

IC 9343

The Material Flow of Salt

By Dennis S. Kostick



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Information Circular 9343

The Material Flow of Salt

By Dennis S. Kostick

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THE MATERIAL FLOW OF SALT

By Dennis S. Kostick¹

ABSTRACT

Salt is a universal mineral commodity used by virtually every person in the world. Although a very common mineral today, at one time, it was considered as precious as gold in certain cultures. This study traces the material flow of salt from its origin through the postconsumer phase of usage. The final disposition of salt in the estimated 14,000 different uses, grouped into several macrocategories, is traced from the dispersive loss of salt into the environment to the ultimate disposal of salt-base products into the waste stream after consumption. The base year for this study is 1990, in which an estimated 196 million short tons of municipal solid waste was discarded by the U.S. population. Approximately three-fourths of domestic salt consumed is released to the environment and unrecovered while about one-fourth is discharged to landfills and incinerators as products derived from salt. Cumulative historical domestic production, trade, and consumption data have been compiled to illustrate the long-term trends within the U.S. salt industry and the cumulative contribution that highway deicing salt has had on the environment.

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INTRODUCTION

This study is one of a series of reports by the U.S. Bureau of Mines that examines the physical movement of a mineral from the time it has been mined to the point after it has been consumed. What happens to this mineral after consumption is the main focus of this report. Minerals are not renewable resources, and, once a mineral is converted into usable consumer products, its significance is often forgotten, but not its identity. The world has a finite quantity of mineral resources to sustain the consumption requirements of the growing world population; therefore, we need to investigate how much of a particular mineral is dispersed to the environment and is permanently lost after usage, how much may be recycled, and how much is incorporated into consumer products that become discarded after use. This "cradle-to-grave" cycle or material flow goes beyond the traditional analysis of the supply-and-demand balance for a mineral; it includes a postconsumption evaluation as well.

Anyone who has ever visited the seashore instantly becomes aware of the presence of salt. You can taste it in the air and see thin films of it deposited along the seashore. Every day we are reminded of its utility because almost every house in the world has a saltshaker somewhere near the kitchen table. Salt is a universal commodity that is consumed by virtually every human being and animal on Earth. Whereas the names of many ferrous, nonferrous, and industrial minerals are unfamiliar

to many people, salt is easily recognizable by its distinctive taste and daily usage. Although salt was considered to be as precious as gold a long time ago, it is one of the most common materials used by all cultures today. Almost every nation has some form of salt resource, but there are widespread differences among countries on the uses of salt, depending on the state of cultural and industrial development. Therefore, a materials flow study could be done for different countries with varying interpretations and results. In this report, only the material flow of salt in the United States will be studied.

The supply-and-demand data in this report are derived primarily from annual Bureau of Mines "Minerals Yearbook" chapters on salt containing data supplied voluntarily by the domestic salt industry. Historical salt production data are available from 1797, and reported end-use consumption statistics begin in 1940. Import and export data on salt trade are available from 1797 and 1790, respectively. All these historical data are used to show the changes in salt consumption patterns over time and the cumulative quantity of salt produced and dispersed through consumption. Because there are ongoing changes in production and processing technology and end-use consumption trends, material flow studies are best understood when examining the factors that influence material flow for a single year. This study will focus on the domestic flow of salt in 1990.

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Bertram, Technical Director, Salt Institute; Mr. Lee Zengurski, Marketing Analyst, Occidental Chemical Corporation; and Mr. Wally Clark, independent consultant on the world salt industry. Their collective comments and reviews were incorporated into this report.

BACKGROUND

The term "salt" has different meanings and definitions to different people. Chemically, salt is a generic term given to any one of a class of similar compounds formed when all or part of the hydrogen ions of an acid are replaced with a metal or a metallic radical. Salt also is the specific chemical name given to sodium chloride. In this study, salt and sodium chloride are synonymous and interchangeable terms. Salt is composed of 40% sodium and 60% chlorine, by weight.

Minerally, salt is known as halite, from the Greek word "hals" for salt. Halite occurs as isometric crystals with perfect cubic cleavage. It has a hardness of 2.5 on the Mohs scale. It is a very stable mineral when pure, but

becomes deliquescent if the salt contains any impurities, such as calcium chloride or magnesium chloride. Salt is water soluble and is an excellent conductor of heat.

Geologically, salt is found in almost every country in the world. The oceans are the largest resource, containing about 46 quadrillion short tons of salt. Continental deposits consist of beds of salt left from the evaporation of ancient seas that retreated, salt domes that intruded upward through old sediments, and dry playa lakes. Landlocked bodies of saline water, such as the Great Salt Lake in Utah, and natural subterranean salt-bearing brines are also found in various parts of the world.

THE GLOBAL BALANCE OF SALT

The history of world salt production and consumption parallels the history of humankind. From primitive to modern times, every human being has had an association with salt. Although not aware of their physiological need for salt, prehistoric human beings obtained their salt primarily from the meat of the animals they hunted. These animals often were found congregating around salt springs or salt licks to satisfy their innate salt cravings. With the beginning of an agricultural society, humankind found the need to supplement vegetable and cereal diets with extra quantities of salt. The quest for salt became more important with the advance of civilization. Because of its solubility, surface deposits of salt were scarce, and new methods to obtain salt were needed. This was the beginning of the world salt mining industry. The basic concepts of salt mining have changed very little since early times; only the refinements in the techniques of extraction and processing have evolved.

The Bureau of Mines has collected and published salt production statistics by country since 1890. Of the more

than 170 nations in the world today, the Bureau collects or estimates production data from 98 different countries, which represents virtually all world output. In 1990, world salt production was 213.3 million short tons, whereas, in 1890, world salt production was only 10.2 million short tons. In the span of one century, the world population increased from 1.6 billion to 5.3 billion individuals. The increase in world salt production compared with the population growth was significantly greater because new uses for salt were discovered that would change the demand pattern.

Salt had been universally used for food flavoring and for food preservation, but it wasn't until the mid-19th century that salt was regarded as an important raw material for the chemical industry. In the early 1860's in Belgium, the Solvay process was developed to make synthetic soda ash from salt. Later, salt became essential in the electrolytic process to make chlorine gas and sodium hydroxide. Today, salt is the largest mineral feedstock consumed by the world chemical industry.

THE GLOBAL SALT CYCLE

How did the oceans get to be salty? Although man has pondered this question for centuries, the answer has been the subject of formal scientific investigations for only about the last 40 years. Present theories indicate that the oceans were formed about 1.5 billion to 2.0 billion years ago. It was once believed that the total salt content of the seas was derived from the chemical and mechanical erosion of rocks and transporting the dissolved and insoluble fractions to the oceans throughout the eons of time. Using the rate of stream delivery, it was estimated that the total quantity of salt in the oceans could have been introduced in "only" 12 million years (a very short period of time geologically). In addition, sodium and chlorine are minor constituents of river water, with average salinities of 0.001% to 1.0%, but are the major components in seawater, with average salinities ranging between 3% to 4%. It was apparent that other factors were involved and that the oceans were not just accumulators of mineral salts. As water evaporates from the oceans, the introduced mineral salts must be removed in the form of minerals. This steady-state concept states that the inflow of materials into the seas must equal the rate of outflow. Calculations on the rates of addition and removal suggest that for at least 100 million years the oceanic system has been in a steady state with fixed rates of chemical composition.

Recent investigations indicate that not only are the oceans in a steady-state system but that their composition is most likely controlled by chemical equilibria involving seawater and minerals found in marine sediments. Sillen

(1) showed that the chemical composition of seawater approximates that of a theoretical solution brought to chemical equilibrium with the minerals quartz, illite, montmorillonite, chlorite, kaolinite, calcite, and phillipsite, and the Earth's atmosphere. These minerals contain the dominant ions introduced by river water—calcium, silica, carbonate, and sulfate. Any changes in the rate of addition or the proportions of the feed material had no effect on the chemical composition of the seawater.

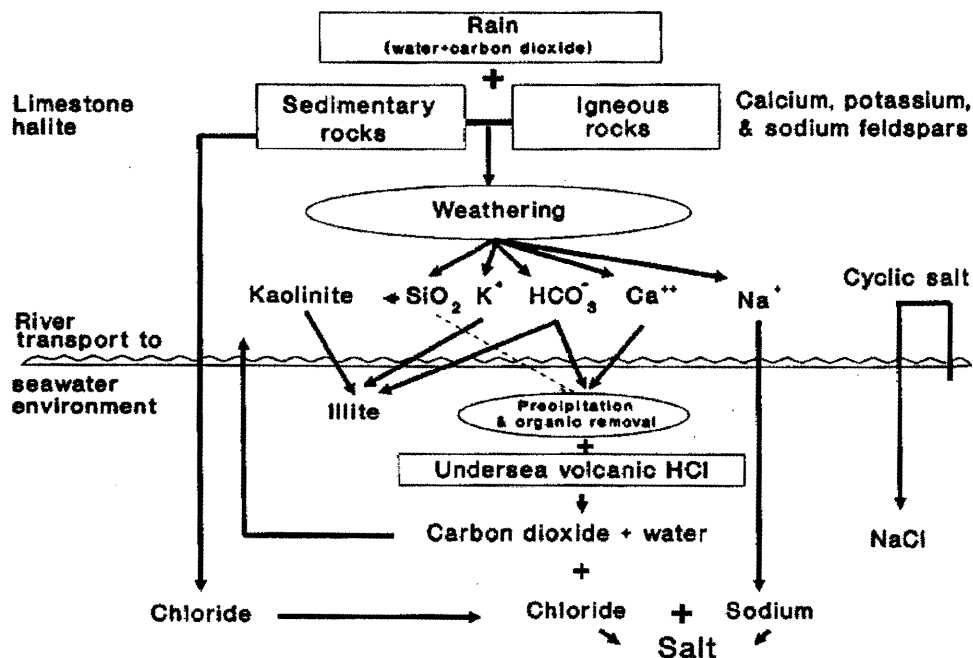
MacIntyre (2) developed a model that showed the chemical weathering of igneous rocks by carbonic acid found in rainwater could lead to the formation of the various minerals discussed by Sillen. The weathering of calcium, potassium, and sodium feldspars releases a solution of alkali and bicarbonate ions and a suspensate of hydrated silica and aluminosilicates that resembles kaolinite. This suspensate forms illite clay when potassium is introduced. Some of the hydrated silica and calcium are removed by the system by marine organisms to make their protective shells, which later form sediments in shallow waters. Submarine volcanism releases hydrochloric acid, which reacts with bicarbonate ions to form carbon dioxide that is released to the atmosphere. These reactions that selectively extract the influx of ions to the oceanic system ultimately leave behind the sodium and chloride ions that combine to form sodium chloride.

Symonds and Rose (3) calculated the quantity of hydrogen chloride and hydrogen fluoride gases that are released annually into the atmosphere by volcanic eruptions.

Using a computer model that measures thermodynamics to predict the chemical reactions that could occur during an eruption, they estimated that 12.1 million short tons of hydrogen chloride and 6.6 million short tons of hydrogen fluoride are liberated by volcanoes throughout the world each year. Only the larger eruptions are capable of propelling the gases into the stratosphere, whereas the gases emitted from the smaller eruptions are absorbed by clouds in the upper stratosphere. The chlorine contained in hydrogen chloride reacts with atmospheric water molecules and precipitates, which contribute to the global chlorine cycle, and therefore the global salt cycle on the Earth. Figure 1 shows a flow diagram that combines the more popular theories on the evolution of salt in the oceans. The diagram also includes cyclic salt, which is salt carried aloft after the wind comes in contact with breaking waves. Reportedly, more than 300 million short tons of cyclic salt

is deposited on the Earth's surface each year and is particularly responsible for the chlorine content of river water that flows to the oceans (4).

Sodium chloride is the most abundant dissolved mineral constituent in seawater. The oceans of the world are estimated to contain about 329 million cubic miles of seawater that contains approximately 46 quadrillion short tons of sodium chloride, as shown in figure 2. One of these cubic miles weighs 4.7 billion short tons, contains 1.1 trillion gallons of seawater, and contains 165 million short tons of dissolved matter, of which 139 million short tons is salt. For comparison, the quantity of salt in one cubic mile of seawater is more than one-half of the quantity of salt produced annually throughout the world, and the amount of seawater in one cubic mile is equal to the volume of 3 days' average flow of the Mississippi River.



Sources: Sillen (7) and MacIntire (2).

Figure 1.—The global salt cycle.

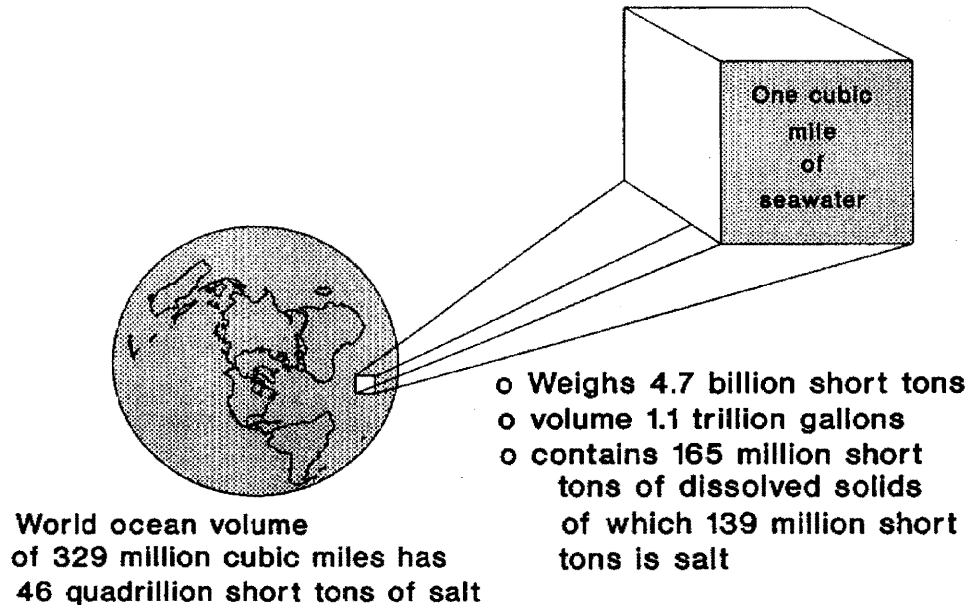


Figure 2.—Abundance of salt in the oceans.

U.S. SALT SUPPLY

The components of U.S. supply are derived from domestic production sources and imports. Beginning inventories are also important and should be included when discussing the supply situation; however, reliable stock data are unavailable. Salt is a large volume, low-priced, bulk commodity that is internationally produced and traded. Because of its solubility and the difficulty of large-scale storage, surface salt inventories are usually kept at minimal levels. Inventories kept underground at rock salt mines are stored for short-term imminent sale, such as for near-future winter use for highway deicing. For practical purposes, the difference between salt production and salt sold or used is the mathematical change in inventory additions or drawdowns.

The United States is the largest salt-producing country in the world. Figure 3 shows U.S. salt production related

to world production from 1950 through 1990. Salt production in 1990 amounted to 40.6 million short tons, representing four types of salt obtained from different mining and recovery techniques. The four types of salt are rock salt, solar salt, salt brine, and vacuum pan salt. Thirty-one companies operated 69 salt-producing plants in 1990 in 14 States as shown in figure 4, which shows the salt production locations of the U.S. salt industry. Imports, the other component of U.S. supply, amounted to 6.6 million short tons, which represents a 9% net import reliance (imports minus exports plus adjustments for industry stock changes) as a percent of apparent consumption during 1990. Figure 5 shows the trend of domestic supply, trade, and consumption from 1950 to 1990.

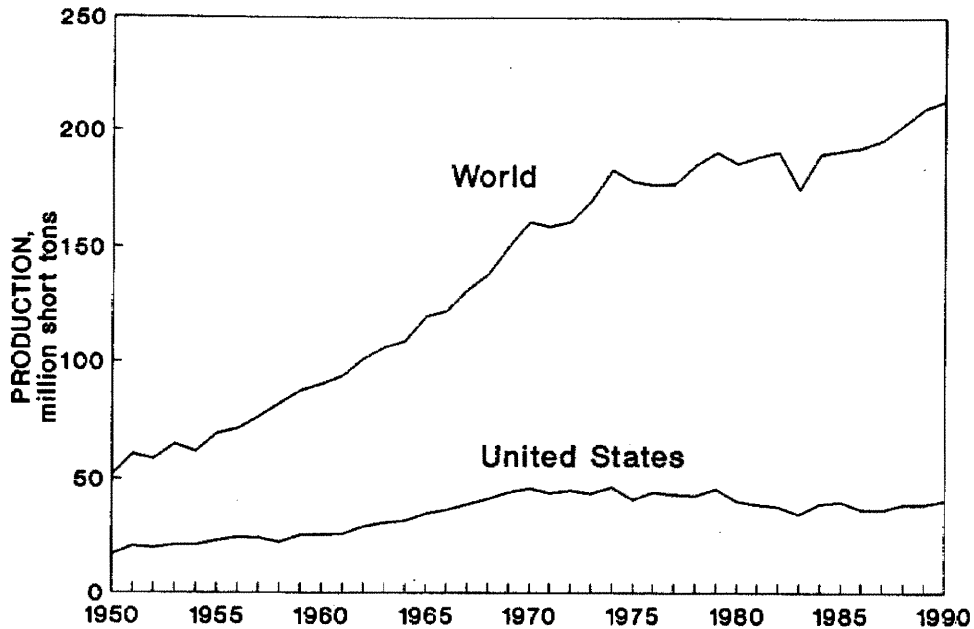


Figure 3.—U.S. and world salt production, 1950-90.

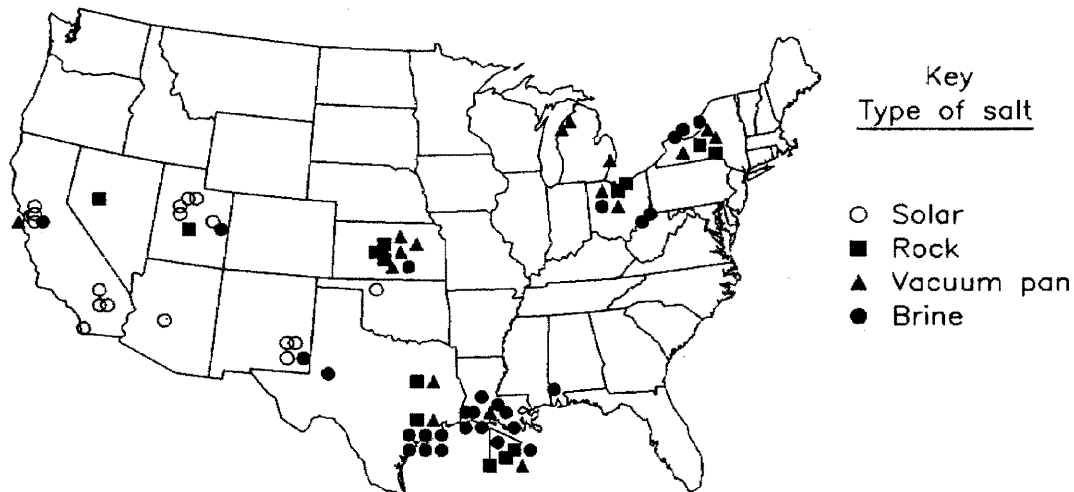


Figure 4.—U.S. salt production locations in 1990.

DOMESTIC PRODUCTION SOURCES

The first salt produced by a nonnative American was in June 1614 by a group of Jamestown colonists who established a solar saltworks on Smith's Island, VA. The solar salt tasted bitter, and the poor climatic conditions were not favorable for the successful long-term outlook for the venture. Imported salt from England sustained the

colonial settlers until other settlements in Massachusetts and New Jersey established coastal saltworks.

By the mid-18th century, pioneer settlers began learning saltmaking techniques from the Indians. The first commercial salt production began almost simultaneously around 1797 at Onondaga Lake, NY, Saltville, VA, and the Kanawha Valley, VA (now part of West Virginia). Salt-bearing brine obtained from salt springs was boiled in

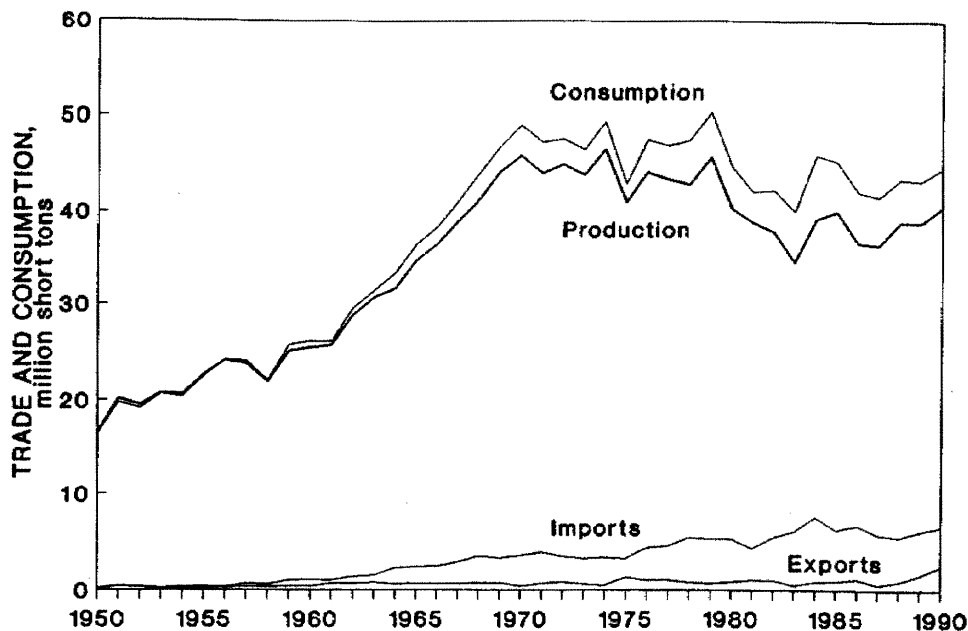


Figure 5.—U.S. salt production, trade, and consumption trends, 1950-90.

block houses containing double-row furnaces with ceramic and iron kettles. The brine was heated using wood obtained from nearby forests. Before too long, the price of wood became expensive because local wood supplies were becoming scarce from extensive farming practices. Production of salt by boiling soon became uneconomic, and other methods were used to manufacture salt more economically.

The U.S. salt industry continued to grow throughout the remainder of the 19th century. The synthetic soda ash industry began at Syracuse, NY, in 1884, and chlorine production commenced in 1892. Both processes used salt as feedstock. Thus, the U.S. chemical industry was underway. From this point on, domestic salt production and consumption increase substantially. Figure 6 shows the growth of U.S. salt production from 1880 to 1990 by type of salt.

Rock Salt

Although rock salt is an evaporite mineral that includes bedded salt, salt domes, and playa salt, underground rock salt mining is confined to bedded salt and salt domes. Rock salt mining has a long history associated with it. Salt deposits in Austria and Israel were mined during Roman times. One rock salt mine in Poland has been in operation continuously since the early Roman period. The first rock salt mine in the United States was at Avery Island,

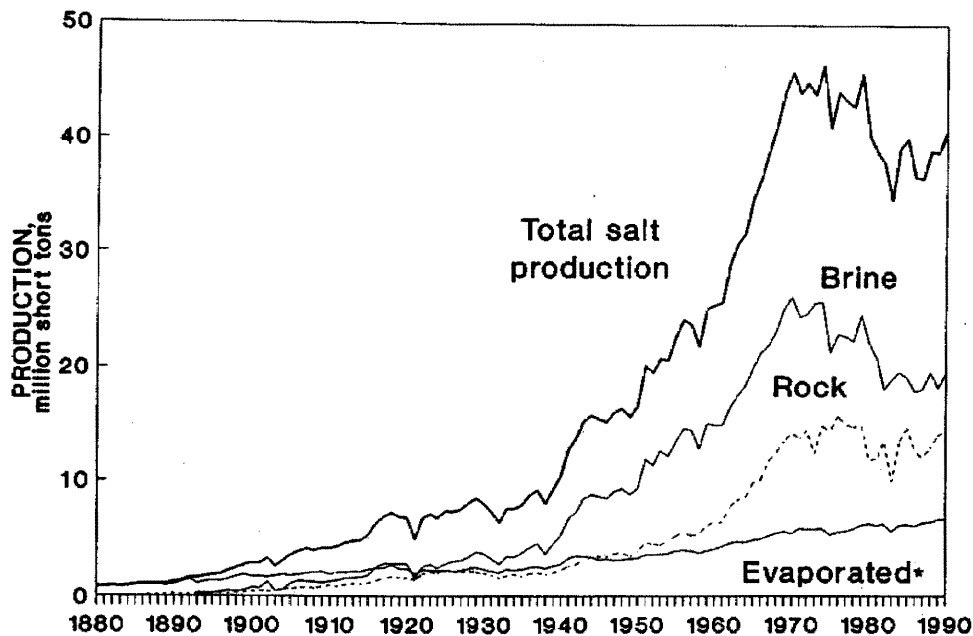
LA. It began in 1862 and supplied part of the salt requirements for the Confederate army during the Civil War.

Bedded Salt

Bedded rock salt deposits were formed by the accumulation of sodium chloride crystals left by the extensive and widespread evaporation of receding ancient marine bodies of water. The salt beds usually are associated with other sedimentary rocks and minerals, such as limestone, sandstone, shale, and gypsum. Although many areas contain repetitive beds of sedimentary strata with multiple beds of salt, the economic beds of salt that are mined usually are greater than 8 feet in thickness. Presently, the only commercially mined bedded salt formations are in Kansas, New York, and Ohio. Bedded salt deposits are vertically restricted but laterally unrestricted as opposed to salt domes, which are vertically unrestricted but laterally restricted.

Salt Domes

Salt domes form when lateral or vertical pressures are applied to stratified salt deposits and the low-density salt flows plastically through the surrounding rocks of higher density. It is not uncommon for salt domes to extend vertically downward 20,000 feet or more. A harder cap rock of anhydrite is common with overlying beds of calcite



Source: U.S. Bureau of Mines.

* Includes solar salt.

Figure 6.—Historical U.S. salt production, 1880-1990.

and gypsum. Oil, gas, and sulfur are associated with many salt domes and are considered valuable mineral resources unto themselves. The only salt domes in the United States are along the gulf coastal region. There are approximately 329 proven onshore and offshore salt domes in that area.

Rock salt mining is similar to other underground mining operations, such as coal, potash, and trona. The salt is mined using the room-and-pillar method. Rock salt is drilled, undercut, blasted, mucked, crushed, screened, and transported to the surface for processing, which usually involves removing some of the impurities and screening the material to finer size fractions before the salt is shipped in bags or in bulk form.

In 1990, 10 salt companies operating 14 plants produced 14.1 million short tons of rock salt in the United States. Rock salt mining accounted for 35% of total U.S. salt production.

Solar Salt

Solar salt is obtained from the extraction of salt by seawater evaporation along coastal margins and by the evaporation of inland landlocked bodies of natural saline water and artificial brines. Salt production uses the wind and the sun to evaporate the water, leaving behind relatively pure crystals of salt. Solar salt production is restricted to areas of the world that have high evaporation

rates and low precipitation, such as Australia, India, and Mexico. The practice of solar salt production from seawater can be traced back many hundreds of years and has not changed much throughout history. Laborers in some countries, such as India, Thailand, Jordan, and Colombia, continue to produce solar salt today in the same manner as their ancestors once did.

Seawater Evaporation

Solar salt production from seawater is restricted to the San Francisco Bay area and southern California area of the United States. Seawater from the Pacific Ocean is collected and allowed to evaporate in specially constructed concentration and evaporation ponds. The initial step concentrates the brine to raise the salinity and to allow various calcium, magnesium, and iron compounds to precipitate from solution. The brine circulates among a network of interconnecting gravity-fed ponds, with salinity increasing with each transfer. It takes approximately 5 years from when seawater is initially introduced before the first salt is ready for harvest.

The brine is treated with lime to remove excess calcium sulfate and then is pumped to evaporation ponds and harvesting ponds to permit the salt to crystallize. After about 85% of the salt has crystallized, the remaining supernatant liquid, called "bitterns," is drained to adjacent ponds for

subsequent extraction of magnesium, potassium, bromine, and sodium compounds. Every year between August and November, solar salt is harvested by mechanical harvesting equipment.

Inland Solar Evaporation

Solar salt is produced from the Great Salt Lake in Utah, which is an example of a landlocked body of saline water. The principles of solar salt concentration and production are similar to those practiced along coastal margins except that salinity in inland lakes usually is greater than that of seawater. As water flows over or beneath the surface, it dissolves minerals from underlying soils and rocks. The salt lakes are topographically lower than most of the surrounding areas and therefore become excellent sumps for mineral accumulation. For example, the Great Salt Lake receives about 2 million short tons of new minerals annually by this process. The percentage of salt in the lake varies, depending on the influx of fresh water.

A second form of inland solar evaporation includes evaporating artificial brines that were discharged as waste products into containment ponds. Some examples are the solar salt operations in New Mexico that are associated with potash mining. Underground commingled deposits of halite and sylvite are mined for the potash, and the salt is discharged during potash processing as a brine to tailing ponds and left to evaporate. Over the years, much salt has accumulated, attracting various companies to recover and sell the salt. Although the network of concentration and evaporation ponds is not required in this case, the harvesting equipment is similar to that used in California, Oklahoma, and Utah. The arid location permits virtually year-round harvesting.

The total quantity of solar salt produced in 1990 in the United States was 3.3 million short tons or 8% of U.S. salt production. Twelve salt companies operated 17 solar evaporation facilities in the United States.

Salt Brine

Salt brines consist of natural brines, which have been recovered in their liquid form, and artificial brines resulting from the dissolution of underground halite beds that have been solution mined. The first reported use of solution mining to obtain salt was about 250 B.C. in China, when holes were drilled into the deep salt deposits. Production of salt brine by solution mining began in the United States in 1806 in what is now part of West Virginia.

Natural Brines

Ground water reacting with underground salt formations can form natural salt brines that often migrate to the

surface to create salt springs. In some States, such as West Virginia, the natural brines are very deep, often as much as 6,000 feet. A few chemical companies have utilized these brines as feedstock to manufacture chlorine and sodium hydroxide. The composition of the brines may vary with location, and the concentration of sodium chloride may also fluctuate. For these reasons, many chemical companies have preferred to produce their own artificial brine by solution-mining salt deposits, allowing many chemical plants to be located nearer the markets they serve.

Artificial Brines

Virtually all the salt brine produced and consumed in the United States today is made using solution-mining technology. Water is introduced into injection wells as a solvent. The wells are pressurized to hydraulically fracture the underlying bedded salt. Once communication between the injection well and the production well is established, the artificial brine is pumped to the surface for treatment. Brine treatment usually consists of adding soda ash to remove undesirable calcium and magnesium ions dissolved with the salt.

Approximately 91% of the salt brine produced in the United States is for captive use by the domestic chloralkali industry. Artificial brine is also produced to supply plants producing refined salt using vacuum pan technology. Production data on the quantity of brine for this type of salt production is not collected, only the quantity of vacuum pan salt produced. Seventeen companies operating 29 salt brine facilities produced 19.2 million short tons of salt brine in 1990. This represented 47% of total U.S. salt production.

Vacuum Pan and Open Pan Salt

Vacuum pan salt is not mined but is a type of salt produced using mechanical evaporation technology. Although any of the other three types of salt may be used to make vacuum pan salt (i.e., rock salt, solar salt, and salt brine), virtually all domestic vacuum pan salt is obtained from solution-mining underground salt formations.

Vacuum pan salt is obtained by dehydrating the incoming brine in combination with a vacuum. The vacuum pan process conserves energy by using multiple-effect evaporators connected to vacuum pumps. A saturated salt solution will boil at a higher temperature than fresh water; however, when a vacuum is applied, the brine boils at a lower temperature, enabling the superheated vapor that is generated to act as the heating medium for the next evaporator.

Another mechanical evaporation process that is used in the United States on a small scale is the open pan process.

Rectangular pans with steam-heated immersion coils are used to evaporate the water in the brine. Rotating rakes scrape the salt that has accumulated on the bottom of the pan into a sump or up a ramp, depending on the method, and onto conveyors for debrining and drying. The open pan process produces a flake-shaped crystal rather than the typical cubic form. Flake salt is preferred for production of cheese, butter, and baked goods. The Alberger process is a modified open pan technique that produces cubic salt with some flake salt.

Five companies operated 17 vacuum pan salt plants accounting for 10% of total U.S. salt production in 1990. Table 1 lists the various types of salt produced in the United States and shows their sources, methods of mining and processing, and final product forms.

IMPORTS

The United States has been dependent on foreign sources of salt since early colonial settlers landed in the New World in 1607. The first salt used in the Jamestown colony was delivered as ballast in the hulls of English sailing ships. Aside from its use for human consumption, salt was extremely important in the fur and fishing industries of New England for animal hide and food preservation. Cured hides and dried and salted fish were two of America's most important initial export commodities.

Domestic salt production did not begin on a commercial basis until 1797; therefore, imported salt was very important for the survival of the early colonial businesses.

For the next 200 years, salt imports would continue to increase. New uses for salt required more salt at the lowest prices. Less expensive salt from Canada, Mexico, and the Caribbean served the regions near domestic coastal ports that were not near any U.S. salt production centers. Barge and ocean freight rates usually were more economical than those of domestic overland transportation charges. Less expensive foreign labor rates, more favorable currency exchange rates, and fewer regulations prompted several U.S. salt producers to eventually establish foreign bases of operation beginning in the mid-1950's. The consolidations and restructuring within the U.S. salt industry since then have strengthened the industry into a competitive North American enterprise operating in the Western Hemisphere.

The United States in 1990 imported more than 2.5 times the quantity of salt that it exported. Although the statistics would indicate that the United States is import reliant on salt to meet its internal requirements, the majority of imported salt was brought in by the foreign subsidiaries of the major U.S. salt producers. Salt will continue to be imported into this country to meet future domestic demand requirements. Figure 5 shows the trend of imports from 1950 through 1990.

Table 1.—The mine-to-market sequence of various salt types

	Solar	Rock	Brine	Vacuum pan
Source of salt ¹	Seawater, saline lakes, and byproduct.	Bedded, dome, and surface.	Artificial and natural . .	Brine, rock, and solar.
Mining	Seasonal harvesting	Room-and-pillar	Injection and production wells.	None.
Processing	Screening, washing, and drying.	Crushing and screening	Impurity removal . . .	Multiple-effect vacuum crystallizers.
Product form ²	Bulk, packaged, pellets, and blocks.	Bulk packaged, and blocks.	Solution	Bulk, packaged, pellets and blocks.

¹In descending order of extraction.

²Packaged salt includes bags, boxes, cylinders, and single-serve packets.

U.S. SALT DEMAND

Analyzing the demand requirements of a commodity are probably more important and also can be more difficult than assessing the supply situation for that material. Producers are limited, whereas the number of consumers appear to be unlimited. The components of U.S. salt demand are composed of salt for domestic consumption and exports.

Salt consumption data are derived from annual surveys as reported by domestic salt producers. Annual end-use

canvasses (based on salt produced and salt sold or used by producers) have been conducted since 1940. This reported consumption data serve to examine salt consumption by end use and may not correspond to apparent consumption, which is a calculated figure arrived at using "sold or used" statistics plus imports and minus exports. "Sold or used" is used rather than production because reliable inventory data, which would be used in determination of apparent consumption, are unavailable. Reported consumption data

differ from apparent consumption calculations because the end-use survey is conducted on the U.S. salt producers only, not domestic consumers. Although the salt survey includes imported salt for consumption, it only includes the quantity under the direct control of the U.S. salt producers, which is usually always less than what is reported to the Bureau of the Census. Any salt imported by direct buyers, distributors, wholesalers, etc., is outside of the scope of the Bureau's canvass.

Using private trade information services from the Journal of Commerce, it was determined that, in 1990, four domestic salt companies composed 52% of the total import market, and five chloralkali manufacturers represented another 26% of total imports. Therefore, 78% of total U.S. imports is under the direct control of companies that respond to annual Bureau surveys. The remaining 22% of total imports that is included in apparent consumption calculations is attributed to various direct buyers for which specific end-use information is unknown.

DOMESTIC CONSUMPTION

Salt consumption in the United States has increased during the past two centuries. Figure 7 shows the effect that certain events have had on domestic per capita consumption. It should be noted that the chemical industry and deicing salt have been responsible for the greatest increases in salt usage. They also have contributed to some of the environmental issues that caused consumption to begin declining after the mid-1970's.

It has been stated that there are approximately 14,000 direct and indirect uses of salt. It would be virtually impossible to survey for all these uses of salt. The Bureau's salt survey includes 27 individual uses in 8 major categories that include chemical, food processing, general industrial, agricultural, water treatment, ice control, distributors, and miscellaneous. These industries are the first-tier consumers of salt; information on most of the other downstream customers (such as those served by distributors) is unavailable to the salt industry. Since end-use data collection began in 1940, there have been shifts in the percent market share distribution, as shown in figure 8. For the purpose of this study, distributors (which is a specific category that the U.S. Bureau of Mines began surveying in 1974) are considered a part of "Other" because the final disposition of the salt is unknown to the salt producer. Agricultural distribution, water conditioning distribution, and a part of grocery wholesale distribution have been incorporated into the appropriate end-use categories.

Chemical Industry

The U.S. chemical industry is the largest consumer of salt, representing 47% of reported consumption in 1990. This category is distinguished by two important subsectors, the chloralkali industry and other chemical manufacturers.

Chloralkali

The chloralkali industry is the largest segment of the chemical sector that uses salt. Traditionally, this end use included salt consumed for chlorine, coproduct sodium hydroxide (also known as caustic soda and lye), and synthetic soda ash; however, since 1986, no synthetic soda ash has been manufactured in the United States. The majority of the rest of the world continues to use salt for synthetic soda ash production.

Salt is used as the primary raw material in chlorine manufacture because it is an inexpensive and widely available source of chlorine ions. For sodium hydroxide production, salt is the main source of the sodium ions. Approximately 97% of the domestic chlorine and sodium hydroxide produced is obtained from the electrolysis of salt brine feedstock using three different cell technologies. The types of cells and percent chlorine manufactured by them are diaphragm, 75%; mercury, 16%; and membrane, 6%. It takes about 1.75 short tons of salt to make 1.0 short ton of chlorine and 1.1 short tons of coproduct caustic soda. The electrolytic process ionizes the sodium chloride compound and selectively allows the ions to migrate through special membranes. Chlorine gas forms at the anode while sodium ions bond with water molecules at the cathode to form sodium hydroxide with hydrogen gas evolving. In 1990, 11.8 million short tons of chlorine and 12.5 million short tons of caustic soda were produced in the United States. The chloralkali subsector is classified under Standard Industrial Classification (SIC) code 2812.

Chlorine and caustic soda are considered to be the first generation of products made from salt. These two chemicals are further used to manufacture other materials, which are considered second-generation products from salt. Each generation of downstream product owes its origin to the previous generation. Figure 9 shows the three generations of chloralkali industry products that are ultimately derived from salt. The individual market sectors for each generation of products will be used later to estimate the quantity of losses to the environment and to the landfills.

Other Chemicals

This subsector includes chemical establishments that make sodium chlorate, metallic sodium, and other downstream chemical operations that use salt as feedstock. In powdered soaps and detergents, salt is used as a bulking agent and as a coagulant for colloidal dispersion after saponification. In pharmaceuticals, salt is a chemical

reagent and is used as the electrolyte in saline solutions. It is also used as a cofeedstock with sulfuric acid to produce sodium sulfate and hydrochloric acid. This subsector is relatively small, composing only 10% of domestic salt sales for the entire chemical sector and only 5% of total domestic salt consumption. These chemicals are classified under SIC 28, excluding SIC 2812, alkalis and chlorine.

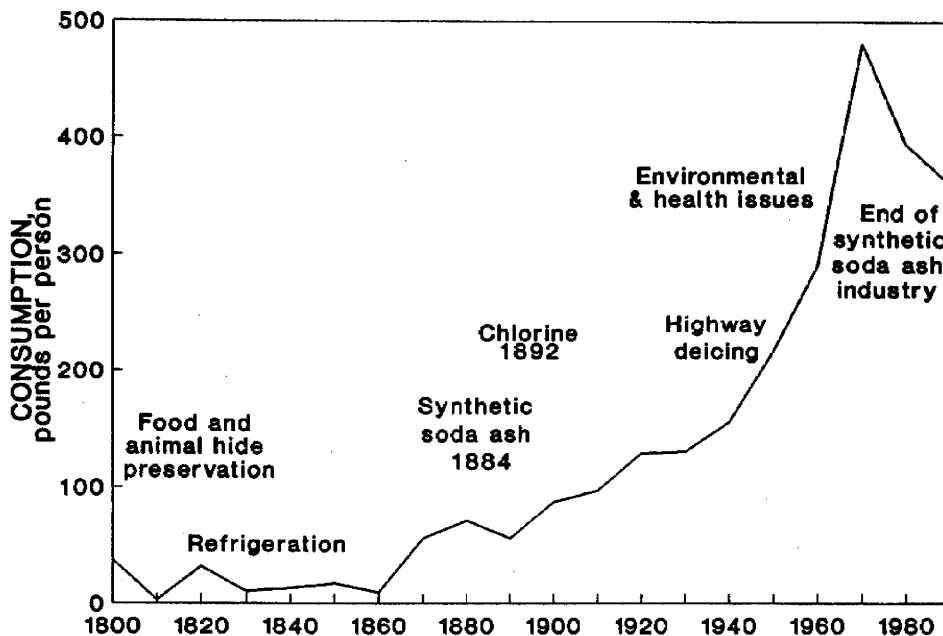


Figure 7.—Factors influencing per capita consumption of salt in the United States, 1880-1990.

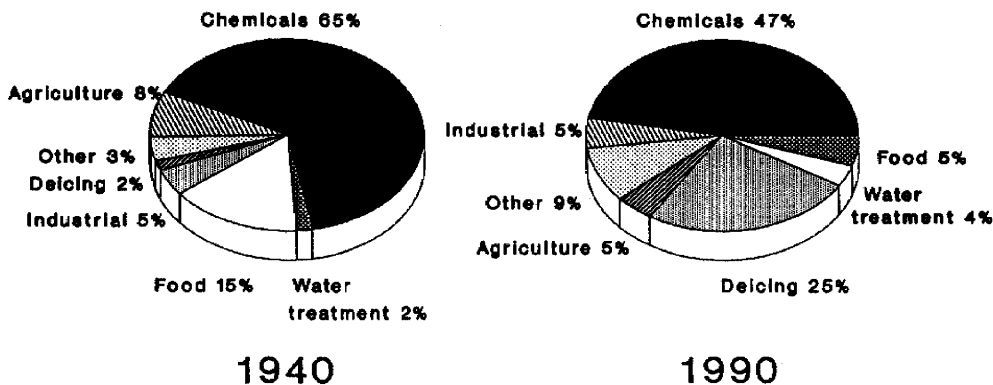


Figure 8.—U.S. salt consumption by end use, 1940 and 1990.

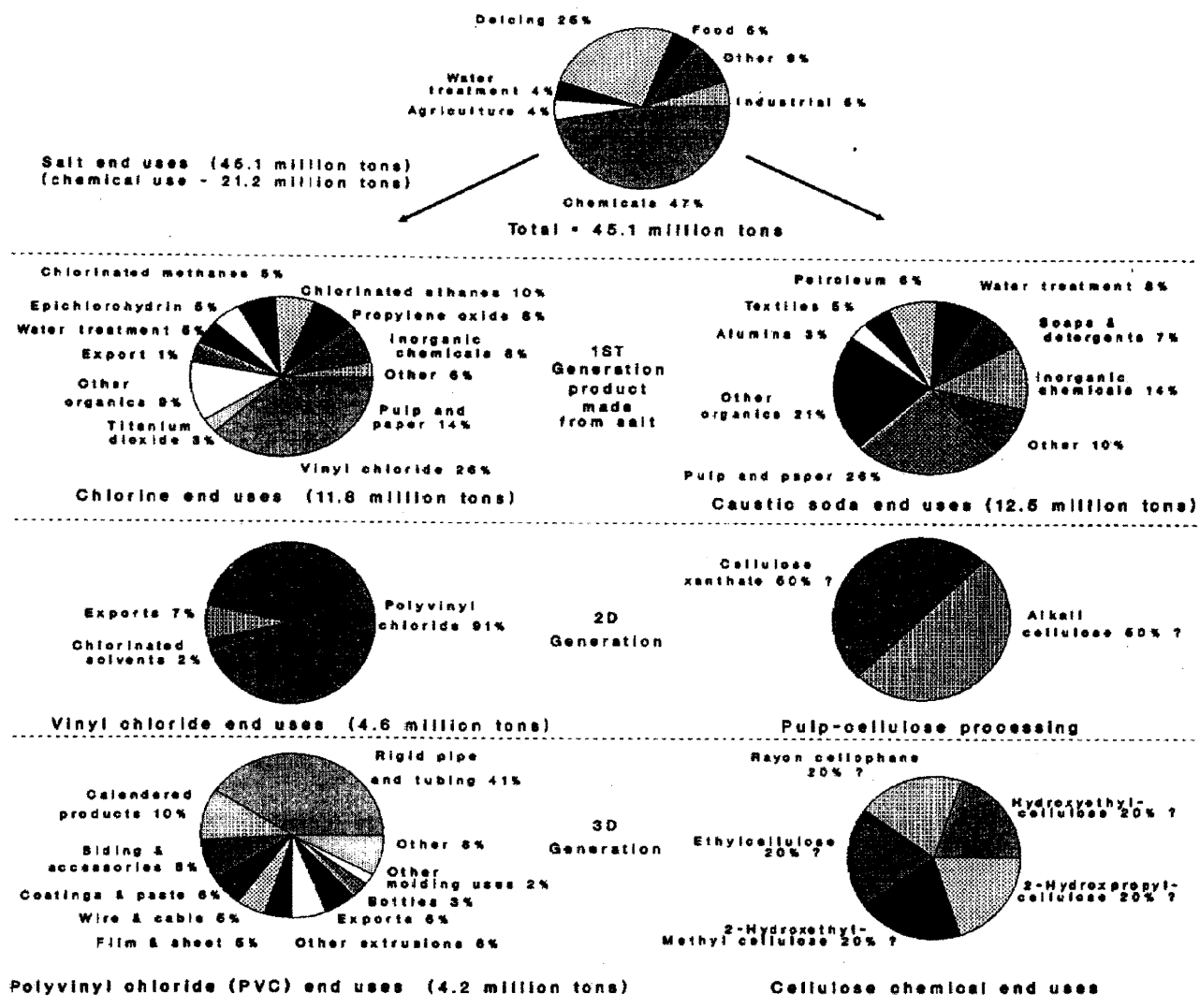


Figure 9.—Distribution of the major end use of three generations of chemicals produced from salt in 1990.

Food Processing Industry

Although every person uses some quantity of salt in their food, the entire category only represented 4% of reported consumption in 1990. Salt is added to food as a flavor enhancer, preservative, binder, fermentation control additive, texture aid, and color developer. This major category is subdivided into six subsectors, in descending order of salt consumption: meat packers, canning, other food processing, baking, dairy, and grain mill products.

Meatpackers

Salt added to processed meats promotes the color development in bacon, ham, and other processed meat products. As a preservative, salt inhibits the growth of bacteria, which would lead to spoilage of the product. Salt acts as a binder in sausages to form a binding gel composed of meat, fat, and moisture. Salt also acts as a flavor enhancer and a tenderizer. This subsector is engaged in slaughtering and processing meat and poultry products and in sausage and other prepared meat manufacturing. It includes SIC codes 2011, 2013, 2016, and 2017.

Canning

Salt is primarily added as a flavor enhancer and preservative. It also is used as a dehydrating agent, tenderizer, enzyme inhibitor, and as a carrier for other ingredients. Establishments that can vegetables, vegetable juices, jams, jellies, pickled fruits, and specialty products such as baby foods and seafood are in this subsector. It includes SIC 2032, 2033, 2035, and 2091.

Other Food Processing

Salt is used mainly as a seasoning agent in this end use. Other food processing includes miscellaneous establishments that make food for human consumption (i.e., potato chips, pretzels) and domestic pet consumption (i.e., dog and cat food). They are included in SIC 206, 207, 208, 2047, 2099, and any other food category not included in aforementioned SIC codes.

Baking

Salt is added to control the rate of fermentation in bread dough. It also is used to strengthen the gluten (the elastic protein-water complex in certain doughs) and as a flavor enhancer, such as a topping on baked goods. This subsector includes companies making bread, cakes, cookies, and other perishable bakery products. It includes SIC codes 205, 2051, and 2052.

Dairy

Salt is added to cheese as a fermentation control agent, and as a color and texture control agent. The dairy subsector includes companies that manufacture creamery butter, natural and processed cheese, condensed and evaporated milk, ice cream, frozen desserts, and specialty dairy products. It incorporates SIC codes 202, 2021, 2022, 2023, 2024, and 2026.

Grain Mill Products

This subsector includes establishments engaged in milling flour and rice and in manufacturing cereal breakfast food and blended or prepared flour. This subsector includes SIC codes 204 (excluding 2047), 2041, 2043, 2044, and 2045.

General Industrial

The industrial uses of salt are diverse. This major sector of salt consumption includes, in descending order of salt usage, oil and gas exploration, metal processing, other industrial, pulp and paper, textiles and dyeing, tanning and leather treatment, and rubber manufacture. In 1990, general industrial applications consumed 5% of total reported salt consumption.

Oil and Gas Exploration

Salt is an important component of drilling fluids in well drilling. It is used to flocculate and to increase the density of the drilling fluid in order to overcome high down-well gas pressures. Whenever drilling activities encounter salt formations, salt is added to the drilling fluid to saturate the solution and minimize the dissolution within the salt strata. Salt is also used to increase the set rate of concrete in cemented casings. This subsector includes companies engaged in oil, gas, and crude petroleum exploration and in refining and compounding lubricating oil. It includes SIC major groups 13 and 29.

Metal Processing

Salt is used in concentrating uranium ore into uranium oxide (yellow cake). It is also used in processing aluminum, beryllium, copper, steel, and vanadium. Establishments engaged in the smelting, refining, and fabrication of ferrous and nonferrous metals represent this subsector, which includes SIC 33, 34, 35, and 37.

Other Industrial

This subsector is represented by any group not included in any of the general industrial groups in this major category.

Pulp and Paper

Salt is used to bleach wood pulp. It also is used to make sodium chlorate, which is added along with sulfuric acid and water to manufacture chlorine dioxide—an excellent oxygen-base bleaching chemical. Although the chlorine dioxide process originated in Germany after World War I, it is becoming more popular because of environmental pressures to reduce or eliminate chlorinated bleaching compounds. Companies that manufacture wood pulp, cellulose fibers, pulp from rags, paper and paperboard, and paper and paperboard converted products are included in this subsector, which includes SIC group 24.

Textiles and Dyeing

In commercial dye manufacture, salt is used as a brine rinse to separate organic contaminants, to promote "salting out" of dyestuff precipitates, and to blend with concentrated dyes to standardize them. One of its main roles is to provide the positive ion charge to promote the absorption of negatively charged ions of dyes. The textile and dyeing industry includes businesses involved in the preparation of fibers, the subsequent manufacturing of yarn and woven fabrics, and the dyeing and finishing of fibers. This includes SIC group 22.

Tanning and Leather Treatment

Salt is added to animal hides to inhibit microbial activity on the underside of the hides and to replace some of the moisture in the hides. This subsector includes establishments curing and/or tanning animal hides. It includes SIC 311.

Rubber Manufacture

Salt is used to make neoprene rubber, white rubber, and buna rubber. Salt brine and sulfuric acid are used to coagulate an emulsified latex made from chlorinated butadiene. Businesses that make rubber and rubber products, such as synthetic rubber, tires and inner tubes, rubber and plastic footwear, reclaimed rubber, rubber and plastic hose and belting, and other fabricated rubber products compose this subsector. It includes SIC codes 2822, 30 (excluding 3079), 3011, 3021, 3031, 3041, and 3069.

Agricultural Industry

Since prehistoric times, humankind has noticed that animals satisfied their salt hunger by locating salt springs, salt licks, or playa lake salt crusts. Barnyard and grazing livestock need supplementary salt rations to maintain proper nutrition. Veterinarians advocate adding loose salt in commercially mixed feeds or in block forms sold to farmers and ranchers. Salt also acts as an excellent carrier for trace elements not found in the vegetation consumed by grazing livestock. Sulfur, selenium, and other essential elements are commonly added to salt licks, or salt blocks, for free-choice feeding.

The agricultural end-use sector contains three subsectors—feed retailers/dealers/retailers-mixers, feed manufacturers, and direct-buying end users. The entire sector represents 4% of total reported consumption in 1990; however, agricultural distribution (contained under the "Distributors" category in individual "Minerals Yearbook" chapters) represented an additional quantity, raising the total agricultural end use to 5%.

Feed Retailers/Dealers/Retailers-Mixers

This subsector includes establishments engaged in the retail distribution of animal feeds, fertilizers, agricultural chemicals, pesticides, seeds, and other farm supplies. It incorporates feed retailers who mix on-site some or all of the feed that they sell and whose primary customers are feed end users, not other feed retailers. There are no suitable SIC classifications for this subsector.

Feed Manufacturers

This subsector includes establishments engaged in preparing feeds and feed ingredients and adjuncts for animals and fowl, including livestock and poultry feed and feed ingredients such as feed supplements and concentrates and premixes. It does not include the local dealer-mixer, whose primary business is the resale of prepackaged feed and feed ingredients to end users, but who does a moderate amount of custom-mixing secondarily. The end use includes SIC 2048.

Direct-Buying End Users

Salt used in this subsector is for consumption by farms, ranches, dairies, feed lots, etc., buying on a direct basis from salt producers. It includes SIC major group 2.

Agricultural Distribution

This subsector of distributors is a second-tier consumer of salt. It includes companies involved in the wholesale

distribution of animal feed products, fertilizers, agricultural chemicals, pesticides, seeds, and other farm supplies to retail feed dealers and some large end users who buy on a wholesale basis. It includes co-op (except mixing operations) and independent wholesalers and/or distributors. SIC 5159 is the subsector category classification.

Water Treatment

Approximately 325 billion gallons of water are used daily in the United States for residential and commercial uses. Many areas of the United States have "hard" water, which contains excessive calcium and magnesium ions that contribute to the buildup of a scale or film of alkaline mineral deposits in household and industrial equipment. Commercial and residential water-softening units use salt to remove the ions causing water hardness. The sodium ions captured on a resin bed are exchanged for the calcium and magnesium ions. Periodically, the water-softening units must be recharged because the sodium ions become depleted. Salt is added and dissolved, and the brine replenishes the lost sodium ions. In 1990, water treatment represented 4% of total domestic reported consumption.

Government and commercial water treatment are the main subsectors of water treatment. Water-treatment distribution is the second-tier market for salt sales.

Government

This subsector includes local, State, and Federal customers purchasing directly from salt producers for water-treatment usage. It includes SIC 2899.

Commercial

This subsector includes all commercial establishments purchasing salt primarily for water treatment and not classified elsewhere. It includes car washes, laundries, and utilities. It also is included in SIC 2899.

Water-Treatment Distributors

This second-tier group is represented by water conditioning salt route operators and distributors, whose exclusive or dominant business is the distribution of water conditioning products to home or industry. It is included in SIC 7399.

Ice Control and Road Stabilization

The second largest end use of salt is for highway deicing. Anyone who has ever driven on snow-covered, icy roads can appreciate the benefits that salt provides. Gabriel Daniel Fahrenheit, the developer of the

Fahrenheit temperature scale (°F), discovered that salt mixed with ice (at a temperature below the freezing point) creates a solution with a lower freezing point than water by itself. The brine forms below the surface of the ice and snow and prevents the water from freezing into ice and bonding with the road surface. Therefore, salt causes snow and ice to melt. Salt is an inexpensive, widely available, and effective ice control agent. It does, however, become less effective as the temperature decreases below about 15° to 20° F. At lower temperatures, more salt would have to be applied to maintain higher brine concentrations to provide the same degree of melting. Most winter snowstorms and ice storms occur between 25° and 32° F, a range in which salt is most effective.

In highway deicing, salt has been associated with corrosion to motor vehicles, bridge decks, unprotected steel structures, and reinforcement bar and wire used in road construction. Surface runoff, vehicle spraying, and windblown actions also affect roadside vegetation, soil, and local surface and ground water supplies. Although there is evidence of environmental loading of salt during peak usage, the spring rains and thaws usually provide sufficient water to dilute the concentrations of sodium in the area.

Salt is also added to stabilize the soil and to provide firmness to the foundation on which highways are built. The salt acts to minimize the effects of shifting caused by changes in humidity and traffic load in the subsurface.

The deicing category includes government (Federal, State, and local) and commercial subsectors of consumption. Approximately 26% of total reported consumption was used in this category during 1990.

Government

More than 95% of this major category is for consumption by separate Federal, State, and local agencies to ensure safe and passable roads during adverse climatic conditions.

Commercial

This subsector includes companies that purchase salt for ice control, such as transportation companies, shopping centers, ice control service contractors, etc. It includes any distributors whose primary or exclusive business is the distribution of salt for ice control purposes to business and/or government. It does not include institutional purchasers. There are no suitable SIC codes for this section.

Other Uses of Salt

The other uses of salt include any consumer that is not included in any of the aforementioned categories. It also

includes sales by distributors, excluding those by agricultural and water conditioning distributors that are included as subsectors under agriculture and water treatment. It includes part of grocery wholesale and retail, institutional wholesale distributors, U.S. Government resale, and other wholesalers and/or retailers.

Institutional Wholesaler Distributors

This subsector includes companies engaged in the distribution of food and other salt products to restaurants, hospitals, schools, and other institutional establishments. These are included in SIC groups 58 and 70.

U.S. Government Resale

Included in this category are Government units, such as military commissaries, that purchase salt for resale to armed forces personnel and dependents at the retail level. It also includes purchases by the Government of food-grade salt used by armed forces and/or Government food-services facilities, as well as all other Government salt purchases not classified elsewhere. SIC 9199 pertains to this subsector.

Other Wholesale and Retail

This subsector includes wholesalers that are not included elsewhere and that are primarily engaged in distributing merchandise for personal and household consumption to retailers, such as hardware stores, home centers, filling stations, and discount centers. It also includes all retail outlets that sell merchandise for personal or household consumption and that purchase directly from salt producers. The SIC category is 5251.

EXPORTS

Salt exports represent an important facet of domestic salt sales. Data obtained from the Journal of Commerce, which used to evaluate the distribution of imports by customer, reveals that 11 domestic salt-producing companies accounted for 79% of the total export market in 1990. The balance was shipped by various companies. This evaluation on the import and export market share of the U.S. salt producers helps substantiate the degree of data integrity obtained from the annual Bureau salt end-use survey. Figure 5 shows the trend of U.S. salt exports from 1950 through 1990.

MATERIAL FLOW OF SALT IN THE UNITED STATES

Even though there is an abundance of salt in the world, salt is a nonrenewable resource. From the moment that salt is mined, there are expected product losses associated with the production, processing, fabricating, and consumption phases. The material flow of salt does not necessarily end at the first point of consumption (i.e., the consumer), but may be traced through its ultimate points of disposition—the environment, landfills, incineration, and recycling.

LOSSES FROM PRODUCTION, PROCESSING, AND FABRICATING

Product losses during the mining, processing, and fabricating of a commodity should be included in a material flow study. The quantity of salt lost during these steps potentially represents the amount of salt unavailable for consumption. Depending on certain factors, the salt lost could also have the same environmental implications as if the salt were sold, consumed, and dissipated.

Most of the rock salt, solar salt, salt brine, and vacuum pan salt operations are on large tracts of land so that environmental disturbance caused by mining and processing is minimal. Any losses encountered in the processes are controllable. Figure 10 shows the mass balance of salt in 1990 and the quantity of salt produced, processed,

imported, exported, and consumed with estimates of how much was dissipated to the environment and to landfills.

Underground mining of bedded or salt dome rock salt involves blasting or cutting the salt at the working face into optimum sizes for different commercial uses. The size distribution generated by mining usually ranges from extremely small, dust-sized particles to large boulder-sized blocks. The challenge of the mining and processing techniques is to reduce the larger fragments into marketable sizes and to minimize the amount of unusable smaller sizes. Some rock salt mines crush and screen the salt underground rather than on the surface. This phase of processing also generates waste fines.

Bleimeister (5) indicated that rock salt mining and milling practices should strive to keep to a minimum the 10-mesh to 12-mesh (from about 1.5 millimeter or 0.06 inch to 2.0 millimeter or 0.08 inch) fractions, which are considered to be too fine by many customers. Based on particle size distribution curves, approximately 27% of the salt mined is considered fine to extremely fine and therefore unsuitable for most applications. Some consumers do, however, prefer the finer fraction for certain uses. The remaining 73% is commercial-grade salt that is sold in various sizes and product forms.

Although much of the 27% of all rock salt mined is unsalable, it is not entirely unusable. All underground

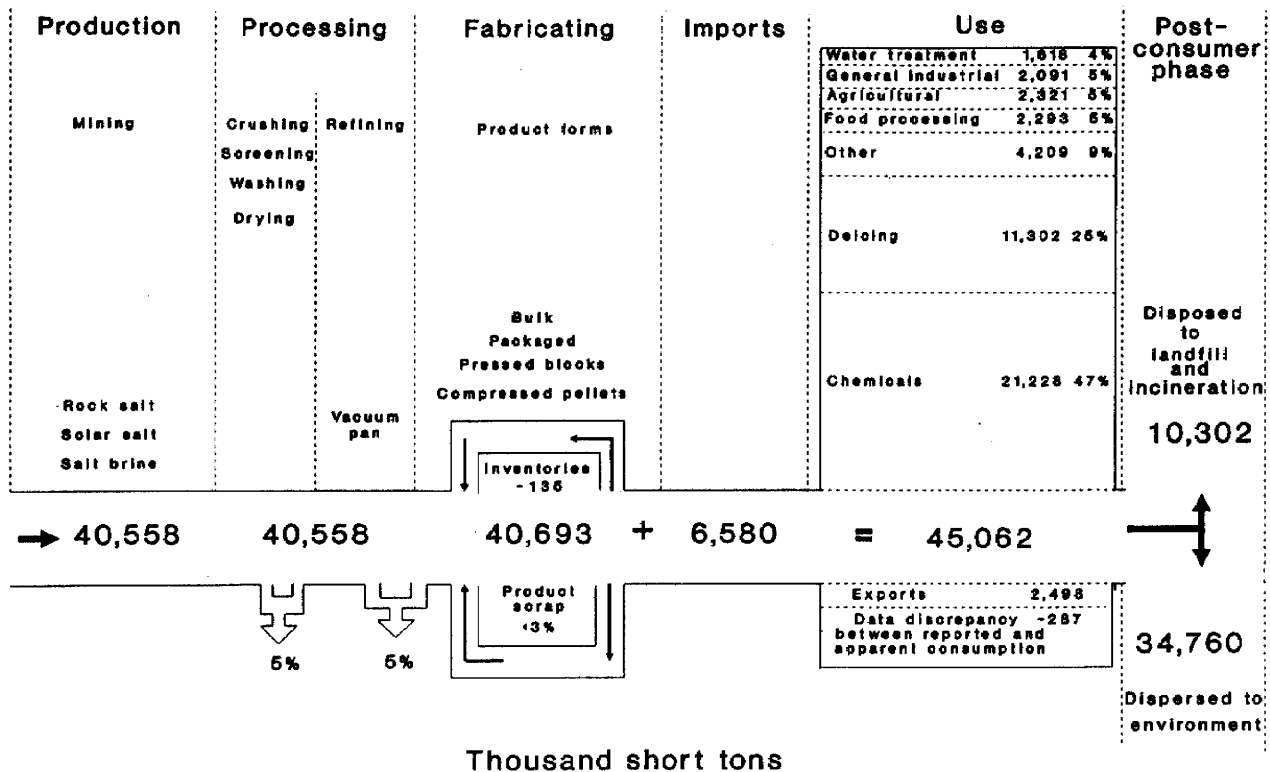


Figure 10.—The mass balance of salt in 1990.

mines use some waste fines as backfill in parts of the mine to restrict access to mined out areas and as permanent brattice barriers to direct air ventilation through main air passageways in the mines.

Rock salt operations that process salt on the surface either sell some of the fine salt that is generated or dispose of it. The fine salt can be dissolved and fed into the vacuum pan circuit as supplementary feedstock. Along the gulf coast, some waste fines are dissolved and pumped as brine out into the Gulf of Mexico. This reportedly has produced positive environmental effects—shrimp apparently prefer the higher salinities near shore where the salt is introduced, and the gulf fishermen do not have to venture out as far to harvest the shrimp.

In solar salt harvesting, some facilities construct a salt floor to serve as the foundation or base for the next season's crystallization and as a protection from damaging the integrity of the underlying pond surface. Salt floors are not regarded as production losses but as sound production practices. Some solar salt is lost, however, when winds carry aloft some fine particles and deposit them around the area.

Vacuum pan salt production is carried out in a closed system with very little loss to the environment. Most spent brine is recovered and returned to the brine feed tank. Some salt is lost in the wash water when the filters are periodically cleaned. This saline water and condensate water produced from the steam that heats the multiple-effect evaporators are often recycled to the salt cavern.

An estimated 5% of salt is lost in the crushing, screening, washing, and drying steps of salt production. Another 5% may be lost in the vacuum pan process as well. In the fabrication phase, salt is made into pressed blocks mainly for animal feed and water treatment and into compressed pellets for water-softening units. Loose salt is either packaged in bags, round cans, shakers, single-serve packets, or other miscellaneous containers or stored and shipped in bulk. Occasionally when a bag tears open or a pressed block breaks, the salt is generally recovered and dissolved in the incoming brine feed tank. Home scrap is estimated to account for 3% of internal product waste that gets recycled. These losses are indicated in figure 10.

DISPOSITION AFTER CONSUMPTION

What happens to salt after it is consumed? Some uses are instantly assimilated by animals or humans while other uses are consumed in the preparation of various consumer products. Depending on the particular end use, the final disposition or "ultimate fate" of salt could be dispersal

to the environment, discarding to landfills, loss through incineration, or a combination of the three with some recycling potentially occurring after consumption. Table 2 shows the material flow of salt in the different end uses. The uses are categorized into main end-use categories with several subsectors.

Table 2.—Material flow of primary product of end use

End use	Method of use ¹	Examples of products	Lost to environment	Lost to landfill	Recycling
Chemicals:					
Chloroalkalies:					
Chlorine	C	Chlorine gas and polyvinyl chloride.	Airborne discharge	Polyvinyl chloride products.	Polyvinyl chloride.
Caustic soda	C	Pulp digester	Waste discharge	Paper products	None.
Synthetic soda ash	C	Glass	Byproduct discharges	Glass	Cullet.
Other chemicals	C	Sodium chlorate	Waste discharge	Chemical products	None.
Food processing:²					
Meatpackers	C, A	Meat products	Bioprocessed waste	Food waste	(³).
Dairy	C, A	Cheese, milk . . . . .	.. do. . . . .	.. do.	(³).
Canning	C, A	Canned vegetables, etc. . . . .	.. do. . . . .	.. do.	(³).
Baking	C, A	Bread . . . . .	.. do. . . . .	.. do.	(³).
Grain mill products	C, A	Cereal . . . . .	.. do. . . . .	.. do.	(³).
Other food processing	C, A	Pretzels, potato chips, etc.	.. do. . . . .	.. do.	(³).
General industrial:					
Textile and dyeing	C	Clothing	Waste discharge	Clothing	None.
Metal processing	C	Metal products . . . . .	.. do.	Metal products	Scrap metal.
Rubber	C	Rubber products . . . . .	.. do.	Tires, hoses	Scrap rubber, tires.
Oil	C	Well completion fluids	Drilling fluids	None	None.
Pulp and paper	C	Paper products	Waste discharge	Paper products	White paper, newspaper.
Tanning/leather	C	Leather products . . . . .	.. do.	Leather products	None.
Other industrial	Unknown	Miscellaneous	Unknown	Unknown	Unknown.
Agricultural (feed dealers, mixers, manufacturers, and distributors).	A	Salt blocks for animals	Bioprocessed waste	None	None.
Water treatment (Government, commercial, and distributors).	A and C	Drinking water and industrial water treatment.	Bioprocessed waste and waste discharge.	.. do.	Recycled process water.
Ice control (Government and commercial).	C	Road salt	Saline solution . . . . .	.. do.	Ultimately as solar salt.
Other ⁴	A and C	Hardware stores, lumber yards, and grocery stores.	Unknown	Unknown	Unknown.

¹Salt is assimilated (A) or consumed in process (C) or consumed in process and assimilated later (C, A).

²Additional salt for food processing included under grocery stores in "Other."

³Although food wastes are not recycled, they can be used as compost.

⁴Includes grocery stores, U.S. Government, institutional wholesalers, and some exports.

When salt is added to processed foods, it is incorporated into the food and remains as sodium chloride after the food is consumed and assimilated by the body. Excess salt is discharged through perspiration and excretion. This also is true for animals for the agricultural uses of salt. In industrial applications, salt is directly consumed in the manufacturing process of that industry and discharged in plant waste effluent to ground water supplies or sewage systems. Salt consumed for water treatment is used for various municipal, industrial, and residential purposes. The salt is usually discharged through sewage disposal systems and then processed in water-treatment or sewage-treatment facilities. In highway deicing, the salt is dissolved and dispersed into the ecosystem.

In almost all of these uses, salt enters the environment after it has been totally consumed. Whether salt entered the environment through ground water, surface water, the air, or the soil, salt ultimately will be transported to the oceans from where it once originated.

Salt-base products may also be discarded to landfills as solid municipal waste. Municipal solid wastes are about 1% of the 11 billion short tons of nonhazardous waste generated annually in the United States (6). In 1990, about 196 million short tons of municipal solid waste was discarded in the Nation. Of this quantity, 67% was sent to landfills, 17% was recycled or composted, and 16% was incinerated (7). The data in the accompanying figures and tables for food processing assume that about 90% of all food is consumed and that 10% is discarded as waste and discharged to landfills or incinerators. It is important to note that the quantities of salt and salt-base products that are discarded are not necessarily thrown away in the same calendar year in which they were produced. Salt incorporated in various products, such as rubber, some metals, and paper also are discarded to landfills in disposable consumers products. Figure 11 illustrates the composition of the municipal solid waste that contain salt-base products in 1990 by type, percent, and quantity.

Salt is a soluble compound that retains its identity until the bond between sodium and chlorine is broken with the input of energy. For example, in chloralkali manufacture using electrolysis, the bonds are broken and each element separates; chlorine is liberated as a gas, and sodium combines with water to form sodium hydroxide. Unless these two elements recombine to form sodium chloride, the material flow of salt theoretically ends and the material flow of chlorine and caustic soda begins.

Rather than debate where the material flow of a compound should end and the study of the material flow of an element should begin, this study will assume that downstream chemical derivatives owe their origin to sodium

chloride. Polyvinyl chloride plastic pipe does not contain any salt but it would have been virtually impossible to economically manufacture it without salt.

Table 3 lists the various subsector end uses of chlorine and caustic soda. Data pertaining to the percent distribution of each end use was obtained from industry sources and trade journals, not from any Bureau of Mines survey. All of the uses of chlorine and caustic soda go into various consumer products that are lost to the atmosphere through use or by incineration, to soil or water environment as dispersive losses, and to landfills as discarded waste. The individual percent loss was estimated based on determining the use of the products made from chlorine and caustic soda. For example, figure 9 shows vinyl chloride made from chlorine is used to make polyvinyl chloride that goes into consumer products (i.e., plastic pipes and bottles) that normally are either recycled or thrown away and taken to landfills. The quantity that gets recycled may be converted into other consumer products. The quantity discarded to landfills is not readily recoverable, and that amount burned through incineration is lost forever (despite recovering any energy obtained from burning); therefore, the estimated percent losses would be 100%. Propylene oxide is made into propylene glycol, which is used in brake fluid, food, cosmetics, and pharmaceuticals (all of which are dispersed) and plastics and cellophane (which are disposed to landfills or incinerated). Percent loss was estimated at about 50% for each type of loss. Other landfill or incinerated wastes include chlorinated methanes used to make methyl chloride used in silicone manufacture. Some silicone products include adhesives, sealants, molds, and water repellent chemicals.

Atmospheric losses would include organic chemicals made from chlorine, such as trichloroethylene and perchloroethylene, that are used in drycleaning fluids, textile-spotting fluids, and paint removers. Although commercial drycleaning establishments have solvent vapor recovery systems, some losses to the air are common. Chlorinated ethanes had been used to manufacture ethyl chloride that was made into tetraethyl lead for gasoline additives. After combustion, the tetraethyl lead was dispersed to the air and ultimately to the surface environment. With the gradual conversion to unleaded gasolines, the use of leaded gasoline in the United States has virtually disappeared.

Chlorine is discharged to the environment by the pulp and paper industry as effluent acids. Chlorine is used to make sodium chlorate (which is used to generate chlorine dioxide) and sodium hypochlorite, both of which are pulp and paper bleaching chemicals. The estimated loss to the environment is 100%.

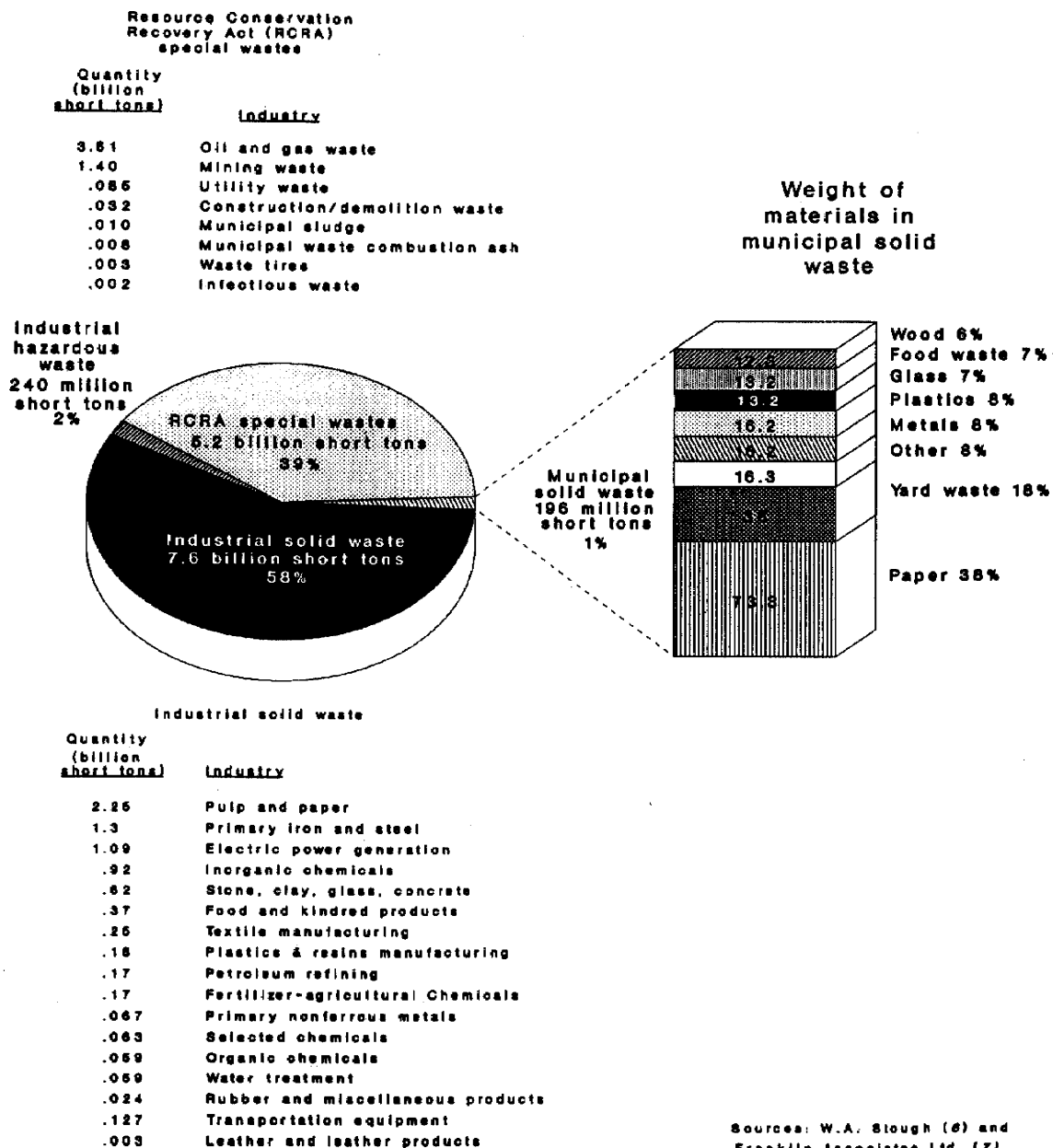


Figure 11.—Volume of solid waste generated in the United States in 1990.

Table 3.—Estimated losses of salt in 1990 in the chemical industry

Sector and subsectors	Percent of end use	Short tons of product	Total percent loss		Percent end use loss	
			To environment	To land-fill	To environment	To land-fill
Chemicals:¹						
Chloralkali chlorine:						
Vinyl chloride	24	2,832	0	100	0	24
Pulp and paper	14	1,652	100	0	14	0
Other organics	12	1,416	50	50	6	6
Propylene oxide	8	944	50	50	4	4
Inorganic chemicals	8	944	100	0	8	0
Chlorinated ethanes	7	826	50	50	3	4
Chlorinated methanes	7	826	25	75	2	5
Epichlorohydrin	5	590	0	100	0	5
Water treatment	5	590	100	0	5	0
Export	4	472	50	50	2	2
Titanium dioxide	3	354	25	75	1	2
Other	3	354	50	50	2	1
Total chlorine	100	11,800	NAp	NAp	47	53
Sodium hydroxide:						
Pulp and paper	24	3,000	75	25	18	6
Other organics	22	2,750	50	50	11	11
Inorganic chemicals	12	1,500	50	50	6	6
Other	10	1,250	50	50	5	5
Petroleum	8	1,000	100	0	8	0
Soaps and detergents	8	1,000	100	0	8	0
Water treatment	8	1,000	100	0	8	0
Textiles	5	625	100	0	5	0
Alumina	3	375	100	0	3	0
Total sodium hydroxide	100	12,500	NAp	NAp	72	28
Weighted average chloralkali percent					60	40
Total salt consumed for chloralkali manufacture	NAp	19,182	NAp	NAp	11,509	7,673
Other chemicals	NAp	2,046	50	50	1,023	1,023
Total chemicals	NAp	21,228	NAp	NAp	12,532	8,696

NAp Not applicable.

¹Salt consumption data on end uses of chlorine and sodium hydroxide are not collected; however, information on percent distribution of end uses were obtained from industry sources. Losses of second and third generation uses of chlorine and sodium hydroxide have been estimated.

Approximately one-fourth of the sodium hydroxide end use is for the pulp and paper industry, as well as for making cellulose for cellophane and rayon fabric. It is also used in the sulfate pulping process in which wood chips are digested in a high-alkaline cooking liquor. In addition, sodium hydroxide is used in waste streams for pH neutralization and in a process to treat waste paper to recover the pulp for recycling. The quantity of sodium hydroxide lost to the environment is estimated at 75% and 25% to landfills and incinerators. Other uses of caustic soda include petroleum (caustic flooding in secondary oil recovery), soaps and detergents, water treatment, textiles

(for making sodium lauryl sulfate—textile wetting agent), and alumina (for leaching bauxite ore). All of these uses are dissipated to the environment.

The total percent losses of chlorine and sodium hydroxide were averaged together to obtain an average of 60% lost to the environment and 40% lost to landfills for the chloralkali end use of salt. This percentage was then applied to the quantity of salt used by the chloralkali industry in 1990. The estimated losses in the chemical sector that are summarized in table 3 were included in the total losses of salt shown in table 4.

Table 4.—Estimated losses of salt in 1990
(Thousand short tons)

End use Sectors and subsectors	Estimated losses					
	Percent of total	Short tons of salt consumed	To envi- ronment ¹	Percent of total	To land- fill ²	Percent of total
Chemicals:						
Chloralkali		19,182	11,509		7,673	
Other chemicals		2,046	1,023		1,023	
Total chemicals	47	21,228	12,532	36	8,696	84
Food processing:³						
Meat packers		598	538		60	
Dairy		140	126		14	
Canning		318	286		32	
Baking		171	154		17	
Grain mill processing		97	87		10	
Other food processing		298	268		30	
Grocery wholesale (3/4 of category) ⁴		671	604		67	
Total food processing	5	2,293	2,063	6	230	2
General industrial:						
Textiles and dyeing		227	227		0	
Metal processing		346	173		173	
Rubber		45	0		45	
Oil		793	793		0	
Pulp and paper		283	283		0	
Tanning and leather		109	109		0	
Other industrial		288	144		144	
Total general industries	5	2,091	1,729	4	362	4
Agricultural:						
Feed retailers and/or dealers-mixers		1,101	1,101		0	
Feed manufacturers		546	546		0	
Direct-buying and user		55	55		0	
Distributors		619	619		0	
Total agricultural	5	2,321	2,321	7	0	0
Water treatment:						
Government		297	297		0	
Commercial		198	198		0	
Distributors		1,123	1,123		0	
Total water treatment	4	1,618	1,618	5	0	0
Ice control/stabilization:						
Government		10,757	10,757		0	
Commercial		545	545		0	
Total ice control	25	11,302	11,302	33	0	0
Other:						
Distributors:						
Grocery wholesale and/or retailers ⁴		223	223		0	
Institutional wholesalers and end users		96	96		0	
U.S. Government resale		9	9		0	
Other wholesale and/or retailers		1,851	1,851		0	
Other		2,030	1,015		1,015	
Total other	9	4,209	3,194	9	1,015	10
Grand total	100	45,062	34,760	100	10,302	100
Percent of total	100	0	77	100	23	100

¹Losses to the environment include those that are lost to ground water (from deicing salt), sewage (water treatment and industrial effluent), soil (deicing salt), air (drycleaning compounds, perfume), and natural dissipation from use (gasoline additives, pharmaceuticals, and cosmetics).

²Losses to landfills include municipal sanitary landfills and toxic and/or hazardous landfills (for solvents, dangerous organic compounds, etc.).

³Some food is lost through spoilage, waste, etc., and discarded to landfills. Some food is recycled as compost. It is estimated that 90% of salt for food processing is ingested and lost to the environment through sewage and 10% of salt in food processing is lost to landfills or incinerators as food waste.

⁴About 75% of this end use, which normally is categorized under "Distributors," goes into products sold in grocery stores and used for human consumption (salt shakers, pickling salt, ice cream salt, etc.) and about 25% for nonhuman consumption (pellets for home water-softening units, bags of sidewalk deicing salt, etc.).

Reported salt consumption in 1990 was 45.1 million short tons, which was disbursed through seven major consuming sectors. Final disposition of salt in the post-consumption phase includes the dispersive loss to the environment and landfill disposal. It is estimated that about 10.3 million short tons of salt was lost to landfill disposal, representing 23% of reported consumption, and 34.8 million short tons of salt, representing 77% of reported consumption, was lost to the environment as dispersive losses. Figure 10 and tables 3 and 4 show the distribution of the salt consumed as to the percent lost to the environment and discarded to landfills and incineration. Recycling of salt or salt-base products is also possible in certain cases, such as using polyvinyl chloride bottles and shredded rubber tires as asphalt extenders for road construction.

The following lists are estimates of how much salt is disbursed to the environment and landfills as either salt or salt-bearing products.

Dispersive Losses

The following end uses of salt are dispersive losses to the environment:

Chemicals—as waste effluent, sewage . . .	12.5 million short tons
Food—through excretion, assimilation . . .	2.1 million short tons
Industrial—as waste effluent, sewage . . .	1.7 million short tons
Agriculture—through excretion, assimilation . . .	2.3 million short tons
Water treatment—through sewage	1.6 million short tons
Deicing—runoff	11.3 million short tons
Other—all the above	<u>3.2 million short tons</u>
Total	34.7 million short tons

THE CUMULATIVE EFFECT OF SALT PRODUCTION AND CONSUMPTION

There is sufficient historical salt production, trade, and consumption data to enable the cumulative effect of salt to be quantified for certain uses. Highway deicing salt is a large component of domestic consumption and has significance in terms of environmental loading. The data in figure 12 and table 5 show that, since 1940, about when salt for this use began and when reported consumption data were first collected, about 268 million short tons of salt has been applied to the Nation's roads and highways. Various studies have been done only on small specific sections of the United States to determine how long it takes for sodium chloride to move through the ecosystem. A major study by the Federal Government and academia performed in 1987 measured the change in the salinity of the Nation's rivers between 1974 and 1981 (8). The investigation used the water quality trends from 388 sampling stations in the National Stream Quality Accounting Network and the National Water Quality Surveillance System.

Disposed to Landfill and Incineration

The following are estimated losses to landfill disposal or incineration of products containing or derived from salt:

Chemicals—plastics, glass, paper	8.7 million short tons
Food—discarded waste food	0.2 million short tons
Industrial—rubber, textiles	0.4 million short tons
Agricultural	0
Water treatment	0
Deicing	0
Other—unknown	<u>1.0 million short tons</u>
Total	10.3 million short tons

It should be noted that, although this study shows the material supply and demand balance for 1990, the estimated quantities of salt and salt-base products that get discarded to landfills or incinerated are not necessarily disposed of during the same calendar year that they were produced. Different products have different shelf lives or lengths of time for usefulness before being discarded.

Recycling of Salt

The only salt-base products that could be recycled are polyvinyl chloride plastics, glass, scrap metal, rubber tires, bleached paper, and newsprint. Direct uses of salt that could be recycled include water-treatment facilities using desalination to recover sodium chloride. Salt introduced into surface water and ground water from deicing salt and water treatment will eventually reach the oceans and mix with the saline resource to be available for future use and to be recovered as solar salt somewhere in the world.

The results indicated that there was a moderate correlation between chloride concentrations and population changes within the study areas. Rising chloride levels were attributed to population increases in which human wastes were dissipated to the environment. Salinity increases were also generated from irrigated agriculture, especially in western rivers. Lastly, the report indicated that salt from highway deicing was a significant contributor to total stream salinity.

A study conducted in 1988 on water quality showed that only seven States regarded road salting as a problem associated with ground water contamination; in fact, none of the surveyed States considered it a first priority issue (9). Contamination from natural salt water intrusion was also not an important concern. The report stated that leakage from underground storage tanks was the major concern among the top 5 contamination sources of the 34 States that participated in the survey. Ground water

problems from municipal landfills placed second as characterized by 25 States, while 23 States place agricultural activity among the top 5 sources of concern. Figure 13

shows the priority ranking of the ground water contamination sources among the States surveyed.

Table 5.—Historical consumption of salt for highway deicing, 1940-90

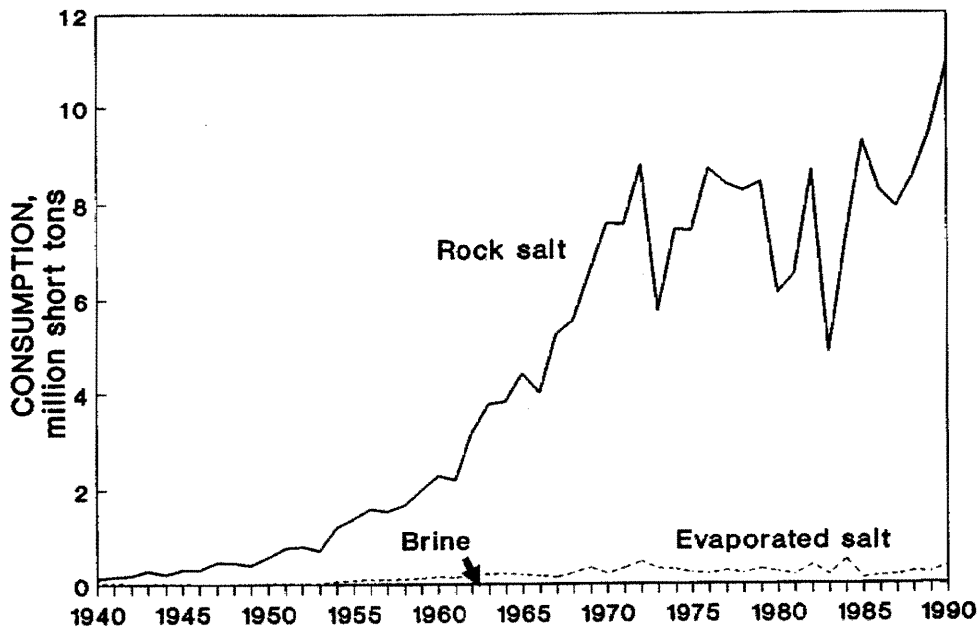
(Short tons)

Year	Evaporated ¹	Rock	Brine	Total	Imports	Grand total
1940	25,596	138,380	NA	163,976	NA	163,976
	26,382	167,126	NA	193,508	NA	193,508
	13,414	197,751	NA	211,165	NA	211,165
	12,912	283,131	NA	296,043	NA	296,043
	9,300	218,903	NA	228,203	NA	228,203
1945	10,149	307,656	NA	317,805	NA	317,805
	7,960	312,164	NA	320,124	NA	320,124
	6,942	466,762	NA	473,704	NA	473,704
	8,260	460,674	NA	468,934	NA	468,934
	7,804	404,634	NA	412,438	NA	412,438
1950	13,000	578,000	NA	591,000	NA	591,000
	19,000	766,000	NA	785,000	NA	785,000
	17,000	800,000	NA	817,000	NA	817,000
	20,000	721,000	NA	741,000	NA	741,000
	66,000	1,217,000	NA	1,283,000	NA	1,283,000
1955	91,000	1,395,000	NA	1,486,000	NA	1,486,000
	99,000	1,593,000	NA	1,692,000	NA	1,692,000
	102,000	1,548,000	NA	1,650,000	NA	1,650,000
	114,000	1,684,000	NA	1,798,000	NA	1,798,000
	135,000	1,986,000	NA	2,121,000	NA	2,121,000
1960	157,000	2,294,000	NA	2,451,000	NA	2,451,000
	148,000	2,210,000	1,000	2,358,000	NA	2,358,000
	193,000	3,175,000	1,000	3,368,000	NA	3,368,000
	216,000	3,776,000	1,000	3,992,000	NA	3,992,000
	226,000	3,822,000	2,000	4,048,000	NA	4,048,000
1965	210,000	4,403,000	3,000	4,613,000	NA	4,613,000
	185,000	3,997,000	5,000	4,182,000	NA	4,182,000
	145,000	5,252,000	3,000	5,397,000	NA	5,397,000
	239,000	5,556,000	3,000	5,795,000	NA	5,795,000
	350,000	6,598,000	4,000	6,948,000	NA	6,948,000
1970	219,000	7,590,000	4,000	7,809,000	2,285,000	10,094,000
	333,000	7,575,000	4,000	7,908,000	1,954,000	9,862,000
	466,000	8,791,000	4,000	9,257,000	1,987,000	11,244,000
	328,000	5,754,000	1,000	6,082,000	1,227,000	7,309,000
	302,000	7,451,000	4,000	7,753,000	1,354,000	9,107,000
1975	237,000	7,439,000	4,000	7,676,000	1,160,000	8,836,000
	218,000	8,707,000	5,000	8,925,000	1,263,000	10,188,000
	278,000	8,395,000	5,000	8,673,000	1,738,000	10,411,000
	231,000	8,251,000	5,000	8,482,000	2,203,000	10,685,000
	308,000	8,433,000	1,000	8,741,000	2,396,000	11,137,000
1980	252,000	6,137,000	1,000	6,389,000	1,087,000	7,476,000
	189,000	6,537,000	1,000	6,726,000	1,581,000	8,307,000
	400,000	8,656,000	1,000	9,056,000	1,786,000	10,842,000
	192,000	4,484,000	1,000	5,040,000	1,848,000	6,888,000
	517,000	7,210,000	1,000	7,727,000	2,993,000	10,720,000
1985	122,000	9,280,000	1,000	9,402,000	1,777,000	11,179,000
	169,000	8,267,000	1,000	8,436,000	2,104,000	10,540,000
	184,000	7,917,000	3,000	8,101,000	1,774,000	9,875,000
	254,000	8,547,000	2,000	8,801,000	2,321,000	11,122,000
	243,000	9,470,000	13,000	9,713,000	1,735,000	11,448,000
1990	374,000	10,927,000	1,000	11,301,000	NA	11,301,000
Total	8,689,719	222,510,181	86,000	231,199,900	36,573,000	267,772,900

NA Not available.

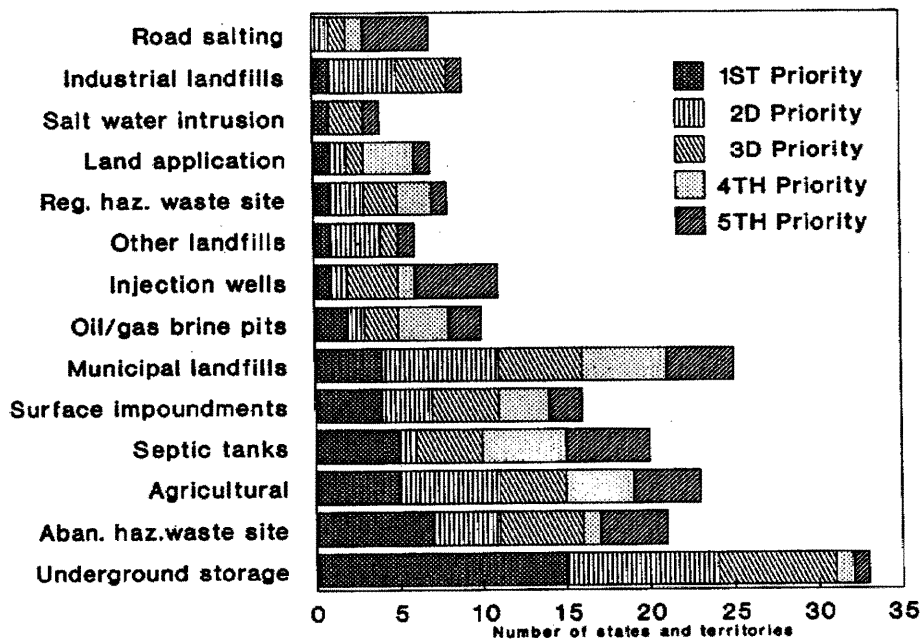
¹Evaporated salt includes solar salt and vacuum pan salt.

NOTE.—Bureau of Mines Annual Mineral Yearbooks began publishing salt by end use beginning in 1940 in 1941 chapter. Deicing salt was for railroads, bus transit companies, State/local/Federal Government, dust control, and soil stabilization. Import data for 1990 included with individual types of salt (unable to break out import data from company reports).



Source: U.S. Bureau of Mines, various "Minerals Yearbooks" chapters.

Figure 12.—Consumption of salt for highway deicing.



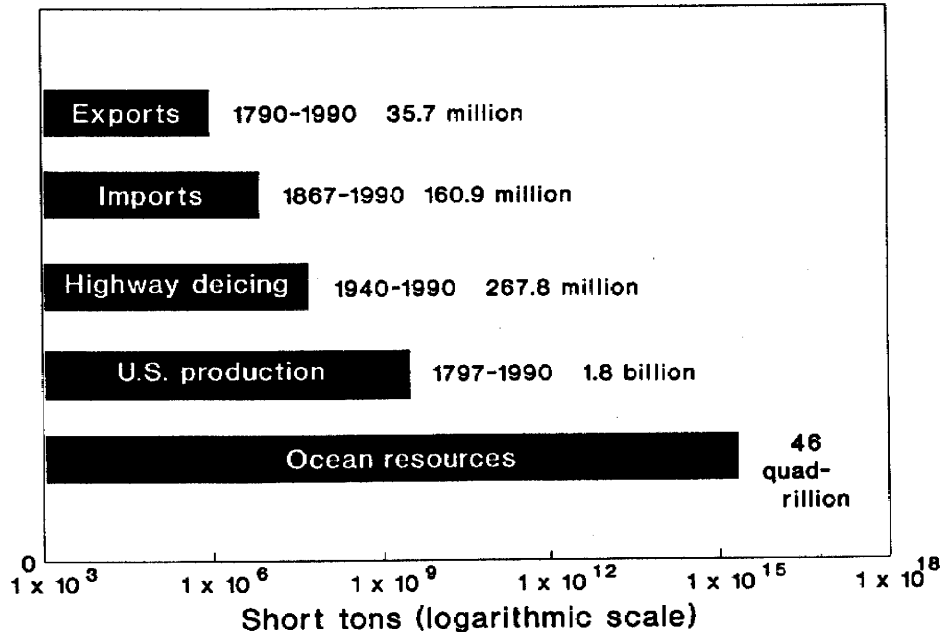
Source: EPA National Water Quality Inventory 1988 Report To Congress (10).

Figure 13.—Priority ranking of ground water contamination sources.

Tests conducted in Maine showed sodium concentrations at a 6-inch depth along the edge of a road rose by four to eight times the background level after 2 or 3 years (10). In areas where road salting had been done for 18 years, sodium levels eight times the normal quantity were detected 45 feet from the highway. The airborne transport of dry or powdered deicing salt has been estimated to be as much as 10% of the salt applied; however, the quantity generally is closer to 1% (11). Although the level of salt used for highway deicing increased about 68 times in 1990 from that quantity used in 1950, there appears to be no serious and permanent ill-effects from the use of more than one-quarter billion short tons of salt in the 50 years that salt has been used in this application. There are negative environmental aspects regarding the use of road salt; however, salt remains as the most economical, effective, and available deicing agent available. In addition, salt

provides tangible benefits, such as energy savings and reduced wage and production losses caused by employee lateness and absenteeism as measured by Brenner and Moshman (12) and Sheflin (13). Lastly, salt also has immeasurable benefits, such as the lives saved because of reduced traffic accidents and the lives saved because of reduced response time to medical emergencies.

Table 6 lists the historical production, trade, and consumption statistics on salt since 1790. Figure 14 shows a comparison of the cumulative domestic salt statistics in relation to the magnitude of oceanic salt resources. Total cumulative U.S. salt production since 1797 is more than 1.8 billion tons. In comparison to the oceanic salt resources (46 quadrillion short tons), the United States has consumed only 0.000004% of the salt available in the oceans. Imports since 1867 amounted to about 161 million short tons while exports were only 36 million short tons.



Source: Minerals Yearbook chapters by the U.S. Bureau of Mines.

Figure 14.—Comparison of cumulative U.S. salt statistics.

Table 6.—U.S. production, trade, and consumption of salt, 1790-1990

(Thousand short tons)

Year	Production	Imports	Exports	Apparent consumption ¹
1790	NA	NA	894	(894)
1791	NA	NA	118	(118)
1792	NA	NA	NA	NA
1793	NA	NA	NA	NA
1794	NA	NA	NA	NA
1795	NA	NA	NA	NA
1796	NA	NA	NA	NA
1797	713	83,381	NA	84,094
1798	1,678	77,155	NA	78,833
1799	1,196	70,376	NA	71,572
1800	1,400	95,811	NA	97,211
1801	1,736	101,051	NA	102,787
1802	2,100	108,444	NA	110,544
1803	2,520	99,200	NA	101,720
1804	2,800	96,152	NA	98,952
1805	4,314	105,905	NA	110,219
1806	3,432	119,356	NA	122,788
1807	4,913	128,717	NA	133,630
1808	8,949	1,370	NA	10,319
1809	3,592	10	NA	3,602
1810	12,600	NA	NA	12,600
1811	5,600	NA	NA	5,600
1812	6,188	NA	NA	6,188
1813	6,328	NA	NA	6,328
1814	25,060	10,615	NA	35,675
1815	9,018	120,729	NA	129,747
1816	9,763	150,289	NA	160,052
1817	11,443	74,928	NA	86,371
1818	11,383	99,622	NA	111,005
1819	15,354	107,055	NA	122,409
1820	12,833	142,288	NA	155,121
1821	14,729	NA	NA	14,729
1822	13,484	NA	NA	13,484
1823	20,356	NA	NA	20,356
1824	22,866	NA	NA	22,866
1825	21,202	NA	NA	21,202
1826	22,709	NA	NA	22,709
1827	49,571	NA	NA	49,571
1828	56,684	NA	NA	56,684
1829	59,333	NA	NA	59,333
1830	65,564	NA	1,330	64,234
1831	69,184	NA	1,284	67,900
1832	75,101	NA	1,262	73,839
1833	87,571	NA	702	86,869
1834	102,094	NA	2,494	99,600
1835	88,773	NA	3,534	85,239
1836	102,908	NA	1,398	101,510
1837	113,336	NA	2,776	110,560
1838	122,811	NA	3,196	119,615
1839	124,822	NA	7,401	117,421
1840	113,162	NA	2,580	110,582
1841	133,964	NA	6,022	127,942
1842	117,916	NA	3,091	114,825
1843	149,111	NA	1,139	147,972
1844	164,597	NA	4,411	160,186
1845	177,544	NA	3,682	173,862
1846	197,782	NA	3,294	194,488
1847	185,960	NA	5,663	180,297

See footnotes at end of table.

Table 5.—U.S. production, trade, and consumption of salt, 1790-1990—Continued

(Thousand short tons)

Year	Production	Imports	Exports	Apparent consumption ¹
1848	213,168	NA	6,136	207,032
1849	224,982	NA	8,738	216,244
1850	207,509	NA	8,937	198,572
1851	209,350	NA	9,634	199,716
1852	214,595	NA	41,095	173,500
1853	227,764	NA	14,444	213,320
1854	225,042	NA	15,349	209,693
1855	212,140	NA	15,010	197,130
1856	202,484	NA	19,557	182,907
1857	156,209	NA	16,132	140,077
1858	196,930	NA	14,927	182,003
1859	193,040	NA	20,083	172,957
1860	157,171	NA	13,312	143,859
1861	219,111	NA	15,047	204,064
1862	287,528	NA	11,130	276,398
1863	287,677	NA	16,377	271,300
1864	317,105	NA	17,795	299,310
1865	269,749	NA	16,507	253,242
1866	293,129	NA	1,978	291,151
1867	316,127	² 483,775	16,963	782,839
1868	363,254	528,421	17,499	874,176
1869	372,151	554,148	12,403	913,896
1870	380,151	706,853	8,348	1,078,656
1871	336,443	623,396	3,364	956,475
1872	323,493	573,701	1,193	896,001
1873	324,158	714,263	2,053	1,036,368
1874	312,597	891,284	886	1,202,995
1875	379,575	830,238	1,319	1,208,494
1876	425,777	829,505	1,428	1,253,854
1877	412,523	935,484	1,842	1,345,165
1878	460,757	867,718	2,028	1,326,447
1879	533,146	904,107	1,224	1,436,029
1880	834,548	959,739	621	1,793,666
1881	868,000	1,075,198	1,273	1,941,925
1882	897,732	863,847	1,178	1,760,401
1883	866,912	867,916	1,516	1,733,312
1884	912,091	908,978	1,960	1,819,109
1885	985,411	903,666	2,051	1,887,027
1886	1,078,991	³ 789,214	2,414	1,865,791
1887	1,120,555	724,569	2,343	1,842,781
1888	1,127,823	625,031	2,680	1,750,174
1889	1,120,779	513,367	2,689	1,631,456
1890	1,242,779	514,647	2,464	1,754,962
1891	1,398,312	474,333	2,224	1,870,421
1892	1,637,845	457,357	2,604	2,092,597
1893	1,665,609	348,519	2,896	2,011,232
1894	1,815,578	434,156	5,427	2,244,307
1895	1,913,751	559,152	3,602	2,469,301
1896	1,939,102	520,412	5,356	2,454,158
1897	2,236,248	418,049	5,797	2,648,501
1898	2,465,769	371,059	8,840	2,828,188
1899	2,759,206	378,103	12,600	3,124,708
1900	2,921,708	399,818	7,511	3,314,015
1901	2,879,333	403,466	9,433	3,273,366
1902	3,338,892	369,528	5,094	3,703,326
1903	2,655,532	327,961	12,750	2,970,743
1904	3,084,200	332,279	13,964	3,402,516
1905	3,635,257	322,317	34,238	3,923,337

See footnotes at end of table.

Table 6.—U.S. production, trade, and consumption of salt, 1790-1990—Continued

(Thousand short tons)

Year	Production	Imports	Exports	Apparent consumption ¹
1906	3,944,133	349,263	33,988	4,259,408
1907	4,158,578	297,598	30,802	4,425,375
1908	5,435,089	319,286	26,627	5,727,747
1909	4,215,070	299,040	40,153	4,473,957
1910	4,242,792	274,206	49,013	4,467,984
1911	4,365,756	284,179	48,873	4,601,062
1912	4,565,473	279,626	62,410	4,882,689
1913	4,815,902	⁴ 309,531	70,289	5,055,143
1914	4,872,656	261,609	82,295	5,051,970
1915	5,352,409	244,653	80,474	5,516,588
1916	6,362,906	122,079	84,065	6,400,920
1917	6,978,177	64,922	113,993	6,929,106
1918	7,238,744	40,290	136,783	7,142,251
1919	6,882,902	59,514	119,416	6,823,000
1920	6,840,029	137,654	139,272	6,838,411
1921	4,981,154	93,095	109,563	4,964,686
1922	6,792,849	113,922	134,989	6,771,782
1923	7,130,713	88,750	125,529	7,093,934
1924	6,803,115	88,938	144,945	6,747,108
1925	7,397,500	85,788	155,079	7,328,209
1926	7,371,600	55,964	158,908	7,268,656
1927	7,568,690	44,968	153,832	7,459,826
1928	8,074,700	42,856	145,396	7,972,160
1929	8,543,560	36,450	109,222	8,470,788
1930	8,054,440	54,021	70,478	8,037,983
1931	7,358,070	33,216	98,710	7,292,576
1932	6,407,973	28,018	63,581	6,372,410
1933	7,604,972	30,128	105,178	7,529,922
1934	7,612,074	53,124	105,365	7,559,833
1935	7,926,897	51,245	112,212	7,865,930
1936	8,828,936	51,041	76,974	8,803,003
1937	9,241,564	45,996	70,111	9,217,449
1938	8,025,768	39,513	67,498	7,997,783
1939	9,277,911	46,033	124,273	9,199,671
1940	10,359,960	30,402	147,044	10,243,318
1941	12,720,629	15,432	123,195	12,612,866
1942	13,693,284	7,754	118,424	13,582,614
1943	15,214,152	1,258	145,803	15,069,607
1944	15,717,171	5,554	198,368	15,524,357
1945	15,394,141	4,553	190,524	15,208,170
1946	15,132,145	4,253	223,426	14,912,972
1947	16,053,882	1,909	188,307	15,867,484
1948	16,403,293	5,621	387,601	16,021,313
1949	15,590,697	6,309	359,776	15,237,230
1950	16,629,809	7,869	190,377	16,447,301
1951	20,207,131	4,329	439,114	19,772,346
1952	19,545,214	7,056	349,971	19,202,299
1953	20,789,003	137,308	249,521	20,676,790
1954	20,669,403	160,770	385,259	20,444,914
1955	22,693,000	185,653	407,131	22,471,522
1956	24,206,000	368,212	336,320	24,237,892
1957	23,844,000	650,845	390,707	24,104,138
1958	21,910,000	611,043	363,000	22,158,043
1959	25,160,000	1,024,629	424,000	25,760,629
1960	25,479,000	1,057,028	420,000	26,116,028
1961	25,707,000	1,050,084	642,000	26,115,084
1962	28,807,000	1,374,219	671,000	29,510,219
1963	30,641,000	⁵ 1,516,159	781,000	31,376,159

See footnotes at end of table.

Table 6.—U.S. production, trade, and consumption of salt, 1790-1990—Continued

(Thousand short tons)

Year	Production	Imports	Exports	Apparent consumption ¹
1964	31,623,000	2,260,442	594,000	33,289,442
1965	34,687,000	2,410,000	688,000	36,409,000
1966	36,463,000	2,479,000	662,000	38,280,000
1967	38,946,000	2,843,000	678,000	41,111,000
1968	41,274,000	3,456,000	728,000	44,002,000
1969	44,245,000	3,302,000	716,000	46,831,000
1970	45,896,000	3,536,000	423,000	49,009,000
1971	44,077,000	3,855,000	670,000	47,262,000
1972	45,022,000	3,463,000	869,000	47,616,000
1973	43,910,000	3,207,000	609,000	46,508,000
1974	46,536,000	3,358,000	521,000	49,373,000
1975	41,030,000	3,215,000	1,332,000	42,913,000
1976	44,191,000	4,352,000	1,007,000	47,536,000
1977	43,412,000	4,529,000	1,008,000	46,933,000
1978	42,869,000	5,380,000	776,000	47,473,000
1979	45,793,000	5,276,000	697,000	50,372,000
1980	40,352,000	5,264,000	831,000	44,785,000
1981	38,907,000	4,319,000	1,046,000	42,180,000
1982	37,894,000	5,451,000	1,001,000	42,344,000
1983	34,573,000	5,997,000	517,000	40,053,000
1984	39,225,000	7,545,000	820,000	45,950,000
1985	40,067,000	6,207,000	904,000	45,370,000
1986	36,663,000	6,665,000	1,165,000	42,163,000
1987	36,493,000	5,716,000	541,000	41,668,000
1988	38,940,000	5,474,000	884,000	43,530,000
1989	38,856,000	6,084,000	1,567,000	43,373,000
1990	40,693,000	6,580,000	2,498,000	44,775,000
Total	1,809,178,842	160,986,232	35,696,496	1,975,161,578

NA Not available.

¹Defined as production plus imports and minus exports.²Year ending June 30.³Year ending December 31.⁴This class was not carried separately after October 3, 1913.⁵Brine imports began September 1, 1963.

SUMMARY

In summary, salt is one of the most important mineral commodities on Earth and has a multitude of end uses. There is an abundant supply of salt to satisfy all human requirements virtually forever. Based on the available data and judgment decisions, it is estimated that approximately one-fourth of all salt that is consumed is disposed to landfills and about three-fourths is lost to the environment.

More quantitative and qualitative studies must be conducted on salt to determine if there are any long-lasting adverse effects of sodium and chlorine dispersal in the environment. However, based on cumulative production and consumption data available from 1797 and several site-specific environmental studies, there do not appear to be any negative impacts to the ecosystem.

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