collected from three wells located along the northwestern shore of the pond show that the top of the plume at this location is more than 10 feet below the water table and the center of the plume is 40 to 50 feet below the water table. Therefore, the uncontaminated ground water overlying the plume (fig. 17) may be the source of discharge to the pond, and most or all of the contaminated ground water may pass beneath the pond bottom.

Path of the Plume

The dissolved substances in the plume from the Otis AFB sewage treatment facility are moving south and southwest (fig. 18). Although samples of the plume were not collected farther than 2.1 miles (11,000 feet) from the sewage treatment plant during this study, the regional water-table map shows that the contaminated ground water moves toward the downstream end of the Coonamessett River and toward other small streams, ponds, wetlands, and saltwater bays east of the river. Delineation of the path of the plume farther than 2.1 miles from the sand beds would require the drilling of additional wells, and the collection and analysis of additional water samples.

Positive identification of the contaminated ground water after it has traveled more than 2.1 miles from the sand beds or as it discharges to surface-water bodies in southern Falmouth may be difficult for two reasons. First, dilution of the contaminated ground water by hydrodynamic dispersion makes it increasingly difficult to distinguish the plume from the surrounding, uncontaminated ground water as the distance from the sand beds increases. Second, contaminants from the treatment facility may be difficult to differentiate from dissolved substances added to ground water from other sources in developed areas in southern Falmouth such as road salts, fertilizers, and domestic wastewater.

The present path of the plume is alined with the regional pattern of ground-water flow (fig. 18). Large-scale ground-water development that changes the direction of ground-water flow also will affect the path of the plume. This development includes pumping for water supply and land disposal of wastewater. Although the Ashumet Well is the only public-supply well in the path of the plume, several potential well sites identified by the town of Falmouth are located along or adjacent to the path of the plume (Richard Witt, Falmouth Department of Public Works, oral commun., 1981).

SUMMARY

A plume of contaminated ground water has been formed by 45 years of disposal of treated sewage to a sand and gravel aquifer at Otis AFB. The secondarily treated sewage is recharged to the aquifer by rapid infiltration through sand beds. The plume extends more than 11,000 feet south and southwest of the sand beds in the same direction as the regional flow of ground water, and is 2,500 to 3,500 feet wide and 75 feet thick. The plume is contained primarily in the 90- to 140-foot-thick permeable sand and gravel that overlies less permeable fine-grained sediments. The plume is overlain by 20 to 50 feet of uncontaminated ground water. The source of the overlying uncontaminated ground water is recharge from precipitation along the path of the plume.

The lateral and vertical extent of the plume was delineated as far as 11,000 feet downgradient of the sand beds. The location of the plume beyond this point was not determined directly by field observations during this study. However, the regional water-table map shows that the contaminated ground water moves toward the downstream end of the Coonamessett River and small streams, ponds, wetlands, and saltwater bays east of the river.

The path and hydrochemistry of the plume is shown by the distributions in the aquifer of 11 physical properties and chemical constituents: Specific conductance, temperature, boron, chloride, sodium, phosphorus, nitrogen, ammonia, nitrate, dissolved oxygen, and detergents. The distributions of these properties and chemicals in the aquifer were determined by chemical analysis of water samples

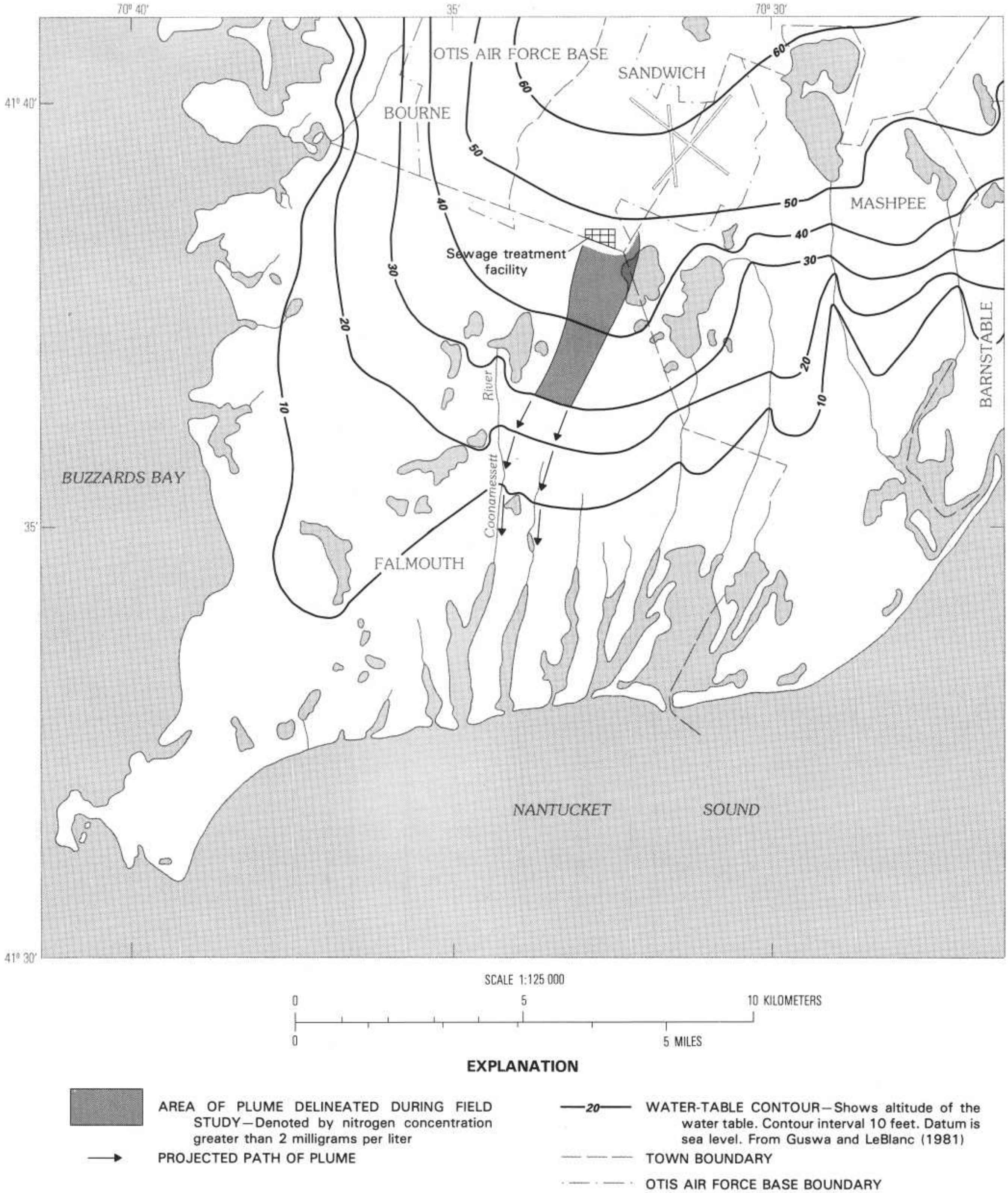

Figure 18. Area and projected path of plume of ground water contaminated by land disposal of treated sewage at Otis Air Force Base.

collected from 66 wells during May 1978 through May 1979.

The specific conductance of ground water in the plume is as high as 405 micromhos per centimeter. The conductance of uncontaminated ground water in the study area generally is less than 80 micromhos per centimeter. The concentrations of boron, chloride, sodium, phosphorus, total nitrogen, ammonia, nitrate, and detergents are higher in the contaminated ground water than in the uncontaminated ground water. The distributions of these substances in the plume are related to the processes that affect the movement of contaminants in the aquifer (advection, hydrodynamic dispersion, and chemical reactions) and to changes in the chemical composition of the treated sewage.

Boron, chloride, and sodium move readily in the aquifer and appear to be attenuated primarily by hydrodynamic dispersion. The movement of phosphorus is greatly restricted, however, by sorption on the sediments. Ammonia in the plume is oxidized to nitrate as the contaminated ground water mixes with uncontaminated ground water containing up to 11 mg/L dissolved oxygen. Concentrations of detergents exceed 0.5 mg/L MBAS from 3,000 feet to 10,000 feet downgradient of the sand beds. The high concentrations of detergents in this zone reflect the use of nonbiodegradable detergents in the United States between 1946 and 1964.

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