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NATIONAL DESALTING AND WATER TREATMENT NEEDS SURVEY

Water Treatment Technology Program Report No. 2

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16. ABSTRACT

This report presents the findings of a survey conducted under the Desalting Technology Program, Bureau of Reclamation, to determine the needs for desalting and water treatment from a national perspective. This survey examines available water quality and information for both raw water and treated water supply. A broad overview is also provided of current and proposed water treatment activity in the following major areas of application: industrial and municipal supply, wastewater reuse, ground-water recharge, irrigation drainage, dual-purpose plants, hazardous waste control, and point-of-use treatment. In addition, the technical, economic, financial, environmental, and regulatory concerns about desalting/water treatment technology are briefly summarized.

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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GLOSSARY

AWWA: American Water Works Association

BAT: best available technology (EPA terminology)

Bgal/d: billion gallons per day

CERCLAC: Comprehensive Environmental Response, Compensation, and Liability Act (Super-fund)

DBCP: dibromochloropropane

DBP: disinfection by-products

DWR: Department of Water Resources

ED/EDR: electrodialysis, electrodialysis reversal

EPA: Environmental Protection Agency (U.S.)

FRDS: Federal Reporting Data System (drinking water)

GAC: granular-activated carbon (filters)

GAO: General Accounting **Office** (U.S.)

GS: U.S. Geological Survey

MCL: maximum contaminant level (primary MCL is an enforceable standard, secondary MCL is recommended)

MF: microfiltration (membrane)

Mgal/d: million gallons per day (water production rate)

mg/L: milligrams per liter

M&I: municipal and industrial

MWD: Metropolitan Water District (Southern California)

NASQAN: National Stream Quality Accounting Network (operated by GS)

NF: nanofiltration (membrane)

NPDES: National Pollutant Discharge Elimination System (EPA)

NPL: National Priorities List (Super-fund)

NSA: National Statistical Assessment (of rural water conditions)

NWRI: National Water Research Institute

NWSIA: National Water Supply Improvement Association

O&M: operations and maintenance

OSW: Office of Saline Water

OTA: Office of Technology Assessment

OWRT: Office of Water Research and Technology

POU: point-of-use (water treatment for home use)

p/b: parts per billion

RCRA: Resources Conservation and Recovery Act

R&D: research and development

RO: reverse osmosis

ROWPU: reverse osmosis water purification unit

SDWA: Safe Drinking Water Act

STORET: Storage and Retrieval of Water Quality Data (EPA)

TCE: trichloroethylene

TDS: total dissolved solids

THM: trihalomethanes

UP: ultrafiltration (membranes)

WATSTOR: water quality database operated by GS

WF21: Water Factory 21, Orange County, California

WIDB: water industry database (operated by AWWA)

INTRODUCTION

Desalting and related water treatment technologies in the United States are increasing to treat industrial and municipal wastewater, reclaim water of impaired quality, and improve the quality of water supply for communities across the nation. In 1992, the Bureau of Reclamation (Reclamation), in concert with private industry, universities, and local communities initiated a major new effort, the Desalting Technology Program, to address a broad range of desalting and related water treatment needs. The primary objective of this research program is to reduce the cost of desalting and provide more feasible alternatives for producing potable water.

As one of nine identified tasks under the Desalting Technology Program, a national treatment needs survey was originally proposed to identify specific needs that can be met through treatment of local water supplies. However, after reviewing available data, the survey report was broadened to provide a more comprehensive “snapshot” or overview regarding general treatment needs, applications, trends, and available databases that hopefully will assist Government agencies, suppliers, water purveyors, water users, etc., in understanding the potential application of desalting and water treatment technologies to critical water problems in the United States today.

SCOPE OF STUDY

The primary emphasis in this survey is to address a broad array of water supply and water quality needs and opportunities from a water user’s point of view. The study makes no attempt to analyze treatment processes, provide comprehensive technology assessments, or provide a marketing analysis. The survey makes use of existing information and databases to assess available trends and statistical date for raw water and treated water supply. Although water treatment needs for small communities are stressed in this report, other areas of application are also addressed, including irrigation drainage, industrial wastewater, process water, municipal wastewater, hazardous waste control, etc. The report includes a sample query of the FRDS (Federal Reporting Data Service) database in order to identify the general extent of water treatment needs by U.S. communities to meet safe drinking water criteria.

OVERVIEW

Since 1952, the Federal Government, through the OSW (Office of Saline Water) and the OWRT (Office of Water Research and Technology), has invested just over $900 million (1985 dollars) in support of desalting research, development, and demonstration projects [OTA (Office of Technology Assessment) 19881. Federal funding for most desalination research was discontinued in 1982. Federal Government support for desalting research reemerged in 1992 on a small scale with a $1 million per year program with Reclamation. Currently, it is estimated that U.S. industry investment in desalting research and development probably ranges from $5 million to $10 million per year (OTA, 1988).

Research spinoff and application of developing desalting technology, particularly membrane technology [i.e., RO (reverse osmosis)] have resulted in a total, installed U.S. desalting capacity of 626 Mgal/d (million gallons per day) with over 1,900 separate plants individually providing more than 25,000 gal/d (International Desalination Association, 1992). There are desalting plants in 46 States and 2 island territories. Seventy percent of desalted water is used primarily for industrial uses with the remainder for drinking water. The use of desalting for public water supply is growing dramatically. Currently, in the United States, there are 168 desalting plants providing 146 Mgal/d of potable water supply [NWSIA (National Water Supply Improvement Association), 19921. There are about 86 RO plants in Florida alone, providing a total capacity of about 50 Mgal/d for public water supply. Florida utilities have plans to add another 190 Mgal/d, using RO, softening membranes, NF (nanofiltration), and UF (ultrafiltration) membrane technology. Recent desalination and water reuse activities in Texas, Arizona, Virginia, southern California, and other States provide new evidence of growing water treatment applications in coastal communities and in water-short and drought-affected areas.

Although hindsight provides a fair assessment of current and past application of desalting treatment technology, there is even less information available at the Federal or State levels in relating future water supply and water quality problems and needs to the development and use of the technology. Extensive water reuse, pollution of groundwater aquifers, and seawater intrusion in coastal areas are examples of current water quality problems that need the best available water treatment technology. Passage of the Federal Drought Relief Act focuses new attention on desalting technology as a viable water supply alternative for drought protection.

EXECUTIVE SUMMARY

Although large computer databases are available for water quality screening, specific site data are generally limited and many data gaps exist in raw water and treated water supplies. Often, funding is not sufficient to maintain water quality monitoring at local agency/utility levels. A watershed approach is needed to better correlate and manage water quality data to avoid the present "patchwork quilt" nature of the problem.

Additional municipal water treatment, particularly for small, rural communities will be needed to meet stiffening safe drinking water requirements. Treatment technologies are available to meet the requirements, but lack of funding, program priorities, and risk assessments seriously hamper implementation.

Installed treatment capacity for treating impaired water is increasing rapidly for municipal water supply using membrane technology (with over 146 Mgal/d installed in the United States in 1992). About 1,000,000 people in the United States today are supplied with desalted water.

Water costs are significantly narrowing between brackish water desalting and conventional water supplies: $2/1,000 to $4/1,000 gal versus $1.27/1,000 gal (current U.S. average cost).

Expansion of coastal desalting treatment into inland areas will depend on resolution of brine/effluent disposal problems and the rising costs of regulatory compliance.

Existing coastal powerplants and cogeneration sites will provide new opportunities for dual-purpose seawater plants with larger water supply capacities (i.e., 100 Mgal/d or more). Cogeneration plants present new financial incentives for combining desalting and water treatment.

Use of membrane treatment technology for groundwater cleanup and wastewater reuse is g-rowing in coastal areas. New treatment technologies are filling a new support role in the development of wetlands and wastewater reuse.

Increasing regulatory pressure is fostering industrial use of membrane treatment technologies for wastewater cleanup, reuse and recycling, and processing water.

Advanced water treatment is filling an expanded role at Super-fund cleanup sites around the country.

In many areas, the public remains concerned about the perceived poor quality of tapwater. Bottled water use and the use of home treatment units are increasing dramatically into a multibillion dollar industry.

Drought and water supply shortfalls, particularly in California, are forcing evaluation of desalting technology as a viable water supply option, with immediate applications to wastewater reclamation and groundwater cleanup.

Large-scale, seawater desalination is not likely to be a major water augmentation resource in the United States for the foreseeable future. However, desalting of groundwater, wastewater, or other brackish sources is a viable water supply/water treatment option that is becoming more economically competitive with conventional supplies.

A new paradigm or model is needed to project the wide diversity of future application of desalting and water treatment technology. For the most part, treatment technology use will not be solely determined by basic “water supply needs,” but will respond more to regulatory requirements and new creative financing and funding mechanisms. This new paradigm will include a framework for a mosaic of treatment technologies ranging from point-of-use units in the home to modular, centralized plants integrated with other water supply/wastewater/power facilities.

INVENTORY OF WATER QUALITY DATABASES

At the national level, there are a number of available water quality databases that can be used to identify problem areas and potential treatment requirements.

Basically, the databases are organized in two main groups:

1. River, tributary, reservoir, and groundwater (raw water), and

2. Finished or tapwater for community water systems.

One obvious limitation in extracting hard data, especially from group 2, is that about half the community water supplies surveyed across the Nation reported no chemical tests or measured data available. In the literature, many community water quality problems reported deal with “perceived” water quality properties of taste, odor, hardness, etc. In general, water quality data related to health impacts and drinking water standards - MCL’s (maximum contaminant levels) for monitored community water supplies are readily available at the State and Federal level, specifically, the EPA (Environmental Protection Agency). Other water quality data (finished or tapwater) related to economic impacts, such as TDS (total dissolved solids), or hardness may vary widely in availability from State to State.

The following is a brief description of the databases identified thus far for each group.

Raw Water Quality Data

a. STORET (Storage and Retrieval of Water Quality Data). - STORET is a nationwide database operated by EPA which provides physical, biological, and chemical water quality data located at over 700,000 sampling sites for all types of groundwater and surface water. Location access to data can be through Station ID, State and county codes, latitude/longitude, or GS (U.S. Geological Survey) hydrologic unit code. No salinity data are reportedly available in STORET. Tabular lists of data are available along with graphical representations. Comparisons can be made with current and historical data along with statistical analysis. Reclamation has direct access to the STORET system for planning purposes.

b. WATSTOR (a nationwide database operated by GS). - WATSTOR provides physical, biological, and chemical water quality (including salinity) data which are uploaded annually to the STORET system.

c. 305B EPA Water Quality Reports. - These reports summarize raw water quality data (physical, biological, and chemical) for the 17 Western States organized by stream reach and water use reclassification.

d. GS NASQAN (National Stream Quality Accounting Network). - Although this system was discontinued in 1975, summaries are provided of physical, biological, and chemical water quality data for surface waters as measured at 345 select stations across the United States, located by latitude and longitude. TDS data are available in this system.

e. GS National Water Supply Summaries and water supply papers (over 2,000) also provide excellent sources of summarized raw water quality data (from NASQAN) for both surface and groundwater across the United States. The National Water Supply Summaries for 1984, 1985, and 1986 are particularly useful in summarizing distributions and trends of key water quality constituents in major rivers and groundwater systems.

f. 1990 National Water Quality Inventory Report. - This report summarizes water quality information submitted by the States to the EPA in response to the Clean Water Act.

Finished or Tapwater Quality Data

a. The NSA (National Statistical Assessment) of Rural Water Conditions provides statistical water quality data for 40 water quality parameters, primarily primary and secondary MCL's, established by EPA These data surveys sampled 2,654 households which represented about 22 million rural households across the country. The NSA survey (1984) of rural water quality suggested problems of greater magnitude and prevalence (especially regarding mercury, lead, cadmium, silver, and selenium) than had been generally expected, based on data from monitoring analysis indicating statistical probability of exceeding MCL's for selected constituents organized by geographical regions of the country (i.e., West, North-Central, South, etc.).

b. **FRDS,** operated by EPA, provides an up-to-date nationwide inventory of 58,000 community drinking water systems focused on water quality enforcement (MCL) data. This database locates facilities by community name, address, and population, and tabulates water quality compliance data reported at least annually, including treatment applied, MCL violations, and enforcement actions.

c. State Offices of Drinking Water all provide various State inventories of public drinking water systems for water quality monitoring and compliance (MCL) data. The States report violations of monitoring requirements and drinking water standards to EPA for use in the national database on systems compliance-FRDS.

State water quality databases vary widely in terms of types and scope of monitored data. For example, some States have extensive data on chemical constituents, TDS, etc.; others do not.

d. **WIDB** (Water Industry Database) is an ongoing national survey and database conducted by the AWWA (American Water Works Association). The database contains both raw water and tapwater quality data for 11 physical and chemical parameters. The three-phase survey covers the following:

Phase I - Survey of all 612 large community systems serving 50,000 or more people

Phase II - Survey of all 2,500 medium-sized community systems serving 10,000 to 50,000 people.

Phase III - A representative sample of 55,600 smaller community systems serving fewer than 10,000 people.

The magnitude and accessibility of water quality databases summarized above are impressive and offers a wealth of information for water resource planners. While extensive computer queries and screening of these databases on a national or regional basis could provide valuable clues as to water treatment needs, their real value is in providing site-specific data when basic problems and needs have been identified and prioritized at the local or State level.

In assessing all the available water quality databases, EPA's FRDS data offered the best current information regarding drinking water treatment needs on a national scale. A sample computer query of FRDS was designed to focus on the serious inorganic, organic, and radiological MCL problems that are affecting small communities for the five States in Region VIII of EPA (appendix table A.3). The query provided a printout of community water systems, locations, population (ranging between 200 and 50,000), and identification of the MCL contaminant.

Although there are many limitations in the use of such a database to identify future treatment needs, some useful information-relative incidence of troublesome constituents and geographical "hotspots"—can be extracted. In a surficial review of the query, it appears that the monitored data generally support the earlier NSA statistical study which identified the major inorganic elements exceeding MCL's in selected regions of the country (table 2).

The FRDS computer query is provided in the appendix of this report for further reference by the reader. Caution must be taken, however, in the general interpretation, extrapolation, and usefulness of the query data contained in the appendix. FRDS is an "exception" system wherein the States only report violations under varying compliance periods.

In the case of chemical and radiological monitoring requirements, the fact that no violations have been reported for a particular system could mean that the water system is in frill compliance - but it could also mean that required monitoring has not been conducted, or the compliance period has not ended yet, or a violation has been detected, but has not yet been reported.

These ambiguities are complicated by inconsistencies in how States track these violations and report them to EPA The required monitoring frequency for chemical and radiological contaminants is every 1, 3, or 4 years, depending on the contaminant and type of water source, and EPA requires no set point within these periods when tests must be conducted. Moreover, some States do not have systems to track compliance with chemical and radiological monitoring requirements. Even when States report violations EPA does not know when the compliance period begins and ends for a particular contaminant (U.S. General Accounting Office, 1990).

Because of these concerns, it is difficult to use the FRDS data management system to generate a SNC (Significant Non-Compliance) list for chemical and radiological monitoring violations. EPA can only report limited information on overall compliance.

Unless improvements are made in the data tracking and monitoring systems, determining the extent of water system compliance with chemical and radiological requirements will be a continuing problem.

IDENTIFIED WATER QUALITY NEEDS AND OPPORTUNITIES

This section summarizes current planning information available on a national or regional level which provides a cross section of treatment needs and other general trends which may influence future desalting technology applications.

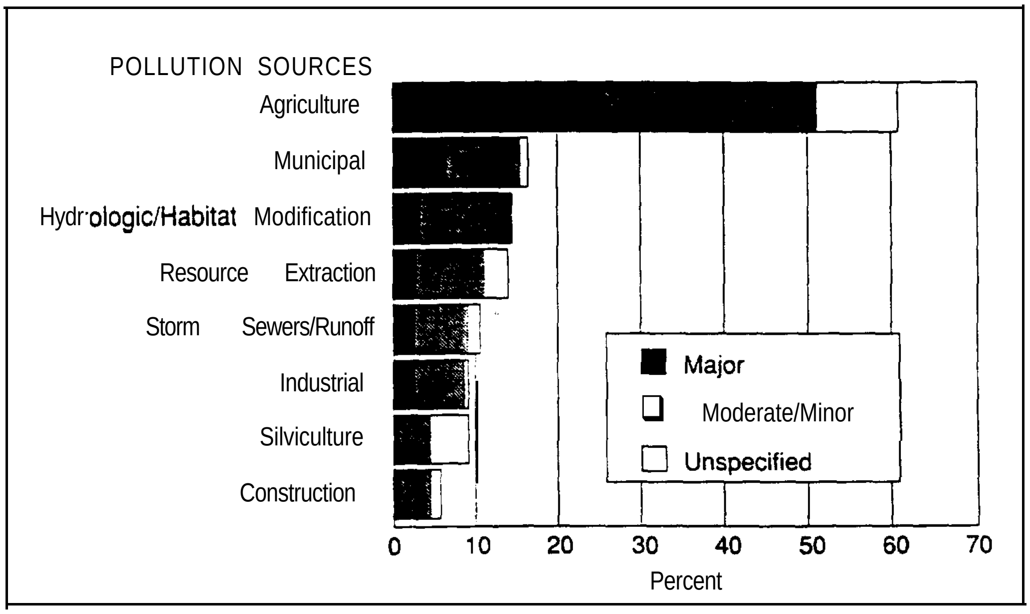
Water Quality Assessment of Raw Water

The 1990 National Water Quality Inventory Report (EPA, 1992)—released by EPA in 1992—provides a unique, but limited, assessment of the Nation's surface and groundwater quality. While based on Clean Water Act (305b) assessments submitted by the States in 1990, it is the only authoritative, national level analysis of the "relative health" of the Nation's water supply. The 1990 Report assessed only about 36 percent of the total river-miles and 47 percent of the total lake acres in the country. Thus, many surface waters of the United States remain unassessed because States are generally constrained by available resources needed to monitor those waters with known or suspected problems. Of the monitored surface waters in the United States, 30 percent of assessed river-miles and 40 percent of the assessed lake acres do not support designated beneficial uses such as drinking water supply, swimming, and aquatic life.

Although, generally, the quality of the Nation's groundwater resources is good, States report an increasing number of pollution incidents which may be due to improved monitoring, increased contamination, or both.

In addition to presenting State water quality assessments, the report briefly discusses the Nation's programs to control pollution in both surface and groundwater. States report that most major point source dischargers to surface waters are meeting permit limits. However, 15 percent of major municipalities and 13 percent of major industries are in significant noncompliance.

In terms of general treatment needs or requirements, figure 1 provides a useful summary of the major types/causes of pollution found in impaired rivers in the United States, as well as the relative extent or magnitude of the problem. The most extensive source of pollution reported for the Nation's rivers is agricultural runoff (sediment, salts, pesticides, etc.), followed by M&I (municipal and industrial) discharges.

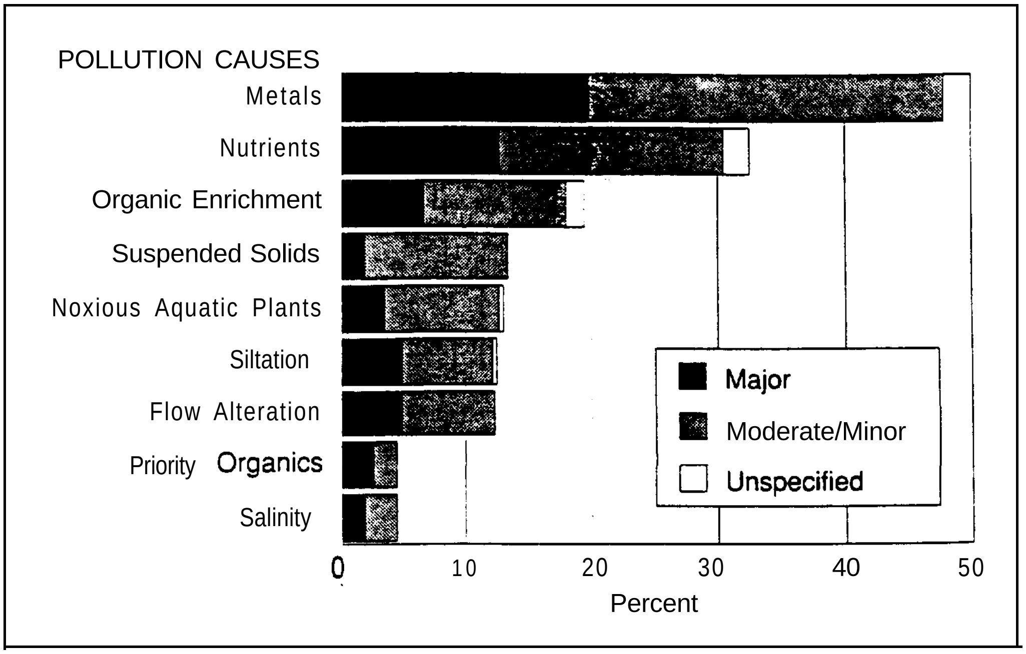


Source: 1990 State Section 305(b) reports.

Figure 1. – Percent of impaired river miles affected by causes of pollution.

Figure 2 displays pollution types and percent of impairment for the Nation's lakes and reservoirs. It is interesting to note that heavy metals are the leading pollutants in this category with an attendant implication of additional treatment requirements.

For the first time in the report, several States addressed the impact of chemical contaminants and other stresses on the quality of existing wetlands. Although monitoring data are limited, figure 3 effectively summarizes water quality problems affecting wetlands in the States as indicated. The selenium problem with wetlands emerged to national prominence with Kesterson Reservoir in California Reclamation evaluated a number of water treatment and remediation actions to control the problem. Ongoing studies within Reclamation are also addressing water quality problems on other Federal wetlands in the Western States.



Source: 1990 State Section 305(b) reports

Figure 2. – Percent of impaired lake acres affected by causes of pollution.

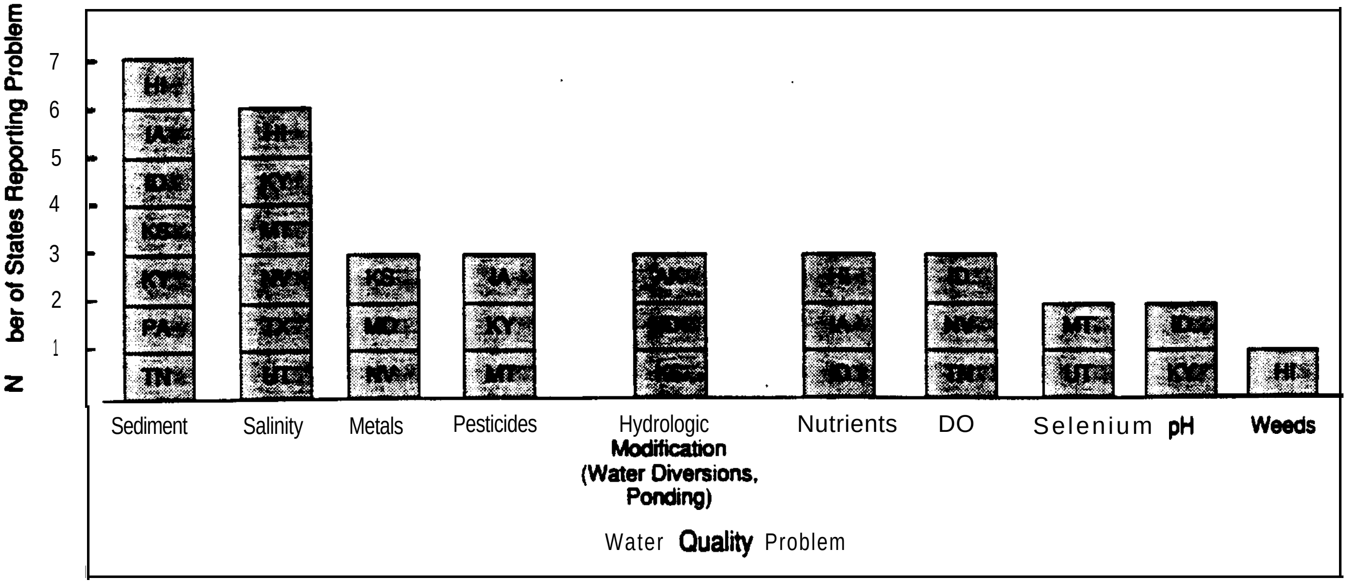
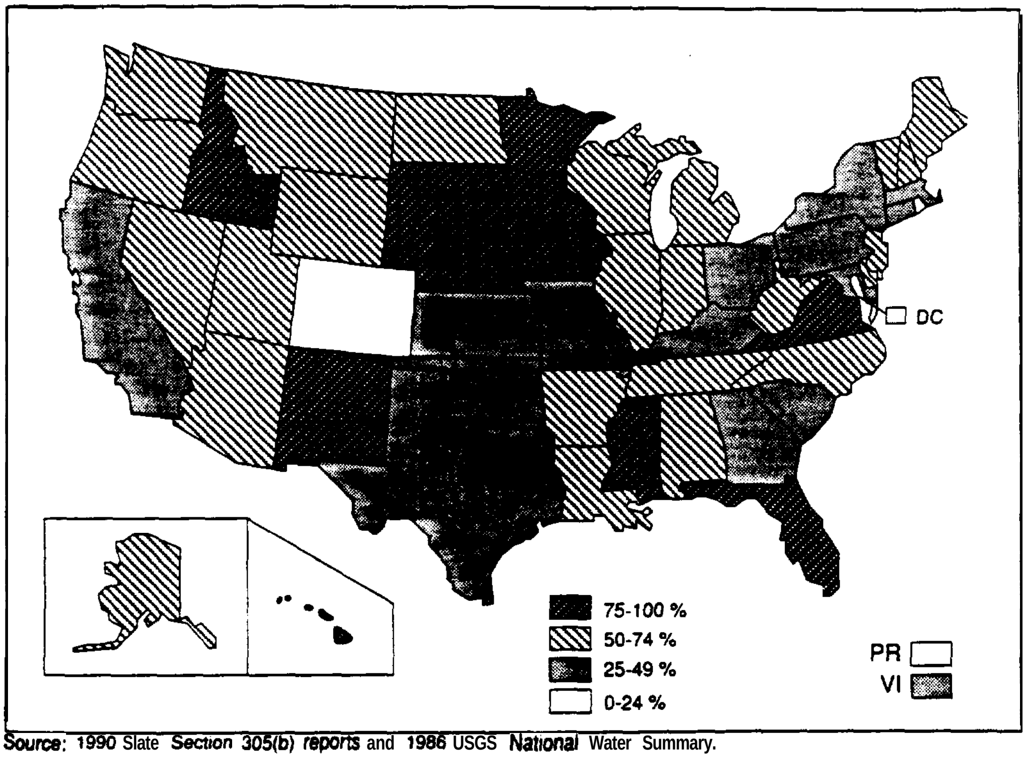


Figure 3. -Water quality problems affecting wetlands.

The national use of groundwater has grown significantly over the past 40 years, reaching a total withdrawal in 1985 of 73 Bgal/d (billion gallons per day). About 51 percent of the U.S. population relies to some extent on groundwater as a source of drinking water. Figure 4 depicts the geographic distribution of the Nation's reliance on groundwater for domestic supply. Many States are conducting broad groundwater quality studies to better identify nonpoint source contamination, particularly by nitrates and pesticides.



Source: 1990 State *Section 305(b) reports* and 1986 USGS *National* Water Summary.

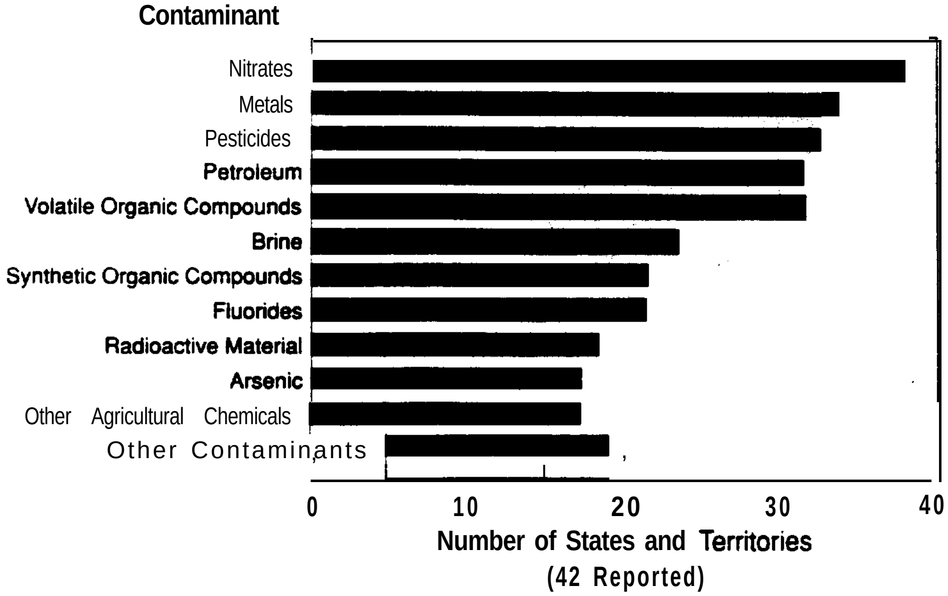
Figure 4. – Groundwater as a source for domestic supply (as a percentage of State population).

Figure 5 summarizes current observations of groundwater contaminants by a number of reporting States and territories. Nitrates, heavy metals, and pesticides appear at the top of the list.

Some of the public fears of raw groundwater quality are well founded. According to the California DWR (Department of Water Resources), all of California's major groundwater basins are contaminated to some degree; however, the contamination is usually concentrated to small areas of the basins. In recent groundwater tests, 1,500 municipal supply wells throughout the State were polluted with one or more chemicals. In 40 percent of those wells, the level of contamination exceeded Federal and/or State drinking water standards (Water Education Foundation, 1992).

In southern California alone, tests revealed that water from nearly 40 percent of MWD's (Metropolitan Water District's) 3,246 municipal wells in their service area did not meet Federal or State drinking water standards. Through a groundwater recovery program, MWD is providing economic incentive to local agencies to clean up and use 200,000 acre-ft annually by the year 2000 (Water Education Foundation, 1992).

The groundwater contamination problem in California is focused mainly around the pesticide dibromochloropropane (DBCP), frequently detected in rural farming areas, and trichloroethylene (TCE), a major pollutant found around industrial areas.



Source: 1990 State Section 305(b) reports.

Figure 5. - Most frequently observed groundwater contaminants by number of states and territories reporting.

EPA released results of the first national survey of pesticides and nitrates in drinking water wells (EPA, 1992). The survey tested water from 1,349 community and domestic rural wells with samples from every State. Survey findings released show that 10 percent of the Nation's community drinking water wells and 4 percent of rural domestic wells have detectable residues of at least one pesticide. Less than 1 percent of all wells exceed the MCL or health advisory level established to protect health. Based on more detailed population exposure analysis, approximately 85 million people are estimated to drink water from community wells that contain nitrates, with about 3 million people exposed to levels of nitrate over the MCL level of 10 mg/L (milligrams per liter) (EPA, 1992). EPA initial tests for lead in drinking water showed that 130 of the Nation's 660 large public water systems exceed "action levels" for lead of 15 p/b (parts per billion) as required under the SDWA (Safe Drinking Water Act) (Eiserer, ed, 1992). Exceeding the action level is not a formal violation of the regulations but triggers additional monitoring and public education. In the case of lead, contamination may be due to the distribution system and not the water supply.

The potential impacts of these national water quality trends and impacts are measured best in economic terms. National cost estimates for current and projected water pollution control programs, as summarized by the EPA, are presented in table 1. The table displays total annual costs for point source and nonpoint source control programs as well as drinking water programs. Point source expenditures are those incurred to control discharges from identified industrial and municipal facilities. Nonpoint source costs result from local runoff, drainage, seepage, including agricultural runoff, irrigation return flows, and urban storm drainage. The costs for drinking water programs are primarily for treating community water supplies as required under the Safe Drinking Water Act. The large historical expenditures for point source control include public expenditures for sewage services and wastewater treatment as well as private costs incurred for control of industrial effluent and pretreatment of wastewater discharges to municipal treatment facilities. Most of the large projected increase in costs to $64 billion per year (by the year 2000) is attributable to additional municipal, industrial, and wastewater treatment facilities.

Table 1. - Total annualized costs of water pollution control in the United States (millions of 1986 dollars)

Program	Year				
	1972	1980	1987	1995	2000
Point source	8,543	22,116	33,642	47,300	56,604
Nonpoint source	567	647	779	893	959
Drinking water	802	1,982	3,111	5,350	6,571
Total water	9,912	24,754	37,532	53,543	64,134

Source: Table *3-3,* p. *3-3, Environmental Investments: The Cost of a Clean Environment -A* Summary, U.S. EPA, Office of Policy, Planning and Evaluation, December 1990.

It is, perhaps, too easy to distort or magnify statistical data from these broad national surveys to promote any particular position or conclusion. The surveys provide the only substance, however, to any definition of the pervasive raw water quality problems in the United States today. The evidence, however limited, strongly suggests that water treatment technology will play a major role in future water resources planning.

Rural Household and Community Water Quality

Although limited data are available for raw water supplies, one cannot solely rely on a survey of source water (groundwater, lakes, streams, etc.) to draw conclusions about community water conditions. Likewise, water quality measured at a community system's treatment plant may differ from that measured at the household tap. For these key considerations and, as required by the Safe Drinking Water Act, an NSA (National Statistical Assessment) of Rural Water Conditions (Cornell University, 1984a and 1984b), was completed in 1984 by EPA. The 1,900-page NSA document is the one and only national survey of the current status of rural domestic water characteristics at the POU (point-of-use). For selected households, data collection involved personal interviews, physical inspection, and water sampling. From 400 counties across the United States, a total of 2,654 households and their associated water supply systems were evaluated. The total statistical sample represented an estimated 22 million rural households. The NSA study considered five dominant characteristics of domestic water: quality, quantity, availability, cost, and affordability.

In terms of water quality data, the NSA assessed 40 "benchmark" constituents incorporating all the contaminants given primary or secondary MCL's (maximum contaminant levels) designation by the EPA (see glossary for definitions). A listing of these constituents and reference values can be found in the appendix table A 1.

Physical and Biological Characteristics. — Among those contaminants which are covered by primary MCL's (because of potential health hazards), total coliform emerged as the most prevalent problem, exceeding the reference value in 29 percent of all rural households.

Turbidity was also measured above the one NTU standard among 16.5 percent of rural households. Color was much less a problem quality characteristic with only 2.3 percent of all rural households exceeding reference values (15 standard color units).

Inorganic Constituents. — A summary of inorganic elements found in rural water supplies is found in table 2. Nationwide, mercury appears to be the most troublesome element found in tapwater. In the west, selenium exceeded the standard level in 41 percent of rural households.

TDS content of water supply is of special interest related to desalting treatment. Households in the NSA survey which had more than the recommended 500 mg/L TDS level were most prominent in the North-Central and Western United States, where one out of every five households exceeded this value. Appendix figures A-l, A-2, A-3, A-4, and A-5 display statistical variations of TDS in the United States and selected regions of the country.

Although high levels of water hardness were reported in the survey, the determination of whether these levels are a problem poses a dilemma for water users. On one hand, hardness (caused most often by calcium and magnesium salts) retards the cleaning action of soaps and detergents and causes a buildup of scale deposits in plumbing and hot water heaters. On the other hand, treatment by artificial water softening may increase the sodium content of water, making it unsuitable for people restricted to low-sodium diets. Soft water also can dissolve metals such as cadmium and lead from water pipes, more readily leading to other adverse health or aesthetic effects. There is also a growing preponderance of evidence that indicates that the softer the water, the higher the incidence of cardiovascular disease. The EPA has concluded that “available information is not sufficient at this time to believe the aesthetic desirability of setting a limit for hardness against the potential health risk of water softening’ (Cornell University, 1984b).

Table 2. - Summary of inorganic elements found in rural water supplies.

Element	Level exceeded (mg/L)	In % of rural households				
		Nationwide	west	North-Central	Northeast	South
Mercury	0.002	24.1	10.4	31.8	22.0	25.0
Iron	0.3	18.7	7.0	28.2	16.0	17.0
Cadmium	0.01	16.8	27.1	20.7	1.6	17.3
Lead	0.05	16.6	*16.9	*10.8	*9.6	*23.1
Manganese	0.05	14.2	4.7	19.9	16.9	12.3
Sodium	100	14.2	15.0	19.2	6.0	14.1
Selenium	0.01	13.7	41.3	25.7	0.0	2.1
Silver	0.05	4.7	2.1	3.7	4.8	4.8
Sulfates	250.0	4.0	11.7	7.4	0.5	0.7
Nitrate-N	10.0	2.7	4.0	5.8	0.3	1.3
Fluoride	1.4	2.5	6.2	1.8	0.0	2.7
Arsenic	0.05	0.8	2.1	1.8	0.0	0.0
Barium	1.0	0.3	0.0	0.0	0.0	0.7
Magnesium	125.0	0.1	0.5	0.1	0.0	0.0
Chromium	0.05	**	0.0	0.0	0.0	0.0
Total dissolved solids	500	14.7	22.2	23.9	5.0	10.2

* May be distorted upwards.

** Not detected.

Source: US. Environmental Protection Agency 1984, National Statistical Assessment of Rural Conditions, Executive Summary, Office of Drinking Water.

Other inorganic substances studied ranged from those largely with aesthetic effects, such as manganese, to those elements predominantly with health effects such as lead. Other notable elements include nitrates that pose a special health risk for infants, sulfates that may make water distasteful and can cause diarrhea, and iron and manganese that have other aesthetic and economic impacts. Of special interest are the potential health implications of high levels of mercury, cadmium, and lead, each having different physiological effects.

Organics. — Organic constituents studied in the NSA were limited to four insecticides and two herbicides. None of the values for these substances exceeded the respective NSA reference values.

Radioactivity. — The sampled household supplies showed low levels of both gross alpha and beta radiation. The presence of background gross alpha radiation, in particular, was not surprising since it is produced by natural sources commonly found in groundwater. Despite the prevalence of the radiation, actual levels of radioactivity were well below the NSA "benchmark' values.

Perceived Water Quality Problems. — In the NSA interviews, residents were questioned about specific health and other impacts of their water supply. Only 2.3 percent reported illnesses associated with water supply. As to problems not related to health, an equivalent 2 million households reported problems resulting from water supply conditions ranging from discolored laundry to scale deposits on household plumbing and appliances.

A truly comprehensive national survey of household water quality would not be complete without the perspective of how water users "feel about" or personally evaluate their water quality. While judgments concerning odor, taste, color, sediment, and cloudiness do not always match up with measured water quality parameters, these intangibles tell a lot about a water supply. The NSA did study the correlations between water *user* perceptions of water quality and measured constituents. Positive correlation indicators of water quality problems were found with TDS, iron, sulfate, and turbidity. The findings generally confirmed that higher levels of TDS were associated with declining acceptability of the water to consumers. The householder% willingness to pay for a better water supply is, perhaps, the best overall indicator of their perception of water quality.

General Findings From the ***NSA.*** — While some of these findings are surprising, the representative data must be kept in perspective. The significant percentage of households exceeding MCL's should not be interpreted to indicate that the community water supplies are not healthy and meeting MCL requirements today. Apparent "high" levels of contaminants do not correlate with any widespread, water-related health problems in the rural United States (Cornell University, 1984b). Rather than being clear indicators of possible health effects, these high percentages of households with water quality problems really reflect the marginality of rural water supplies against the "benchmark" MCL's mandated for community water systems. The relative high occurrences of particular inorganic elements in tapwater provide valuable information for water treatment research and planning.

Drinking Water Compliance Under the Safe Drinking Water Act

GAO (General Accounting Office) (1980) released one of the first survey reports on community water systems in the United States. Out of 65,000 community water systems, 13,600 communities could not meet applicable drinking water standards. Many communities were cited for failure to submit monitoring reports and test water sources. This report generally confirmed the lack of comprehensive water quality data at local levels.

Using 1988 statistics, EPA estimated that (1) 72 percent of all *community* water systems had no reported violations, (2) only 2 percent of community water systems were classified as "significant noncompliance," and (3) 25 percent of the water systems were identified as "other noncompliers" (GAO, 1990).

Such statistics would appear to indicate that most water systems are monitoring their water and meeting quality standards and that the majority of violations that do occur are not serious. However, as discussed in the GAO report (1990): (1) the criteria used to distinguish between "significant non-compliance" and other violations minimizes some potentially serous problems; and (2) the number of water systems reported to be in full compliance may be overstated by a significant margin, reflecting problems at the water system, State, and Federal levels.

More recently, GAO (1992) reported on the growing problem of matching water treatment needs and available funding for communities failing to meet drinking water requirements. The report cited chronic shortages of funding at the Federal and State levels needed for compliance. Currently, the FY93 EPA budget provides only $59 million in grant assistance available to all 50 States (GAO, 1992). According to EPA, annual compliance costs for improved water treatment systems are expected to reach $3 billion for the next 20 years. These costs are over and above major capital requirements estimated at more than $150 billion needed for repair, replacement, and growth in basic water supply infrastructure. The funding outlook is not promising at the State level. Thirty-three States have budget deficits this year, totaling more than $15 billion. Some limited options of returning enforcement "primacy" to EPA by the State and restricting enforcement actions only to "serious health risks" are being considered in the short term. Until the financial impasse is resolved, however, any broad-based expansion of water treatment in communities unable to meet drinking water standards does not appear to have a high probability of success.

Indian Drinking Water Quality

According to the 1990 Census, there are about 2 million Native Americans in the United States, 38 percent of whom live on 56 million acres of reservation and trust lands. In 1986, the EPA and IHS (Indian Health Service) released a survey study of Indian drinking water supplies (1986). In this survey, over 836 public water systems (serving more than 25 people) were identified on 190 reservations. National databases were screened and 274 tribes were contacted to obtain data on drinking water problems. While the survey identified only 6 percent of the public water systems that had MCL violations for microbiological contamination, there were no reliable data on organics, inorganics, pesticides, or heavy metals. Site visits confirmed the lack of compliance with Safe Drinking Water Act monitoring requirements, again reflecting the same lack of water quality data as found in the non-Indian communities. Yet another survey (MS, 1992) found over 20,000 Native American homes without potable water. This latter MS report also identified over $1 billion in needed projects to provide tribal communities with safe water supply and sewage disposal systems. Current IHS funding for sanitation facilities is about $38 million (1992).

Communities Survey and Studies of Excess TDS in Water Supplies

In addition to the 1984 NSA survey which provided a statistical sampling of TDS in community water supply, there is little "hard data" aside from earlier OSW reports to provide any guidance on the extent of "mineralization" or salinity of community water supplies. Although outdated, one report (OSW, 1969) provided a nationwide survey of community water systems with water containing more than 1,000 mg/L TDS. This survey identified over 420 communities in 29 States with an equivalent population of 2.8 million in which the TDS of their drinking water greatly exceeded the Secondary (nonenforceable) MCL Drinking Water Standard of 500 mg/L.

Although the population data of this report were based on the 1960 Census and some communities have long since changed or modified their water supplies, the basic (high TDS) problem remains for most communities.

Many communities today in the United States are using highly mineralized water supplies that greatly exceed recommended drinking water standards. While a highly mineralized water supply can be bacteriologically safe, it may be objectionable from the standpoint of taste, odor, and other physiological effects, as well as from direct economic losses for the water user, in terms of higher treatment and maintenance costs.

A comprehensive study to update the economic impacts of salinity in Colorado River water delivered to 18 million people in the Southwest was recently completed and published (Reclamation, 1988). The study provided a comprehensive estimate of total damages due to high river salinity (TDS), which for 1986 averaged $311 million annually. These losses were primarily associated with the municipal- and industrial-use sectors resulting from municipal water treatment costs, accelerated pipe deterioration and appliance wear, automotive radiator repair, increased soap and detergent needs, and decreased water potability.

For over 20 years, OSW probed the technical and economic feasibility of applying desalting technology to provide improved quality water supply for selected communities in a number of States. Detailed studies assessing desalting treatment for community water supplies were completed for Arizona, Colorado, Iowa, Kansas, Montana, Nevada, New Mexico, North Dakota, Oklahoma, South Dakota, and Texas [OSW R&D (research and development) Progress Reports No. 919, 9702, 998, 869, 783, 920, 767, 902, 997, 918, and 250, respectively].

While the feasibility studies provided excellent insight into the technical opportunities and limitations of treatment technology at the time, most communities could not afford new plant installations. Many of the opportunities and limitations identified in these State-level studies provide important insight in assessing future applications.

WATER QUALITY/WATER SUPPLY CONNECTION

Although the emphasis in this survey is on water quality problems and needs across the country, treatment of water, either to protect or augment water supply, cannot be easily segregated. In general, only about 20 percent of water withdrawn for use in the United States is actually consumed. Most of the water is discharged into rivers, lakes, and estuaries as wastewater or irrigation return flow, which is frequently reused at downstream locations. For each reuse of water, concentrations of pollutants (especially salts) increase in the discharged water. As such, water quality problems are inexorably tied to areas where frequency of water reuse is high, such as in the arid areas of the West and along heavily industrialized waterways in the East.

In coastal areas of the United States, extensive use of groundwater aquifers is increasing seawater intrusion. Saltwater intrusion is a significant water supply and water quality problem in Florida; Southern California; Long Island, New York; and several other coastal areas. In California, water treatment and reclamation of contaminated groundwater aquifers is significantly augmenting local water supplies. In the Los Angeles and San Diego metropolitan areas, wastewater reclamation of up to 500,000 acre-ft of water per year is considered a viable, economic water supply alternative to interbasin transfer and other water supply sources. In a recent study by the San Diego County Water Authority (P. M. MacLaggan, 1992), the costs of wastewater reclamation and groundwater recovery (desalination) as reliable supplies proved to be among the least-cost options.

Desalting has filled a critical water supply niche in the Virgin Islands for years where other surface and groundwater supplies are severely limited. In water-short or drought-affected areas in California, seawater desalting studies are examining the potential benefits of dual-purpose plants (power production and distillation/RO) which could lead to desalting cost reductions compared to standalone plants. Existing coastal powerplants and cogeneration plants could provide new opportunities for dual-purpose plants of large capacity (100 Mgal/d or more).

Many rapidly growing communities, particularly coastal communities, are evaluating adding increments of desalting capacity of brackish water supply rather than developing larger than necessary water supply from *conventional* sources. Local groundwater desalination also avoids the potential political problems associated with the transfer of surface waters from one political jurisdiction to another.

For some smaller communities, the “economies of scale” may also be realized if several adjacent communities jointly treat or desalt their water supplies in a shared facility. In other situations where existing drinking water supplies are inadequate or low quality, bottled water, POU treatment, or wellhead treatment are extensively used.

CURRENT AND PROJECTED DESALTING AND WATER TREATMENT ACTIVITY IN THE UNITED STATES

Past attempts to create computer models to project the future use of desalting technology on a national basis have not provided useful planning information. Moreover, there are few 'Federal or State water plans" (per se) that attempt to define future supply and water treatment needs, much less the roles of new technology. The expanding scope of applications and uses of desalting technology today give only a hint of future large-scale activity.

As of 1992, the total installed capacity of desalting plants in the United States for all uses is 626 Mgal/d, representing over 1,900 plants which individually produce 25,000 gal/d or more (IDA, 1992). The current, major use of desalting technology is in the industrial sector with approximately 70 percent of total installed capacity. In terms of total service capacity, desalting provides only about 4 percent of the total 15 Bgal/d of water used today in the United States for municipal and industrial purposes.

Until recently, desalting technology was viewed only in terms of seawater or brackish water supply scenarios. Desalting technology is now being used in an ever-widening arena of applications:

Treatment of industrial effluent, process water
Municipal supply for small communities
Wastewater reuse
Groundwater recharge
Irrigation drainage
Dual-purpose plants
Hazardous waste control/treatment
POU treatment
Military uses

A sampling of current and planned activity in each one of these expanding areas of application provides an interesting user cross section and, possibly, a glimpse of the direction of future development to meet new needs.

Industrial Uses and Application

U.S. industry consumes about 8 percent, or 8 Bgal of total freshwater per day (OTA, 1988), for processing and cooling. Although desalting provides only a small percentage of this total amount, the majority of desalting treatment capacity in the United States (70 percent) is used by industry to treat feed water, process water, or wastewater prior to discharge or reuse. High quality water is needed for manufacturing many products, including textiles, paper, pharmaceuticals and other chemicals, beverages, dairy, and *other* food products.

Water treatment varies widely for different industries, but typically may involve conventional water treatment techniques, such as filtering and softening, to more sophisticated systems involving membrane processes (RO, ED (electrodialysis), ion exchange) or combinations thereof.

For example, ultrapure, deionized water is widely used by the electronics industry for manufacturing integrated circuits and semiconductor components. Highly treated water is also used for medical applications, electroplating, petroleum processing, and boiler feed water for powerplants (OTA, 1988).

Industrial wastewater discharge represents a major continuing need for water treatment technology. Currently, there are over 200,000 commercial and industrial facilities in the United States that discharge an estimated 18 Bgal of wastewater daily (OTA, 1988); 55 percent of which remains untreated. A study just released by the EPA (Pollution Engineering, 1992b) shows that more than 50 percent of industrial facilities discharging to wastewater treatment plants were in significant noncompliance in 1990. Under EPA's NPDES (National Pollutant Discharge Elimination System), industry is starting to use advanced wastewater treatment techniques to remove and/or concentrate contaminants in wastewater. New treatment systems may also be encouraged under the Clean Water Act amendments of 1987 which requires BAT (best available technology), that is economically achievable to meet limitations on 126 toxic "priority pollutants" (Pollution Engineering, 1992). Under EPA's new Corrective Action Program, permits and/or administrative orders under the existing RCRA (Resources Conservation and Recovery Act) will be used to compel site cleanups. Under this new program, industrial facility owners bear sole responsibility for cleanup costs, in contrast to the Superfund program which seeks out potentially responsible parties to share cleanup costs (Pollution Engineering, 1992a). In some States, "zero discharge" requirements under NPDES have forced some industries to use distillation and/or membrane processes to minimize or eliminate wastewater discharges. In some select industries (photographic, electroplating, pulp and paper, etc.), desalting technologies are being used to recover and reuse valuable chemicals from wastewater. However, the recovery of potentially useful chemicals/materials from wastewater is often not economical because of low concentrations in the wastewater. Ifrecovery is practiced, industries generally favor segregating, treating, and reusing streams from individual processes rather than trying to treat the combined waste flows.

Current mining industry in the United States remains fertile ground for water treatment application. With about 3 Bgal/d (billion gallons per day) of wastewater discharged from mining activity in the United States, 32 percent remains untreated (Water Encyclopedia, 1990).

The future of desalting and related treatment technologies for industrial wastewater recovery, reuse, or disposal is a large marketing opportunity dependent on individual company/industry response to tightening EPA and State regulations. For ultrapure water requirements and high quality process water over a wide spectrum of applications, the opportunities for membrane separation technology (RO, UF) innovation are significant.

An excellent example of membrane technology applied to an industrial setting can be found at the Diablo Canyon Power-plant in California. Here, recent installation of a triple membrane system [UF, EDR (electrodialysis reversal), and RO] provides 600 gal/min of ultrapure boiler feed water from seawater.

Other recent inroads of treatment technology into industry applications include in situ mining and cooling tower blowdown. In each of these cases, desalting treatment is being effectively used to produce a high quality product water while concentrating brine effluent for final disposal.

Municipal Water Supply

Currently, in small communities across the United States, there are 168 operating desalting plants supplying 146 Mgal/d of potable water to meet the needs of about 1,000,000 people. (A 1-Mgal/d plant will supply the water needs of about 7,000 people using 150 gal/day.) Of the 146 Mgal/d of installed and operating plant capacity, 100 Mgal/d of supply comes from brackish water sources, 22 Mgal/d from seawater, and about 24 Mgal/d represents membrane softening treatment plants (NWSIA, 1992).

Geographically, most of the operating plant capacity is found in Florida, the Virgin Islands, California, Texas, Arizona, and the Carolinas. In addition to specific site needs and economics, close proximity of most of these plants for ocean brine disposal is considered a major factor in the growth patterns of municipal desalting.

In 1962, the town of Buckeye, Arizona, became the first U.S. community to treat all of its municipal water supply by desalting. Located about 35 miles west of Phoenix, the community of 4,000 people has been reliably served for 30 years with a desalted water supply derived from saline well water which varies from 1,500 to 4,000 Mg/L TDS. Buckeye is not unique among the smaller municipal water systems, being located in arid or semiarid regions of the country, which rely on poor quality groundwater for water supply (Carpenter and Gershecker, 1989).

The following summary of operating, planned, or projected plants is not intended to represent a complete inventory of municipal plants. However, this survey is provided to illustrate the wide diversity in application, location, capacity, and special needs that will influence future supply/treatment opportunities.

- In Santa Barbara, California, a $30 million, 6.7-Mgal/d seawater desalting facility was dedicated in 1992 to provide a “droughtproof water supply alternative for this coastal community. The “creative financing” of this plant provides a new model for privatization of similar facilities. In this case, the manufacturer designed, constructed, owns, operates, and maintains the desalting plant. The city, in a “take or pay” contract, agreed to pay for either delivered water or for holding the project on standby.

- In the Santa Ana Watershed southeast of Los Angeles, California, a comprehensive groundwater remediation program is underway to reclaim water for municipal supply. The Tustin Desalting Plant (1.3 Mgal/d) is being operated to remove nitrates in an agricultural area. The Arlington Plant (6 Mgal/d) is also currently operated to remove high levels of nitrate and salts from a groundwater supply near Riverside, 👍♋●♓♐□❒■♓♋ Future projects to treat groundwater for municipal supply in the basin include (Reclamation, 1991): Irvine Desalting (3 Mgal/d) and Chino Desalting Units 1 and 2 (12 Mgal/d). Local officials estimate that desalting capacity in the basin could increase by another 80 Mgal/d by the year 2015.

- In the State of Florida alone, there are approximately 86 operational membrane plants (110 Mgal/d) treating brackish groundwater for municipal supply. The larger capacity plants are located in the City of Plantation, Collier County, Vero Beach, Cape Coral, Ft. Meyers, Sanibel, Jupiter, Dunedin, Englewood, Sarasota, and Venice. (NWSIA, 1992). Florida utilities have another 190 Mgal/d of plant capacity under planning study.

- The City of Sherman, Texas, is currently constructing a 4.5-Mgal/d membrane desalting facility for drinking water supply. The facility will treat brackish surface water from Lake Texoma where the lake water constituents currently exceed Federal and State drinking water standards (Lozier et al., 1992).

- Recent water shortages prompted studies by the Corps of Engineers to examine the feasibility of a desalted water supply for townships around Cape May, New Jersey. Three plants, ranging in capacity of 2.1 Mgal/d to 9.5 Mgal/d were recommended by the studies to meet expected water supply demands (Smith, pub/ed., 1992).

- Honolulu, Hawaii, water supply officials are currently studying prospects for a desalination plant (10 Mgal/d, expandable to 50 Mgal/d) to make up for shortage of groundwater supply predicted by the end of the decade (Smith, pub., 1992).

- A pilot solar-powered desalting plant being installed near Gallup, New Mexico, on the Navajo Reservation will be evaluated under remote conditions. Power supplied from a solar photovoltaic collector system will be used to pump and desalt brackish well water for potable supply. This state-of-the-art, advanced technology system, as provided by Reclamation, is expected to provide about 750 gal/d.

- The Eastern MWD in Southern California is building a 3-Mgal/d membrane treatment plant to recover brackish groundwater in the Menifee Basin for potable supply.

- The City of Suffolk, Virginia, is currently operating a membrane treatment system of 2.8 Mgal/d to remove high levels of fluoride from groundwater well supplies (Werner and Waldron, 1992).

- In Mount Pleasant, South Carolina, two membrane treatment plants (a total of 2.5 Mgal/d) are reducing high TDS and fluoride levels from a deep groundwater aquifer for potable supply.

- Recent retrofitting of a municipal water treatment plant by Reclamation for Lidgerwood, North Dakota, was highly successful. Treated water from the original treatment plant failed to meet primary drinking water standards for arsenic. Changes and modifications to the equipment and operation of a filtration/coagulation treatment process brought the plant into compliance (EPA and Reclamation, 1989).

- Reclamation currently has a 45- to 56-Mgal/d desalting plant under study to treat Virgin River water for municipal supply in Las Vegas, Nevada.

- A new 4-Mgal/d RO desalting plant is under construction in Brighton, Colorado, to remove nitrates from groundwater supply.

- Also under study in California is a 3-Mgal/d seawater RO plant for the Monterey Peninsula Water Management District.

- Under a new program in California MWD of Southern California is offering financial assistance to local supply agencies to recover up to 200,000 acre-ft per year of contaminated groundwater. Over 40 projects costing MWD $30 to $40 million per year are expected by the year 2000 (Sienkiewich, 1992).

- Other specific desalting and treatment projects already approved under the assistance plan include:

  City of Oceanside (1.8 Mgal/d)
  West Basin Municipal Water (Torrance) (1.3 Mgal/d)
  City of Santa Monica (1.6 Mgal/d)

- The West Basin Municipal Water District recently announced plans for a 20-Mgal/d water reclamation treatment plant with a 5-Mgal/d RO train. The RO train will supply water to a groundwater basin for seawater intrusion protection.

- The city of Ventura, California, is also evaluating plans for a 6.2-Mgal/d seawater desalting plant.

Wastewater Reuse

Advanced wastewater treatment and desalting processes now provide many new opportunities for wastewater reuse. Wastewater from sewage treatment plants is one of the largest potential sources of water, particularly in arid areas of the West. In the United States today, 60 to 90 percent of municipal water delivered to city residents is discharged into wastewater collection systems. In southern California alone, over 2 million acre-ft per year of municipal and industrial wastewater is discharged to the ocean.

Most wastewater can be treated by conventional means to remove contaminants and pathogens to permit water reuse in agricultural and parks irrigation, industrial reuse, groundwater recharge, and potable supply. In California, a recent study (State Water Conservation Coalition, 1991) of reclaimed water in the State inventoried current (1989) uses of over 350,000 acre-ft per year. About 55 percent of the reclaimed water is used for agriculture, 21 percent for groundwater recharge, 15 percent for landscaping, and the remaining 9 percent for other uses.

Indirect use of treated municipal wastewater for potable purposes was pioneered in California by Orange County Water District's "Water Factory 21." In 1977, the district began integrating treated wastewater from an existing sewage treatment plant into its water supply aquifer to prevent seawater intrusion and allow indirect reuse of the treated water. In addition to other conventional treatment processes, the District uses a 5-Mgal/d RO plant as an integral part of its overall 15-Mgal/d treatment and injection system. During the 15-year operating history of the WF21 (Water Factory 21, Orange County, California) plant, it has consistently produced over 75,000 acre-ft of reclaimed water, meeting California drinking water standards (Wehmer, 1992). In 1991, WF21 was granted permission by regulatory agencies to inject 100 percent reclaimed water (without direct blending) into the Orange County groundwater basin to maintain a seawater barrier and to replenish aquifers used for domestic water supply (Wehmer, 1992). Although WF21 is still considered a "research and demonstration" project, removal of some regulatory requirements shows growing public confidence in water reuse.

Studies are also currently underway to expand the desalting capacity of WF21 from 5 Mgal/d to 25 Mgal/d.

There are many other communities in the Nation that also indirectly reuse treated wastewater which is usually blended with other streamflows or storm runoff. Under planned or indirect reuse, treated and blended wastewater flows are generally injected or percolated into intermediary groundwater reservoirs.

Advanced treatment and **direct reuse** of municipal wastewater for potable use is under continuing research and pilot development. Although now in "mothballs," in 1985, the Denver Water Board completed construction and operated a 1-Mgal/d advanced treatment facility which included RO to demonstrate direct wastewater reuse for potable reuse. Today, controversy continues over the health, safety, and economic issues related to direct potable reuse of wastewater.

A sampling of other notable wastewater treatment and reuse projects includes:

- The Alamitos Gap Project in southern California - a joint treatment project under study between Orange County and Los Angeles County with a total capacity of 8 Mgal/d. The facility is planned to receive reclaimed wastewater, desalt, and then inject the treated water into groundwater aquifers to retard saltwater intrusion (Reclamation, 1991).
- In Scottsdale, Arizona, an advanced wastewater treatment RO plant is under design to provide 6 Mgal/d with future expansion up to 44 Mgal/d of treated wastewater for irrigation and groundwater recharge.
- Wastewater treatment does not always involve 'high tech" or advanced treatment technology. Constructed or artificial wetlands are now being used in about 70 rural communities in the United States to supplement, or in some cases, supply the entire wastewater treatment needs. A recent study of an artificial wetland system in Santee, California, determined successful removal of heavy metals from wastewater with 97 to 99 percent removal efficiency (EPA, 1984).
- An advanced wastewater treatment and RO plant (1 Mgal/d) is under construction at the San Pasqual facility in San Diego. In Livermore, California, another 0.75 Mgal/d wastewater plant with RO is under design to demonstrate the feasibility of wastewater recycling.

  The city of San Diego recently completed a HES (Health Effects Study) as part of a larger water reclamation-water supply (Thompson et al., 1992). The HES was a comprehensive research effort to estimate the potential health risk associated with the use of treated wastewater as a potable water supply. The overall conclusion of the HES was that the health risk associated with the use of advanced wastewater treatment plant effluent as a raw water supply is less than or equal to that for the existing raw water supply.

  It is readily apparent that serious progress in municipal wastewater treatment and reuse is underway in California. *In Water Recycling 2000: California's Plan for the Future* (State Water Conservation Coalition, 1991), the report estimates that reclaimed water use could increase by an additional 393,000 acre-ft per year under existing constraints. If existing constraints were resolved, that estimate could increase to about 826,000 acre-ft per year by the year 2000.

Under the 1992 Reclamation Wastewater and Groundwater Study and Facilities Act (Public Law 102-575), the Secretary of the Interior is authorized to conduct studies for the design and construction of demonstration and permanent facilities to reclaim and reuse wastewater. The Secretary is also authorized to conduct research, including desalting, for the reclamation of wastewater and naturally impaired ground and surface waters. Feasibility studies of research and demonstration projects of appropriate treatment technologies for the reclamation of municipal, industrial, domestic, agricultural wastewater, and other impaired waters were specifically authorized in the following areas:

Southern California
San Jose area, California
Phoenix Metro area, Arizona
Tucson area, Arizona
Lake Cheraw, Colorado
San Francisco area, California
San Diego area, California
Los Angeles area, California
San Gabriel Basin, California

Although no funds have yet been appropriated to carry out the study provisions of the act, there is a clear expression of national resolve to expand the use of appropriate treatment technologies in wastewater reclamation.

The key problem areas in municipal wastewater reuse are not the treatment technologies or technical concerns. Major issues are more related to funding, regulatory, institutional, and legal constraints, and most importantly, public acceptance.

At all resource levels, Federal, State, and local funding is still the No. 1 barrier to expanded water reuse.

Groundwater Recharge

In the Western United States, projects that reclaim and reuse water to augment local water supplies have blossomed. Groundwater recharge is already an important tool for water management, particularly in Arizona, California, Colorado, Nevada, and Texas.

In order to demonstrate a variety of artificial recharge technologies under varying site conditions in the United States, Reclamation is cooperating with local agencies in conducting groundwater recharge projects under the High Plains States Groundwater Demonstration Program, as authorized by Public Law 38434. Currently, nine projects are operating, four are under construction, and three are deferred until funds become available. Each demonstration project will operate for 5 years, with local agencies providing a minimum of 20 percent cost share with the Government. In cooperation with other agencies, Reclamation is focusing on recharge technology using storm water, treated municipal wastewater, and irrigation return flows.

Demonstration projects under the program that require water treatment before recharge are shown in table 3.

Table 3. - High Plains States groundwater demonstration projects requiring water treatment (Reclamation, 1992).

Project	Location	Water source	Technology
Arcade	Arcade Water District, California	American River	Treatment and injection
Denver Basin aquifer	Willows Water District, Colorado	Denver water supply	Treatment and injection
Equus beds injection	City of Newton, Kansas	Reclaimed water	Wastewater treatment
Big Creek water banking	City of Hays, Kansas	Reclaimed water	Wastewater treatment and basin percolation
York injection	Upper Big Blue, Nebraska, Natural Resources	Runoff and industrial	Partial treatment and basins
Washoe	Washoe County Department of Public Works, Nevada	Truckee River	Treatment and injection
Huron	South Dakota State University, South Dakota	James River	Treatment and injection
Hueco Bolson injection	El Paso Water Utilities Public Service Board, Texas	Reclaimed water	Wastewater treatment

As shown in table 3, the demonstration projects address different technologies and hydrogeologic conditions, and will go a long way in determining the future of groundwater recharge and attendant water treatment requirements.

In the Huron project, excess flows from the James River will be injected into a buried glacial aquifer. Since the water will be treated at the Huron Water Treatment Plant, the injected water may actually improve aquifer water quality. In the Hueco Bolson project in Texas, the study will closely monitor treated wastewater that is currently injected into the 10 million-acre-ft freshwater Hueco Bolson Aquifer. Water remains in the aquifer for 2 to 6 years before being recovered for use by the City of El Paso. Recently, this study was expanded to include a U.S. Geological Survey investigation of the fate and movement of THM's (trihalomethanes) compounds associated with treated wastewater injection (Reclamation, 1992).

As previously referred to under Wastewater Reclamation, the Orange County Water District's WF21 has already demonstrated advanced treatment technology for reclaiming wastewater through groundwater recharge and retarding saltwater intrusion in a coastal area. The progressive expansion of WF21 and announcement of plans to build another similar project, the 8-Mgal/d Alamitos Gap Project, supports increasing use of groundwater recharge as a comprehensive water management strategy for the future.

Another interesting blend of water treatment and management techniques is the recent development of artificial wetlands and groundwater recharge. Over the past 10 years, numerous communities across the United States have constructed wetlands and aquatic plant systems for municipal wastewater treatments. Recently, in Southern California, Reclamation and the Eastern Municipal Water District launched a multipurpose wetlands research and demonstration program of regional and national significance (Reclamation, 1991). The program will evaluate the effectiveness and feasibility of integrating constructed wetlands with wastewater treatment for environmental enhancement and ultimate reuse of reclaimed water. The constructed wetlands will be evaluated as an alternative to conventional treatment, including polishing and disposal of wastewater for recharge, recovery, and reuse operations.

- Significant benefits of this multipurpose program relate to:
- Fish and wildlife production and habitat improvement
- Open space and green belt
- Recreation and community involvement
- Air quality improvement

A unique attribute of the program at one of three sites under construction (Hemet Demonstration Site) is the installation of a 5,000-gal/d RO plant. In addition to using the RO plant to reclaim brackish groundwater for municipal and industrial use and/or groundwater recharge, the study will determine the feasibility of using the reject stream (brine) in vegetated, salt-tolerant marshes to support green belts and open space areas. Figure 6 displays a schematic of the pilot plant process.

Irrigation Drainage

Irrigation requirements in the Western United States consume over 80 percent of all water used in the country today. In theory, irrigation water could be desalinated and/or treated to improve crop yields. Studies in the 1960's and 70's, however, indicated that desalting irrigation water for agricultural reuse is generally not economical in the United States.

Intensive irrigation of western lands over the past 90 years has generated other problems that have renewed interest in desalting and water treatment/management technologies. Each time river water is used for irrigation, salt is leached from the soils as the excess, applied water migrates back into surface and groundwater supplies. Due to intensive reuse of the Colorado River water (over seven times in the Basin) and other natural salt sources, the salinity (TDS) of the Colorado River increases from about 50 mg/L in its headwaters to approximately 700 to 750 mg/L at Imperial Dam near Yuma, Arizona. High salinity in Colorado River water has impacted the Republic of Mexico and inflicted economic damages to U.S. agricultural and municipal/industrial water users.

Other areas of intensive irrigation in the West, such as in the San Joaquin Valley of California, have focused new attention on the disposal of saline, agricultural drainage water. Here, increasing concerns about the impact of drainwater on waterfowl and fish at Kesterson National Wildlife Refuge in California has raised national consciousness over the potential hazards of selenium and other trace elements found in irrigation return water.

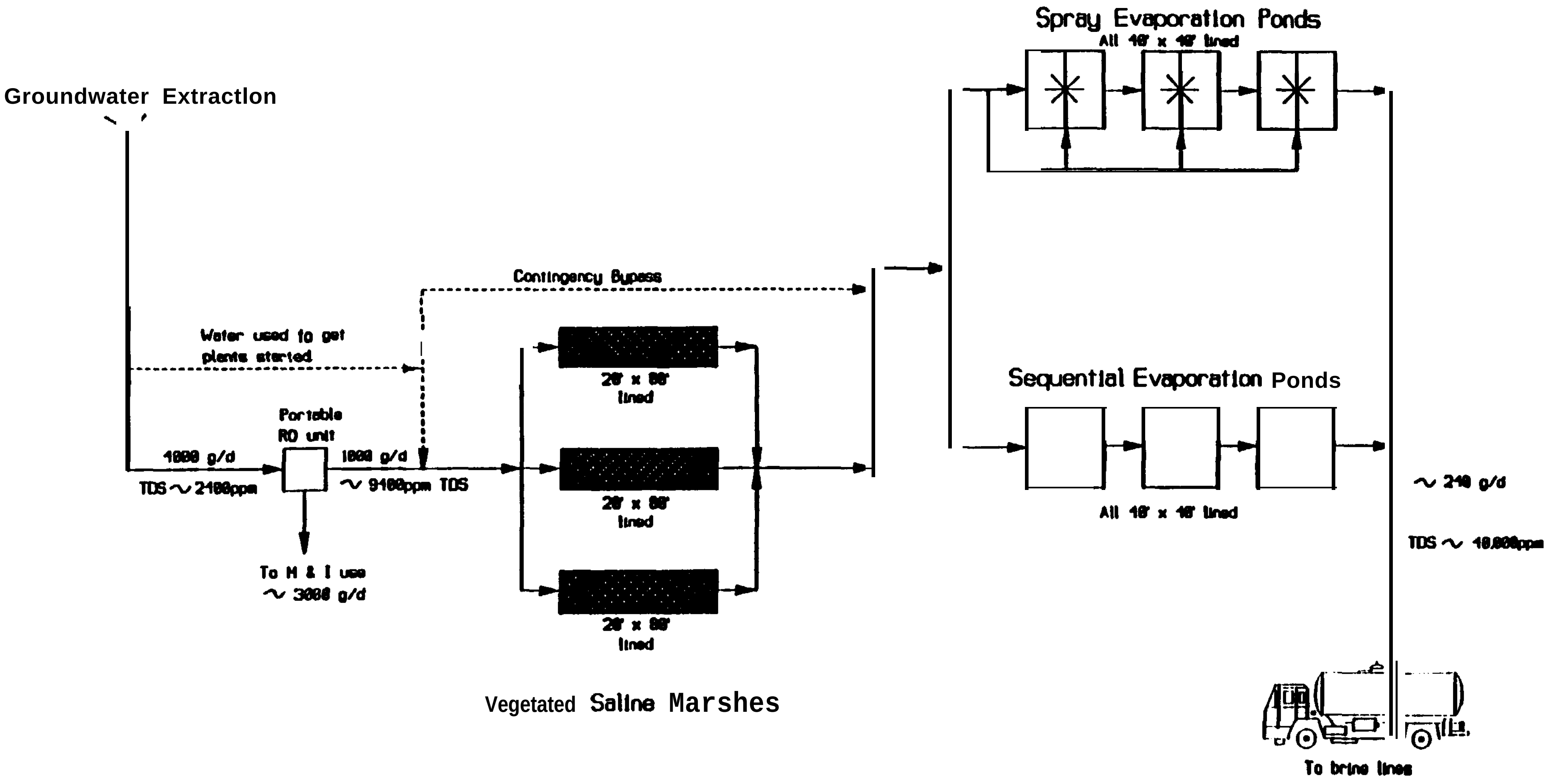


Figure 6. -Vegetated saline marsh pilot program, Eastern Municipal Water Distrii, Hemet demonstration site.

In response to those concerns about the quality of surface and subsurface drainwater from irrigated lands, Reclamation is participating in the National Irrigation Water Quality Program. As a member of the DOI (Department of the Interior) Interagency Task Group, Reclamation is currently investigating selected areas in the Western United States to address selenium and other water quality concerns, over which the DO1 has responsibility.

From 1983 through 1990, studies completed under the State-Federal San Joaquin Valley Drainage Program examined management options for solving several drainage problems from one of the United States' most productive agricultural regions (Smith, 1992). Since the early 1970's, the California DWR (Department of Water Resources) has investigated the use of desalination, primarily the RO process, to reclaim a portion of brackish drainage water for beneficial use. Extensive testing at Firebaugh and Los Banos, California, has shown that agricultural drainage water can be successfully desalted. The DWR also operated a 0.Bacre solar salt-gradient pond from 1985 to 1989 at Los Banos to effectively demonstrate the storage and use of remaining brine (from desalting plants) to produce thermal and electrical energy (Smith, 1992). Other new concepts in agricultural drainage water management include the use of tile drainwater on progressively more salt-tolerant plants, such as eucalyptus plantations and saline wetlands to concentrate drainage for final disposal in brine concentrators or solar ponds.

In order to protect 1 million acres of irrigated farmland in the Western San Joaquin Valley which are threatened by inadequate drainage and salt accumulation, currently over 100,000 acre-ft of drainage water must be disposed of in an environmentally safe manner (Hayes and Kipps, 1992).

In the final analysis, disposal of saline drainage water without some beneficial use will probably not be acceptable. A combination of management options including on-farm water conservation, use of salt-tolerant plants, brackish groundwater desalting, use of solar ponds, and other water treatment techniques will be needed

The world's largest RO plant is now desalting 3,000-mg/L TDS brackish irrigation drainage water that would otherwise flow into the Gulf of California. The Yuma Desalting Plant was authorized for construction as a cornerstone project under the Colorado River Basin Salinity Control Act of 1974.

The Yuma Desalting Plant is designed to improve the quality of Colorado River water delivered to Mexico under treaty requirements. The plant will also salvage irrigation drainage water now being wasted to the Gulf of California to become part of the U.S. water deliveries to Mexico. At the installed capacity of 72 Mgal/d, the plant will produce an average of about 68,000 acre-ft of product water per year at about 300-mg/L TDS. This flow will be mixed with raw drainage water to develop a total of 78,500 acre-ft/yr of low TDS, blended water for delivery to the Colorado River and Republic of Mexico.

The process recovers 70 percent of the feedwater with the remaining 30 percent being discharged as a brine. The rejected brine flows through an energy recovery system before being discharged to a concrete-lined drain canal for disposal in the Gulf of California.

A small but important feature of the plant is a 1-Mgal/d research and development test train. The test train provides a ique facility to evaluate advancements in both pretreatment and desalting technology. Moreover, the plant (fig. 7) serves as a “proving ground” for continuous technology assessment for operations, equipment replacement, and operator training.

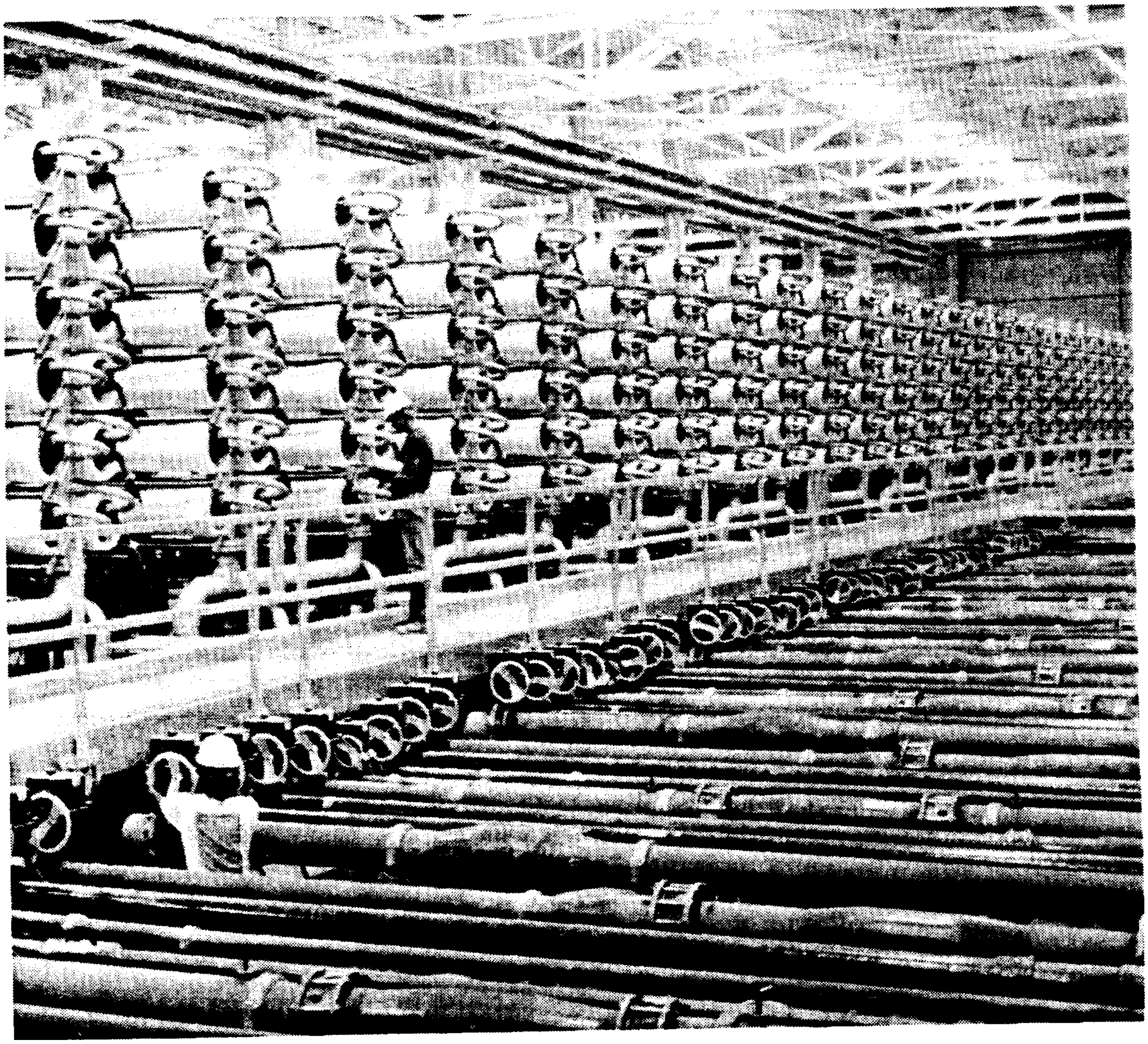


Figure 7. - Membrane modules - Yuma Desalting Plant.

The plant began initial delivery of desalted water to the Colorado River in May 1992 and is presently operating at one-third capacity (approximately 22 Mgal/d). Future operating capacity and water production schedules remain to be determined by the Secretary of the Interior.

Some may view the Yuma Desalting Plant as an isolated, unique application of desalting technology solely dedicated to “the Colorado River problem.” However, there are other rivers and limited water supplies in arid, Middle Eastern countries with similar problems dealing with shared water supplies of degraded water quality. Eventually, desalination may play a greater role in reclaiming water on an international basis.

Dual-Purpose Plants

Desalting studies in the 1960's assumed that large-scale, dual-purpose (power/desalting), nuclear-powered complexes would be constructed in coastal areas to provide an inexhaustible, low-cost water supply from seawater. Today, that "Popular Science" scenario for the future has been realistically modified. Based on actual experience in Saudi Arabia, we know that conventional dual-purpose plants can lead to some distillation cost reductions of 20 to 30 percent compared to the overall cost of separate power and desalination plants. It is not the economics of dual-purpose plants, however, that make this concept so attractive. Today, stringent environmental and regulatory constraints, particularly in coastal areas, have become the primary consideration in citing any basic resource plant complex. Hence, it is the existing powerplants in coastal areas that may offer dual-purpose sites that minimize environmental impacts of desalting. Moreover, the integration of desalination with existing or planned cogeneration power systems offers sign&cant potential for energy conservation.

The MWD of Southern California is currently investigating these new concepts for large-scale, water supply augmentation. MWD is proceeding with a demonstration program and construction of a dual-purpose plant to supply 80 Mgal/d from seawater by the turn of the century. The program is slated to begin with a 2,000-gal/d test unit to be operated at the Huntington Beach power station. Only after comprehensive evaluation of a follow-up 5-Mgal/d demonstration plant would the 80 Mgal/d multieffect, distillation plant be completed (Hammond et al., 1992). For a distillation process, this means using "secondhand" steam that has first been used to generate electricity. Thus, from the onset, this large plant will be constrained to existing coastal power station sites. Southern California has about 14 such stations, and the coastline is under such demand that it is highly unlikely that any new ones will be built (Hammond et al., 1992). Some of these power stations are planning to repower with modern gas turbine, combined cycle units. The coupling of a distillation plant using exhaust steam from an efficient, cogeneration process provides a least-cost source of energy. Economics are also realized by shared land, seawater intake facilities, brine disposal systems, and O&M (operation and maintenance) labor costs. Reliability of plant operation, as well as environmental and ecological impacts of the plant will be closely monitored in California.

In a concurrent effort, the San Diego County Water Authority and the San Diego Gas and Electric Company recently completed studies of dual-purpose desalting (Hess and Morin, 1992). These studies focused on the technical and cost aspects of a dual-purpose facility using both a combined cycle powerplant and repowering of an existing unit. This preliminary evaluation cited the advantages of multistage flash and multieffect distillation options along with RO for the seawater plant.

In yet another recent study, Southern California water and power utilities recently completed the Baja California Desalination Project Feasibility Study which was designed to provide 100 Mgal/d of potable water and 500 MW of power for the region (Nerell et al., 1992). The study was completed to demonstrate the technical, financial, and economic feasibility of introducing seawater desalting using the latest distillation and membrane technologies coupled to efficient, combined-cycle, gas-turbine power generation facilities. For this new site study, the estimated water costs of potable water from the desalination plant were higher than most current average water costs in the area. Although these particular results were discouraging, the basic concepts are being pursued elsewhere.

In Florida, the viability of converting existing Florida Power and Light Company powerplants to dual-purpose power and water desalination plants was also recently evaluated (LaBar et al., 1992). The study concluded that both low-temperature, multieffect distillation and RO were suitable technologies for large-scale, dual-purpose plant conversion of either brackish water or seawater. The site screening study involved five coastal oil/gas powerplants for desalting of seawater and three inland oil/gas plants for desalting of brackish water. The study also concluded that lower cost water was obtained from dual-purpose RO plants than for dual-purpose distillation from either seawater or brackish water sources.

Thus, it is apparent that due to basic energy considerations, regulatory climate, site constraints, etc., future, large-scale desalting in the United States will not develop as a standalone technology. Desalting technology, in this context, will proceed only as a synergistic partner in dual-purpose or multipurpose applications.

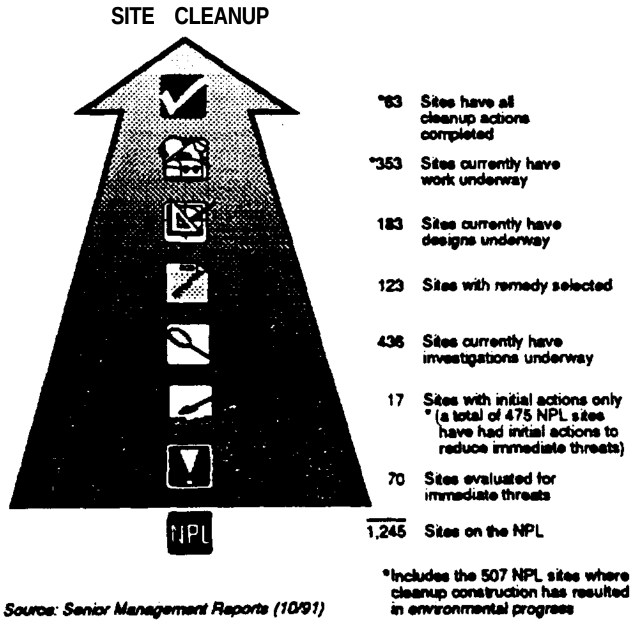
In examining prospects for using renewable energy resources in future multipurpose applications, the 5-year-old El Paso Solar Pond Project stands out. The El Paso Solar Pond is a research, development and demonstration project operated by the University of Texas at El Paso and funded by Reclamation and the State of Texas. Solar pond technology utilizes a waste product, i.e., reject brine to store solar thermal energy in ponds which can be used for several practical applications. Currently, the El Paso Solar Pond (0.8 acre in size) is producing industrial process heat, grid-connected electricity, and potable desalted water (University of Texas at El Paso, 1992). Promising accomplishments include:

- Generating peak power output exceeding 100 kW and sustained output at 55 kW
- Producing 5,000 gal/d of potable desalted water on a sustained basis
- Maintaining near-boiling storage zone water temperatures

Inland solar pond technology has promising implications for both water treatment and wastewater (irrigation drainage) management in arid climates. Alternative energy researchers are also experimenting with combinations of wind generators and photovoltaics for power generation and water supply at remote sites.

Hazardous Waste Control

Since the passage of the CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act), commonly called Superfund, the Nation is committed to cleaning up the hazardous waste dumps of the past that threaten public health and the environment. EPA, to date, has logged more than 35,000 sites on its National Hazardous Waste Site inventory. Of these assessed sites, EPA has identified 1,245 hazardous waste sites as the most serious in the Nation (EPA, 1991). These sites comprise the NPL (National Priorities List) with the sites targeted for cleanup under the Superfund. Eventually, the NPL is expected to grow each year, potentially reaching 2,100 sites by the year 2000. Current funding for Super-fund is $8.5 billion under the 1986 CERCLA amendments, but EPA now estimates that Superfund will spend more than $27 billion on cleanup construction at sites now on the NPL. Currently, the average cost of cleanup is $26 million per site. Responsible parties are expected to pick up 65 percent of cleanup costs. Although cleanup progress has been slow, 63 NPL sites have all cleanup actions completed. The status of all NPL sites under various stages of cleanup is shown in figure 8 (EPA, 1991).



*Includes the 507 NPL sites where cleanup construction has resulted in environmental progress

Source: Senior Management Reports (10/91)

Figure 8. – NPL sites – current stages of cleanup.

The largest threat of NPL hazardous wastes are to groundwater (85 percent of sites) and drinking water impacts (73 percent of sites). Potential contamination to water supplies from the “toxic soup” of hazardous wastes include heavy metals, solvents, organic and inorganic chemicals, pesticides, paint/oils, and radioactive wastes.

Since 1986, NPL site cleanup solutions have moved away from containment and/or removal to treatment technologies in order to reduce toxicity, mobility, and waste volume. During 1990, 79 percent of the sites specified treatment remedies to control the sources of contamination. Groundwater treated to date at 97 sites totals approximately 6.3 Bgal, with treated surface water now at 300 Mgal (at 64 sites) (EPA, 1991). Conventional water treatment processes are being used along with bioremediation techniques for effective cleanup.

In view of the size and complexity of the Superfund Program, the potential need for water treatment technology is impressive. The main constraint is still funding. In this case, the 1994 reauthorization of CERCLA (Superfund) will have to address the protracted court battles over making responsible parties pay their share of cleanup costs. New encouragement is needed for those parties to settle so that site remediation can proceed at a reasonable pace.

Abandoned mining in the United States has left a legacy of waste rock, mine tailings, and drainage tunnels carrying contaminated waters to prime receiving waters. Acid mine drainage is one of the most damaging environmental impacts from mining today and yet represents a situation where treatment technology holds great promise.

There are over 66,000 sources of acid coal mine drainage pollution in Appalachia, in active and inactive mines (Cohen and Staub, 1992). In the Rocky Mountain region, hundreds of abandoned small mines and tailings piles pollute streams with acidic and metal-laden water.

With Federal legislation under the Surface Mining Control and Reclamation Act and Superfund, as well as State statutes and regulations, conventional, as well as new water treatment processes, are being investigated at many sites, particularly those on the NPL.

Rather than attempting to inventory cleanup activities on abandoned mine sites, a brief sampling of representative mine sites, some of which are also on the NPL list, yield an interesting picture:

- California Gulch – Located near Leadville, Colorado, the Yak Tunnel drains over 210 tons per year of heavy metal contaminated mine waters into the headwaters of the Arkansas River (EPA, 1991). The Bureau of Reclamation provided technical assistance to EPA in the design of a chemical coagulation treatment process to remove heavy metals.

- Central City/Clear Creek – Located near Idaho Springs, Colorado, treatment of acid mine drainage using wetlands to apply biogeochemical processes to concentrate and immobilize metals is a promising new approach (EPA, 1991). Prototype treatment systems have also been constructed in Pennsylvania and West Virginia

- Eagle Mine – Over 7 million tons of zinc mining deposits and mine drainage are contaminating the Eagle River near Minturn, Colorado. Reclamation is also providing technical assistance in evaluating biological treatment along with more conventional chemical treatment systems.

- Leadville Mine Drainage Tunnel – Near Leadville, Colorado, a fully automated (3.3-Mgal/d) conventional clarification treatment plant, designed and operated by the Bureau of Reclamation delivers treated water to the high country headwaters of the Arkansas River.

“High tech” or advanced treatment technology is not always required to convert acid mine drainage to compliance quality water. According to development work on manmade wetland ecosystems by the TVA (Tennessee Valley Authority)(Environmental Science and Technology, 1992), these new biotreatment systems may treat mine drainage at costs far less than traditional chemical treatment. Approximately 400 constructed wetland treatment systems have been built in the United States, reinforcing the biotreatment approach.

Point-of-Use Water Treatment

Over 40 million people in the United States obtain drinking water from small water supply systems and private wells (EPA, 1991). As described in recent surveys, the occurrence of potentially hazardous industrial and agricultural chemicals in drinking water aquifers is on the increase. For many small community and private systems with brackish water and/or contaminated water or other perceived water quality problems, treatment utilizing membrane technology-R0 or ED-at a centralized facility may be impractical or prohibitively expensive.

The main alternatives to centralized water treatment today are the use of purchased bottled water for drinking and cooking and POU (point-of-use) treatment of water in the home. Nearly half of the participants in a 1990 statewide poll in California said they regularly used at-home filters or bought bottled drinking water (Water Education Foundation, 1992).

According to some estimates, 3 to 6 percent of the U.S. population consistently buys bottled water. Sales of bottled water in this country have grown from $100 million in 1975 to almost $2 billion today. California is the 'bottled water capital" of the United States with over 40 percent of the market (Water Encyclopedia, 1990). Assuming an average cost of about 85 cents for a gallon of bottled water, a family of four using only 1/2 gal of bottled water per person per day for drinking and cooking would spend about $50 a month on bottled water. In contrast, costs for publicly supplied, conventionally treated water in metropolitan areas of the U.S. average about $1.27 per 1,000 gal for water treatment and delivery (Water Encyclopedia, 1990). Based on the same family of four using a total of 150 gal per person per day (average), the average monthly water supply bill in the United States is about $23/month. In a recent independent study (AWWA, 1990a), a cost comparison between a central demineralization plant and the purchase of bottled water by individual consumers showed that central or system-wide treatment is less costly to most residential consumers.

In 1985, the Water Quality Association estimated residential sales of POU treatment devices (filters, RO, etc.) at more than $700 million. Moreover, the market for POU water treatment equipment is growing at a rate of about 8 to 10 percent per year, making POU treatment a $1.6 billion per year industry today (OTA, 1988).

Ion exchange water softeners have been used for many years in POU systems to reduce calcium and magnesium concentrations by exchange with sodium as the water flows through chemical resins in the home water softener. Although softeners may reduce the amount of scaling inside a home's water pipes and appliances, there are lingering doubts about possible adverse health effects (e.g., increased blood pressure associated with drinking high-sodium water). Moreover, regeneration salts used in the softener adds to the typical increase in TDS load (average 300 mg/L) of wastewater leaving the home. Salt loading from home softeners has aggravated a high TDS problem in some Western States. Whole-house water softening unit costs vary between $300 and $1,000 (depending on installed capacity, plus the cost of installation and periodic regeneration of the resin) (OTA, 1988).

High TDS and many other inorganic/organic contaminants can be removed by small RO or distillation units attached to tapwater lines. These countertop, under-the-sink, or standalone units typically cost from about $80 to $800 (1988) depending on capacity, which range from about 5 to 15 gal/d (OTA, 1988). Operating and maintenance costs for RO or distillation typically average about 25 cents a gallon. Thus, after purchasing home RO or distillation units, the monthly cost for a family of four would be about $15 per month.

GAC (granular-activated carbon) water filters can also be attached to faucet spigots for POU treatment to remove some particulates and organic contaminants from tapwater at low cost. Under-the-sink and whole-house GAC filters can cost as much as a few hundred dollars depending on size. All types of GAC and POU treatment units require periodic cleaning and/or parts replacement by the homeowner. The lack of control over monitoring for treatment effectiveness and assuring routine maintenance is a major concern that Federal and State regulatory agencies have about POU treatment.

Some States have recently experienced a flood of unscrupulous vendors using scare tactics and other deceptive practices to market POU devices (EPA, 1988). These marketing tactics have bilked unsuspecting residents of considerable sums of money for unneeded water treatment, and, at times, marketed devices that further contribute to health problems.

Despite these problems and the relatively high costs of bottled water and individual POU systems, public concern over the water quality of drinking water is slowly eroding public acceptance and confidence in public water systems.

It also appears that an important “niche” of home treatment is developing within the broad spectrum of current water treatment needs and application. Thus, “think small” in terms of low cost, low maintenance POU treatment systems may provide appropriate technology to ease the future burden on centralized treatment plants in some areas of the country.

Military Applications

The U.S. Army, Navy, and Marine Corps are all developing water production and treatment capability using distillation and RO membrane technology. For many years, the U.S. Navy has used shipboard distillation to provide drinking water and boiler feed water. Currently, RO membrane units are being tested/installed on several classes of new ships in the fleet. RO is also under evaluation at several Navy land-based facilities.

Over the last 10 years, both the Army and Marine Corps have upgraded water production capabilities of field and hospital units with the acquisition of over 900 skid-mounted ROWPU’s (reverse osmosis water purification units). The ROWPU’s are capable of treating brackish water, seawater, and contaminated water with a basic production capacity of 15,000 gal/d. Larger, trailer-mounted units of 70,000 gal/d are also in use. Along with RO, these units incorporate other conventional treatment processes including filtration, coagulation, ion exchange, and disinfection. The smaller units are designed to be dropped by parachute while the larger units can be airlifted or transported by ship. The Army has also developed a water treatment barge with two 300,000 gal/d RO units capable of treating brackish water or seawater and pumping treated water ashore (OTA, 1988).

TECHNOLOGY MATCHUP WITH TREATMENT NEEDS

A survey of treatment needs would not be complete without an assessment of treatment technology potential to address identified problem areas. EPA has established a general guide to view treatment technology related to the treatment objectives of filtration, disinfection, organic and inorganic contaminant removal, and corrosion control (EPA, 1990). Appendix table A2 indicates four levels of treatment technology acceptance: experimental, emerging, established, and BAT. Experimental technologies have shown promise in some applications, but have not been extensively tested Emerging technologies have proven themselves in the laboratory, but not in the field. Established treatments are commonly used in the water industry. BAT is a regulatory designation that indicates the level of contaminant removal achievable through specifications of a technology rather than an MCL. RO technology, for example, is classified as “emerging” for organics removal, as well as “established” or even “BAT’ for some inorganic removal applications.

Under the 1986 Safe Drinking Water Amendments, whenever EPA established an MCL drinking water requirement for a particular contaminant, the agency must also identify the Best Available Technology (BAT) for removing or reducing contaminant levels. To date, EPA has determined that the following treatment technologies are considered BAT, taking both efficiency and costs into consideration (EPA, 1989b). It is important to note that alternative treatment technologies are allowable if it is proven to the State that the new technology is at least as effective as the specified BAT:

- Disinfection is the BAT for total and fecal coliform bacteria
- Filtration and disinfection are the treatment techniques for various microbiological contaminants as specified in the final Surface Water Treatment Rule.
- Coagulation/filtration, lime softening, ion exchange, and RO are the BAT's for various inorganic chemicals.
- GAC and packed tower aeration are the BAT's for various synthetic organic chemical removal.

There is no apparent shortage of BAT and other appropriate technologies needed to address the major inorganic contaminants identified in the raw water and tapwater quality surveys summarized in this report. Tables 4 and 5 (EPA, 1990), identify, in broad terms, the potential treatment technologies for specific organic and inorganic contaminant removal. Some treatment technologies like coagulation/filtration have a narrow range of contaminant removal while the newer membrane technologies like RO, ED, and NF have a broad spectrum of control potential.

There are several emerging and potential applications of membrane technology that will have significant impact on drinking water quality. Application of membrane processes just over the past 10 years include hardness removal (membrane softening), organics removal (THM precursors and color), and specific inorganic ion removal (nitrates and fluoride).

Since its introduction in 1986, NF membrane treatment is being used instead of lime softening by Florida municipalities with surface and groundwater supplies high in organics, color, or hardness (AWWA, 1989a; 1989b). Over 50 Mgal/d of NF membrane capacity is planned in the State within the next 5 years. There is also some indication of the ability of NF membranes to remove heavy metals (MCL) (Taylor, 1972).

To comply with the new Surface Water Treatment Rule, most municipalities using surface water, and some with groundwater supplies, will be required to provide filtration prior to distribution. Ultrafiltration (UF) and MF (microfiltration) membrane systems are expected to offer attractive alternatives to conventional media filtration in some cases.

Figure 9 shows the general spectrum of filtration potential for all the membrane processes.

The promising potential for new membranes in removing pesticides and herbicides from drinking water is shown in figure 10.

Typical removal rates of heavy metals from wastewater for both RO membrane treatment and conventional activated sludge treatment is displayed in figure 11. Very high removal rates are reported for RO membrane treatment.

Table 4. – Treatment technology removal effectiveness reported for **organic** contaminants **(percent).** Source: EPA, **1990.**

Contaminant	Coagulation/ filtration	GAC	PCA	PAC	Diffused aeration	**Oxidation**[a]	Reverse osmosis
Acrylamide	5	NA	o-29	13	NA	NA	o-97
Alachlor	o-49	70-100	70-100	36-100	NA	70-100	70-100
Aldicarb	NA	NA	o-29	NA	NA	NA	94-99
Benzene	o-29	70-100	70-100	NA	NA	70-100	o-29
Carbofuran	54-79	70-100	o-29	45-75	1 l-20	70-100	70-100
Carbon tetrachloride	o-29	70-100	70-100	0-25	NA	o-29	70-100
Chlordane	NA	70-100	o-29	NA	**NA**	NA	NA
Chlorobenzene	o-29	70-100	70-100	NA	**NA**	30-69	70-100
2,4-D	o-29	70-100	70-100	69-100	NA	W	0-65
1,2-Dichloroethane	o-29	70-100	70-100	NA	42-77	o-29	15-70
1,2-Dichloropropane	o-29	70-100	70-100	NA	12-79	o-29	10-100
Dibromochloropropane	o-29	70-100	30-69	NA	NA	o-29	NA
Dichlorobenzene	NA	70-100	NA	NA	NA	NA	NA
o-Dichlorobenzene	o-29	70-100	70-100	38-95	1472	30-88	30-69
p-Dichlorobenzene	o-29	**70-100**	70-100	**NA**	NA	30-69	0-10
1,l-Dichloroethylene	o-29	70-100	70-100	**NA**	97	**70-100**	NA
cis-1,2-Dichloroethylene	o-29	70-100	70-100	**NA**	32-85	70-100	0-30
trans-1,2-Dichloroethylene	o-29	70-100	70-100	**NA**	37-96	70-100	0-30
Epichlorohydrin	NA	NA	o-29	NA	NA	o-29	NA
Ethylbenzene	o-29	70-100	70-100	33-99	2489	70-100	0-30
Ethylene dibromide	o-29	70-100	70-100	NA	NA	o-29	37-100
Heptachlor	64	70-100	70-100	53-97	NA	70-100	NA
Heptachlor epoxide	**NA**	NA	NA	NA	NA	26	NA
High molecular weight hydrocarbons (gasoline, dyes, **amines, humics)**	**NA**	W	NA	NA	NA	NA	NA
Lindane	o-29	70-100	o-29	82-97	NA	0-100	50-75
Methoxychlor	NA	70-100	NA	NA	NA	NA	**>90**
Monochlorobenzene	NA	NA	NA	1499	1485	86-98	50-100
Natural organic material	P	P	NA	P	NA	W	P
PCBs	NA	70-100	70-100	**NA**	NA	NA	**95**
Phenol and chlorophenols	NA	W	NA	**NA**	NA	W	**NA**
Pentachlorophenol	NA	70-100	**0**	NA	NA	70-100	NA
Styrene	o-29	NA	**NA**	NA	NA	70-100	NA
Tetrachloroethylene	NA	70-100	NA	73-95	73-95	W	70-90
Trichloroethylene	o-29	70-100	70-100	53-95	53-95	30-69	0-100
Trichloroethane	NA	70-100	NA	NA	NA	NA	NA
1,1,1-Trichloroethane	o-29	70-100	**70-100**	5890	58-90	o-29	15-100
Toluene	o-29	70-100	70-100	22-89	22-89	70-100	NA
2,4,5-TP	63	70-100	NA	NA	NA	30-69	NA
Toxaphene	o-29	70-100	70-100	NA	NA	NA	NA
Vinyl chloride	o-29	70-100	70-100	NA	NA	70-100	NA
Xylenes	o-29	70-100	70-100	**18-89**	1889	70-100	**10-85**

W = well removed.

P = poorly removed.

NA = not available.

“The specifics of the oxidation processes effective in removing each contaminant are provided in Chapter 6.

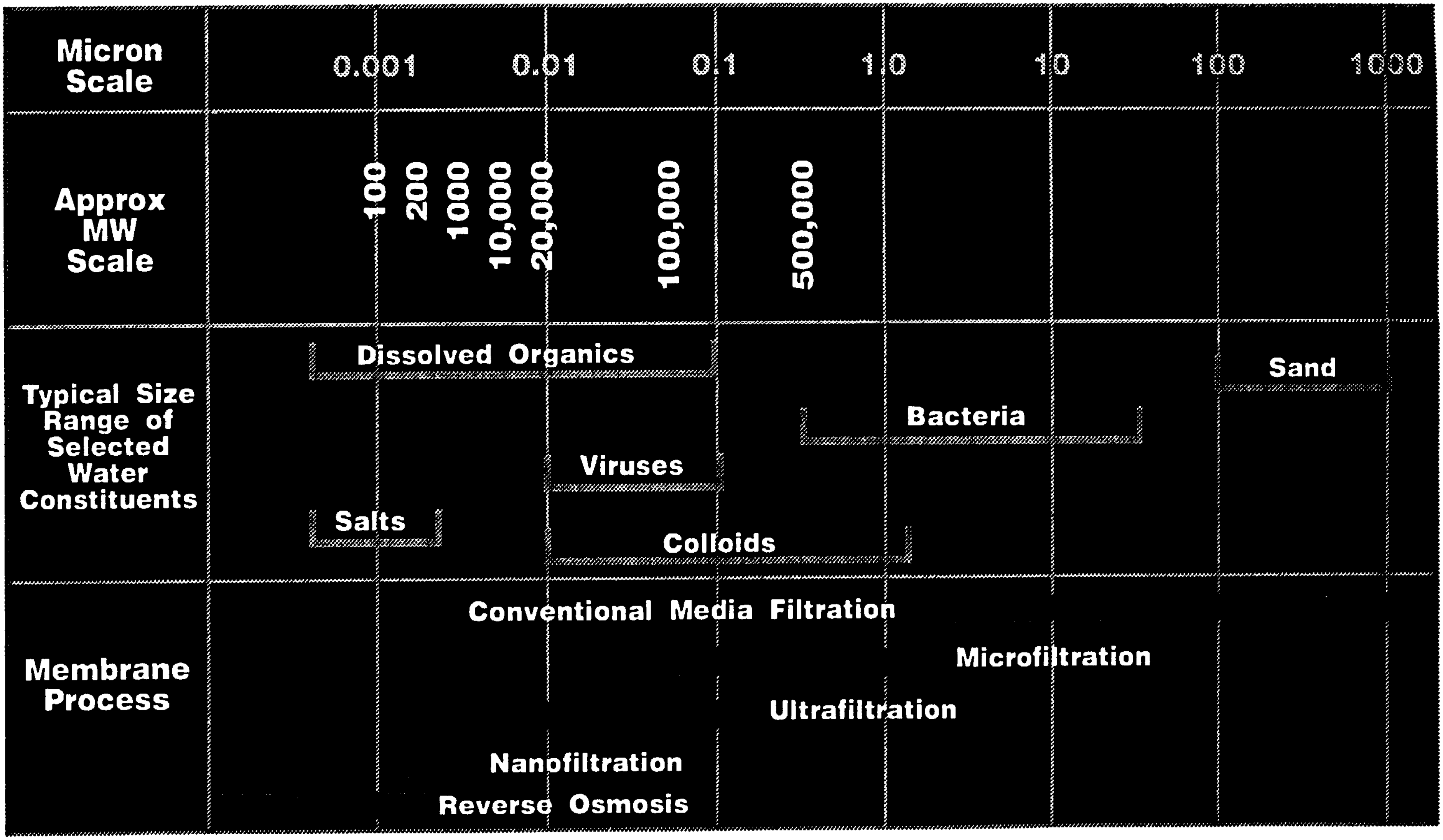
Note: Little or no specific performance data were available for:

1. Multiple Tray Aeration
2. **Catenary** Aeration
3. **Higee** Aeration
4. Resins
5. Ultrafiltration
6. Mechanical Aeration

Table 5. - Removal effectiveness for nine processes by inorganic contaminant. Source: EPA, 1990.

Treatment	Contaminant																				
	Ag	As	As^{III}	As^{V}	Eta	Cd	Cr	Cr^{III}	Cr^{VI}	F	Hg	$Hg^{(O)}$	$Hg^{(I)}$	NO_3	Pb	Ra	Rn	Se	$Se^{(VI)}$	$Se^{(IV)}$	u
Conventional treatment	H		M	H	L	H	-	H	H	L	-	M	M	L	H	L	-	-	M	L	M
Coagulation - aluminum	H			H	-	M	-	H	-	-	M	-	-	-	H	-	-	-	-	-	-
Coagulation - iron	M			H	-	-	-	H	H	-	-	-	-	-	-	-	-	-	-	-	-
Lime softening	-		M	H	H	H	-	H	L	M	-	L	M	L	H	H	-	-	M	L	H
Reverse osmosis and electrodialysis	H		M	H	H	H	H	-	-	H	H	-	-	M	H	H	-	H	-	-	H
Cation exchange	-	L		-	H	H	-	H	L	L	-	-	-	L	H	H	-	L	-	-	H
Anion exchange	-			-	M	M	-	M	H	-	-	-	-	H	M	M	-	H	-	-	H
Activated alumina	-		H	-	L	L	-	-	-	H	-	-	-	-	-	L	-	H	-	-	-
Powdered activated carbon	L			-	L	M	-	L	-	L	-	M	M	L	-	L	-	-	-	-	-
Granular activated carbon	-			-	L	M	-	L	-	L	-	H	H	L	-	L	H	-	-	-	-

H = High = >80% removal.
M = Medium = 20430% removal.
L = Low = <20% removal.
"-" = indicate no data were provided.



MW = molecular weight

Figure 9. -General filtration spectrum. Source: Fundamentals of Membranes Training Course by K. Frank, 1992.

DESAL-1 REJECTION CHARACTERISTICS

The following **Desal-1** pesticide rejection data were reported by the Canadian EPA. Test pressure was 800 psig at 50% recovery.

INSECTICIDE/HERBICIDE REJECTIONS

Compound	Feed Concentration mg/l	Rejection, %
2, 4-D	299.0	98.8
Mecoprop	18.0	95.6
Dursban	15.0	99.9
Malathion	3.2	99.3
Methoxychlor	2.0	>99.0

NOTES: (1) **Desal-1** is a proprietary Thin-Film-Composite Membrane made by Desalination Systems Inc.

(2) Tabulation adapted from the Desalination Systems Catalog.

Figure 10. - Typical separation characteristics.

metal	Activated Sludge Treatment (3) Concentration in ug/L		% Removal	RO Treatment @ 10% Salt Passage (2) Concentration ug/L	% Removal	Proposed Limits (1) ug/L
	Influent	Effluent				
Cadmium	2	1	50	0.1	90	0.66
Chromium (Total)	35	18	50	1.8	90	11.0
Copper	120	36	70	3.6	90	6.5
Lead	25	5	80	0.5	90	1.3
Mercury	0.2	0.08	60	0.008	90	0.012
Zinc	240	108	55	10.8	90	59.0
Cyanide	15	9	40	0.9	90	10.0

(1) Water Quality Standard Requirements (Basin Plan and Inland Surface Waters Plan)

(2) Salt Passage = 100 - Salt Rejection /Removal

(3) Data from Sacramento Regional Wastewater Treatment Plant - JCE master Plan Report (1991)

Figure 11. - Typical removals of heavy metals.

Traditional membrane applications of ED and RO for brackish water and seawater desalting will remain important for the augmentation of water supplies in general. However, the newer uses of membrane technology for improving the water quality of public water supplies is becoming more significant. Membranes have been developed that can be used to effectively remove particulates, organic and inorganic compounds, and radionuclides. Other applications in hazardous waste control include removal of volatile organics, sulfide stripping, oxygen enrichment or air drying for ozonation systems, and concentration of stripping gases associated with GAC treatment.

It is also interesting to note that NF and RO membrane processes have good potential for THM control and DBP (disinfection byproduct) removal at a reasonable cost.

Reclamation is currently preparing a manual/guide to membranes for municipal water treatment (Wilbert, 1992 draft). The manual presents detailed information on membrane preparation, cleaning, storage, operational parameters, and vital statistics on available membranes on the market.

The new regulatory climate for drinking water improvement appears to be driving membrane technology development more than the traditional needs for water supply from brackish or seawater sources.

In general, the U.S. water treatment industry continued to show steady growth in 1990, reaching over $7 billion in total revenues, according to a recent Water Quality Association report (Clean Water Report, 1992a). The report also projects about $12 billion in total sales revenues in the year 1995.

According to another report (Clean Water Report, 1992b) the RO water treatment industry alone, incorporating desalination, wastewater treatment, commercial/industrial applications, and residential water treatment reached a $600 million level of sales in 1991. Thus, public concerns over drinking water, the tightening regulatory climate, and new technology development are all contributing to a new growth industry.

ECONOMICS OF TREATED WATER SUPPLY

One of the main concerns often raised about desalting and advanced treatment technologies is the cost to the consumer. Desalting costs have been declining steadily since the early 1960's. Modest cost reductions are expected to continue, but no major breakthroughs are expected.

The cost of membrane processes is expected to decrease in response to technical improvements, continued research, and industry competition. Dual-purpose plants (for power production and water treatment) can lead to cost reductions of 20 to 30 percent compared to the overall costs of separate power and desalting plants.

An interesting perspective of supply and treatment cost is a comparative analysis of current municipal treatment costs, bottled water, brackish water RO, seawater desalting, and new conventional supply costs. Figure 12 displays current estimated ranges of all these costs on a common "yardstick" scale of dollars per 1,000 gal and dollars per month for a typical family of four in the United States. Current costs summarized in figure 12 represent estimates/data from 1986 to 1992 (National Water Supply Improvement Association, 1992; Water Encyclopedia, 1990). One may note that the relative cost differences in the selected supply/treatment sectors are narrowing as the development of new supplies will be more expensive than existing supplies. There is also a pronounced overlap in costs to the consumer between bottled water and brackish water treatment. The costs of developing conventional water supplies will increase over a wide range as nearby sources are expended and environmental and legal complications arise. For example, in Florida and California, it is now more economical to desalinate and treat relatively small volumes of brackish groundwater than to import fresh water from inland areas. In some areas, seawater desalting is already cost competitive with the next increment of conventional, imported water supply.

As previously stated, the cost of desalting or advanced water treatment to the consumer will determine, in large part, the degree of compliance with drinking water standards. For small communities, monthly water bills average about $21, with many such systems having rates that are significantly higher. Figure 13 also shows the average costs or water rate differences between large and small community systems. The smaller communities, already faced with higher water costs, will experience even higher costs in complying with new drinking water standards. Figure 14 displays the percentage of median family income spent on various utilities since 1950. Note that water rates have consistently remained below 1 percent, significantly lower than telephone, electricity, and natural gas services (EPA, 1989b). As a basic resource, good quality water remains undervalued in the scheme of things, but there are clear indications that most Americans are willing to pay more (i.e., bottled water) for clean water.

ENVIRONMENTAL AND REGULATORY CONSIDERATIONS

There are currently six major Federal laws that provide the general framework for restoring and maintaining the water we drink and for protecting the environment from hazardous and toxic substances in water:

- Safe Drinking Water Act
- Clean Water Act
- Resource Conservation and Recovery Act
- Comprehensive Environmental Response, Compensation, and Liability Act (Super-fund)
- Toxic Substance Control Act
- Federal Insecticide, Fungicide, and Rodenticide Act.

In general, it is our societal response to these laws that is determining the nature and rate of technology progress and application in water treatment.

Before desalting and related treatment technologies can be expected to play a major role in meeting future water supply needs, some of these vital environmental laws and regulatory considerations must be addressed.

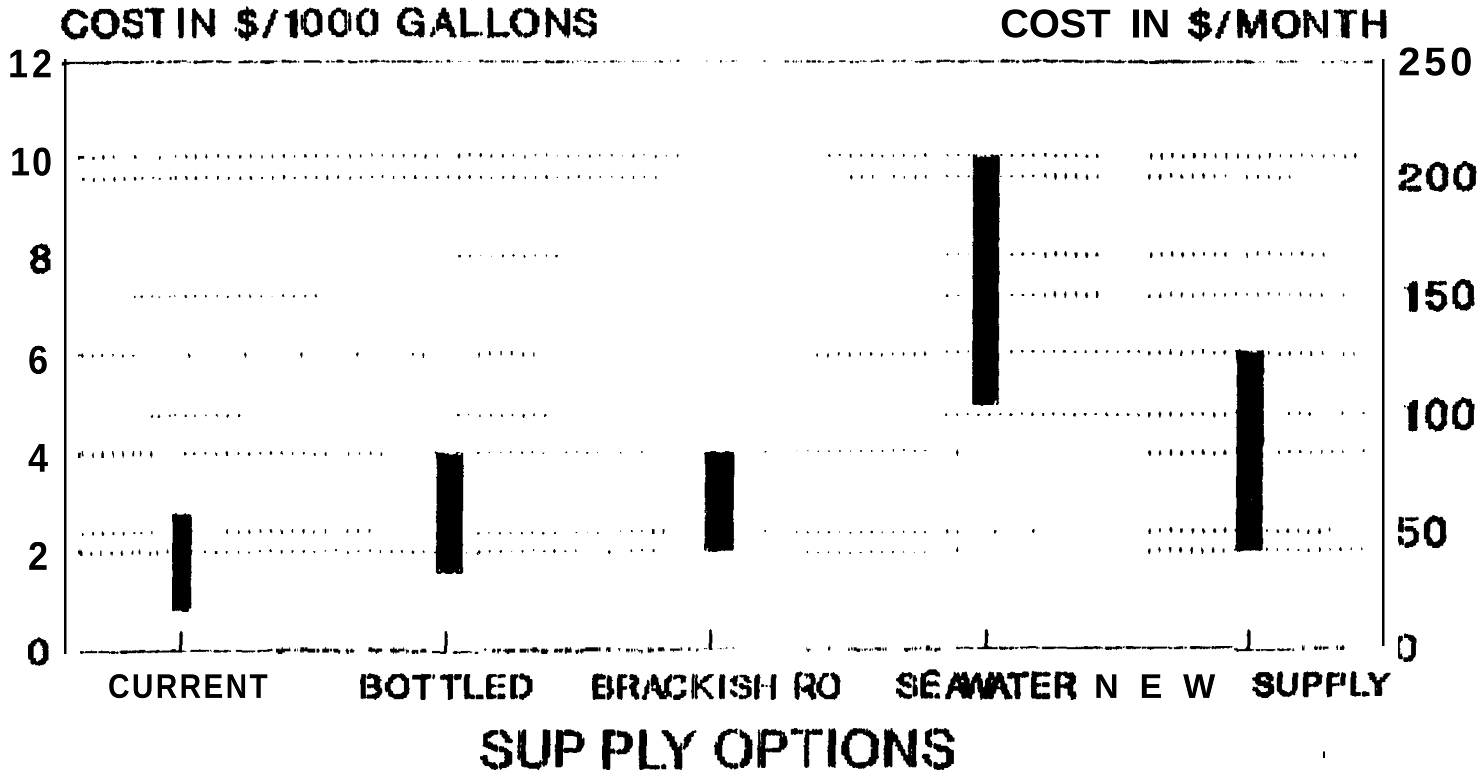
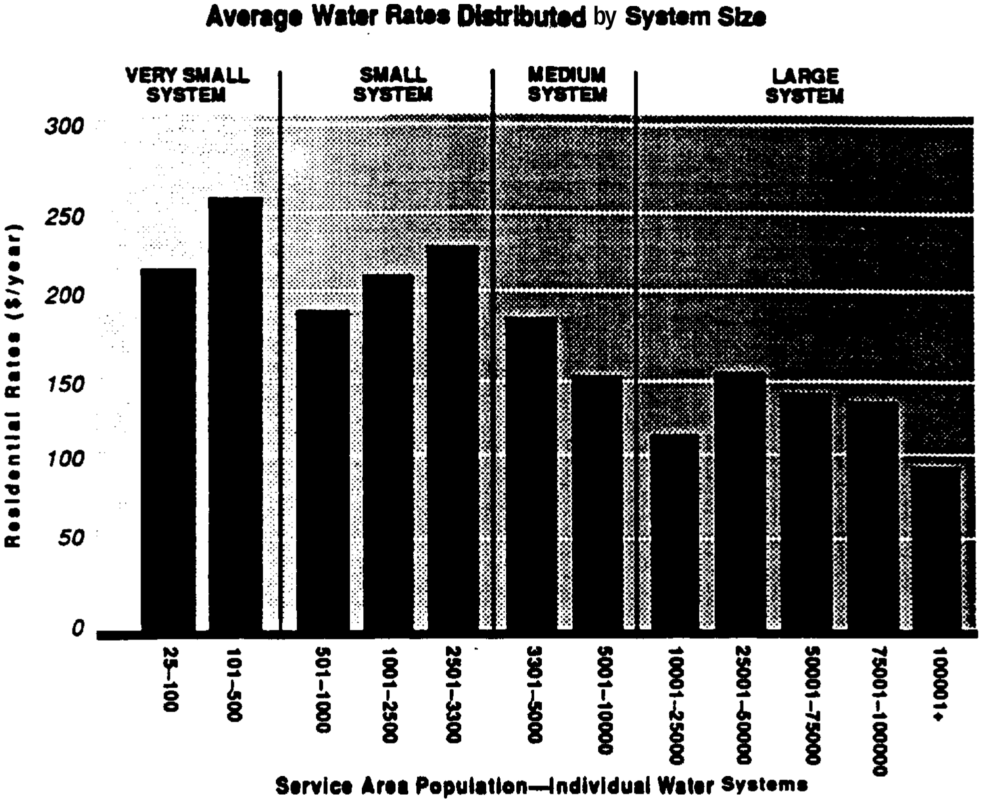


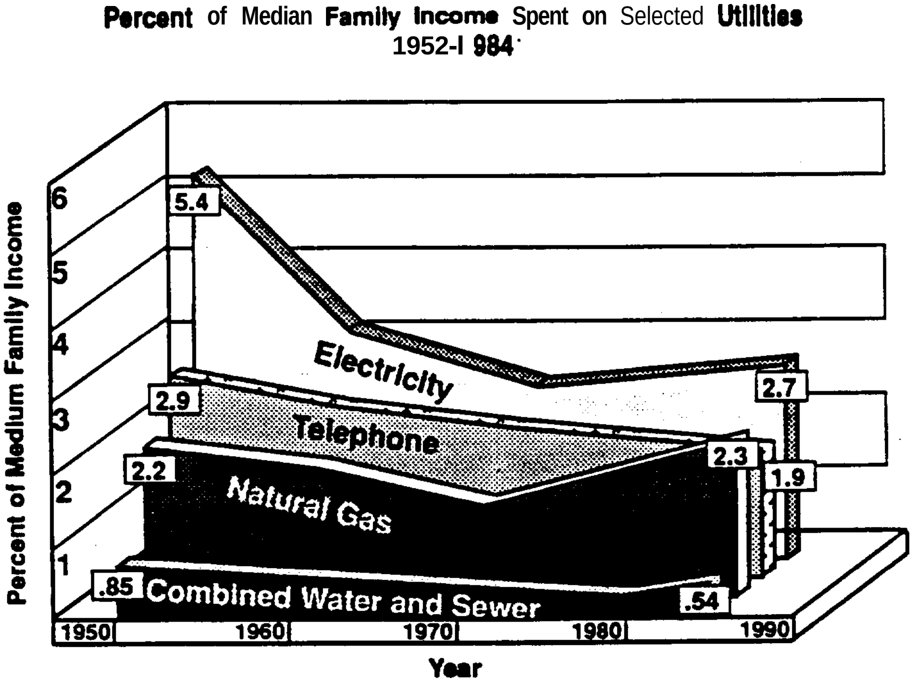
Figure 12. – Municipal water supply and treatment costs. Source: NWSIA, 1992; Water Encyclopedia, 1990.



Average Water Rates Distributed by System Size

Out of the population—
39% pays less than $100 annually
39% pays between $100-200 annually
3% pays more than $500 annually

Figure 13. -Average water rates distributed by system size. Source: EPA, 1989b.



Percent of Median Family Income Spent on Selected Utilities 1952-1984

Figure 14. - Percent of median family income spent on selected utilities. Source: EPA, 1989b.

One of the major environmental concerns over desalting treatment in the United States today is the disposal of waste brine from distillation or membrane separation processes. Figure 15 outlines the five ultimate options for final disposal of brine: the oceans or inland seas, land application, deep well injection, landfill, and evaporation ponds.

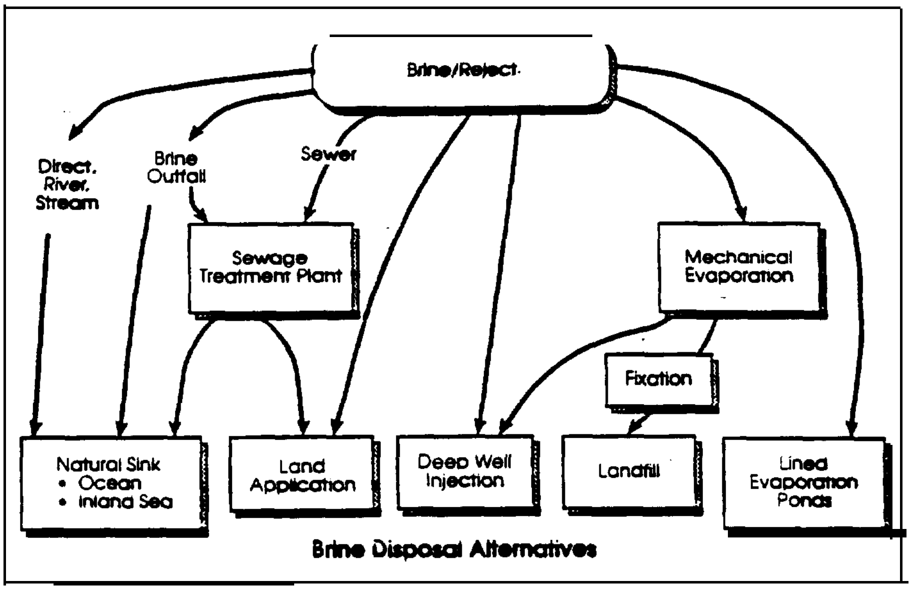


Figure 15. - Brine disposal alternatives.

All desalting processes produce a high saline waste product or concentrate, which varies in amount roughly from 10 to 50 percent of the process feed water. Distillation processes may also have moderately elevated temperatures in their waste effluent. Membrane processes can generate other waste substances such as acids, spent cleaning solutions, scaling inhibitors, antifouling agents, spent cartridge filters or spent membranes. In addition, pretreatment techniques used prior to desalting can produce chemical wastes similar to sludges produced by current municipal water treatment plants.

It is important to note that no major detrimental environmental damages have been identified with, or in any way constraining, water treatment technology. However, compliance with Federal/State environmental regulations and permitting processes, is starting to affect specific plant applications across the country.

In some States, desalting process wastes have been classified as industrial wastes and, for example, must meet all requirements for deep well disposal of industrial wastes. Some states are even banning deep well injection of industrial wastes. The long-term impacts of permitting and regulatory requirements are increasing disposal costs, restricting sites for desalting plants, and forcing construction delays for permits.

Brine and waste disposal is a significant concern in inland areas where there are risks of surface water and groundwater contamination. Disposal costs (using lined ponds or disposal wells) may range from 5 to 33 percent of the total cost of desalination. Costs per deep well injection alone can range from 10 cents to $1.15 per 1,000 gal (OTA, 1988) of desalted water. Lined pond disposal costs may vary widely with current technology, i.e., double-lined, fully monitored ponds, costing about $100,000 per acre. Using solar evaporation ponds to concentrate waste streams to a solid costs $1.15 to 1.85 per 1,000 gal of desalinated water (OTA, 1988). If distillation techniques are used to further concentrate brines, processing costs can be as high as $4 to $5 per 1,000 gal.

Current research work with brine disposal suggests that in the future it may be economical to generate power from solar salt gradient ponds or extract minerals from waste concentrates. The Bureau of Reclamation, with other university and industry partners, is examining the technical and economic feasibility of a $500,000 solar, salt-gradient pond pilot project near El Paso, Texas, to produce power and fresh water (University of Texas at El Paso, 1992).

Due to high levels of dilution available in most coastal or marine environments, brine disposal is generally less of an environmental/economic concern in coastal locations. However, regardless of potential salinity or temperature impacts, direct discharges of waste brines into estuaries or the ocean would require a NPDES (National Pollutant Discharge Elimination System) permit under the Clean Water Act and State permits as well. For example, in California, coastal management laws require permits for any development in defined coastal zones.

Depending on the composition of any waste products from desalting or pretreatment processes, if waste sludges are classified as hazardous by EPA, the new desalting plant may be subject to licensing, monitoring, and reporting requirements under the RCRA New regulations under the Safe Drinking Water Act (as amended) may directly affect the design and/or operation of desalting and water treatment processes. Product water delivered from RO systems may have to meet trihalomethane or disinfection by-product limitations. The new Surface Water Treatment Rules may also require additional post treatment of distillate product water.

Under the initial 1974 Safe Drinking Water Act, EPA was mandated to set and regulate standards for 21 substances. When the Act was amended in 1986, Congress directed EPA to set standards for an additional 83 contaminants by June of 1989, followed by 25 more every 3 years.

As of May 1992, EPA has actually set standards for 79 of the 83 contaminants identified in the 1986 Amendments, Public debate is continuing over the estimated costs to meet the growing multiplicity of standards versus reduced health risks to the public. The Act was scheduled for reauthorization this year, but Congress is not expected to review the issue until 1993. The latest debate is over the controversial rules for radon, lead, and THM's. Some THM's such as chloroform are suspected human carcinogens. Chlorine can combine with organic materials in raw water to form THM's during the treatment process. Research studies into alternative disinfection treatment processes have indicated that other carcinogenic DBP can also be found As a consequence, DBP regulations may be expected similar to THM regulations. Thus, the compounding of new contaminant standards for drinking water may also force research and development of new water treatment processes.

An interesting dichotomy is developing — safe drinking water standards are promoting the use of desalting and water treatment technologies while the RCRA, NPDES, and other permitting regulations are putting new constraints on plant sites and increasing process and disposal costs.

The major challenge today in addressing public fears of contaminated water supply is the shaping of a rational public policy to balance the costs, risks, and benefits of applying appropriate water treatment technology.

The continuing promulgation of more stringent drinking water standards and "leapfrogging" technical capability to detect and remove minute substances in water are fueling the debate. Often the lack of adequate or accurate technical information compounded by intensive media attention distort the key issues. One key issue: people are concerned about cancer. Drinking water standards for substances believed to be carcinogenic are generally placed at a level that would cause one-in-a-million cancer risk over a 70-year lifespan (EPA, 1984b).

EPA classifies known and/or suspected health problems associated with drinking contaminated drinking water into three broad categories: acute, chronic, and carcinogenic effects. Gastroenteritis is the most common acute illness, accompanied by headaches, vomiting, diarrhea, fatigue, and nausea. These symptoms usually only last for a few days after ingestion. Chronic health effects generally appear after longer incubation periods (months to years). The most commonly known chronic health effects include hepatitis and damage to the liver, kidneys, heart, and other body organ/systems. The most dangerous potential health effects involve contaminants that cause carcinogenic effects which are most difficult to detect and attribute to contaminated drinking water. Most information available on the chronic and carcinogenic health effects is based on the results of laboratory tests on animals (GAO, 1990).

One eminent cancer expert (Science, 1983; Cothern et al., 1986) estimates that 99.99 percent of all the carcinogens we ingest come from more traditional sources such as cigarettes, coffee, alcohol, chemicals found in fried or barbecued foods, and many vegetables and spices. Compared to the health risks of water supply, the equivalent risks of death from other activities in life may provide a better perspective. See table 6 (EPA, 1984b).

Today we have the necessary treatment technology to implement an ambitious water quality improvement program across the nation. However, the multibillion costs are staggering and the relative public health benefits questionable. Hopefully, the general public, the regulators, and water purveyors can be better informed to make the tough choices ahead. Hence future needs for water treatment will not be determined by technologists with sophisticated computer models. It is in the arena of public policy where the harsh reality of consumer costs, risks, and benefits will determine the rate and extent of technology applications.

Table 6. – Risks that increase the chance of death by one part in one million.

Activitv	Cause of death
Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 1/2 liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black Lung disease
Living 2 days in New York or Boston	Air pollution
Traveling 300 miles by car	Accident
Flying 1,000 miles by jet	Accident
Flying 6,000 miles by jet	Cancer caused by cosmic radiation
Living 2 months in Denver on vacation from New York	Cancer caused by cosmic radiation
One chest x-ray at the hospital	Cancer caused by radiation
Living 2 months with a cigarette smoker	Cancer, heart disease
Eating 40 tablespoons of peanut butter	Liver cancer caused by Aflatoxin B
Drinking thirty 12-oz cans of diet soda	Cancer caused by saccharin
Eating 100 charcoal-broiled steaks	Cancer from benzopyrene

RESEARCH NEEDS FOR DESALTING AND WATER TREATMENT

This survey has attempted to identify the general needs for desalting and water treatment from a water quality, water supply, economic, and regulatory basis. Although the needs are great in terms of protecting and preserving a clean water supply, basic resources (funding) to support needed technology research are lacking.

Fundamental governmental program priorities can be extracted from the FY92 Federal Budget of $1.5 trillion. Only about 15 percent or $220 billion is available for "discretionary domestic funding." Approximately $31 billion of "domestic funding' is allocated to nondefense, research and development (R&D) (Environmental Science and Technology, 1990). A breakdown of this R&D budget allocated about $250 million to the DO1 with about $2 million of that amount specifically dedicated to desalting and water treatment research in Reclamation. Thus, current Federal funding for research and development of desalting technology in Reclamation amounts to less than 1 percent of DOI's R&D budget. Proposed legislation before the Congress, Senate Bill (S.481) would increase Federal spending for desalting and water treatment R&D to a total of $5 to $10 million per year.

A recent intergovernmental conference of Federal agencies provides an interesting cross section of government-sponsored desalting research outside of the Department of the Interior and Reclamation (1990). The following is a brief summary of Federal agency research activity in membrane technology research and development:

> *Department of Defense, U.S. Army Fort Belvoir RD&E Center.* — Operational improvements for ROWPU's, advanced water treatment, individual water purification devices, membrane cleaning.
>
> *National Institute of Standards and Technology.* — Advanced thin-film membranes, UF, ion-exchange membranes, thin-film coatings.

EPA, Office of Research and Development. — Best Available Technology (BAT) studies of membrane technology including DBP removal, NF pilot plant, UF treatment with package plants, and development of a membrane research facility. Current rate of R&D expenditure is estimated at $100,000 to $200,000 per year.

Department of Defense, U.S. Navy (Annapolis and Navy Civil Engineering Laboratory). — ROWPU testing and evaluation, RO energy recovery, studies of RO shipboard units and membrane distillation.

Department of Energy, Office of Uranium Enrichment. — Investigations of inorganic membrane technology with potential applications in U.S. industry, such as wastewater cleanup, gas separation, water/chemical purification, juice clarification, biotechnology, gas cleanup, and food processing.

Centers for Disease Control. — Health effects of water supply.

National Aeronautics and Space Administration. — Membrane development for closed systems.

Outside of the Federal establishment, current estimates of U.S. industry investment in desalting research and technology development range from $5 million to $10 million per year. Under a new consortium of Federal, State, and local agencies, the NWRI (National Water Research Institute) in Fountain Valley, California, is funding water treatment research with specific studies in membrane systems.

While efforts are being made to share information on widely diverse desalting and water treatment research activities, there is no formal coordination or linkage between public and private sectors to focus research on national needs. The NWSIA (National Water Supply and Improvement Association) has provided a dedicated organization of manufacturers, water users, Federal, and State agencies to serve as a general "clearinghouse" of information and support for the advancement of desalting, recycling, and water science technologies.

Effective use of limited research funding will require setting early program priorities. The emerging potential of membrane processes, for example, in softening treatment, disinfection byproduct removal, turbidity removal, and biological control merits research support. Low pressure RO and NF membrane processes look attractive for small treatment system application. Continued demonstrations of the economics and performance of membrane process treatment should have high priority, particularly for small communities.

Another critical area of research relates to addressing the environmental and regulatory concerns of brine and waste disposal. Energy requirements for large-scale desalting plants will focus new attention on dual-purpose plants, cogeneration, and solar-powered options for the future.

Many other specific R&D needs for desalting and water treatment for upgrading substantial water supplies are documented in a 1991 Reclamation Workshop Seminar Report (Reclamation, 19911.

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APPENDIX

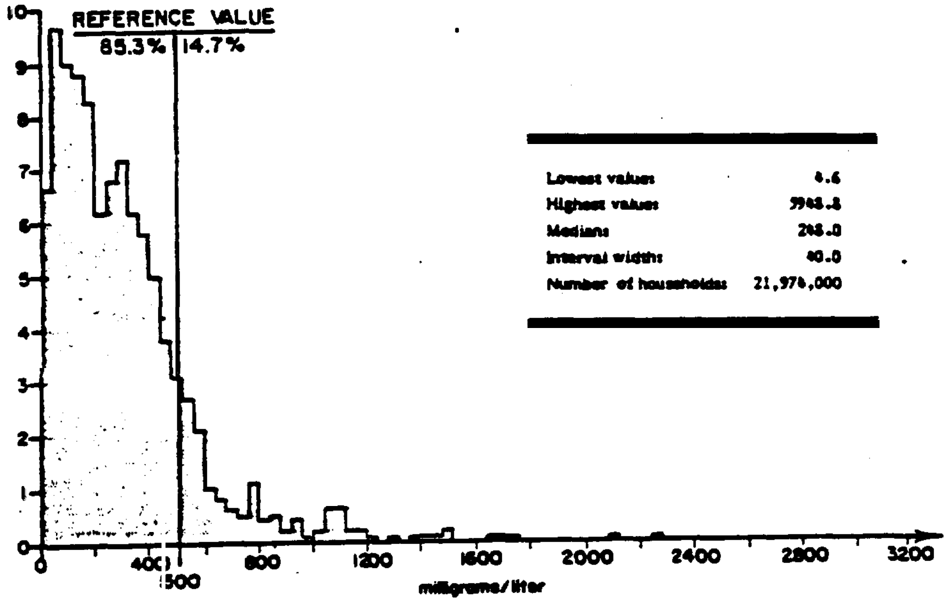

Figure A-l. – Estimated TDS in U.S. rural **household** supplies.

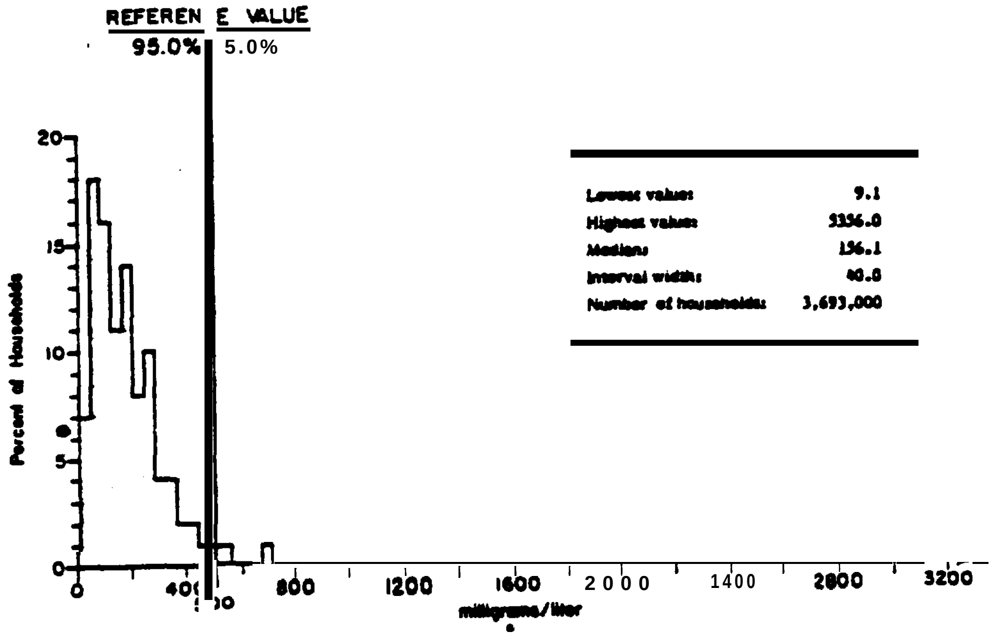

Figure A-2. – Regional variiion in estimated TDS in the Northeast.

Source: EPA, 1984 (NSA Report).

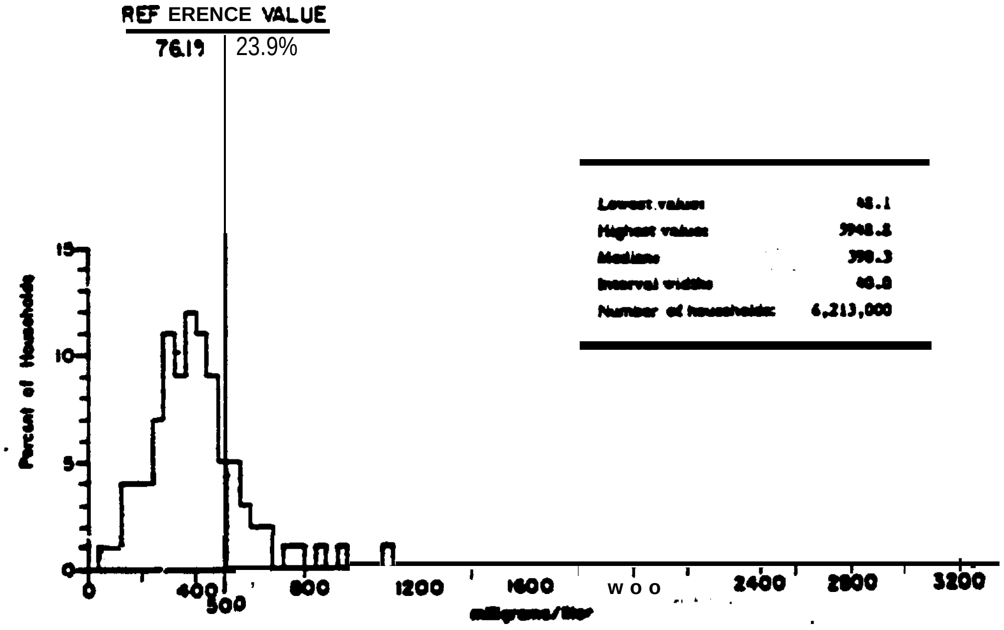

Figure A-3. – Regional variation in estimated TDS in North-Central United States.

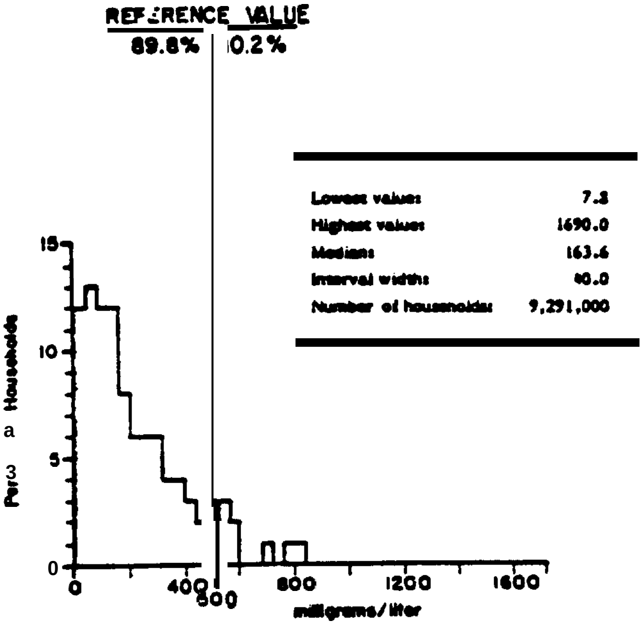

Figure A-4. – Regional variation in estimated TDS in the South.

Source: EPA, 1984 (NSA Report).

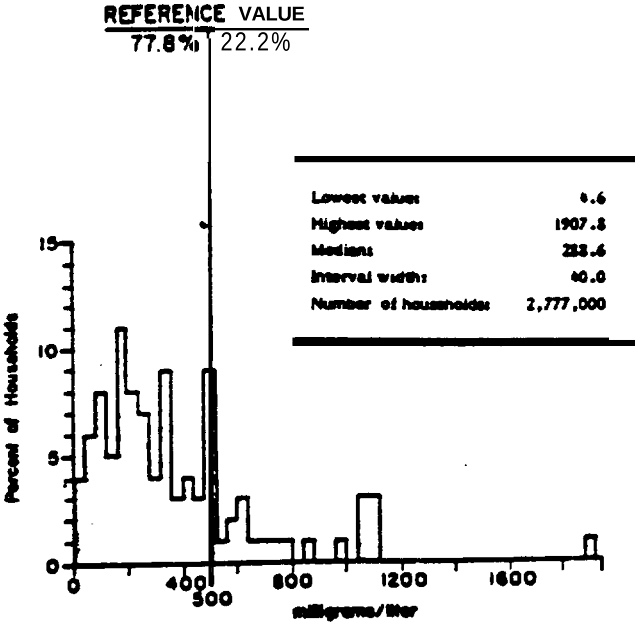

Figure A-5. - Regional variation in estimated TDS in the West.
Source: EPA, **1984** (NSA Report).

Table A.l. – NSA reference values for constituents measured in NSA survey.
Source: EPA, 1984 (NSA Report).

constituent	NSA Reference Value (milligrams per liter of water, unless otherwise noted)	Reference Value	Purpose or Effect of Constituent
Total coliform bacteria	Not more than one bacterium per 100 milliliters of water	MCL(P)	Indicator of infectious disease potential
Fecal coliform bacteria	Complete absence of bacteria in a 100-milliliter sample	EPA	Indicator of infectious disease potential
Fecal streptococci	None		Indicator of possible infectious disease potential
Fecal coliform/ fecal streptococcus ratio	None		Indicator of human versus animal contamination
Standard plate count	500 colony-forming units per one milliliter of water	NRC	General indicator of bacteria level
Turbidity	None		Aesthetic, health
Color	15 color units	MCL(S)	Aesthetic
Temperature	None		Aesthetic
Specific conductance (normalized at 25° C)	None		Used for estimating total dissolved solids
Total dissolved solids (as derived from specific conductance)	500	MCL(S)	Economic, aesthetic

Table A.1. - NSA reference values for constituents measured in NSA survey — Continued.

Constituent	NSA Reference Value (milligrams per liter of water, unless otherwise noted)	*Basis for Reference Value	Purpose or Effect of Constituent
Hardness	None		Economic
Calcium	None		Aesthetic, economic
Magnesium	125	Various	Aesthetic, economic, health
Nitrate-N	10	MCL(P)	Health
Sulfates	250	MCL(S)	Aesthetic, health
Iron	0.3	MCL(S)	Aesthetic
Manganese	0.05	MCL(S)	Economic, aesthetic
Sodium	More stringent: 20 Less stringent: 100	NRC	Health
Lead	0.05	MCL(P)	Health
Arsenic	0.05	MCL(P)	Health
Selenium	0.01	MCL(P)	Health
Fluoride	1.4	MCL(P)	Health
Cadmium	0.01	MCL(P)	Health
Mercury	0.002	MU(P)	Health

Table A.1. – NSA reference values for constituents measured in NSA survey – Continued.

Constituent	NSA Reference Value (milligrams Per liter of water, unless otherwise noted)	*Basis for Reference Value	purpose or Effect of Constituent
Chromium	0.05	MCL(P)	Health
Barium	1	MCL(P)	Health
Silver	0.05	MCL(P)	Health
Endrin	0.0002	MCL(P)	Health
Lindane	0.004	MCL(P)	Health
Methoxychlor	0.1	MCL(P)	Health
Toxaphene	0.005	MCL(P)	Health
2, 4-D	0.1	MCL(P)	Health
2, 4, 5-TP	0.01	MCL(P)	Health
Gross alpha radioactivity	See Figure V-28	MCL(P)	Health
Gross beta radioactivity	50 pCi	MCL(P)	Health
Radium 226 Radium 228 Other radionuclides (uranium, strontiun-89, strontiun-90, cesium-134, tritiun, iodine-131)	These constituents were not measured frequently enough to provide independent national estimates (See text for details about NSA reference values.)		Health

*See text far details MCL(P) indicates interim primary Maximum Contaminant Level, MCL(S) indicates secondary Maximum Contaminant Level; EPA stands for US Environmental Protection Agency, NRC for the National Research Council, and "Various" fur several sources which are described in the text.

Table A.2. - Overview of water treatment technologies.
Source: EPA, 1990.

Treatment Requirements Under the New Regulations	Technological Options to Meet Regulatory Requirements	Stage of Acceptability	Size Suitability	Comments
Filtration of **surface** water supplii **to control turbidity** end **microbial contamination**				
	Conventional filtration	Established	All	Most common: **adaptable** for adding other **processes**
	Direct **filtration**	**Established**	All	**Lower cost alternative to conventional** filtration
	Slow sand filtration	**Established**	**Especially** Smell. but all **sizes**	**Operationally** simple: low cost but **requires large land areas**
	Package plant filtrabon	**Established**	**Mostly** smell	**Compact; variety** of process **combinations available**
	Diatomaceous earth filtrabon	**Established**	**Mostly small**	**Limited** applicability; **potentially** expensive for small **systems**
	Membrane filtration	**Emerging**	Mostly small	**Experimental,** expensive
	Cartridge filtration	**Emerging**	Small	**Experimental, expensive**
Disinfection of all **public** water **supplies**				
	Chlorine	**Established**	All	**Most widely used** method: concerns about health effects Of by-products
	Chlorine dioxide	**Established**	All	**Relatively** new to the United States: concerns about **inorganic by-products**
	Monochloramine	Established	All	Secondary **disinfectant only;** some **by-product** concerns
	Ozone	**Established**	All	**Very effective** end **requires** a **secondary disinfectant**
	Ultraviolet radiation	Established	All	Simple, no **established** harmful by-products **and** requires secondary **disinfectant**
	Advanced oxidation (ozone plus H_2O_2 end **ozone plus ultraviolet radiation)**	**Emerging**	All	Not much **information** concerning disinfecbon aspects of **this** process
Organic contamination control, **including 50 specific compounds**				
	Granular activated carbon	BAT	All	Highly effective; **potential waste disposal issues**
	Packed column **aeration**	BAT	All	**Highly effective** for **volatile** compounds; **potential** air emissions Issues
	Powdered **activated carbon**	**Established**	Large	Requires **conventional** treatment **process** tram for **application**
	Diffused aeration	**Established**	All	**Variable removal effectiveness**
	Multiple tray **aeration**	Established	All	**Variable** removal **effectiveness**
	Oxidation	**Experimental**	All	By-products concerns
	Reverse osmosis	**Emerging**	Smell to medium	**Variable** removal **effectiveness; expensive**
	Mechanical aeration	**Experimental**	All	**Mostly for wastewater treatment;** high energy **requirements, easy** to **operate**
	Catenary grid	**Experimental**	All	Perfomlance data are scarce; potential air **emissions** issues
	Higee aeration	**Experimental**	Small	Compact, high energy **requirements; potential** air emissions **issues**

Table A.2. – Overview of water treatment technologies – Continued.

Treatment Requirements Under the New Regulations	Technological Options to Meet Regulatory Requirements	Stage of Acceptability	Size Suitability	Comments
	Resins	Experimental	Small	Data scarce
	Ultrafiltration	Emerging	Small	Primarily for turbidity; data for organics removal are scarce
Inorganic contamination control, including 36 specific inorganic contaminants, and 5 radioactive contaminants	Reverse osmosis	Established	Small to medium	Highly effective; expensive: potential waste disposal issues
	Ion exchange	Established	Small to medium	Highly effective; expensive; potential waste disposal issues
	Activated alumina	Established	Small	Highly effective; expensive: potential waste disposal issues
	Granular activated carbon	Experimental	Small	Experimental for radionuclide removal; potential waste disposal issues
Corrosion control[9]	pH control	Established	All	Potential to conflict with other treatments
	Corrosion inhibitors	Established	All	Variable effectiveness depending on type of inhibitor

Table A.3. - FRDS legend and printout for EPA Region VIII (Colorado, Montana, North Dakota, South Dakota, Wyoming). Source: Reclamation/EPA, 1992.

LEGEND FOR-WATER QUALITY VIOLATIONS
REGION VIII

PWS ID. TYPE	EPA'S IDENTIFICATION FOR THE STATE AND PUBLIC WATER SYSTEM.
SYSTEM NAME	THE NAME OF THE PUBLIC WATER SYSTEM.
ADDRESS	ADDRESS OR POST OFFICE BOX.
CITY	TOWN OR CITY.
ZIP	ZIP CODE OF THE PUBLIC WATER SYSTEM.
POPULATION SERVED	NUMBER OF PERSONS SERVED USING THE PUBLIC WATER SYSTEM.
PRIM SRC	THE PUBLIC WATER SYSTEMS SOURCE OF THE WATER. G = GROUNDWATER, NON-PURCHASED P = SURFACE, PURCHASED S = SURFACE, NON-PURCHASED W = GROUNDWATER, PURCHASED
SAMPLE ID	THE VIOLATION NUMBER ASSIGNED TO THE WATER SAMPLE.
CNTAM CODE	VIOLATION CONTAMINANT.
MAXIMUM CONTAMINANT LEVEL	VIOLATION ANALYSIS RESULT.
CONC	THE CONCENTRATION OF THE CONTAMINANT.
RESULT	THE LEVEL OF THE CONTAMINANT'S ANALYSIS.
DATE	THE VIOLATION COMP-PERIOD BEGIN DATE.

WATER QUALITY VIOLATIONS FOR THE STATE OF COLORADO

PWS ID. TYPE	SYSTEM NAME	ADDRESS	CITY	ZIP	POPULATION SERVED	PRIM SRC	SAMPLE D	CNTAM NAME	CNTAM CWDE	MAXIMUM CONTAMINANT LEVEL	WNC.	RESULT	DATE
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	8993510	TURBDITY	loo	0.50	MU	2	04/01/89
CO01 19467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	8663174	TURBDITY	100	0.50	NTU	I . w	08/01/86
CO0126188	CRESTED BUTTE, TOWN OF	UNKNOWN	CRESTED BUTTE	CO 81224	1200	S	9003704	TURBDITY	loo	0.50	NTU	0	08/01/90
cool 19467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RO.	VAIL	CO 81657	200	S	8993511	TURBDITY	loo	0.50	Nlu	0	05/01/89
CO0119467	LAKE CREEK MEADOWS WD /SEND	846 FOREST RD.	VAIL	CO 81657	200	S	8993512	TURBDITY	100	0.50	NTU	0	08/01/89
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	8663171	TURBDITY	100	0.50	NTU	8	05/01/86
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9003702	TURSDITY	100	0.50	NTU	0	05/01/90
CO0160100	CRIPPLE CREEK, CITY OF	UNKNOWN	CRIPPLE CREEK	CO 80813	750	S	8663173	TURBDITY	loo	0.50	Nlu	1.98	05/01/86
CO0160100	CRIPPLE CREEK, CITY OF	UNKNOW	CRIPPLE CREEK	CO 80813	750	S	8662033	TURBDITY	loo	0.50	NTU	10	01/01/86
CO0160100	CRIPPLE CREEK, CITY OF	UNKNOWN	CRIPPLE CREEK	CO 80813	750	S	8664249	TURSDITY	100	0.50	NTU	(1.4	07/01/86
CO0160100	CRIPPLE CREEK, CITY OF	UNKNOWN	CRIPPLE CREEK	CO 80813	750	S	8663175	TURBDITY	100	0.50	NTU	10.1	08/01/86
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	8994500	TURBDITY	100	0.50	MU	0	07/01/89
CO0160100	CRIPPLE CREEK, CITY OF	UNKNOWN	CRIPPLE CREEK	CO 80813	750	S	8663170	TURBDITY	100	0.50	NTU	2.2	04/01/86
CO0126188	CRESTED BUTTE TOW OF	UNKNOWN	CRESTED BUTTE	CO 81224	1200	S	8993513	TURSDITY	100	0.50	NTU	2	05/01/89
CO0142900	MONTEZUMA WATER COMPANY	209 CENTRAL STREET	DOLORES	CO 81323	7000	S	8661091	TURSDITY	100	0.50	NTU	1.1	10/01/85
CO0160700	VICTOR, CITY OF	500 VICTOR AVE	VICTOR	CO 80860	400	S	8993515	TURBDITY	100	0.50	NTU	0.00001	08/01/89
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	8994501	TURBDITY	100	0.50	NTU	0.02	08/01/89
CO0157800	TELLURIDE, TOW OF	UNKNOWN	TELLURIDE	CO 81435	1200	S	9004241	TURSDITY	100	0.50	NTU	0	09/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEN)	846 FOREST RD.	VAIL	CO 81657	200	S	9003703	TURBDITY	100	0.50	NTU	0	08/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9004237	TURBDITY	100	0.50	NTU	0	09/01/90
CO0157800	TELLLRIDE, TOW OF	UNKNOW	TELLURIDE	CO 81435	1200	S	8663172	TURBDITY	100	0.50	NTU	1.25	05/01/86
CO0104500	PAGOSA SPRINGS, TOW OF	UNKNOWN	PAGOSA SPRINGS	CO 81147	1400	S	8664251	TURBDITY	100	0.50	NTU	2	08/01/86
CO0104500	PAGOSA SPRINGS TOW OF	UNKNOWN	PAGOSA SPRINGS	CO 81147	1400	S	8664250	TURBDITY	100	0.50	NTU	3.08	05/01/86
CO0107538	NEDERLAND, TOW OF	ATTN: BRYAN HOOKER	NEDERLAND	CO 80466	1099	S	8994498	TURSDITY	100	0.50	NTU	0.2	08/01/89
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9230029	TURBDITY	100	0 50	NTU	2 5	08/01/92
CO01 19467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9230028	TURBDITY	loo	0.50	NTU	1.6	05/01/92
cool 19467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9004239	TURBDITY	100	0.50	NTU	0	08/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9210016	TURBDITY	100	0.50	NTU	1.5	10/01/91
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9004238	TURBDITY	100	0.50	NTU	0	07/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9004240	TURBDITY	100	0.50	NTU	0	09/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	8993509	TURSDITY	100	0.50	NTU	0	08/01/89
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9004235	TURBDITY	100	0.50	NTU	0	07/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9003701	TURBDITY	100	0.50	NTU	0	08/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9004236	TURBDITY	100	0.50	NTU	0	08/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FOREST RD.	VAIL	CO 81657	200	S	9003700	TURSDITY	loo	0.50	NTU	0	05/01/90
CO0119467	LAKE CREEK MEADOWS WD /BEND	846 FORESTRD.	VAIL	CO 81657	200	S	8994499	TURBDITY	100	0.50	NTU	0.00001	07/01/89
CO0102800	TOW 'N' COUNTRY M.H. LWGE	7519 w. HWY 160	ALAMOSA	CO 81101	261	G	8941016	ARSENIC	1005	0.05	MG/L	0.067	01/20/83
CO0101025	BRIGHTON, CITY OF	22 S. 4 AVE.	BRIGHTON	CO 80601	14000	G	8941017	NITRATE-NITRITE	1038	10.00	MG/L	11.5	08/21/86
CO0109011	KIT CARSON. TOW OF	301 MAIN STREET	KIT CARSON	CO 80825	264	G	8941018	NITRATE-NITRITE	1038	10.00	M M	11	03/01/85
CO0162466	LA SALLE TOW OF	119 MAIN STREET	LA SALLE	CO 80645	1932	P	8941027	NITRATE-NITRITE	1038	10.00	MG/L	24	06/10/86
CO0162833	WATTENBURG IMPROVEMENT ASSN	1826 MARY AVENUE	FT. LUPTON	CO 80621	258	G	8941031	NITRATE-NITRITE	1038	10.00	MG/L	10.4	09/01/86
CO0138045	STERLING, CITY OF	CENTENNIAL SQUARE	STWLING	CO 80751	10300	G	8941021	NITRATE-NITRITE	1038	10.00	MG/L	11	
CO0162610	PIERCE, TOWN OF	240 MAIN STREET	PIERCE	CO 80650	950	P	8941028	NITRATE-NITRITE	1038	10.00	MM	12	01/03/86
CO0162310	GILCREST, TOW OF	PO BOX 128	GILCREST	CO 80623	1150	G	8941025	NITRATE-NITRITE	1038	10.00	MG/L	23	02/10/84
CO0162359	HUDSON, TOW OF	UNKNOW	HUDSON	CO 80642	805	G	8941026.	NITRATE-NITRITE	lo32	10.00	MG/L	12	01/07/84
CO0162485	LOCHSUIE-BEEBE DRAW W&SD	1407 CHASE STREET	LAKEWOOD	CO 80214	1000	G	9236001	NITRATE	1040	10.00	MG/L	12	01/01/89
CO0102291	FT.. LUPTON. . CITY OF	UNKNOWN	FT. LUPTON	CO 80621	5150	G	9236002	NITRATE	1040	10.00	MG/L	11	01/01/89
CO0121275	FOUNTAIN, CITY OF	116 S MAIN ST	FOUNTAIN	CO 80817	9160	S	8941036	SELENIUM	lo45	0.05	MG/L	0 . 0 %	10/26/84
CO0151250	JOSEPH WC	2107 E CFR	PUEBLO	CO 81006	300	G	8941050	SELENIUM	1045	0.05	MG/L	0.053	07/10/86
CO0128600	NAVAJO WESTERN WD	1047 CHEROKEE DR	WALSENBURG	CO 81089	200	G	8941040	SELENIUM	1045	0.05	MG/L	0.023	09/30/85
COO137015	LIMON, TOW OF	UNKNOW	LIMON	CO 80828	2000	G	8941046	SELENIUM	1045	0.05	MG/L	0.024	08/19/83
CO0109011	KIT CARSON, TOW OF	301 MAIN STREET	KIT CARSON	CO 80825	264	G	8841034	SELENIUM	1045	0.05	MG/L	0.025	03/01/85
cool 13100	CROWLEY COUNTY WATER ASSOC.	UNKNOWN	ORDWAY	CO 81063	1710	G	8941035	SELENIUM	1045	0.05	MG/L	0.055	04/06/86
CO0101025	BRIGHTON, CITY OF	22 S. 4 AVE.	BRIGHTON	CO 80601	14000	G	8941032	SELENIUM	1045	0.05	MG/L	0.03	01/13/84
CO0121900	WIDEFIELD HOMES WC	3 WIDEFIELD BLVD	WIDEFIELD	CO 80911	12300	P	8941937	SELENIUM	lo45	0.05	MG/L	0.023	03/13/86
CO0123185	COTTONWOOD SWINGS MHP	6695 C.R. 214 - % TOM TRPLA	NEW CASTLE	CO 81647	400	G	8941038	SELENIUM	1045	0.05	MG/L	0.013	04/11/85
CO0151150	BOONE, TOW OF	UNKNOW	SCONE	CO 81025	487	G	8941049	SELENIUM	lo43	0.05	MG/L	0.021	09/07/85
CO0131400	EADS, TOW OF	110 W. 13TH ST.	E M S	CO 81036	900	G	8941042	SELENIUM	1045	0.05	MG/L	0.023	04/09/82
CO0145210	FOWLER, TOW OF	114 E CRANSTON AVE	FOWLER	CO 81039	1300	G	8941047	SELENIUM	1045	0.05	MG/L	0.039	06/20/81
CO0145420	LA JUNTA, CITY OF	PO BOX 489	LA JUNTA	CO 81050	8500	G	8941048	SELENIUM	1045	0.05	MG/L	0.013	04/20/84
CO0113200	CROWLEY COUNTY WATER SYSTEM	6TH & MAIN % GARY KIDD	ORDWAY	CO 81063	3366	G	8941053	SELENIUM	1045	0.05	MG/L	0.036	09/18/84
CO0150600	HOLLY, TOW OF	UNKNOW	HOLLY	CO 81047	970	G	8941012	COMBINED RADIUM	4010	20.00	pCI/L	5.4	12/14/79
CO0145060	BENTS FORT WC	UNKNOWN	LA JUNTA	CO 81050	1500	G	8941003	COMBINED RADIUM	4010	20.00	pCI/L	6.1	02/29/84
CO0145090	CHERAW, TOW OF	UNKNOWN	CHERAW	CO 81030	200	G	8941004	RADIUM-226	4020	2 0 . m	pCI/L	8.2	02/03/85
CO0145690	SOUTH SWINK WC	UNKNOWN	SWINK	CO 81077	610	G	Se41011	RADIUM-228	4020	20.00	pCI/L	3.2	04/21/79

WATER QUALITY VIOLATIONS FOR THE STATE OF MONTANA

Pws IO. TYPE	SYSETM NAME	ADDRESS	CITY	ZIP	POPULATION SERVED	PRM SRC	SAMPLE ID	CNTAM NAME	CNTAM CODE	MAXIMUM CONTAMINANT LEVEL	CONC.	RESULT	DATE
MT0000199	DENTON TOWN OF	UNKNOWN	DENTON	MT 59430	350	G	8773001	NITRATE	1040	10.00	MG/L	0.12	04/16/87
MT0000269	LAMBERT SEWER & WATER ASSN	UNKNOWN	LAMBERT	MT59243	250	G	8773002	FLUORIDE	1025	4.00	MG/L	4.0	04/24/87
MT0000458	ASHLAND WATER AND SEWER DIS	UNKNOWN	ASHLAND	MT 59003	300	G	8663002	FLUORIDE	1025	4.00	MG/L	2.7	07/14/86

WATER QUALITY VIOLATIONS FOR THE STATE OF NORTH DAKOTA

PWS ID. TYPE	SYSETM NAME	ADDRESS	CITY	ZIP AND PHONE #	POPULATION SERVED	PRIM SRC	SAMPLE ID	CNTAM NAME	CNTAM CODE	MAXIMUM CONTAMINANT LEVEL	CONC.	RESULT	DATE
ND2810954	COAL CREEK STATION	UNKNOWN	UNDERWOOD	ND 58576 (701) 442-3211	486	S	8800050	ARSENIC	1005	0.05	MG/L	0.06	07/01/87
ND1800410	GRAND FORKS, CITY OF	UNKNOWN	GRAND FORKS	N J 58201 (701) 775-8103	49425	S	8900058	TThm	2950	0.01	MG/L	0.11	10/01/88
ND1800410	GRAND FORKS, CITY OF	UNKNOWN	GRAND FORKS	ND 56201 (701) 775-8103	49425	S	8700207	TThm	2950	0.01	MG/L	0.11	04/01/87
ND1800410	GRAND FORKS, CITY OF	UNKNOWN	GRAND FORKS	ND 58201 (701) 775-8103	49425	S	8800049	TThm	2950	0.01	MG/L	0.12	10/01/87
ND1800410	GRAND FORKS, CITY OF	UNKNOWN	GRAND FORKS	ND 56201 (701) 775-8103	49425	S	8700306	TThm	2950	0.01	MG/L	0.12	07/01/87
ND4500242	DICKINSON, CITY OF	UNKNOWN	DICKINSON	ND 58602 (701) 225-6765	16097	P	8700060	TThm	2950	0.01	MG/L	0.13	10/01/86
ND1800410	GRAND FORKS, CITY OF	UNKNOWN	GRAND FORKS	ND 58201 (701) 775-8103	49425	S	8800318	TThm	2950	0.01	MG/L	0.13	09/01/88
ND1800410	GRAND FORKS, CITY OF	UNKNOWN	GRAND FORKS	ND 58201 (701) 775-8103	49425	S	8800097	TThm	2950	0.01	MG/L	0.13	01/01/88
ND4500242	DICKINSON, UN OF	UNKNOWN	DICKINSON	N D 58602 (701) 225-6765	16097	P	8600206	TThm	2950	0.01	MG/L	0.14	04/01/86
ND4500242	DICKINSON, UN OF	UNKNOWN	DICKINSON	ND 58602 (701) 225-6765	16097	P	8600106	TThm	2950	0.01	MG/L	0.14	01/01/86
ND4500242	DICKINSON, CITY OF	UNKNOWN	DICKINSON	N J 58602 (701) 225-6765	16097	P	8600078	TThm	2950	0.01	MG/L	0.14	10/01/85
ND4500242	DICKINSON, CITY OF	UNKNOWN	DICKJNSON	ND 58602 (701) 225-6765	16097	P	8800096	TThm	2950	0.01	MG/L	0.16	01/01/88
ND4500242	DICKINSON. CITY OF	UNKNOWN	DICKINSON	NJ 58602 (701) 225-6765	16027	P	8800317	TThm	2950	0.01	MG/L	0.18	09/01/88
ND4500242	DICKINSON, CITY OF	UNKNOWN	DICKINSON	ND 58602 (701) 225-6765	16097	P	8700305	TThm	2950	0.01	MG/L	0.18	07/01/87
ND4500242	DICKINSON, UN OF	UNKNOWN	DICKINSON	ND 58602 (701) 225-6765	16097	P	8700106	TThm	2950	0.01	MG/L	0.18	01/01/87
ND4500242	DICKINSON. UN OF	UNKNOWN	DICKINSON	ND 58602 (701) 225-6765	16097	P	8600300	TThm	2950	0.01	MG/L	0.16	07/01/86
ND4500242	DICKINSON, UN OF	UNKNOWN	DICKINSON	ND 58602 (701) 225-6765	16097	P	8800046	TThm	2950	0.01	MG/L	0.17	10/01/87
ND4500242	DICKINSON. UN OF	UNKNOWN	DICKINSON	ND 58602 (701) 225-6765	16097	P	8700206	TThm	2950	0.01	MG/L	0.17	04/01/87
ND2810954	COAL CREEK STATION	UNKNOWN	UNDERWOOD	ND 58576 (701) 442-3211	486	S	8800051	TURBIDITY	100	0.50	NTU	2	12/01/87
ND0100812	REEDER, CITY OF	UNKNOWN	REEDER	ND 58649 (701) 567-2302	252	G	8800053	FLUORIDE	1025	4.00	MG/L	4.2	11/01/87
ND4500891	SOUTH HEART, CITY OF	UNKNOWN	SOUTH HEART	ND 58655 (701) 677-5882	297	G	8800054	FLUORIDE	1025	4.w	MG/L	4.9	12/01/87
ND1300276	DUNN CENTER. CITY OF	UNKNOWN	DUNN CENTER	ND 58626 (701) 548-4755	200	G	8600303	FLUORIDE	1025	4.00	MG/L	5	10/01/85
ND1300432	HALLIDAY, CITY OF	UNKNOWN	HALLIDAY	ND 58636 (701) 938-4581	288	G	8600305	FLUORIDE	1025	4.w	MG/L	5	10/01/85
ND4500398	GLADSTONE, CITY OF	UNKNOWN	GLADSTONE	N D 58630 (701) 227-0316	224	G	8600304	FLUORIDE	1025	4.00	MG/L	5	10/01/85
ND2100704	MOTT, UN OF	UNKNOWN	MOTT	ND 58646 (701) 824-2163	1019	G	8800052	FLUORIDE	1025	4.w	MG/L	5.2	12/01/87
ND5300948	TRENTON WATER USERS ASSOC	UNKNOWN	TRENTON	ND 58853 (701) 572-6792	462	P	9000326	FLUORIDE	1025	4.w	MG/L	5.6	10/01/90
ND5300948	TRENTON WATER USERS ASSOC	UNKNOWN	TRENTON	ND 58853 (701) 572-6792	462	P	8700308	FLUORIDE	1025	4.00	MG/L	6	10/01/86

WATER QUALITY VIOLATIONS FOR THE STATE OF SOUTH DAKOTA

PWS ID. TYPE	SYSETM NAME	ADDRESS	CITY	ZIP AND PHONE #	POPULATION SERVED	PRIM W C	SAMPLE ID	CNTAM NAME	CNTAM CODE	MAXIMUM CONTAMINANT LEVEL	CONC	RESULT	DATE
SD4600175	ISABEL	PO BOX 132	ISABEL	SD 57633 (605) 466-2177	315	S	9200106	TURBIDITY	100	0.50	MU	I.4	04/01/92
SD4600175	ISABEL	PO BOX 132	ISABEL	SD 57633 (605) 466-2177	315	S	9200103	TURBIDITY	100	0.50	NTU	2.9	12/01/91
SD4600175	ISABEL	PO BOX 122	ISABEL	SD 57633 (605) 466-2177	315	S	9200105	TURBIDITY	100	0.50	MU	1.7	03/01/92
SD4600175	ISABEL	PO BOX 132	ISABEL	SD 57633 (605) 466-2177	315	S	9200104	TURBIDITY	100	0.50	NTU	1.7	02/01/92
SD4600175	ISABEL	PO BOX 132	ISABEL	SD 57633 (605) 466-2177	315	S	9200102	TURBIDITY	100	0.50	NTU	1.4	01/01/92
SD4600175	ISABEL	PO BOX 122	ISABEL	SD 57633 (605) 466-2177	315	S	9200101	TURBIDITY	100	0.50	NTU	1.4	11/01/91
SD4600119	ESTELLINE	PO Box 162	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L	24.4	08/06/90
SD4600119	ESTELLINE	PO BOX 162	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L	24.4	08/06/90
SD4600119	ESTELLINE	PO BOX 162	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L	24.4	08/06/90
SD4600119	ESTELLINE	PO Box 162	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L	24.4	08/06/90
SD4600119	ESTELLINE	PO BOX 162	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L	24.4	08/06/90
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.8	04/18/89
SD4600119	ESTELLINE	PO Box 162	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L	24 4	08/06/90
SD4600119	ESTELLINE	PO BOX 162	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L		08/06/90
SD4600119	ESTELLINE	PO BOX 142	ESTELLINE	SD 57234 (605) 873-2388	650	G	9000100	NITRATE	1040	10.00	MG/L	24 4	08/06/90
SD4600622	BRUCE	POBOX244	BRUCE	SD 57220 (605) 627-5323	240	W	9200109	NITRATE	1040	1000	MG/L	10.4	11/04/91
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.8	04/18/89
SD4600058	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	4000100	NITRATE	1040	10.00	MG/L	14	04/09/90
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.4	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.4	04/18/89
SD4600058	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	9000100	NITRATE	1040	10.00	MG/L	14	04/09/90
SD4600058	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	4000100	NITRATE	1040	10.00	MG/L	14	04/09/90
SD4600058	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	9000100	NITRATE	1040	10.00	MG/L	14	04/09/90
SD4600058	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	9000100	NITRATE	1040	10.00	MG/L	14	04/09/90
SD4600058	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	9000100	NITRATE	1040	10.00	MG/L	15	04/09/90
SD4600056	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	9000100	NITRATE	1040	10.00	MG/L	14	04/09/90
SD4600058	AURORA	PO BOX 335	AURORA	SD 57002 (605) 693-3752	619	W	9000100	NITRATE	1040	10.00	MG/L	14	04/09/90
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.8	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.8	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.8	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	IO.00	MG/L	23.8	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	224	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	Io.w	MG/L	23.8	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	P.4	04/18/89
SD4600117	ELKTON	PO BOX 308	ELKTON	SD 57026	602	W	8600001	NITRATE	1040	10.00	MG/L	23.8	04/18/89
SD4601081	COUNTRYSIDE	7577 CROSSBILL CIRCLE	RAPID CITY	SD 57702	425	a	9100100	GROSS ALPHA,EXCL. RADON & U	4000	14.00	pCi/L	14.4	10/01/90
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	9000100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	17.4	10/01/89
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	9000101	COMBINED RADIUM (-226 & -228)	4010	20.m	pCi/L	14.4	01/01/90
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	G	8800103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.4	07/01/88
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	8900100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	10.4	10/01/88
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	G	8900101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	124	01/01/89
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	a	8900102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.1	04/01/89
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	a	8900103	COMBINED RADIUM (-226 & -228)	4010	20.w	pCi/L	14.4	07/01/89
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	8800101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.4	01/01/88
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	G	8700103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.7	07/01/87
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	9000102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.4	04/01/90
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	a	9000103	COMBINED RADIUM (-2244 -228)	4010	20.00	pCi/L	14.4	07/01/90
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	9100104	COMBINED RADIUM (-226 & -228)	4010	20.00	pa/L	14	10/01/90
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	9100105	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.4	01/01/91
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	a	9100106	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	124	04/01/91
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	G	8800102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	I24	04/01/88
SD4600182	KENNEBEC	PO BOX 282	KENNEBEC	SD 57544 (605) 869-2241	284		8800100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	4.4	01/01/88
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	8	88001 00	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	18	10/01/87
SD4600236	PHILIP	PO BOX 862	PHILIP	SD 57567 (605) 859-2572	1070	S	9200103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	4.4	10/01/91
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	8600100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.2	10/01/85
SD4601081	COUNTRYSIDE	7577 CROSSBILL CIRCLE	RAPID CITY	SD 57702	425	G	9100101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	4.4	01/01/91
SD4601081	COUNTRYSIDE	7577 CROSSBILL CIRCLE	RAPID CITY	SD 57702	425	G	9100102	COMBINED RADIUM (-226 & -228)	4010		pCi/L	4.7	07/01/91
SD4601081	COUNTRYSIDE	7577 CROSSBILL CIRCLE	RAPID CITY	SD 57702	425	G	9200103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	4.4	10/01/91
SD4600136	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	a	9200106	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.4	01/01/92
SD4600236	PHILIP	PO BOX 862	PHILIP	SD 57567 (605) 859-2572	1070	8	9100102	COMBINED RADIUM (-226 & -228)	4010	20.m	pCi/L	4.4	07/01/91
SD4600182	KENNEBEC	PO BOX 282	KENNEBEC	SD 57544 (605) 869-2241	284	S	8900100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	4.2	10/01/88
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	8700102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.2	04/01/87
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	G	8600101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	17	01/01/86
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	G	8600102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.4	04/01/86
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	8600103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.2	07/01/86
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	G	8700100	COMBINED RADIUM (-226 & -228)	4010	20.w	pCi/L	14.4	10/01/86
SD4600223	BUTTE-MEADE RWS	PO BOX 5	NEWELL	SD 57760 (605) 456-2288	1200	G	8700101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	14.8	01/01/87
SD4600223	BUTTE-MEADE RWS	POBOXS	NEWELL	SD 57760 (605) 456-2288	1200	a	9100107	COMBINED RADIUM (-2244 -228)	4010	20.00	pCi/L	1.4	07/01/91
SD4600136	GARRETSON	704 MAIN ST.-BOX 470	GARRETSON	SD 57030 (605) 594-6721	924	G	8900103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	13.1	07/01/89
SD4600182	KENNEBEC	PO BOX 282	KENNEBEC	SD 57544 (605) 869-2241	284	S	8800101	COMBINED RADIUM (-226 & -228)	4010	20.w	pCi/L	4.7	04/01/88
SD4600138	GARRETSON	704 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8700102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.4	04/01/87
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8700103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.4	07/01/87
SD4600136	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8600101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.5	01/01/86
204400134	GARRETSON	704 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	a	8600102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	122	04/01/86

WATER QUALITY VIOLATIONS FOR THE STATE OF SOUTH DAKOTA

PWS ID. TWE	SYSETM NAME	ADDRESS	CITY	ZIP AND PHONE #	POPULATION SERVED	PRIM SRC	SAMPLE ID	CNTAM NAME	CNTAM CODE	MAXIMUM CONTAMINANT LEVEL	CONC.	RESULT	DATE
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8600103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.0	07/01/86
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8700100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.7	10/01/86
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8700101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.7	01/01/87
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	moolol	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	10.3	01/01/90
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	9000103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	10.4	07/01/90
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8800100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	10.4	10/01/87
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8800101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	9.9	01/01/88
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8800102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	9.9	04/01/88
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8900100	COMBINED RADIUM (-226 & -228)	4010	a.00	pCi/L	10.0	10/01/88
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8900101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	124	01/01/89
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	9000100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	127	10/01/89
SD4600138	GARRETSON	703 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8900102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	13.3	04/01/89
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	9000102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	10.1	04/01/90
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9000103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	7.2	07/01/90
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9100100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	6.5	10/01/90
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	8900102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	5.8	04/01/89
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	8900103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	5.2	07/01/89
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9000100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	6	10/01/89
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9000101	COMBINED RADIUM (-226 & -228)	4010	20.4)	pCi/L	6.1	01/01/90
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9000102	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	6.8	04/01/90
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	8900101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	as	01/01/89
SD4600138	GARRETSON	705 MNN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	9100104	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	10.8	10/01/90
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9100101	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	2.2	01/01/91
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9100103	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	5.7	04/01/91
SD4600182	KENNEBEC	PO BOX 262	KENNEBEC	SD 57544 (605) 869-2241	284	S	9100104	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	5.5	07/01/91
SD4600138	GARRETSON	705 W N ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	9100107	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	12.2	07/01/91
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	9100106	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	122	04/01/91
SD4600138	GARRETSON	705 MAIN ST.-BOX 370	GARRETSON	SD 57030 (605) 594-6721	924	G	8600100	COMBINED RADIUM (-226 & -228)	4010	20.00	pCi/L	11.4	10/01/85

WATER QUALITY VIOLATIONS FOR THE STATE OF WYOMINQ

PCS ID. TYPE	SYSETM NAME	ADDRESS	CITY	ZIP	POPULATION SERVED	PRIM SRC	SAMPLE ID	CNTAM NAME	CNTAM CODE	MAXIMUM CONTAMINANT LEVEL	CONC.	RESULT	DATE
WY5600246	VISTA WEST SUBDIVISION	P.O. BOX 115	SUNDANCE	WY 52725	300	S	90V0004	TURBIDITY	100	0.05	N N	2.5050	05/01/90
WY5600245	HSTA WEST SUBDIVISION	P.O. BOX 115	SJNDANCE	WY 52725	300	S	90V0002	TURBIDITY	100	0.05	N N	2.0000	04/01/90
WY5600291	DAVE JOHNSTON POWER PLANT	1551 TANK FARM R	GLENROCK	WY 52537	250	S	89V0001	TURBIDITY	100	0.05	N N	14.5000	10/01/88
WY5500251	DAVE JOHNSTON POWER PLANT	1591 TANK FARM R	GLENROCK	WY 52537	250	S	88V0005	TURBIDITY	100	0.05	N N	13.0000	08/01/88
WY5600291	DAVE JOHNSTON POWER PLANT	1551 TANK FARM R	QLENROCK	WY 52537	250	S	88V0003	TURBIDITY	100	0.05	N N	12.0500	06/01/88
WY5600291	DAVE JOHNSTON POWER PUNT	1591 TANK FARM R	QLENROCK	WY 52537	250	S	66V0002	TURBIDITY	100	0.05	N N	11.5050	05/01/88
WY5500251	DAVE JOHNSTON POWER PLANT	1551 TANK FARM R	GLENROCK	WY 52537	250	S	aavoool	TURBIDITY	100	0.05	N N	19.0000	04/01/88
WY5600634	RHONE-POULENC OF WYOMING CO	P.O. BOX 513	QREEN RIVER	WY 52535	530	S	89V0003	TURBIDITY	100	0.05	N N	33.5000	05/01/89
WY5600634	RHONE-POULENC OF WYOMINQ CO	P.O. BOX 513	QREEN RIVER	WY 52935	530	S	89V0002	TURBIDITY	100	0.05	N N	32.0000	04/01/89
WY5550534	RHONE-POULENC OF WYOMINQ CO	P.O. BOX 513	GREEN RIVER	WY 52935	530	S	88V0007	TURBIDITY	100	0.01	N N	6.0000	06/01/88
WY5600634	RHONE-POULENC OF WYOMING CO	P.O. BOX 513	GREEN RIVER	WY 52935	530	S	66V0006	TURBIDITY	100	0.05	N N	5.5000	05/01/88
WY3550534	RHONE-POULENC OF WYOMING CO	P.O. BOX 513	GREEN RIVER	WY 52935	530	S	66V0005	TURBIDITY	100	0.05	N N	6.0000	04/01/88
WY5550534	RHONE-PUJLENCOF WYOMING CO	P.O. BOX 513	GREEN RIVER	WY 52535	530	S	88V0002	TURBIDITY	100	0.05	N N	28.0000	02/01/88
WY5600634	RHONE-PCYJLENCOF WYOMINQ CO	P.O. BOX 513	GREEN RIVER	WY 52935	530	S	68V0001	TURBIDITY	100	0.05	N N	29.0000	01/01/88
WY5600636	QENERAL CHEMICAL CORPORATIO	P.O. BOX 551	GREEN RIVER	WY 52935	600	S	89V0003	TURBIDITY	100	0.05	N N	9.0000	03/01/89
WY5600636	GENERAL CHEMICAL CORPORATIO	P.O. BOX 551	QREEN RIVER	WY 52935	500	S	89V0001	TURBIDITY	100	0.05	N N	8.0000	10/01/88
WY5600636	QENERAL CHEMICAL CORPORATIO	P.O. BOX 551	QREEN RIVER	WY 52535	500	S	88V0004	TURBIDITY	100	0.05	N N	6.0000	08/01/88
WY5500535	QENERAL CHEMICAL CORPORATIO	P.O. BOX 551	GREEN RIVER	WY 52935	600	S	66V0003	TURBIDITY	100	0.05	N N	10.0000	06/01/88
WY5600636	GENERAL CHEMICAL CORPORATIO	P.O. BOX 551	QREEN RIVER	WY 52535	500	S	68V0002	NRBIDIM	100	0.01	N N	8.0000	05/01/88
WY5600636	GENERAL CHEMICAL CORPORATIO	P.O. BOX 551	GREEN RIVER	WY 52535	600	S	68V0001	TURBIDITY	100	0.05	N N	8.0000	04/01/88
WY5600639	JIM BRIDGER POWER PLANT	PO BOX 1 58	POINT OF ROCKS	WY 52542	500	S	66V0006	TURBIDITY	100	0.05	N N	22.0000	08/01/88
WY5600639	JIM BRIDGER POWER PLANT	PO BOX 155	POINT OF ROCKS	WY 52542	600	S	88V0005	TURBIDITY	100	0.05	N N	19.0000	07/01/88
WY5600639	JIM BRIDGER POWER PLANT	PO BOX 155	POINT OF ROCKS	WV 52942	600	S	66V0004	TURBIDITY	100	0.05	N N	19.0000	06/01/88
WY5600639	JIM BRIDGER POWER PLANT	PO BOX 155	POINT OF ROCKS	WY 52542	600	S	88V0003	NRBIDIM	100	0.05	NTU	15.5005	05/01/88
WY5550539	JIM BRIDGER POWER PLANT	PO BOX 158	POINT OF ROCKS	WY 52542	600	S	88V0002	TURBIDITY	100	0.05	N N	21.0000	04/01/88
WY5600647	TG SODA ASH, INC.	P.O. BOX 100	GRANGER	WY 02534	300	S	68V0008	NRBIDIM	100	0.05	N N	7.0000	08/01/88
WY5600728	FMC WYOMING CORPORATION	P.O. BOX 572	GREEN RIVER	WY 52535	1200	S	68V0004	TURBIDITY	100	0.05	N N	14.0000	06/01/88
WY5600814	NAUGHTON POWER PLANT	BOX 151	KEMMERER	WY 53101	250	S	89V0005	TURBIDITY	100	0.05	N N	12.0000	05/01/89
WY5600814	NAUQHTON POWER PLANT	BOX 191	KEMMERER	WY 53101	250	S	89V0004	TURBIDITY	100	0.05	N N	79.0000	01/01/89
WY5600814	NAUGHTON POWER PLANT	BOX 191	KEMMERER	WV 53101	250	S	89V0003	TURBIDITY	100	0.05	N N	26.0000	12/01/88
WY5600814	NAUGHTON POWER PLANT	BOX 191	KEMMERER	WY 53101	250	S	89V0002	TURBIDITY	100	0.05	N N	41.0000	11/01/88
WY5600814	NAUQHTON POWER PLANT	BOX 191	KEMMERER	WY 53101	250	S	89V0001	TURBIDITY	100	0.05	N N	46.0000	10/01/88
WY5600914	TENNECO SODA ASH JNT. VENTU	#1 WESTVACO RO.	GREEN RIVER	WY 52535	300	S	89V0001	NRBIDIM	100	0.05	N N	5.0000	10/01/88
WY5600919	EXXON SHUTE CREEK PLANT SIT	P.O.BOX 98	FRONTIER	WY 53132	215	S	89V0006	TURBIDITY	100	0.05	N N	70.5000	07/01/89
WY5680074	YELLOWSTONE NP CANYON VILLA	PO BOX 155	YELLOWSTONE NT	WY52150	1500	S	55VOWI	TURBIDITY	100	0.05	N N	10.0000	05/01/88
WY5680077	YELLOWSTONE NP GRANT VILLAG	P.O. BOX 155	YELLOWSTONE NT	WY 52150	1500	S	88V0002	NRBIDIM	100	0.05	N N	29.0000	08/01/88

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, **Attn D-7923H,** PO Box 25007, Denver Federal Center, Denver CO 802254007.