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Affordable Drinking Water Treatment For Public Water Systems Contaminated By Excess Levels Of Natural Fluoride

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NATIONAL NETWORK FOR
ENVIRONMENTAL MANAGEMENT STUDIES

RESEARCH REPORT

AFFORDABLE DRINKING WATER TREATMENT
FOR PUBLIC WATER SYSTEMS
CONTAMINATED BY EXCESS LEVELS OF NATURAL FLUORIDE

BY

CARL MASTROPAOLO

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STUDY APPROACH

This study was performed during the period 10 June through early September 1991. The author researched the published literature regarding fluoride occurrence in groundwater, remediation techniques associated with its removal, and the dose-related health effects associated with exposure. Sources explored included texts and professional journals, and technical articles written by the United States Environmental Protection Agency, or by individuals or companies under EPA contracts. Professional papers and water resources investigations prepared by the United States Geological Survey were also consulted.

In addition, over fifty telephone conversations unearthed information deemed relevant for inclusion in this report. Telephone calls were placed to other EPA regional offices, headquarters EPA in Washington DC, the EPA research facility in Cincinnati, various state level drinking or groundwater offices, the National Institute of Health, medical and dental experts, United States Geological Survey offices, university researchers, public water system managers and operators, private contractors involved in the water industry, and other individuals. A number of these contacts submitted written or faxed information, a considerable amount of which has been referenced in this report.

An attempt was made to quantify various treatment technology construction, operation and maintenance, chemical, and disposal costs, and to determine whether a centralized treatment facility, or a point-of-use/point-of-entry treatment is more cost effective based upon the average flow rate of a given public water system. Cost figures were primarily generated by updating data contained in an extensive cost study of small water treatment facilities performed by Culp/Wesner/Culp under EPA contract during the period September 1981 through January 1984 (84-1).

We feel that the cost and technology information acquired in this research could be applied to any public water system experiencing excessive fluoride concentrations. We attempted to specifically apply this information to a group of southeastern Virginia public water systems regulated by the Commonwealth of Virginia which experience excessive fluoride groundwater concentrations.

We wish to note that there were many avenues which we could not explore since this research project lasted for only three months. We have tried to highlight some of these in the hope that further studies might be performed. Specifically we hope that further research is able to determine costs associated with the following compliance options: drilling a new well; connecting or hauling water from another public water system; point-of-entry treatment; and distributing bottled water.

A draft copy of this report was circulated among various individuals both within and outside the Environmental Protection Agency for their comments. The author of this report agreed to review these comments and incorporate them into the final version of this report during a one week period in December 1991. It was determined however that a considerable amount of research time would be required in order to properly address some of the comments submitted. The author has attempted to address all comments and to note within the text of this report those comments which could not be fully addressed due to the short time frame set aside for developing the final version.

HISTORICAL PERSPECTIVE

The physiological effects of fluoride upon human health have been studied since the early part of this century. As early as 1925 (25-1) dental fluorosis, a condition characterized by discoloration and softening of teeth (90-4), was attributable to drinking water.

During the 1930s and 1940s, scientific research established that the incidence of dental fluorosis was directly related to the fluoride content of drinking water. High fluoride exposure was also linked to increased bone density of the spine and pelvis, lenticular opaqueness of the eye, and brittleness and blotching of fingernails (53-1).

In response to growing scientific evidence regarding the negative effects of exposure to excessive fluoride, the United States Public Health Service (PHS) established a range of recommended concentrations for fluoride in drinking water (1.4 to 2.4 mg/L), dependent upon the maximum daily air temperature of the location of the water supply (62-1). A temperature dependent value was required to compensate for increased water consumption in warmer climates.

Several reports and studies in the 1960s and 1970s established both the risks of high fluoride dosing and the benefits of minimal exposure. Low drinking water concentrations of fluoride were deemed responsible for inhibiting dental caries (tooth decay), while higher concentrations were linked to permanent tooth fluorosis, and skeletal fluorosis, the latter responsible for aberrations ranging from stiffness to crippling rigidity (65-1, 70-2, 70-3, 71-1, 73-2, 73-3, 73-4, 75-2). One of these studies (71-1), performed by the National Academy of Science, determined that dental tissues and the skeleton accumulate fluoride more rapidly during formation and mineralization thus negatively impacting children up to about 10 years old more so than the general population.

Through continued scientific research, it became apparent that an optimal intermediate concentration of about 1 mg/L would produce the benefit of reduced tooth decay without the risks associated with higher doses (70-1).

1975 National Interim Primary Drinking Water Regulations

In 1975, pursuant to the 1974 Safe Drinking Water Act, the United States Environmental Protection Agency promulgated the National Interim Primary Drinking Water Regulations, establishing maximum contamination levels (MCLs) for ten inorganic contaminants, including fluoride, as well as for turbidity, coliform bacteria, pesticides, herbicides, total trihalomethanes, and radionuclides. EPA adopted the Public Health Service

temperature dependent standards for fluoride (1.4 to 2.4 mg/L).

As part of its on-going regulatory review process, EPA requested the advice of the National Academy of Science concerning MCLs for fluoride and other contaminants. In 1980 the National Academy of Science concluded that while "dental mottling and changes in tooth structure may develop in children when fluoride levels exceed approximately .7 to 1.3 mg/L", consumption of drinking water with concentrations as high as 4 mg/L provides a beneficial reduction in osteoporosis (80-2). Scientific evidence was therefore suggesting that concentrations between about 1.3 and 4.0 mg/L produced both positive and negative effects.

In 1981, the state of South Carolina petitioned that EPA delete fluoride from the Primary Drinking Water Regulation and, in 1984, formally sued EPA seeking faster action on the petition. A consent decree signed by both parties on January 18, 1985 set EPA about the task of re-evaluating the fluoride MCL.

Considerable scientific evidence had been accumulating in the interim. Responding to an EPA request to examine "the issue of the relationship of fluoride in drinking water and the health aspects of dental fluorosis", former Surgeon General Koop concurred with the conclusion reached by the PHS's ad-hoc committee on dental fluorosis: "No sound evidence exists which shows that drinking water with the various concentration of fluoride found naturally in public water supplies in the United States has any adverse effect on dental health as measured by loss of function and tooth mortality" (82-2).

And in 1984, in response to an EPA request to review the non-dental effects of fluoride, Koop stated (84-5):

> Adverse health effects were defined by the
> committee as death (poisoning), gastrointestinal
> hemorrhage, gastrointestinal irritation,
> arthralgias, and crippling fluorosis. No record
> exists of poisoning death from fluorides consumed
> in drinking water. There are no scientifically
> credible reports of gastrointestinal effects at
> levels found in drinking water. Clinical
> experience suggests that arthralgias are not
> likely to occur in patients who are on therapeutic
> regimens of less than 20 milligrams per day.
> Crippling fluorosis has been detected in some
> people who have consumed 20 mg or more of fluoride
> per day from all sources for twenty or more years.
> Such a situation does not exist in the U.S. today.

Meanwhile, in 1984, the World Health Organization deemed fluoride concentrations exceeding 1.5 mg/L as excessive on the

basis of mottling of teeth (84-4).

1985 RMCL Proposal

In proposing a recommended maximum contamination level (RMCL) for fluoride in 1985, EPA extensively reviewed literature, public comments, and professional advice from diverse sources and concluded (R85-1):

* exposure to fluoride levels of about 1 to 2 mg/L can contribute to dental fluorosis, frequency and severity increasing with that of the fluoride concentration
* exposure to levels between 1 and 4 mg/L have been shown to contribute to reduced dental caries formation
* exposure to levels greater than 4 mg/L "can result in asymptomatic osteosclerosis (increased bone density) in a small percentage of individuals"

As a result of its review, EPA established an RMCL of 4.0 mg/L to prevent crippling skeletal fluorosis, and planned to propose a secondary maximum contamination level (SMCL) of 2.0 mg/L to guard against mottling of teeth.

The Office of Management and Budget, as well as medical, dental, and public health groups throughout the United States opposed EPA's handling of the naturally occurring fluoride issue and its assessment of negative fluoride effects in the period between the promulgation of the National Interim Primary Drinking Water Regulations and the establishment of the RMCL.

In October 1979 the American Dental Association House of Delegates "resolved, that based on present knowledge, it is the opinion of the American Dental Association that the natural fluoride levels of drinking water in the United States do not constitute a health hazard". The resolution was supported by the American Association of Public Health Dentists.

In March 1980 the Association of State and Territorial Dental Directors unanimously approved a resolution that opposed EPA's inclusion of fluoride in the primary standards of the National Interim Primary Drinking Water Regulations at levels of twice the optimum and above as a contaminant and health hazard. It further requested that "fluoride be changed from the Primary to the Secondary Drinking Water Regulations".

In a May 7, 1982 letter to the HQ EPA Administrator Anne Gorsuch, the American Medical Association concurred with the previously stated American Dental Association position indicating that AMA was "unaware of any unequivocal evidence showing that naturally occurring fluorides have adverse effects on the public health".

In March 1985 EPA requested the Office of Management and Budget to review the draft notice of proposed rulemaking (NPRM) which would establish the RMCL for fluoride. In response, the OMB questioned "the need for national health standards for fluoride in view of the infinitesimal health risk and quite small population exposure" (85-5). Using EPA's own NPRM figures, OMB indicated that only 184,000 people were served by the 282 public water systems (PWSs) which then had fluoride concentrations exceeding 4 mg/L. "This is less than 0.1% of the total population of 190-200 million served by the 60,000 drinking water systems that are subject to the SDWA." In referring to the fact that only 17,000 people were then exposed to concentrations exceeding 6 mg/L, and 3,000 to 4,000 to those exceeding 8 mg/L, OMB further commented that "at all these concentrations, the Surgeon General and his "world class" panels have found <u>no</u> demonstrated cases of adverse affects on the health of persons".

<u>1986 Final Fluoride Rule</u>

Prior to establishing the primary MCL for fluoride at 4.0 mg/L, EPA solicited comments relating to three options under consideration for the regulation of fluoride:

Option 1: "Propose a National Revised Primary Drinking Water Regulation to protect against moderate and severe dental fluorosis and set the RMCL at 1 or 2 mg/L, as appropriate" (R86-1)

Option 2: "Propose a National Revised Primary Drinking Water Regulation finding that crippling skeletal fluorosis (but not dental fluorosis) is an adverse health effect and set the RMCL at 4 mg/L; propose a National Secondary Drinking Water Regulation to warn against dental fluorosis (a cosmetic effect), setting a secondary MCL at 2 mg/L." (R86-1)

Option 3: "Delete fluoride from the National Primary Drinking Water Regulations based upon a finding that levels of fluoride in U.S. drinking water are not associated with any adverse health effects; propose a Secondary MCL of 2 mg/L to warn against the cosmetic effects of dental fluorosis." (R86-1)

"The Agency proposed Option 2 for the regulation of fluoride. In making this decision, the Agency concluded that 'based upon the information available at this time, EPA believes that crippling skeletal fluorosis is an adverse health effect that can be caused by excessive amounts of fluoride in drinking water, and that 4 mg/L is the level below which no known or anticipated adverse effect on health of persons occur and which allows an adequate margin of safety. Thus, an RMCL is proposed at 4 mg/L' (50 FR 20164). The Agency stated that it now believed that

objectionable (moderate and severe) dental fluorosis is not an adverse health effect under the Safe Drinking Water Act, but rather a cosmetic effect that would adversely affect public welfare and it should be regulated under the NSDWRs. The Agency, therefore stated that at the time of proposal of the MCL for fluoride, it planned to propose a Secondary MCL at 2 mg/L." (R86-1).

In responding to comments relating to these three options, EPA considered various independent study results, some of which were submitted by commenters. Some of the studies cited in the final fluoride rule, and their impact upon the decision making process, follow:

A draft National Institute of Dental Health study (84-8), submitted by a commenter, concluded that the consumption of drinking water containing 4 mg/L or less has no adverse effects upon the teeth and that increasing fluoride exposure from .7 to 4 mg/L results in increasing the level of dental attrition, but does not pose a concern of clinical importance.

Commenters also noted two independent studies which cited two cases of crippling skeletal fluorosis suffered by individuals who had been exposed to fluoride concentration between 2.4 and 3.5 mg/L and 4.0 and 7.8 mg/L, respectively (71-2, 65-2). It is estimated that these individuals consumed about 6 liters of water per day each, and consumed large undetermined quantities of tea, a beverage with a considerably higher fluoride concentration than most foods, 97.0 parts per million (70-2).

EPA also cited the Knox Report, an epidemiological study performed by the British government (85-7), and concurred with its findings that there is no evidence that naturally or artificially occurring fluoride is capable of inducing cancer.

On April 2, 1986, after review of all pertinent scientific data, EPA promulgated the final fluoride rule (R86-1), establishing an enforceable MCL of 4.0 mg/L "to protect against crippling skeletal fluorosis" and a non-enforceable SMCL of 2.0 mg/L "to protect against objectionable dental fluorosis" (R86-1). Activated alumina adsorption and reverse osmosis were identified as best technologies generally available (BTGA-this is currently known as BAT: best available technology) for purposes of fluoride variances.

1991 Public Health Service Fluoride Report

Since the 1986 ruling the most comprehensive toxicological analysis of the effects of fluoride was rendered by the Public Health Service's February 1991 report entitled Review of Fluoride, Benefits and Risks. The PHS addressed cancer, dental fluorosis, and skeletal disorders as the significant health

conditions in their evaluation of the health risks associated with fluoride intake. A brief summary of the report's findings related to each of these conditions follows:

Regarding cancer: Optimal fluoridation does not pose a cancer risk to humans as evidenced by extensive human epidemiological data. Two methodologically acceptable animal carcinogenicity studies published in 1990 by Proctor and Gamble (90-6), and the National Toxicology Program, Public Health Service, Department of Health and Human Services (90-7) "taken together...fail to establish an association between fluoride and cancer".

Regarding dental fluorosis: Total exposure to fluoride has increased since the 1940's due to the introduction of fluoride into dental products. Accordingly the incidence of dental fluorosis has increased even in non-fluoridated areas. The PHS recommends that unnecessary and inappropriate fluoride exposure be reduced.

Regarding skeletal disorders: "Crippling skeletal fluorosis is not a public health problem in the United States, as evidenced by the reports of only five cases in 30 years." It was established that two of these subjects consumed between 15 and 20 mg/day for 20 years. PHS noted that, in foreign literature, Moudgil, et al (86-2) had identified 41 children with evidence of crippling skeletal deformities who had consumed water with fluoride concentrations ranging from 7.3 to 29 mg/L. PHS concluded "human crippling skeletal fluorosis is endemic in several countries in the world, but is extremely rare in the United States".

Current Opinions Regarding EPA Policy

Some medical and toxicological experts still oppose EPA regulatory policy regarding fluoride. While the primary MCL for fluoride has been established to guard against crippling skeletal fluorosis, those in opposition refer to studies which indicate that the probability of occurrence of the disease in the United States is virtually zero.

Other opposition centers upon views regarding the effects of dental fluorosis, with some experts favoring the reestablishment of a temperature-dependent standard, since water consumption is known to increase with rising temperatures. This is the view still held, for example, by the National Institute of Health in considering the optimal fluoride exposure to reduce dental caries. Other dissenters still view dental fluorosis as a cosmetic problem and not a health problem, and cite studies indicating greater incidence of dental fluorosis in non-fluoridating areas, the result of consumer use of increasing numbers of fluoridated products, including dental care items. Further, they note, dental fluorosis only adversely effects teeth of young children, a known factor which can be readily

compensated for by means other than to treat an entire community's water supply.

SOURCES OF FLUORIDE IN GROUNDWATER

Fluoride is the most electronegative element having a valence of negative 1 and is the smallest atom of the halogen family. It is not found in nature in the elemental state but rather it combines with other elements to form fluoride compounds.

Fluoride is the anion (negatively charged ion) of the fluorine atom. Under the proper conditions in a water environment, fluoride compounds may dissociate to produce fluoride ions in solution.

Fluoride occurrences in groundwater have two sources: anthropogenic and natural.

Anthropogenic Sources

Anthropogenic fluoride sources originate with the use of various forms of fluoride-bearing minerals or reagents in industrial processes. Effluent from electroplating operations may contain fluoride due to surface preparation or electroplating with metal fluoborate salts. Wastewater from steel production facilities contain fluoride, attributable to pickling of stainless steel with hydrofluoric acid. Wet scrubbing of emissions from furnaces in which aluminum is separated from bauxite ore in the presence of the fluoride-bearing mineral cryolite results in fluoride presence in the waste stream, as does the removal of phosphate from fluorophosphate (fluorapatite-$Ca_5F(PO_4)_3$) during the production of fertilizers. Glass manufacturing also produces fluoride-rich effluent (75-1). Fluorine and fluoride compounds are also used in the electronics industries for production of semiconductors or internal washing of cathode ray tubes. In the wastewater discharged from some of these industries, fluoride concentrations can sometimes reach several hundred mg/L (88-6).

Natural Sources

Geochemical dissolution of fluoride-bearing minerals is responsible for the occurrence of natural fluoride in water supplies of the United States (85-1). Fluorite (CaF_2) is the most common fluoride-bearing mineral and is usually present in sandstone, limestone, dolomite, and granite, all of which are common in the United States. Other less common fluoride-bearing minerals include fluorapatite, cryolite, rhyolite and hornblends. Fluoride also may displace other ions in the structures of micas and clays (85-1, 89-4, 59-1). Water with high naturally occurring fluoride is usually found at the foot of mountain ranges and in areas with certain geological formations, particularly those of marine origin (88-3). Fluorite in sedimentary rocks has been identified in marine carbonates and related evaporites ranging in geologic age from Cambrian to

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Cretaceous. Experiments have shown (51-1) that fluorite could precipitate from seawater brines. Subsequent geochemical dissolution could reintroduce fluoride into fresh water aquifers upon geologic time-scale marine regressions. Groundwater fluoride concentrations may sometimes exceed 100 mg/L as the result of volcanic activity.

GEOGRAPHIC AREAS WITH EXCESS FLUORIDE

Fluoride concentrations in excess of the EPA MCL effect groundwater-source public water systems throughout the continental United States. All EPA regions were contacted to determine the degree to which excess fluoride in groundwater poses a problem today. While EPA regions I and II could identify no problem areas, all other regions regulate at least one public water system with fluoride concentrations exceeding the MCL.

The number of PWSs with high fluoride groundwater is especially large in both Texas and Virginia. A 1982 national survey performed by the American Water Works Association (83-1) indicated, for example, that 328 Texas and 104 Virginia community water systems (CWSs) were exceeding the then current fluoride MCL (1.4 to 2.4 mg/L). At the time, the total number of CWSs exceeding the MCL nationally was 907.

Recent conversations with EPA Region VI (Dallas) personnel and the Virginia Department of Health, as well as reference to the Federal Reporting Data System (FRDS II), indicate that Texas and Virginia PWSs still currently experience excessive fluoride concentrations. For example, 51 Virginia public water systems, 34 in Suffolk City County, have groundwater fluoride concentrations exceeding the EPA MCL of 4.0 mg/L. Twenty-nine of these have concentrations which also exceed the unreasonable risk to health (URTH) level of 5.0 mg/L, the highest being 6.60 mg/L.

A number of PWSs in Oklahoma, Arizona, New Mexico and South Carolina also currently experience excessive fluoride levels as do a smaller number of PWSs in Indiana, Illinois, Ohio, Missouri, Wyoming, Nevada, North Dakota and Idaho. In most of these cases personnel from the various EPA regions indicate concentrations are in the 5 mg/L range. Data from the 1982 AWWA survey, for example, indicated that 177 CWSs had fluoride concentrations exceeding 4.0 mg/L while only 85 exceeded 5.0 mg/L.

Since most sources of fluoride are natural, and naturally occurring fluoride concentrations change very slowly (on a geologic time scale), AWWA's 1982 data should reasonably reflect the current fluoride concentration distribution among CWSs nationally. It should be noted however that the number of CWSs nationwide with excessive fluoride concentrations has decreased since the early 1980s. Contacts at several EPA regional offices have indicated, for example, that a considerable number of smaller water systems have chosen to either locate another drinking water source, connect to a large local water system, or pursue other options in order to avoid costly defluoridation treatment. As a result the number of CWSs in each concentration category below probably overstates the current situation:

Distribution of Fluoride Concentrations Nationally
(source: 1982 AWWA survey:83-1)

concentrations exceeding (mg/L)	number of CWSs
4.0	177
5.0	85
6.0	34
7.0	16
8.0	9
9.0	8

Fluoride-rich groundwater apparently occurs in geographic "pockets" and normally does not effect groundwater on a regional-scale. The North Carolina state water agency's regional office in the eastern part of the state, for example, reports that no PWSs in the area are in violation of the fluoride MCL, despite close proximity to the Suffolk Virginia public water systems experiencing excessive fluoride. Concentrations are in the 2.0 to 3.5 mg/L range. A Gates County North Carolina water supply operator whose wells are about 20 to 25 miles from Suffolk Virginia, indicates that fluoride levels in his wells are about 3.1 mg/L.

COMPLIANCE OPTIONS

The Safe Drinking Water Act (SDWA) affects approximately 230,000 public water systems (PWSs). Of these, approximately 60,000 are community water systems (CWSs) which, by definition, serve at least 15 service connections used by year-round residents, or regularly serve at least 25 year-round residents. About 88% of these systems serve 10,000 residents or less, accounting for 22% of the total population served by CWSs (91-7). In addition approximately 25,000 non-transient, non-community water systems (NTNCWSs) and 145,000 non-community water systems (NCWSs) are effected by the SDWA.

PWSs which produce water with excess fluoride may exercise a variety of options in order to provide water which meets regulatory standards. These options can broadly be characterized as treatment versus non-treatment.

Treatment	Non-treatment
central	develop a new well which produces water which meets the MCL
point of use (POU)	connect to or haul water from a PWS which produces water which meets the MCL
point of entry (POE)	purchase and distribute bottled water which meets the MCL

While each of these options is technically capable of reducing fluoride concentrations, current Safe Drinking Water Act regulations do not permit a PWS to employ POU treatment, or purchase and distribution of bottled water, as compliance options to attain the MCL. Rather, POU treatment and bottled water are only permissible as short-term options. It should be noted that the January 30, 1991 final rule for volatile organic compounds (R91-1) allows POE devices to be used to meet regulatory requirements, although such devices are not considered BAT.

In most cases the first three compliance options which are considered acceptable from a regulatory standpoint are relatively expensive operations which can be pursued cost-effectively only by larger PWSs which can spread capital, and operation and maintenance costs over a larger customer base. For many of these options, fixed capital costs, which are independent of the number of customers serviced by the PWS, are quite large. For example, sinking a new well to develop a new water source may cost in the order of ten thousand dollars. To a PWS which services only 50 households, this represents a one time cost on the order of $200 per household. To a PWS servicing 500 households, this cost is only about $20 per household. In addition, some marginal costs,

which are dependent upon the number of customers serviced by the PWS, are also subject to an economy of scale, in effect financially penalizing smaller systems.

A PWS can also comply with SDWA regulations by applying for and receiving a variance or exemption (SDWA, Sections 1415 and 1416). While EPA does not consider POU treatment, or purchase and distribution of bottled water as viable long-term options to attain regulatory compliance, it does permit the regulatory agency (usually the State) to require a PWS to pursue such options as a condition of granting an exemption or variance.

The feasibility of pursuing any one of these treatment or non-treatment compliance options is often contingent upon a multitude of factors including those of geography, geology, and economics. Many small South Carolina PWSs in the North Atlantic Coastal Plain, for example, which had experienced problems with excess fluoride, opted to connect to larger water systems instead of adding treatment. This was technically feasible due to the relatively dense population along the coast and the subsequent proximity of larger water systems which were already treating for fluoride. By contrast, about 50 PWSs scattered throughout the Arizona desert, some servicing as few as 25 to 30 people, have been required to install POE devices as a condition for receiving a variance or exemption. Due to their isolation these systems did not have an option to connect to a larger system.

AVAILABLE TREATMENT TECHNOLOGIES

The treatment technologies to remove fluoride are, for the most part, well documented. They include:

adsorption by activated alumina
adsorption by bone char
reverse osmosis
electrodialysis
alum coagulation
lime softening
anion exchange
nanofiltration

All of these technologies can be applied as central treatment. Only activated alumina, reverse osmosis and anion exchange POU/POE treatment are currently commercially available, although at least one commercial producer of bone char is attempting to market his product as a POU/POE device ingredient.

In addition to the treatment technologies listed above, research for this report revealed a recently developed and patented defluoridation technique involving adsorption by rare earth compounds.

A considerable amount of research has been conducted regarding operation of, and costs associated with, most of these treatment technologies. Gumerman, et al (84-1) provides a detailed cost analysis for small centralized systems. Bellen and Anderson (85-1) specifically evaluate the comparative efficiencies and costs of defluoridation based upon evaluation of a number of centralized and POU facilities. Proceedings of a 1987 EPA sponsored POU conference (88-5) provides discussion of a broad range of POU related topics as well as unit costs. Rogers (90-5, 88-4) relates the development of a POU reverse osmosis pilot study in New Mexico from prior to request-for-proposal preparation through cost and efficiency analysis.

A brief description of each treatment technology follows.

Activated Alumina

Activated alumina is manufactured by low temperature dehydration of hydrous aluminum oxide, the process creating a porous adsorbent of moderately high surface area (81-2). The mechanism of fluoride adsorption involves the attachment of fluoride (F^-) to the activated alumina and the loss of hydroxyl ion (OH^-) from activated alumina to the water (86-1). The optimal pH range for this anion exchange is pH 5 to 6. Below this range activated alumina dissolves in the acidic environment producing loss of adsorbing media. Above pH 6, the predominant hydroxyl ions are preferred over fluoride for adsorption. One

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gram of activated alumina is reported to adsorb between 2.3 and 10.1 mg of fluoride, dependent upon other raw water conditions (81-2).

In central treatment, raw water is adjusted to the optimal pH range and fluoride is adsorbed until the alumina bed is saturated. Fluoride is then removed by adding a caustic (usually sodium hydroxide) to produce a high pH water which removes fluoride in favor of hydroxyl (regenerative step). After regeneration the pH is reduced to the optimal range and the cycle begins anew.

POU/POE activated alumina treatment uses canisters containing approximately .5 to 1.0 cubic feet of activated alumina and does not involve pH adjustment to optimize the canister's adsorption capacity. Once the fluoride adsorption capacity of the medium is exhausted, the canister is replaced. The contents of the spent canister can be regenerated by exposure to high alkali water, as is done in central treatment, and reused. This is usually done off-site.

While activated alumina readily adsorbs fluoride, other raw water parameters have an impact upon adsorptive capacity. High concentrations of total dissolved solids (TDS), for example, can result in fouling of the alumina bed and high concentrations of sulfates and carbonates can result in ionic competition. Application of activated alumina treatment is most favorable when fluoride alone must be removed from drinking water (81-2).

Bone Char

Bone char is crushed and burned animal bone, having an approximate chemical composition of hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$ (91-1). This treatment process normally also includes carbon adsorption to remove color and odor.

The bone char process for fluoride removal is similar to that for activated alumina. Regeneration of the media, by removing fluoride, can be accomplished by exposure to dilute caustic soda (84-6), or to a regenerating solution using bone char particles too small for use in the bone char bed (91-1).

POU/POE bone char treatment has been proposed for a number of years (see for example 68-1) and has been practiced in Third World villages (88-3), in which case media is not regenerated, the village being supplied instead with replacement filter bags. Researchers have expressed the intent of providing villagers with high-temperature furnaces to prepare filter ingredients (88-3).

A New Hampshire vendor who has been using a POE bone char device to eliminate excessive arsenic, is currently researching the device's ability to reduce groundwater fluoride levels. As

of the writing of this report no results had been reported.

Bone char's capacity to adsorb fluoride is reportedly far less than that attained by activated alumina (84-6, for example). However, while a considerable amount of research has been performed to determine optimal processing parameters for activated alumina, such as pH, influent flow rate, and contaminant loading concentration (see for example 79-1), little in this regard had been done to optimize processing with bone char. A recently published study supported in part by the World Health Organization, however, claims bone char adsorption capacity of about 9.8 mg fluoride per g of bone char (91-1). This is comparable with activated alumina capacity. Furthermore, after regeneration of spent columns with calcium phosphate at pH 3, the column is reportedly at least as effective as it was originally.

Reverse Osmosis

Reverse osmosis (RO) utilizes a pressure gradient and semi-permeable membranes to remove a high percentage of almost all inorganic contaminants, as well as turbidity, bacteria and viruses. The membrane essentially operates as a molecular sieve. Fluoride removal efficiencies greater than 80%, and sometimes as high as 98% have been documented for both central and POU treatment techniques (90-5, 88-4, 86-1, 85-1, 85-4).

RO membranes are susceptible to scaling or fouling. Chlorine also damages certain membrane materials. As a result chemical pre-treatment or granular activated carbon adsorption is often required in the process line prior to the reverse osmosis unit. Pre-carbon adsorbers are apparently now standard for all POU/POE units.

Reverse osmosis units incur substantial process electricity costs. Low pressure units require less electricity than high pressure units but remove a smaller percentage of contaminants.

Reverse osmosis units tend to produce a relatively small volume of water with respect to the waste stream generated. A 1983 POU reverse osmosis pilot study resulted in an average waste stream of 89% for 47 devices (85-1), that is, only 11% of raw water influent was eventually processed into product drinking water.

Electrodialysis

In the electrodialysis (ED) process, water flows between alternate cation permeable and anion permeable membranes, with direct electric current providing the driving force to cause ions to migrate through the membranes. Electrodialysis reversal (EDR) is essentially the same process as ED except that the electric

charge on each membrane is occasionally automatically reversed to expel any ions which may have collected. Virtually all electrodialysis plants constructed since 1975 are EDR.

Fluoride removal efficiencies greater than 80% have been reported (84-3) for these processes.

EDR plants operate with a relatively high water recovery rate, especially when compared with RO. An EDR defluoridation plant processing 3 million gallons per day and operated by the City of Suffolk, Virginia, for example, typically recovers about 94% of influent as product water.

Apparently POU/POE EDR is not a viable option. Neither the proceedings of the 1987 EPA conference on point-of-use (88-5) nor Gumerman, et al's extensive review of available small systems completed in 1984 (84-1) mention an EDR POU/POE option.

A contact from the Office of Ground Water and Drinking Water, EPA reports that pending regulations may include ED as BAT for fluoride.

Alum Coagulation

Upon addition to water, alum ($Al_2 (SO_4)_3 18H_2O$) dissociates to form an aluminum hydroxide complex which removes fluoride either by floc enmeshment or sorption. The insoluble complex precipitates out of solution.

EPA has reported that this treatment technique tends to be expensive for small system applications (84-6), requiring addition of large quantities of alum. More recently, however, Nawlakhe & Bulusu (89-4) have developed a combination alum/lime defluoridation treatment (referred to as the Nalgonda technique) which they contend is inexpensive, effective, and adaptable to both the domestic and community levels. The technique is specifically designed to be operated by illiterate people in rural communities in India.

Lime softening

Fluoride is removed by treatment systems which utilize lime softening (lime is calcium hydroxide) to remove calcium and magnesium hardness. Since fluoride is coprecipitated in this process with magnesium hydroxide (86-1, 84-6), this method requires the raw water magnesium concentration to be sufficient to enmesh enough fluoride to produce residual concentrations below the MCL. Substantial quantities of magnesium are required to produce this effect, as well as the addition of large quantities of lime.

Lime softening treatment can be performed either as a single

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stage or two stage process. As indicated in Gumerman, et al (84-1), the majority of lime softening systems utilize single stage processing. Two stage processing is required to remove significantly high raw water magnesium concentrations.

While lime softening is primarily used to remove hardness, considerable fluoride reduction is a by-product. For example, the Yuma Bureau of Reclamations Desalting Plant typically removes about 45% of raw Colorado River water fluoride concentration in its lime softening operation.

As indicated in the discussion on alum coagulation, a small scale treatment technique which employs alum and lime has reportedly been developed which is effective and inexpensive at the domestic and community levels.

Anion Exchange

Ion exchange is a process in which ions held by electrostatic forces to charged functional groups on the surface of a solid are exchanged for ions of similar charge in a solution in which the solid is immersed (72-1).

Though this technique theoretically has potential application for defluoridation, little information regarding its use could be obtained either through personal contacts or literature review. EPA pilot studies in Oregon and Alaska utilized anion exchange as a POU arsenic removal technique (87-3) but apparently did not pursue the device's ability to remove fluoride. EPA-sponsored research conducted by the University of Houston (84-3) indicates that anion exchange resins prefer exchange with chloride rather than fluoride. Since chloride is a common major anion in groundwater sources, especially in coastal regions experiencing varying degrees of salt water intrusion, its competitive advantage over fluoride in an anion exchange process would tend to minimize this technology's effectiveness for fluoride removal.

Nanofiltration

Nanofiltration is a relatively new water treatment technique which has been commercially available since 1986. The nanofilter operates on a molecular scale, removing molecular species with diameters greater than or equal to 10 angstroms (a nanometer). The technology has the ability of removing smaller materials than ultrafiltration, but is incapable of removing some of the smaller materials removable by reverse osmosis. Because of the coarser membrane with respect to reverse osmosis, nanofiltration requires lower operating pressures (typically between 80 to 100 psi) than RO to force water through the membrane and therefore substantially less energy (89-5, 89-6, 87-2).

The coarser membrane also produces a substantially higher

water recovery rate than RO resulting in a much smaller waste stream. According to a nanofiltration researcher from the University of Arizona, the process experiences a 95% water recovery rate. The researcher reports that several Florida locations are using this technology, and the city of Fort Myers is presently constructing a 20 million gallon per day plant which utilizes a groundwater source.

While the researcher's bench scale tests have been designed to determine the effects of the treatment on salinity, hardness, bacteria, virus, and organic precursors, tests with recharged municipal effluent in the city of Phoenix indicate that nanofiltration was able to reduce fluoride levels from .7 to .2 mg/L (89-5).

The nanofiltration researcher is currently in the process of developing a nanofiltration device for home use.

Adsorption Involving Rare Earth Compounds

Nomura et al (90-3, 88-6) have developed and patented a high efficiency method of selectively removing fluoride and fluoride compounds at low concentrations in water by adsorption onto hydrated rare earth oxides or insoluble hydrated rare earth salts, particularly hydrous rare earth phosphates or hydrous rare earth fluorides, effective within the pH range of 2 to 7. The adsorbent can be prepared as a filtration cake, a dried powder, or fabricated as a pre-formed mold upon a carrier porous material, preferably a polymeric organic (88-6).

The mechanism of adsorption, similar to that by activated alumina, is by anion exchange between the hydroxyl groups on the adsorbent and fluoride or fluoride compounds in solution. The percentage of removal of fluoride increases abruptly at pH 7 or lower, approaching 100% rapidly as pH decreases. The percentage removal of other common anions, such as chloride, nitrate, and sulfate, is considerably lower and the pH at which these anions are optimally adsorbed is at pH ranges less than 4. As a result fluoride is selectively adsorbed. Below pH 2, the adsorbent itself is highly soluble, while above pH 7 adsorption capacity decreases significantly.

The selectivity for fluoride is reflected in data published in Nomura, et al's patent application (88-6). In a pH 5 solution containing equal concentrations of fluoride, chloride, nitrate, and sulfate, fluoride was selectively adsorbed by a ratio range of 100 to 1000 over chloride, 200 to 5000 over nitrate, and 30 to 200 over sulfate. Here selectivity is defined (using chloride as an example) by the following:

$$\frac{[F]_{ads}}{[F]_{aq}} \frac{[Cl]_{aq}}{[Cl]_{ads}}$$

where: $[X]_{aq}$ = concentration of species X in solution (mmol/L)
$[X]_{ads}$ = concentration of species X in adsorbent (meq/g of adsorbent)

Desorption of fluoride and subsequent regeneration of the adsorbing media is accomplished by exposure of the media to high alkalinity water (preferably pH 12 or above) to permit replacement of fluoride ions by hydroxyl ions on the adsorbing media. The desorption and regeneration process is similar to that for activated alumina treatment.

Since their initial patent application, Nomura, et al have maximized adsorption capacity by developing a carrier bead of polyolefinic resin bearing an adsorbent of hydrous cerium oxide powder. Optimal adsorption occurs in the 2 to 5 pH range. Sodium hydroxide is used to regenerate the adsorbent media, with calcium fluoride precipitating from solution upon addition of calcium chloride (90-3).

Nomura and his co-workers compared the adsorptive capacities of activated alumina and hydrous cerium oxide by running tests with influent containing a fluoride concentration of 100 mg/L. The water treated with activated alumina was adjusted to pH 6 (optimal for activated alumina adsorption), while water treated by hydrous cerium oxide was adjusted to pH 3. Results indicate that hydrous cerium oxide is nearly six times as effective as activated alumina in removing fluoride when compared on the basis of mole of fluoride adsorbed per mole of metal in the adsorbent:

Adsorption Capacity

	mg fluoride/ g adsorbent	mole fluoride/ mole metal
CeO_2 1.6 H_2O	105	1.13
Al_2O_3	69	.20

It should be noted however that Nomura, et al have pursued this technique primarily to treat wastewater and that the influent fluoride concentration (100 mg/L) of the water used for testing comparison far exceeds fluoride concentrations normally encountered in the United States.

While their patent application indicates their process is economical, no cost data is presented in their published material. Attempts to contact the two editors of the text containing Nomura, et al's publication were unsuccessful. Nomura and his co-workers reside in Japan.

Disposal

Each of these treatment technologies generates a waste stream of sludge or brine which requires an appropriate disposal strategy which meets regulatory requirements since each of these waste streams contains concentrated quantities of removed contaminants. Several disposal strategies exist, two or more applicable to a given treatment technology (following modified from Gumerman, et al, 84-1):

		Disposal strategy		
Treatment technology	sludge lagoon	sanitary sewer	sand beds	evaporation ponds
activated alumina		X		X
bone char		X		X
reverse osmosis		X		X
electrodialysis reversal		X		X
alum coagulation	X	X	X	
lime softening	X	X	X	
nanofiltration		X		X

Disposal into a sanitary sewer system is a realistic strategy only if a sewer line is available and a centralized treatment facility can operationally handle the increase in sludge. Slowly releasing the sludge over a period of time (equalizing discharge), would enable the centralized treatment facility to more efficiently respond to the added sludge volume, and reduce the probability of producing sudden changes in pH, temperature, dissolved oxygen concentration, or other physicochemical characteristics of the system.

The State may also approve sludge discharges to surface waters, or sludge injections into deep wells when contaminant concentrations are low. In either case, equalizing the discharge is recommended.

Sludge lagoons and evaporation ponds are frequently designed to accommodate several years of waste before removal of precipitated solids to a permanent disposal location is required (84-1). The economic feasibility of sludge lagoons and evaporation ponds is dependent upon the availability and cost of land in the vicinity of the treatment facility, as well as the

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evapotranspiration rate of the locale. In southeastern Virginia,
where the average annual precipitation rate, 43 inches per year
(90-2), exceeds the average evapotranspiration rate, 21.5 inches
per year (90-2), these strategies are not applicable. By
contrast, these options are favorable in desert locations of
Arizona where annual precipitation is low, evapotranspiration is
high, and land is abundant and relatively inexpensive.

MORE ON POINT-OF-USE AND POINT-OF-ENTRY

POU treatment techniques, and purchasing and distributing bottled water are both capable of reducing groundwater fluoride levels below the MCL. Currently, EPA does not accept these options as methods of attaining long-term compliance with the federal fluoride regulations but does permit the regulatory agency (usually the State) to require a public water system to use these options as a condition of granting an exemption or variance from the fluoride MCL.

The following discussion intends to provide some insight into the POU and POE options based upon two reports published in 1990 and recent discussions with several contacts, including personnel at various EPA offices. The short time frame of this current research prevented the gathering of detailed information regarding the bottled water option.

The final volatile organic compound rule (R91-1) defines specific criteria which a public water system must meet in order to receive an exemption or variance using these options. This rule was promulgated on January 30, 1991, to become effective July 30, 1992. A synopsis of these criteria follows:

Public water systems that use POU/POE devices as a condition for obtaining an exemption or variance must:
1-maintain the POU/POE devices
2-obtain the approval of a monitoring plan which ensures the devices provide health protection equivalent to that provided by central treatment
3-apply effective technology and maintain micro-biological safety
4-provide the State with certification of performance
5-consider the potential for heterotrophic bacteria and provide a means to assure that the microbiological safety of the water is not compromised
6-assure the State that the devices are sufficient in number, and that they are properly installed, maintained, and monitored

Public water systems that use bottled water as a condition for receiving an exemption or variance must:
1-develop a monitoring program for State approval
2-receive certification from the bottled water company that the supply is taken from an approved source
3-assume full responsibility for providing a sufficient supply of bottled water to every person supplied by the public water system via door-to-door delivery

POU/POE devices both require a relatively small capital investment when compared with central treatment. While operation and maintenance costs on a per gallon basis are usually higher for these devices than for central treatment, POU devices treat only drinking (and possible cooking) water which is usually about 10% of the total household water usage. As a result overall POU operation and maintenance costs can be smaller than that for central treatment, especially for small systems.

Some of the disadvantages of using POU/POE devices include: the potential for bacterial growth on the surface of the media within the treatment units; inability to optimize process parameters; and difficulties associated with monitoring, testing, and servicing.

Two recently published studies, one sponsored by EPA, the other performed by the National Sanitation Foundation, address the problems associated with POU/POE drinking water treatment.

Seventy-two under-the-sink model reverse osmosis POU units were installed and monitored in the village of San Ysidro, New Mexico in an EPA-sponsored study (90-5). The local groundwater source contains leachate from geothermal activity and therefore is high in mineral content. At the time of the study the groundwater exceeded EPA primary MCLs for arsenic and fluoride, and secondary MCLs for iron, manganese, chloride, and total dissolved solids. Eighteen months of operational and maintenance data were collected and evaluated. Study results indicate:

* POU drinking water treatment is an effective, economical, reliable, and viable alternative to central treatment for the community
* A POU treatment system requires a more time-intensive monitoring program than that for central treatment
* A POU treatment system requires special municipal regulations regarding customer responsibilities, and water utility responsibilities
* POU systems require special considerations from regulatory agencies to determine appropriate methods for record keeping, monitoring, and testing frequencies
* A POU treatment system requires customers to permit access for monitoring, testing, and maintenance of equipment
* A POU reverse osmosis unit can reduce raw water arsenic and fluoride levels which exceed the EPA MCL to below regulatory limits
* A POU reverse osmosis unit can reduce raw water iron, manganese, chloride, and total dissolved solids levels which exceed the EPA secondary MCL to below those regulatory limits
* While the monthly treatment cost on a per gallon basis is about 3 times that of a central treatment facility, the actual household treatment cost is less than half since POU

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devices treat only that small portion of household water demand used for drinking and cooking

During the testing a few RO-treated water samples tested positive for coliforms. An investigation revealed that all RO units had been installed with the RO drain connected directly to the kitchen sink drain without an air gap. This was strongly suspected to be causing the positive coliform test results. After the air gap problem was corrected, all coliform test results were negative.

The National Sanitation Foundation study pursued the viability of using POE treatment to reduce radium levels in the town of Bellevue, Wisconsin (90-8). Results from this study indicate that:

* Residents did not perceive POE devices as a treatment technology
* Residents were unwilling to permit equipment inspections more than twice per year
* The legal issues that will be most difficult to address involve access and entry to private property for maintenance, inspection, and monitoring
* Although the capital costs may be favorable when compared with central treatment or connection to an existing system, the monitoring, maintenance and administrative costs associated with POE treatment would be much greater than other possible options

Due to its proximity to a central treatment facility in Green Bay, the city of Bellevue is currently deciding whether to connect to the Green Bay system. The study reveals a general public uneasiness regarding decentralized treatment.

People contacted during this study had varying opinions regarding decentralized treatment. Many people concurred with some of the findings of the two previously mentioned studies, specifically that decentralized treatment is effective but presents monitoring, testing and maintenance problems since entrance to the consumer's property is always required for POU devices, and usually required for POE devices. Many contacts were also concerned about contaminant breakthrough once the device's media had become saturated. Should breakthrough occur undetected, the consumer is potentially susceptible to larger contaminant doses than is contained in the raw water due to contaminant concentration in the device's media. A contact from the state of Arizona's drinking water office pointed out that monitoring a few devices is not effective since it assumes that devices at each residence respond identically. This may not be the case.

Other contacts, however argued that, while POU/POE devices may

not be preferred over centralized treatment, they are sometimes the only cost effective alternative for small systems. A contact from the Rural Water Association, for example, had visited a number of sites using POE devices managed by a contracted "circuit-rider", or system monitor, in the Arizona desert and felt the monitoring system worked well. He indicated that, for a POE treatment system to be viable, the state regulatory agency should specify that a contract must exist between the home owner and the PWS for reasons of monitoring, testing, and maintenance so that access to the customer's property is assured. He feels in general that management must be more creative and evaluate the trade offs between centralized and decentralized treatment. When this contact was informed regarding the natural fluoride contamination currently being experienced by small PWSs in southeastern Virginia, he indicated that the Virginia office of the Rural Water Association would be available for assistance should EPA be interested in pursuing a pilot decentralized program in the state.

One contact from the National Sanitation Foundation maintains that EPA should be working with the small public water systems in determining optimal monitoring procedures and in sharing decentralized system cost information. The State of California, according to a contact in the State's Department of Health Services, has wholeheartedly adopted the philosophy of the National Sanitation Foundation. The State of California contact, however indicated that California, Iowa, and Wisconsin are the only states with laws regarding regulation of POU/POE devices.

The King's Point Subdivision in the City of Suffolk, Virginia is expected to be a test site for POU/POE fluoride removal. When contacted in late July 1991 the HQ EPA coordinator for the Low-cost Innovative Small System Initiative indicated that requests for proposal (RFPs) should have been disseminated by early August 1991. He expected that a mix of POU and POE devices would probably be installed. The coordinator further indicated that POU/POE technology is progressing. Some systems, for example are currently capable of on-line real-time assessment of treatment plant operations. A New Hampshire vendor, for example, indicates that his company has developed a bone char POE device for arsenic removal which is automatically backwashed.

Subsequent comments submitted by the coordinator for the Low-cost Innovative Small System Initiative (91-12) indicate that award announcements for the King's Point Subdivision project are expected sometime in December 1991. A December 1991 telephone call to the consulting firm hired to coordinate the project indicates that the State of Virginia and the Subdivision are currently reviewing the proposals submitted by four bidders. The firm is encouraging the acceptance of all four proposals.

An EPA Cincinnati contact indicated that he, in conjunction

with the Water Quality Association, recently polled between 250 and 300 POU/POE manufacturers nationwide to assess currently available products. While many manufacturers were reluctant to furnish effectiveness data, some significant information was collected.

Another HQ EPA contact ventured to predict that POU/POE devices will one day be considered BAT but probably not for many years, citing the legal and managerial problems previously mentioned in this report.

It should be noted that in extreme cases POU/POE may be the only option available to small public water systems. A case in point is an Indiana public water system servicing about 6500 people. An EPA Region V contact indicated that the system has been producing groundwater source drinking water with fluoride levels consistently in the upper 4 mg/L range for the past 13 years. A contractor hired by the PWS to assess treatment options determined that he could provide neither centralized activated alumina nor centralized reverse osmosis (the two BAT choices) at any reasonable cost. When the beleaguered system pursued connecting to another water system it discovered that such action required approval by Canada and other states bordering the Great Lakes watershed. The case has yet to be resolved and is awaiting action by the US Department of Justice.

TREATMENT COSTS

While nine available treatment techniques have been
identified, we propose to explore related costs for only six of
these as central treatments (activated alumina, reverse osmosis,
electrodialysis, alum coagulation, lime softening, and
nanofiltration), and two as POU treatments (activated alumina and
reverse osmosis). Bone char and rare earth adsorption costs are
not available in the literature. Anion exchange costs were not
explored due to the uncertain nature of its application for
defluoridation. Activated alumina and reverse osmosis are the
only techniques for which POU/POE defluoridation treatment is
currently available. However only detailed POU costs are
available in the literature. POE costs are therefore not
included below.

The following discussion and development of treatment
technology costs is largely based upon cost analysis performed by
Culp/Wesner/Culp Consulting Engineers (Gumerman, et al, 84-1).
Under EPA contract, Culp/Wesner/Culp undertook an extensive two
and a half year study in 1981 to determine costs associated with
unit processes capable of removing contaminants included in the
National Interim Primary Drinking Water Regulations. The study
(84-1), performed during the period September 1981 to January
1984, considered cost data for 45 centralized and five POU/POE
treatment techniques.

The discussion and development of disposal strategy costs,
while partially based upon the Culp/Wesner/Culp study, draws also
upon a 1989 feasibility study performed by Engineering-Science,
Inc. (89-7) which studied four west Texas public water systems
experiencing excess fluoride levels and developed cost
projections for remediation using centralized activated alumina
and reverse osmosis at each location.

Costs related to nanofiltration are derived from a 1989 journal
article (89-8) and telephone conversations with a researcher from
the University of Arizona and his marketing representative.

Comments submitted by the Office of Ground Water and Drinking
Water (OGWDW), HQ EPA, (91-12), indicate reluctance on the part
of the OGWDW to rely heavily upon the Culp/Wesner/Culp model for
small system costs. According to OGWDW, the model, which was
developed under contract to the EPA Office of Research and
Development, does not necessarily accurately reflect the method
small systems employ to solve water treatment issues. Instead of
hiring consulting engineers to design and build treatment
facilities, as the Culp/Wesner/Culp model suggests, smaller
systems tend to rely upon pre-engineered complete systems which
are not custom designed.

Cost Categories

Centralized treatment facilities incur costs which can be separated into four categories: Construction, operation and maintenance, chemical, and disposal. Construction costs demand a one-time consumer expenditure whereas the other three cost categories require annual consumer expenditures. POU/POE technologies incur only construction, and operation and maintenance costs.

Culp/Wesner/Culp developed construction cost data by segregating costs into eight principal components which were selected to aid in subsequent cost updating: excavation and site work, manufactured equipment, concrete, steel, labor , pipe and valves, electrical equipment and instrumentation, and housing. The subtotal of the costs of these components includes the cost of material and equipment purchase and installation, and a subcontractor's overhead and profit. A 15% contingency allowance is then added to the subtotal to determine the total process cost.

It should be noted that Culp/Wesner/Culp construction cost data do not represent capital cost. To convert the construction cost data into capital cost data requires adjustments for the following, where appropriate:

- overall site work, interface piping, roads
- general contractor's overhead and profit
- engineering
- land
- legal, fiscal, and administrative costs
- interest during construction

It is also important to realize that Culp/Wesner/Culp construction cost data do not include costs associated with constructing disposal facilities or installing pumps. While it is extremely likely that an existing public water system already has pumps in place (an exception might be a PWS with an artesian well water supply), it is extremely unlikely that a PWS which is not currently treating for a contaminant would already have a sanitary sewer, sand bed, evaporation pond, or sludge lagoon in place.

Culp/Wesner/Culp developed operation and maintenance costs for three separate components: energy, maintenance material, and labor. The energy component includes process and building electrical energy, and diesel fuel where appropriate. Maintenance material costs include those for replacement parts but does not include chemical costs. Labor requirements include both operational and maintenance costs.

Chemical costs are incurred by all centralized treatment

facilities.   Included are costs for coagulants, such as alum and lime, adsorbers, such as activated alumina, and acids and alkalies, typically sulfuric acid and sodium hydroxide, respectively.

Disposal costs are associated with the various fluoride treatment disposal strategies, including sludge lagoons, sanitary sewers, sand beds, and evaporation ponds.   All centralized treatment facilities incur such costs.   While technically spent POU/POE activated alumina canisters require disposition, canister contents are regenerated and/or disposed off-site.   Labor costs associated with delivery of spent canisters to off-site regeneration/disposal facilities are included in operation and maintenance costs.

Cost Standardization

In nearly all categories, Culp/Wesner/Culp based costs upon standardized Bureau of Labor Statistics (BLS) or Engineering News-Record (ENR) indices, or, in the case of electricity, upon the current cost per kilowatt hour (kWh).

While all costs are in December 1983 dollars, the Culp/Wesner/Culp report provides the means by which cost figures can be updated.

Each of the eight construction cost components is associated with either a Bureau of Labor Statistics (BLS) or Engineering News-Record (ENR) standardized cost index.

Operation and maintenance costs are segregated into the three individual components: energy, maintenance material, and labor. Since the report provides energy requirements in Kwh/yr, applying current cost of electricity quantifies energy costs.   Maintenance material costs are based upon the Producer Price Index for Finished Goods.   Operation and maintenance labor costs can be updated using the ENR skilled labor index.   Culp/Wesner/Culp applied labor costs of $11.00 per hour for 1983 operation and maintenance costs.

The Culp/Wesner/Culp report does not explicitly identify specific BLS or ENR indices for chemical costs.   However a series of BLS chemical indices were selected by this researcher for cost updating purposes.

Construction Cost Component	Index
Excavation and site work	ENR Skilled Labor index
Manufactured equipment	BLS General Purpose Machinery and Equipment (Code 114)
Concrete	BLS Concrete Ingredients and Related Products (Code 132)
Steel	BLS Steel Mill Products (Code 1017)
Labor	ENR Skilled Labor index
Pipe & Valves	BLS Miscellaneous Gen'l Purpose Equipment (Code 1149)
Electrical	BLS Electrical Machinery & Equipment (Code 117)
Housing	ENR Building Cost index

Operation and Maintenance Cost Component	Index
Energy	Current electricity rate in $/Kwh
Maintenance materials	BLS Producer Price index for Finished Goods
Labor	ENR skilled labor index

Chemical Cost Component	Index
sodium hydroxide	BLS Sodium Hydroxide (Code 2812-3)
carbon dioxide	BLS Carbon Dioxide (Code 2813-3)
sulfuric acid	BLS Sulfuric Acid (Code 2819-3)
alum	BLS Other Aluminum Cmpnds (Code 2819-671)
soda ash	BLS Sodium Cmpnds (Code 2819-7A)
sodium hexametaphosphate	BLS Other Sodium Phosphates (Code 2819-739)
lime	BLS Alkali Earth Metal Cmpnds (Code 2819-9A)

Disposal costs present a much more complex problem. For the purposes of developing comparative costs, this researcher has decided to update only those disposal costs associated with disposal to an existing sanitary sewer. While this is a gross generalization, several factors influence this decision:

1-The sanitary sewer disposal strategy is the only strategy common to all of the centralized treatment technologies under consideration. It was therefore felt that updating sewage disposal costs would be most useful in general.

2-Since two or more disposal strategies apply to each treatment technology, quantifying disposal costs would require updating a large volume of data.

3-Culp/Wesner/Culp construction costs for disposal to sanitary sewers is based upon sludge flow rate in gallons per day. Knowing the ratio of average sludge flow rate (in gallons per day) to the average plant flow rate (in gallons per day) would permit a relatively straight forward computation of sanitary sewer disposal costs. It is felt that these ratios can reasonably be estimated. For activated alumina it is well established that the waste flow is between 1 and 4% of plant flow (89-7, 85-1, 84-1, 80-4). The average ratio for RO for the four PWSs researched in the west Texas study (89-7) was 13%. Considering the relatively low water recovery of RO when compared with other treatment technologies, this figure should

be an upper bound and can be conservatively applied
to the other treatment technologies.

4-By contrast, Culp/Wesner/Culp costs for disposal to sludge
  lagoons is based upon lagoon volume, and to sand beds and
  evaporation ponds upon surface area. Determining the
  size of these disposal facilities based upon average plant
  flow rate is a complex site-specific computation. Costing
  these disposal strategies is therefore complex.

5-The short three month duration of this current
  research precludes exploring all possible options.

Culp/Wesner/Culp determined costs for disposal to sanitary sewers
based upon a 1982 survey of 40 wastewater treatment plants (82-
3). No standardized indices were used. This researcher selected
the BLS index for General Purpose Machinery and Equipment for
cost updating purposes:

<u>Disposal Cost Component</u>   <u>Index</u>

    disposal   BLS General Purpose
                                                Machinery & Equipment
                                                (Code 114)

The Culp/Wesner/Culp costs for disposal to sanitary sewers is
given for a wide range of groundwater suspended solids
concentration, with costs increasing as suspended solids
concentration increases. Costs were updated assuming a suspended
solids concentration of 2,000 mg/L as a conservative average.

    It should be noted that disposal to an existing sanitary sewer
is the least costly of all disposal strategies. Comments
received from the Office of Ground Water and Drinking Water
(OGWDW) HQ EPA, (91-11) indicate that OGWDW has updated cost
figures (1990) for several disposal options. The author of this
current report was unaware of this data at the time the draft
report was written. The short time frame set aside for the final
version of this report precluded investigation into disposal cost
data available from OGWDW.

Updating Costs

    The intent of this current report is to update these cost
figures based upon current dollars.

    Culp/Wesner/Culp based costs associated with ENR indices upon
the 8 December 1983 index values. To develop current costs for
ENR categories, it is necessary to divide the current skilled
labor cost index, and current building cost index (values
contained in 91-8) by their respective 8 December 1983

counterparts (values contained in 83-2). The resulting factors are then multiplied by the Culp/Wesner/Culp 1983 costs to generate 1991 costs.

Culp/Wesner/Culp based costs associated with BLS indices upon the December 1983 index values. To develop current costs for BLS categories, it is necessary to divide the current index values for each of the various BLS indices by their respective December 1983 counterparts (both sets of values supplied by Philadelphia BLS office personnel). The resulting factors are then multiplied by the Culp/Wesner/Culp 1983 costs to generate 1991 costs.

The only remaining cost category is for electricity. Per Philadelphia area BLS personnel, the June 1991 electricity cost is $.134 per kwh. Applying this rate to Culp/Wesner/Culp electricity requirements generates 1991 electricity costs.

Computation of the cost factors follows:

ENR Categories

	22 Dec 83	29 Jul 91	cost factor
Skilled labor index	3674.72	4475.35	1.218
Building cost index	2405.56	2757.18	1.146

BLS Categories

	Dec 83	Jun 91	cost factor
Genl Purpose Machinery & Equip (Code 114)	101.9	128.1	1.257
Concrete Ingredients & Related Prods (Code 132)	101.5	119.0	1.172
Steel Mill Products (Code 1017)	103.0	109.8	1.066
Misc Genl Purpose Equipment (Code 1149)	101.1	136.7	1.352
Electrical Machinery & Equip (Code 117)	105.3	120.9	1.148
Producer Price Index for Finished Products	102.3	121.9	1.192
Sodium Hydroxide (Code 2812-3)	86.3	167.5	1.941
Carbon Dioxide (Code 2813-3)	124.5	118.4	.951
Sulfuric Acid (Code 2819-3)	94.2	104.8	1.113
Other Aluminum Compounds (Code 2819-671)	100.0	131.0	1.310
Sodium Compounds (Code 2819-7A)	102.8	112.4	1.093
Other Sodium Phosphates (Code 2819-739)	101.4	113.2	1.116
Alkali Earth Metal Cmpnds (Code 2819-9A)	101.5	114.3	1.126

SUMMARY OF CONSTRUCTION COSTS

A summary of construction costs for both central and POU defluoridation treatment follows. Total household cost (THC) is based upon an average of 3 people per household (HH) using 150 gallons per day (gpd) each.

Most costs have been derived by updating costs developed by Culp/Wesner/Culp (84-1) by using cost factors generated in this current report. Cost estimates for the nanofiltration technology were provided by a nanofiltration researcher and his marketing representative and may or may not contain all of the cost components considered by Culp/Wesner/Culp for the other technologies. The smaller of the two POU RO costs is derived from the EPA-sponsored San Ysidro, New Mexico experience.

Costs associated with constructing disposal facilities were not explored due to the short duration of this study, and are therefore not included in the following construction costs.

Average plant flow rates are in units of thousands of gallons per day.

Central Treatment

Avg Plant Flow Rate	Number of HH	THC ($ one-time cost per household)					
		AA	RO	ED	Alum	Lime	Nano
1.5	3			12,100			
2.5	6		9,000				
7	16						640
8	18			4,400			
10	22		3,100				
15	33					3,100	
30	67			2,400			
40	89						680
46	100	562					
50	110		1,246				
63	140						560
72	160				600		
100	220	384	1,000	1,100			
150	330					490	
180	400	293					
216	480				280		
300	670			730			
406	900	168					
430	960				180	230	
500	1,100		700				430
560	1,250	158			160		
720	1,600	142					
>750	>1,700	130	650	720	130	170	340

POU Treatment

THC ($ one-time cost per household)

Activated Alumina   Reverse Osmosis

407-597   417- 547

    The updated construction costs indicate that POU treatment is
more cost effective than central treatment for PWSs servicing
less than approximately 100 to 200 households (300 to 600
consumers). For systems servicing greater than about 200
households (600 consumers) which have a realistic option of
disposing to an existing sanitary sewer, central defluoridation
treatment becomes increasingly more cost effective than POU.
Should disposal to an existing sanitary sewer not be a realistic
option, a greater number of households is required for central
defluoridation treatment to be more cost effective than POU.

SUMMARY OF ANNUAL COSTS

A summary of total annual costs for both central and POU
defluoridation treatment follows. Costs represent the sum of
operation and maintenance, chemical, and disposal cost
components. Total household cost is based upon an average of 3
people per household (HH) using 150 gallons per day (gpd) each.

Most costs have been derived by updating costs developed by
Culp/Wesner/Culp (84-1) by using the cost factors generated in
this current report. Cost estimates for the nanofiltration
technology were provided by a nanofiltration researcher and his
marketing representative and may or may not contain all of the
cost components considered by Culp/Wesner/Culp for the other
technologies. The smaller of the two POU RO costs is derived
from the EPA-sponsored San Ysidro, New Mexico experience.

Comments from the Office of Ground Water and Drinking Water
(OGWDW), HQ EPA, (91-11) indicates that strict reliance upon the
Culp/Wesner/Culp report (84-1) for approximating costs based upon
average and design flow rates will not reflect EPA's best
estimates, contending that OGWDW is developing a new flow regime
which will result in sharply decreased estimates for small system
treatment costs. OGWDW has been in the process of revising the
estimation of household usage as a function of flow rate for the
past two years, using not only the Culp/Wesner/Culp report, but
also a document which is referred to as the "Fluoride Design
Manual" (84-6). A December 1991 conversation with an employee
from the OGWDW, however, indicated that OGWDW's revisions are
still in progress, and that the average daily water usage per
person used by this researcher in this current study (150 gallons
per day) is reasonable. Since the OGWDW anticipates updating
fluoride technology and cost data, contacting that office at some
future time and applying their cost estimates to this current
study may result in more refined cost estimate for smaller
systems.

It should be noted that the raw water fluoride concentrations
of many PWSs exceed the primary MCL by only a few mg/L (see chart
on page 14 of this report). For these systems the blending of
treated and untreated water can result in a product which meets
the primary MCL at a lower cost than treating all of the raw
water. While this is a valid option for many PWSs, the short
duration of this study precluded developing costs related to this
option.

Disposal costs assume disposal to an existing sanitary sewer.
The short time frame of this report and other considerations
prevented the development of costs for other disposal options
(see the discussion on pages 34 and 35 of this report). It
should be noted that other disposal options would be more costly
than disposal to an existing sanitary sewer.

Average plant flow rates in the following table are in units of thousands of gallons per day.

Central Treatment

Avg Plant Flow Rate	Number of HH	Total Household Cost ($/yr)					
		AA	RO	ED	Alum	Lime	Nano
1.5	3			1395			
2.5	6		1553-1780				
8	18			509			
10	22		603-738				
15	33					599-842	
30	67			311			
40	89						216
46	100	194-297					
50	110		374-482				
72	160				162		
100	220	153-198	315-414	243			
150	330					113-158	
216	480				153		
500	1,100						158

POU Treatment

Total Household Cost ($/yr)	
Activated Alumina	Reverse Osmosis
252	112 - 327

The annual central treatment costs presented above are segregated by operation and maintenance, chemical, and disposal costs for each treatment technology below. Total household cost (THC) is based upon an average of 3 people per household using 150 gallons per day (gpd) each.

Central Treatment

Activated Alumina

Avg Plant Flow Rate (gpd)	Number of H-holds	O & M ($/gpd)	Chem ($/gpd)	Disp ($/gpd)	Total ($/gpd)	THC ($/yr)
45,000	100	.19-.42	.21	.03	.43-.66	194-297
100,000	220	.10-.20	.21	.03	.34-.44	153-198

Reverse Osmosis

Avg Plant Flow Rate (gpd)	Number of H-holds	O & M ($/gpd)	Chem ($/gpd)	Disp ($/gpd)	Total ($/gpd)	THC ($/yr)
2,500	6	2.74-3.18	.15	.12	3.01-3.45	1553-1780
10,000	22	1.08-1.38	.15	.11	1.34-1.64	603- 738
50,000	110	.60- .84	.12	.11	.83-1.07	374- 482
100,000	220	.50- .72	.09	.11	.70- .92	315- 414

Electrodialysis

Avg Plant Flow Rate (gpd)	Number of H-holds	O & M ($/gpd)	Chem ($/gpd)	Disp ($/gpd)	Total ($/gpd)	THC ($/yr)
1,500	3	2.98	0	.12	3.10	1395
8,000	18	1.02	0	.11	1.13	509
30,000	67	.58	0	.11	.69	311
100,000	220	.43	0	.11	.54	243

Alum Coagulation

Avg Plant Flow Rate (gpd)	Number of H-holds	O & M ($/gpd)	Chem ($/gpd)	Disp ($/gpd)	Total ($/gpd)	THC ($/yr)
72,000	160	.04	.21	.11	.36	162
216,000	480	.02	.21	.11	.34	153

Lime Softening

Avg Plant Flow Rate (gpd)	Number of H-holds	O & M ($/gpd)	Chem ($/gpd)	Disp ($/gpd)	Total ($/gpd)	THC ($/yr)
15,000	33	1.21-1.71	.01-.05	.11	1.33-1.87	599-842
150,000	330	.13- .19	.01-.05	.11	.25- .35	113-158

Nanofiltration

Avg Plant Flow Rate (gpd)	Number of H-holds	O & M & Chem ($/gpd)	Disp ($/gpd)	Total ($/gpd)	THC ($/yr)
40,000	89	.37	.11	.48	216
500,000	1,100	.24	.11	.35	158

These updated annual costs indicate that POU treatment is more cost effective than central treatment for PWSs servicing less than approximately 100 to 200 households (300 to 600 consumers). For systems servicing greater than about 200 households (600 consumers), which have a realistic option of disposing to an existing sanitary sewer, central defluoridation treatment becomes increasingly more cost effective than POU. Should disposal to an existing sanitary sewer not be a realistic option, a greater number of households would be required for central defluoridation treatment to be more cost effective than POU.

MISCELLANEOUS NOTES REGARDING COST CALCULATIONS

BLS Indices

The value of Bureau of Labor Statistics index 2812-3, Sodium Hydroxide, is not available for the period January 1981 through November 1985. In December 1980 the value of the index was 100.0 and in December 1985 it was 86.3 with the value falling throughout 1986. For the purposes of updating costs we have conservatively assumed the December 1983 value to be 86.3.

The value of BLS index 2819-671, Other Aluminum Compounds, is not available prior to June 1987, when it was 100.0 and remained 100.0 throughout most of 1988. For the purposes of updating costs we have assumed the December 1983 value to be 100.0.

Activated Alumina

Regarding chemical costs, an economy of scale is apparent in these figures. Annual sulfuric acid cost requirements for a 473,000 gallon per day facility may actually be cheaper than that for an 11,900 gpd operation since the larger facility can buy sulfuric acid in quantities of tons in lieu of gallons.

Alum Coagulation

Regarding construction costs, Culp/Wesner/Culp provides the following conversion between settling surface area and average plant flow rate (84-1, p 395):

surface area	x	rise rate	=	avg plant flow rate
(ft x ft)		(gpd/ft x ft)		(gpd)
70		1,030		72,100
140		1,540		216,000
250		1,730		432,000
370		1,560		576,000
740		1,560		1,152,000

Regarding chemical costs, researchers have determined that 250 mg/L of alum are required to reduce fluoride concentrations from 3.5 mg/L to 1.5 mg/L, and 350 mg/L to reduce concentrations from 3.5 mg/L to 1.0 mg/L (78-2). For cost calculations we will conservatively assume application of 350 mg/L.

The following sample calculation will indicate how to determine annual chemical costs for a 72,000 gal per day facility:

$$\frac{350 \text{ mg}}{L} \cdot \frac{72,000 \text{ gal}}{\text{day}} \cdot \frac{365 \text{ days}}{\text{year}} \cdot \frac{3.785 \text{ L}}{\text{gal}} \cdot \frac{2.205 \times 10^{-6} \text{ lb}}{\text{mg}} = \frac{76,800 \text{ lb alum}}{\text{yr}}$$

Multiplying this figure by current alum costs per lb yields annual chemical costs. Culp/Wesner/Culp used a figure of $.15 per lb of alum in Dec 1983 dollars.

Reverse Osmosis

Costs associated with the San Ysidro, New Mexico POU RO study have been updated using appropriate BLS and ENR indices and included in the construction cost summary and operation and maintenance cost summary. Since the San Ysidro report was completed in November 1988, we are assuming all costs were in November 1988 dollars.

Construction costs include manufactured equipment (BLS General Purpose Machinery and Equipment, Code 114) and labor (ENR Skilled Labor Index). Development of construction cost factors follows:

	Nov 1988	Jun 1991	29 July 1991	cost factor
BLS code 114	115.1	128.1		1.113
ENR skilled labor	4133.54		4475.35	1.083

Applying these factors to San Ysidro cost of $290 for equipment (RO unit) and $36 for labor (installation), yields summer 1991 values of $323 and $40, respectively. It should be noted that the San Ysidro costs for RO units resulted from receiving a sizeable manufacturer's discount since 80 units were bought at once.

About 67% of the operation and maintenance costs associated with the San Ysidro experience were for labor. To update San Ysidro's 1988 costs we have chosen therefore to simply apply the ENR Skilled Labor Index cost factor of 1.083 as developed above to San Ysidro's actual monthly operation and maintenance costs of $8.60 per household. This yields a summer 1991 value of $9.31 per household per month, or $112 per household per year in summer 1991 dollars.

APPLICATION TO VIRGINIA PUBLIC WATER SYSTEMS

Areas With Excessive Fluoride

Information contained in the Federal Reporting Data System
(FRDS II) was used to determine geographic areas in Virginia
which experience groundwater fluoride concentrations which exceed
the EPA MCL. Fifty-one Virginia PWSs were so identified.
Twenty-nine of these had concentrations which also exceeded the
unreasonable risk to health (URTH) level of 5.0 mg/L, the highest
being 6.60 mg/L.

Virginia Public Water Systems with Excess Fluoride

County/City	# of PWSs exceeding 4.0 mg/L	# of PWSs exceeding 5.0 mg/L	# of PWSs exceeding 6.0 mg/L	Highest
Isle of Wight Cnty	10	2	0	5.13
James City Cnty	1	0	0	4.41
Southampton Cnty	4	2	2	6.28
Chesapeake City	2	0	0	4.33
*Suffolk City	34	25	2	6.60
	51	29	4	

source: FRDS II: Summary Violations and Related Enforcement

* while technically a city, Suffolk has incorporated what
was formerly Nansemond County

With the exception of the one PWS in James City County which is
just north of the James River on the York-James Peninsula, the
other PWSs all are located in the southeastern corner of
Virginia, in an area bounded by the James River to the north, the
North Carolina border to the south, and Virginia Beach to the
east.

Fluoride-rich groundwater apparently occurs in geographic
"pockets" and normally does not effect groundwater on a regional-
scale. For example the North Carolina state water agency's
regional office in the eastern part of the state reports that no
PWSs in the area are in violation of the fluoride MCL,
concentrations being in the 2.0 to 3.5 mg/L range. A Gates
County North Carolina water supply operator whose wells are about
20 to 25 miles from Suffolk Virginia, for example, indicates that
fluoride levels in his wells are about 3.1 mg/L.

Hydrogeologic Research of Southeastern Virginia

The reasons for the high fluoride groundwater concentration in
southeastern Virginia groundwater supplies are unclear. Over the

past few years, however, the United States Geological Survey, has been performing a series of hydrogeologic studies of the Virginia Coastal Plain, of which southeastern Virginia is a part (see for example, 90-2, 89-1, 89-2, 88-1, 81-1). Some of this research relates to major ion transport, including fluoride.

Recently Published USGS Research

The most comprehensive of these USGS studies is a 1988 report (88-1) which defined hydrogeologic characteristics for the water-table aquifer and seven confined aquifers and intervening confining units in southeastern Virginia. The groundwater system was modeled based upon known prepumping water levels, that is, prior to 1891. Using the model, pumping conditions were simulated to reflect current pumpage rates. Model results were consistent with current known water level data, therefore validating the model. USGS then tested the response of the groundwater flow system to increased pumping and determined that water level decline would be substantial, resulting in considerable well interference and degradation of water quality. By testing system response with various pumping scenarios, USGS determined that year-round pumping at a constant rate would prevent extreme water level declines normally experienced during the seasonally dry three month summer period.

This USGS study divides each of the eight aquifers of the model area into 4,784 geographic squares, each measuring 1.75 miles on a side (3 square miles per square), and assigns hydraulic properties, such as transmissivity, hydraulic conductivity, and specific yield, to each square, based upon values quantified in the field, the laboratory, or published literature. Isocline maps are included in the report, as well as maps which demonstrate the effects of increased pumping simulation, and the resulting creation of, or increase in, cones of depression.

Such analysis is included for the shallower aquifers which are considered lacking in sufficient water to support a PWS, but provide good quality potable drinking water with fluoride levels below the MCL. As a result, this USGS report represents a potentially valuable water resources management tool which could be used to optimize pumping of good quality water from shallower aquifers by small PWSs.

Current Research

A contact from the USGS Water Resources Division, Richmond office, is currently in the early stages of a review process in which he is mapping the major ions in the major water producing aquifers of the area. This review may take several months to complete.

Another contact from the USGS Richmond office is currently writing two reports regarding the hydrogeologic characteristics of the aquifers of the Virginia Coastal Plain. One of these reports discusses the results of water flow and ion transport (including fluoride) modeling which USGS has performed on the specific area in southeastern Virginia which is experiencing the excess fluoride problem.

The second report is concerned with the decrease in hydraulic conductivity of the Virginia Coastal Plain from the fall line in the west to the ocean in the east. Hydraulic conductivity is a property of the porous media consistency of a particular aquifer. When multiplied by aquifer thickness, the resulting quantity, transmissivity, provides a measure of an aquifer's water yield. This report will provide transmissivity values for all aquifers in the Virginia Coastal Plain area, including those shallower aquifers which have excellent water quality in general, including low fluoride levels, but are often considered to have insufficient yields to support PWSs in the area.

These reports may be available for public review starting in the fall 1991.

A graduate researcher at Old Dominion University in Norfolk Virginia, is exploring the mineralogy of the coastal region to specifically determine the source of groundwater fluoride. His research has indicated that sodium bicarbonate water worldwide tends to be fluoride-rich, a correlation existing between concentration of sodium bicarbonate and fluoride solubility. The southeastern Virginia fluoride-rich PWSs are in fact in a hydrogeologic band of sodium bicarbonate-rich water.

USGS personnel indicated there are no anthropogenic fluoride sources in southeastern Virginia.

Defluoridation Costs

The number of consumers serviced by the 51 Virginia PWSs with fluoride concentrations exceeding the EPA MCL (4.0 mg/L) is highlighted below:

# of consumers	# of PWSs	% of total # of PWSs
< 300	33	65
300 – 600	15	29
601 –1080	3	6
	51	

Before we discuss the means by which these PWSs can most cost effectively defluoridate, it should be noted that, of the four disposal strategies, only sanitary sewers and sand beds can be

considered as realistic options for southeastern Virginia since sludge lagoons and evaporation ponds are viable options only in relatively dry locales with high evapotranspiration rates. In southeastern Virginia, where the average annual precipitation rate, 43 inches per year (90-2), exceeds the average evapotranspiration rate, 21.5 inches per year (90-2), these disposal strategies are unrealistic.

As indicated earlier in this report, POU is more cost effective than central defluoridation treatment for PWSs servicing less than approximately 100 to 200 households (300 to 600 consumers). POU defluoridation is therefore more cost effective for at least 65% and possibly as high as 94% of the 51 Virginia PWSs with excessive fluoride groundwater concentrations.

This cost analysis is based upon central treatment disposal to existing sanitary sewers. This current research has not determined however whether any of the 51 PWSs are located in close proximity to an existing sanitary sewer. Should a PWS be required to construct either a sanitary sewer or a sand bed, a greater number of households would be required for central defluoridation treatment to be more cost effective than POU.

It is possible that PWSs of a given size might more cost effectively comply with federal fluoride regulations by exercising other compliance options such as: developing a new well which produces water which meets the MCL; connecting to or hauling water from a PWS which produces water which meets the MCL; or purchasing and distributing bottled water which meets the MCL. The short time frame of this current research, however, has prevented this researcher from exploring costs related to these options.

CONCLUSIONS

1.   On 2 April 1986 EPA promulgated the final fluoride rule
      (R86-1), establishing an enforceable primary MCL of 4.0 mg/L
      "to protect against crippling skeletal fluorosis", and a
      non-enforceable secondary MCL of 2.0 mg/L "to protect
      against objectionable dental fluorosis". The regulation
      also identified activated alumina and reverse osmosis as
      BAT. This is the currently applicable federal fluoride
      regulation.

2.   Some prominent national medical, dental and public health
      groups did not support EPA's inclusion of fluoride as a
      contaminant to be regulated by the Primary Drinking Water
      Regulations. Representatives from these organizations still
      maintain opposition.

3.   The most recent comprehensive toxicological analysis of the
      effects of fluoride was published by the Public Health
      Service in February 1991. PHS concluded there is no
      link between fluoride and cancer, and that crippling
      skeletal fluorosis is extremely rare in the United States.
      EPA review of the PHS and other documents is currently in
      progress.

4.   In 1985 about 185,000 people nationwide were serviced by
      public water systems with fluoride concentrations exceeding
      4 mg/L, 17,000 people by those exceeding 6 mg/L, and 3,000
      people by those exceeding 8 mg/L. Some of these public
      water systems have since pursued other drinking water
      sources in order to avoid defluoridation costs. While the
      total number of PWSs with excessive fluoride has decreased,
      this report has not identified whether the total number of
      consumers exposed to excessive fluoride in drinking water
      has changed.

      Comments from the Office of Ground Water and Drinking Water
      (OGWDW), HQ EPA (91-12), indicate that OGWDW has estimates
      regarding population exposure to fluoride at various
      concentrations and that this information will be updated
      concurrent with the next review of the fluoride rule.

5.   Public water systems faced with excess fluoride in their
      groundwater drinking water supply currently have only
      four options to permanently meet fluoride regulations:
      construction of central treatment; developing a new well
      which meets the fluoride regulations; connecting to or
      hauling water from a public water system which is meeting
      the fluoride regulations; or installing point-of-entry
      (POE) devices. In most cases these compliance options are
      relatively expensive operations. Small systems are, in
      effect, penalized by the principle of economy of scale in

constructing and operating central treatment facilities, and in developing new wells.

This report has not identified costs related to connecting to or hauling water from a public water system which is already complying with federal fluoride regulations. Developing costs associated with drilling new wells and connecting to compliant systems, in conjunction with costs developed in this report for other compliance options, would more completely determine the best compliance option which a public water system of a given size should pursue in order to meet federal fluoride regulations.

6. Point-of-use treatment, and purchasing and distributing bottled water are not currently acceptable as long-term options to meet fluoride regulations. For small systems these are oftentimes the only compliance options which are affordable.

7. The effectiveness of POU/POE activated alumina and reverse osmosis defluoridation techniques has been proven. Most experts agree that legal and managerial problems relating to monitoring, testing, and maintenance preclude POU/POE as BAT for fluoride. Some of the operational, legal, and managerial problems associated with POU/POE have been addressed by various reports and studies, particularly, the San Ysidro, New Mexico EPA-sponsored research, and solutions to some of these problems have been proposed.

8. On a per gallon basis, monthly treatment costs for POU/POE technologies are substantially higher than that for central treatment. However, while POE technology processes 100% of household water demand, POU technology requires treatment of only about 10% of such demand. As a result, POU monthly household treatment costs are less than that for both central treatment and POE devices.

9. One time construction costs for POU techniques are substantially less than construction costs for central treatment facilities, especially for small water systems.

10. EPA Cincinnati is currently in the process of writing an RFP to hire a contractor to assess performance of the San Ysidro test.

11. POU/POE technology is still in a state of development but some systems are incorporating techniques approaching state of the art.

12. Construction and annual treatment costs updated for this report indicate that POU defluoridation treatment is more cost effective than central treatment for public water

systems servicing less than about 100 to 200 households (300 to 600 consumers). For public water systems servicing greater than about 200 households (600 consumers), which have a realistic option of disposing to an existing sanitary sewer, central defluoridation becomes increasingly more cost effective than POU. Should disposal to an existing sanitary sewer not be a realistic option, a greater number of households would be required for central defluoridation treatment to be more cost effective than POU.

13. The HQ EPA Low-cost Innovative Small System Initiative anticipates that a mix of POU and POE technologies will be used at the King's Point Subdivision site in Suffolk Virginia to assess the possibilities of defluoridation by decentralized technologies. As of the writing of this report the State of Virginia and the Subdivision were in the process of reviewing the bids submitted by four contractors.

14. A New Hampshire vendor is currently exploring the effectiveness of a POE bone char device to remove fluoride. The device's ability to effectively remove arsenic has been demonstrated. It is known that arsenic and fluoride are similarly removed, in fact competitively, with arsenic removal dominating fluoride removal. A proven arsenic removal technique could potentially remove fluoride, especially in a groundwater source which has small arsenic concentrations.

15. Regarding bone char as a treatment technique, little research has been done to determine optimal processing parameters, though researchers have developed simple operating techniques using bone char for use by illiterate Third World communities. A recently published World Health Organization study indicates that bone char adsorption capacity is comparable to that of activated alumina. Activated alumina is BAT for fluoride. No cost analyses regarding bone char are currently available.

16. A combined alum/lime small-scale defluoridation treatment known as the Nalgonda technique has been developed for use by illiterate people in rural communities in India.

17. The nanofiltration treatment technique has been developed since the April 2, 1986 promulgation of the final fluoride rule. Researchers indicate that the technology requires less energy and produces a substantially smaller waste stream than reverse osmosis. Reverse osmosis is considered best available technology (BAT) for fluoride. Home use nanofiltration devices are currently being developed.

18. A defluoridation technique using hydrous cerium oxide has

recently been developed and patented. While the technique has been used predominantly to treat wastewater, it may be effective for treating groundwater. No cost figures are currently available.

19. Fluoride concentrations in excess of the EPA MCL (4.0 mg/L) effect groundwater-source public water systems throughout the continental United States. Fluoride-rich groundwater occurs in geographic "pockets" and does not normally effect groundwater on a regional-scale. Fluoride in groundwater is predominantly a naturally occurring phenomena.

20. On-going United States Geological Survey research is quantifying major hydrogeological and water chemistry parameters of the Virginia Coastal Plain on an aquifer by aquifer basis using modeling nodes separated by as few as two miles. This data represents a potentially valuable water resources management tool which could be used to assist local public water systems in selecting well sites. Some of the reports which USGS is currently preparing may be available for public view as early as fall 1991.

21. While 51 Virginia public water systems use groundwater drinking water sources which exceed the EPA fluoride MCL (4.0 mg/L), only four of these water supplies have concentrations exceeding 6.0 mg/L, the highest being 6.60 mg/L.

22. POU defluoridation is more cost effective than central treatment for at least 65% and possibly as high as 94% of the 51 Virginia public water systems with fluoride concentrations exceeding the EPA MCL. Should any of these systems be required to construct either a sanitary sewer or a sand bed, the number of systems for which POU is more cost effective would increase. This report has not identified the proximity of existing sanitary sewers to any of the 51 public water systems.

23. It is possible that some of the 51 Virginia public water systems with excessive groundwater fluoride concentrations might comply more cost effectively with federal fluoride regulations by either developing a new compliant well, connecting to or hauling water from a compliant public water system, or purchasing and distributing compliant bottled water. This report has not identified costs associated with these three options.

RECOMMENDATIONS

1. EPA could profitably gain by continuing efforts to determine
    the number of consumers exposed to excessive fluoride at
    various levels in drinking water in order to determine risk
    factors associated with fluoride exposure in the United
    States today.
    (See conclusion 4)

2. EPA could profitably gain from efforts to develop costs
    associated with drilling new wells, connecting to compliant
    systems, and purchasing and distributing compliant bottled
    water to determine the best compliance option which a public
    water system of a given size should pursue in order to meet
    federal fluoride regulations.
    (See conclusion 5 and 23)

3. EPA could profitably gain by continuing to address the
    operational, legal and managerial problems associated with
    POU/POE techniques, as revealed in the San Ysidro, New
    Mexico research and other POU/POE studies. Resolving these
    problems could lead to eventual inclusion of POU/POE
    defluoridation as BAT.
    (See conclusions 6 through 12, and 22)

4. EPA could profitably gain by continuing to stimulate
    industry development of POU/POE techniques by encouraging
    industry to engage in the Low-cost Innovative Small System
    Initiative and other creative and alternative programs. The
    San Ysidro experience should assist EPA in honing RFP
    requirements to achieve better industry response.
    (See conclusions 10, 11 and 13)

5. EPA could profitably gain from efforts to assess the
    effectiveness of bone char as both a central and POU/POE
    treatment technique.
    (See conclusions 14 and 15)

6. EPA could profitably gain from efforts to assess the
    effectiveness of the Nalgonda technique as a small-scale
    defluoridation option.
    (See conclusion 16)

7. EPA could profitably gain from efforts to assess the
    effectiveness of nanofiltration as both a central and
    POU/POE defluoridation option.
    (See conclusion 17)

8. EPA could profitably gain from efforts to assess the
    effectiveness of adsorption by cerium oxide as a
    defluoridation option.
    (See conclusion 18)

9. EPA could profitably gain by working in conjunction with the
    United States Geological Survey in assisting public water
    systems in selecting well drilling sites.
    (See conclusions 19 and 20)

REFERENCES

Regulations:

R91-1   Federal Register, Part II, Environmental
           Protection Agency, 40 CFR Parts 141,142, and 143
           National Primary Drinking Water Regulations;
           Final Rule, January 30, 1991

R86-1   Federal Register, Part II, Environmental
           Protection Agency, 40 CFR Parts 141, 142 and 143
           National Primary and Secondary Drinking Water
           Regulations; Fluoride; Final Rule, April 2, 1986

R85-1   Federal Register, Part II, Environmental
           Protection Agency, 40 CFR Part 141 Fluoride;
           National Primary Drinking Water Regulations;
           Proposed Rule, May 14, 1985

Journals, Technical Articles, Texts and Correspondences:

91-1   Regeneration by Surface-Coating of Bone Char Used for
       Defluoridation of Water, by J. Christoffersen, M.
       Christoffersen, Larsen & Moller, Water Resources, v25, n2,
       1991

91-2   Review of Fluoride Benefits and Risks, Report of the Ad Hoc
       Subcommittee on Fluoride of the Committee to Coordinate
       Environmental Health and Related Programs, conducted by the
       National Toxicology Program of the Public Health Service, US
       Department of Health and Human Services, February 1991

91-3   Completed Questionnaire for Potential Public-Private
       Partnership Demonstration Projects submitted by the Public
       Utilities Manager, Town of Colchester, Connecticut to EPA
       Region I. Provided by George Mollineaux, P3 contact point,
       EPA Region I

91-4   Fax from Chuck Botdorf, Yuma Proving Grounds, 10 July 1991

91-5   Fax from Chuck Botdorf, Yuma Proving Grounds, 15 July 1991

91-6   Information package re: HMR Black (Bone Char) submitted by
       Pristine Filter Corporation, Melvindale Michigan, contact:
       Mike Szczepanik, 15 July 1991

91-7   Revised Draft Workgroup Version of Variance and Exemption
       Rule Preamble and Regulations, originated by Office of
       Ground Water and Drinking Water, WH550E, HQ EPA, cover
       letter dated 16 May 1991

91-8 Engineering News-Record, 29 July 1991

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TELEPHONE CONTACTS

Note: The following contacts furnished information deemed
      pertinent to this report.

HQ EPA

        Mark Parrotta, Office of Drinking Water and Ground Water

        Dr. Ken Bailey, Office of Science and Technology

        Al Havinga, regarding POU/POE policy

        Dr. David Schnare, regarding low-cost technology initiative

EPA Cincinnati Research Facility

        Tom Sorg

        Jim Smith

        Ben Lykins

EPA Regional Offices

        John Haederlie, Region I, Boston

        George Mollineaux, Region I, Boston

        Steve Gould, Region II, New York

        Kenneth Dean, Region IV, Atlanta

        Harry Pawlowski, Region V, Chicago

        Chris Urban, Region V, Chicago

        Bill Davis, Region VI, Dallas

        Len Pardee, Region VI, Dallas

        Stan Calow, Region VII, Kansas City

        Melanie Abel, Region VIII, Denver

        Bob Benson, Region VIII, Denver

        Bruce Macler, Region IX, San Francisco

Alan Hemming, Region, X, Seattle

National Institute of Health, Public Health Service

John Small, fluoride expert

State Drinking Water Personnel

Dan Horne, Field Office Director, Virginia Dept of Health

Shahram Mohsenin, engineer, Virginia Department of Health,
Virginia Beach Regional Office

Michael Bell, North Carolina State's Regional Drinking Water
Office in eastern part of the state, Washington NC

Marvin Murray, South Carolina Drinking Water Office

John Dahl, Arizona State's Drinking Water Office

Bob Burns, California Department of Health Services

Norm Hahn, Wisconsin Department of Natural Resources

Private Research Organizations

Gordon Bellen, National Sanitation Foundation, Ann
Arbor, Michigan

Tom Stevens, National Sanitation Foundation, Ann
Arbor, Michigan

Joe Harrison, technical director, Waste Quality
Association, Lisle, Illinois

John Trax, National Rural Water Association, Washington DC

Water Utility Managers/Operators

Chuck Botdorf, Yuma Proving Grounds

Bud Eure, Gates County North Carolina Water Supply

Chester Antonick, Sue Juan Water Co., Arizona

Tom Werner, engineer in charge of water protection,
City of Suffolk, Virginia

Wayne Johnson, head of water lab, Yuma Bureau of
Reclamation Desalting Plant

William Harrell, Director of Public Utilities, City
of Suffolk, Virginia

University Research Facilities

Paul Maciuika, graduate student researching fluoride
in southeastern Virginia groundwater, Old Dominion
University, Norfolk, Virginia

Dr. Brent Cluff, nanofiltration researcher, University
of Arizona at Tucson

Medical Profession

Dr. Mike Morgan, Oklahoma State Health Department, State
Dental Director, former Chairman of the Association of
State and Territorial Dental Directors

Dr. Lum Young, Nebraska State Health Department, State
Dental Director, former Chairman, Fluoride Committee,
Association of State and Territorial Dental Directors

Dr. Duncan Clark, American Medical Association, New York
City

Tom Reeves, Center for Disease Control, Atlanta Georgia

Dr. Mel Ringelberg, Florida State Dental Director, Chairman
Fluoride Committee, Tallahassee, Florida

Water Industry Consulting/Marketing/Production Personnel

Ron Saylor, marketing representative, nanofiltration
technology

Frank Brigano, Culligan

Bob Lake, Water Treatment Engineers, consulting firm,
Tucson Arizona

Mike & Ann Szczepanik, Ebonex Co., producers of bone black
(bone char), Melvindale Michigan

Mark Widdison, Culligan of New Hampshire

Greg Gwaltney, ECOS, consulting firm coordinating the King's

Point Subdivision Low-cost Innovative Small System
Initiative

United States Geological Survey

Gary Speiran, Richmond Virginia office

Mike Socazio, Richmond Virginia office

Bob Mixon, Reston Virginia office

Other

Joe Carpenter Jr., private developer in Suffolk, Virginia
area

Chris Mauro, Bureau of Labor Statistics, Philadelphia PA

Andrea Jones, Bureau of Labor Statistics, Philadelphia PA

Debra Darr, Hampton Roads Planning District Commission,
Hampton Roads, Virginia

CONSTRUCTION COST SUMMARY - CENTRAL TREATMENT - ACTIVATED ALUMINA

Cost Category	plant capacity (millions of gallons per day)						
	.046	.102	.180	.406	.552	.720	1.080
Excavation and sitework	5,725	5,725	5,725	5,725	5,725	5,725	5,725
Manufactured equipment							
Equipment	16,090	30,042	49,149	63,604	81,077	91,635	126,957
Activated alumina	1,834	4,061	7,074	15,589	20,174	25,676	38,514
Concrete	469	1,406	2,110	2,344	2,930	3,750	4,805
Labor	1,462	1,827	2,436	3,410	4,019	4,141	5,116
Piping & valves	7,030	8,788	8,788	11,357	17,306	17,982	27,175
Electrical instrumentation	7,347	7,347	7,347	9,184	9,184	9,758	11,021
Housing	9,970	16,502	19,367	20,513	28,421	39,422	50,309
Subtotal	49,927	75,698	101,996	131,726	168,836	198,089	269,622
Design contingencies	7,489	11,355	15,299	19,759	25,325	29,713	40,443
TOTAL ***	57,416	87,053	117,295	151,485	194,161	227,802	310,065

*** based on labor cost of $13.40 per hour

OPERATION AND MAINTENANCE COST SUMMARY - CENTRAL TREATMENT - ACTIVATED ALUMINA

avg plant flow rate (gpd)	act alumina volume (cubic feet)	bldng	energy ($/yr) process	total	maintenance material ($/yr)	labor ($/yr)	total cost *** ($/yr)
Regeneration frequency = 4.5 days							
45,000	31.4	268	590	858	1,073	17,152	19,083
101,000	70.7	469	1,273	1,742	1,907	17,152	20,801
180,000	126	603	2,224	2,827	2,980	17,849	23,656
406,000	283	657	2,452	3,109	6,079	17,849	27,037
553,000	385	978	2,452	3,430	8,106	18,546	30,082
722,000	503	1,635	2,452	4,087	10,370	18,546	33,003
1,083,000	754	2,291	2,452	4,743	15,138	24,683	44,564
Regeneration frequency = 8 days							
45,000	31.4	268	590	858	834	12,248	13,940
101,000	70.7	469	1,273	1,742	1,311	12,248	15,301
180,000	126	603	2,224	2,827	1,907	12,944	17,678
406,000	283	657	2,452	3,109	3,576	12,944	19,629
553,000	385	978	2,452	3,430	4,768	13,641	21,839
722,000	503	1,635	2,452	4,087	5,960	13,641	23,688
1,083,000	754	2,291	2,452	4,743	8,702	17,326	30,771
Regeneration frequency = 12 days							
45,000	31.4	268	590	858	715	10,398	11,971
101,000	70.7	469	1,273	1,742	1,073	10,398	13,213
180,000	126	603	2,224	2,827	1,550	11,095	15,472
406,000	283	657	2,452	3,109	2,622	11,095	16,826
553,000	385	978	2,452	3,430	3,457	11,792	18,679
722,000	503	1,635	2,452	4,087	4,410	11,792	20,289
1,083,000	754	2,291	2,452	4,743	6,198	14,539	25,480

*** based upon labor costs of $13.40 per hour and energy costs of $.134 per kwh

OPERATION AND MAINTENANCE COST SUMMARY - CENTRAL TREATMENT - ACTIVATED ALUMINA

avg plant flow rate (gpd)	act alumina volume (cubic feet)	bldng	energy ($/yr) process	total	maintenance material ($/yr)	labor ($/yr)	total cost *** ($/yr)
Regeneration frequency = 19 days							
45,000	31.4	268	590	858	596	8,844	10,298
101,000	70.7	469	1,273	1,742	834	8,844	11,420
180,000	126	603	2,224	2,827	1,192	9,541	13,560
406,000	283	657	2,452	3,109	1,907	9,541	14,557
553,000	385	978	2,452	3,430	2,384	10,238	16,052
722,000	503	1,635	2,452	4,087	2,980	10,238	17,305
1,083,000	754	2,291	2,452	4,743	4,172	12,221	21,136
Regeneration frequency = 33 days							
45,000	31.4	268	590	858	596	7,772	9,226
101,000	70.7	469	1,273	1,742	715	7,772	10,229
180,000	126	603	2,224	2,827	954	8,469	12,250
406,000	283	657	2,452	3,109	1,311	8,469	12,889
553,000	385	978	2,452	3,430	1,669	9,166	14,265
722,000	503	1,635	2,452	4,087	2,026	9,166	15,279
1,083,000	754	2,291	2,452	4,743	2,742	10,613	18,098
Regeneration frequency = 48 days							
45,000	31.4	268	590	858	596	7,316	8,770
101,000	70.7	469	1,273	1,742	596	7,316	9,654
180,000	126	603	2,224	2,827	834	8,013	11,674
406,000	283	657	2,452	3,109	1,192	8,013	12,314
553,000	385	978	2,452	3,430	1,430	8,710	13,570
722,000	503	1,635	2,452	4,087	1,669	8,710	14,466
1,083,000	754	2,291	2,452	4,743	2,146	9,916	16,805

*** based upon labor costs of $13.40 per hour and energy costs of $.134 per kwh

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CHEMICAL COST SUMMARY - CENTRAL TREATMENT - ACTIVATED ALUMINA

avg plant flow rate (gpd)	sulfuric * acid ($/yr)	sodium * hydroxide ($/yr)	total cost ($/yr)
11,900	535	2,017	2,552
473,000	550	17,100	17,650

* see discussion in paragraph entitled MISCELLANEOUS NOTES REGARDING COST CALCULATIONS

DISPOSAL COST SUMMARY - CENTRAL TREATMENT - ACTIVATED ALUMINA

avg plant flow rate (gpd)	avg sludge flow rate (gpd)	total cost *** ($/yr)
670	20	19
1,700	50	38
3,300	100	88
6,700	200	175
16,700	500	427
33,300	1,000	855
66,700	2,000	1,760
167,000	5,000	4,300
333,000	10,000	8,500
667,000	20,000	17,100

*** assumes a suspended solids concentration on the order of 2,000 mg/L

CONSTRUCTION COST SUMMARY - CENTRAL TREATMENT - REVERSE OSMOSIS

Cost Category	plant capacity (gallons per day)					
	2,500	10,000	50,000	100,000	500,000	1,000,000
Manufactured equipment	25,517	37,710	87,487	154,611	571,684	1,102,892
Labor	974	1,462	1,827	3,410	9,135	17,783
Electrical instrumentation	3,674	5,281	12,284	21,468	52,693	71,291
Housing	13,637	15,929	18,794	21,201	44,006	60,165
Subtotal	43,802	60,382	120,392	200,690	677,518	1,252,131
Design contingencies	6,570	9,057	18,059	30,104	101,628	187,820
TOTAL ***	50,372	69,439	138,451	230,794	779,146	1,439,951

*** based on labor costs of $13.40 per hour

OPERATION AND MAINTENANCE COST SUMMARY -CENTRAL TREATMENT- REVERSE OSMOSIS (Low Pressure)

avg plant flow rate (qpd)	energy ($/yr) bldng	energy ($/yr) process	energy ($/yr) total	maintenance material ($/yr)	labor ($/yr)	total cost*** ($/yr)
TDS concentration = 5,000 mg/L						
2,500	375	1,327	1,702	596	4,556	6,854
10,000	442	3,524	3,966	2,026	4,824	10,816
50,000	549	13,413	13,962	9,536	6,432	29,930
100,000	657	24,174	24,831	17,403	8,174	50,408
500,000	2,090	114,329	116,419	79,983	11,658	208,060
1,000,000	3,926	215,204	219,130	140,537	15,142	374,809

*** based upon labor costs of $13.40 per hour and energy cost of $.134 per kwh

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OPERATION AND MAINTENANCE COST SUMMARY -CENTRAL TREATMENT- REVERSE OSMOSIS (High Pressure)

avg plant flow rate (gpd)	bldng	energy ($/yr) process	total	maintenance material ($/yr)	labor ($/yr)	total cost*** ($/yr)
TDS concentration = 5,000 mg/L						
2,500	375	2,412	2,787	596	4,556	7,939
10,000	442	6,459	6,901	2,026	4,824	13,751
50,000	549	25,607	26,156	9,536	6,432	42,124
100,000	657	46,150	46,807	17,403	8,174	72,384
500,000	2,090	218,286	220,376	79,983	11,658	312,017
1,000,000	3,926	410,844	414,770	140,537	15,142	570,379
TDS concentration = 8,000 mg/L						
2,500	375	2,412	2,787	596	4,556	7,939
10,000	442	6,459	6,901	2,026	4,824	13,751
50,000	549	25,607	26,156	9,536	6,432	42,124
100,000	657	49,982	50,639	17,761	8,442	76,842
500,000	2,090	272,851	274,941	83,678	12,596	371,215
1,000,000	3,926	513,555	517,481	146,497	16,348	680,326
TDS concentration = 10,000 mg/L						
2,500	375	2,412	2,787	596	4,556	7,939
10,000	442	6,459	6,901	2,026	4,824	13,751
50,000	549	25,607	26,156	9,536	6,432	42,124
100,000	657	59,992	60,649	18,476	9,112	88,237
500,000	2,090	327,429	329,519	87,254	13,668	430,441
1,000,000	3,926	616,266	620,192	152,218	17,554	789,964

*** based upon labor costs of $13.40 per hour and energy costs of $.134 per kwh

CHEMICAL COST SUMMARY - CENTRAL TREATMENT - REVERSE OSMOSIS

avg plant flow rate (gpd)	sodium hexametaphosphate ($/yr)	sulfuric acid ($/yr)	sodium hydroxide ($/yr)	total cost ($/yr)
2,500	145	134	97	376
10,000	558	512	388	1,458
50,000	2,232	2,037	1,514	5,783
100,000	3,460	3,116	2,329	8,905
500,000	14,954	13,579	10,093	38,626

DISPOSAL COST SUMMARY – CENTRAL TREATMENT – REVERSE OSMOSIS

avg plant flow rate (gpd)	avg sludge flow rate (gpd)	total cost *** ($/yr)
150	20	19
390	50	38
770	100	88
1,540	200	175
3,850	500	427
7,700	1,000	855
15,400	2,000	1,760
38,500	5,000	4,300
77,000	10,000	8,500
154,000	20,000	17,100

*** assumes suspended solids concentration on the order of 2,000 mg/L

CONSTRUCTION COST SUMMARY - CENTRAL TREATMENT - ELECTRODIALYSIS

Cost Category	plant capacity (gallons per day)					
	1,500	8,000	30,000	100,000	300,000	1,000,000
Excavation and sitework	2,558	3,654	4,263	5,725	6,090	11,327
Manufactured equipment	19,484	45,378	103,577	161,902	349,572	1,229,975
Concrete	352	586	1,055	1,524	2,696	5,274
Labor	853	1,827	2,071	3,167	7,064	24,725
Electrical instrumentation	2,755	4,936	9,414	11,824	22,271	67,158
Housing	8,939	12,377	20,628	25,785	36,787	48,132
Subtotal	34,941	68,758	141,008	209,927	424,480	1,386,591
Design contingencies	5,241	10,314	21,151	31,489	63,672	207,989
TOTAL ***	40,182	79,072	162,159	241,416	488,152	1,594,580

*** based upon labor costs of $13.40 per hour

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OPERATION AND MAINTENANCE COST SUMMARY - CENTRAL TREATMENT - ELECTRODIALYSIS

avg plant flow rate (gpd)	bldng	energy ($/yr) process	total	maintenance material ($/yr)	labor ($/yr)	total cost*** ($/yr)
TDS concentration = 1,000 mg/L						
1,500	268	348	616	238	3,618	4,472
8,000	389	1,876	2,265	954	4,958	8,177
30,000	791	7,048	7,839	3,338	6,164	17,341
100,000	1,072	23,477	24,549	10,966	7,370	42,885
300,000	1,997	70,430	72,427	27,416	8,576	108,419
1,000,000	6,553	234,768	241,321	108,830	14,740	364,891
TDS concentration = 2,000 mg/L						
1,500	268	496	764	238	4,020	5,022
8,000	389	2,667	3,056	1,073	5,494	9,623
30,000	791	9,983	10,774	3,934	6,834	21,542
100,000	1,072	33,259	34,331	13,112	8,174	55,617
300,000	1,997	99,776	101,773	32,661	9,380	143,814
1,000,000	6,553	332,588	339,141	130,524	16,080	485,745
TDS concentration = 3,000 mg/L						
1,500	268	643	911	238	4,422	5,571
8,000	389	3,444	3,833	1,311	6,030	11,174
30,000	791	12,918	13,709	4,649	7,504	25,862
100,000	1,072	43,041	44,113	15,258	8,978	68,349
300,000	1,997	129,122	131,119	38,144	10,318	179,581
1,000,000	6,553	430,408	436,961	152,338	17,688	606,987

*** based upon labor costs of $13.40 per hour and energy costs of $.134 per kwh

DISPOSAL COST SUMMARY - CENTRAL TREATMENT - ELECTRODIALYSIS

avg plant flow rate (gpd)	avg sludge flow rate (gpd)	total cost *** ($/yr)
150	20	19
390	50	38
770	100	88
1,540	200	175
3,850	500	427
7,700	1,000	855
15,400	2,000	1,760
38,500	5,000	4,300
77,000	10,000	8,500
154,000	20,000	17,100

*** assumes suspended solids concentration on the order of 2,000 mg/L

CONSTRUCTION COST SUMMARY - CENTRAL TREATMENT - ALUM COAGULATION

Cost Category	average plant flow rate (gallons per day)				
	72,100	216,000	432,000	576,000	1,152,000
Excavation and sitework	3,289	5,116	6,577	8,891	14,860
Manufactured equipment	39,344	56,314	73,157	84,848	161,902
Concrete	4,805	7,149	10,079	12,775	22,385
Labor - installation	7,917	10,109	11,693	12,667	24,360
Piping & valves	1,217	3,921	5,949	7,571	11,357
Electrical instrumentation	2,985	3,329	3,559	4,018	6,084
Housing	21,774	29,108	35,984	43,548	59,019
Subtotal	81,331	115,046	146,998	174,318	299,967
Design contingencies	12,200	17,257	22,050	26,148	44,995
TOTAL ***	93,531	132,303	169,048	200,466	344,962

*** based upon labor costs of $13.40 per hour

OPERATION AND MAINTENANCE COST SUMMARY – CENTRAL TREATMENT – ALUM COAGULATION

settling surface area (square feet)	avg plant flow rate (gpd)	bldng	energy ($/yr) process	total	maintenance material ($/yr)	labor ($/yr)	total cost *** ($/yr)
70	72,000	657	442	1,099	298	1,742	3,139
140	216,000	1,018	442	1,460	358	2,613	4,431
250	432,000	1,461	670	2,131	447	2,787	5,365
370	576,000	1,983	898	2,881	536	3,484	6,901
740	1,152,000	3,739	1,782	5,521	1,013	4,529	11,063

*** based upon labor costs of $13.40 per hour and energy costs of $.134 per kwh

CHEMICAL COST SUMMARY - CENTRAL TREATMENT - ALUM COAGULATION

avg plant flow rate (gpd)	total cost * ($/yr)
72,000	15,091
216,000	45,273

* see discussion in paragraph entitled MISCELLANEOUS NOTES REGARDING COST CALCULATIONS

DISPOSAL COST SUMMARY - CENTRAL TREATMENT - ALUM COAGULATION

avg plant flow rate (gpd)	avg sludge flow rate (gpd)	total cost *** ($/yr)
150	20	19
390	50	38
770	100	88
1,540	200	175
3,850	500	427
7,700	1,000	855
15,400	2,000	1,760
38,500	5,000	4,300
77,000	10,000	8,500
154,000	20,000	17,100

*** assumes suspended solids concentration on the order of 2,000 mg/L

CONSTRUCTION COST SUMMARY - CENTRAL TREATMENT - LIME SOFTENING

	plant capacity (gallons per day)				
Cost Category	15,000	150,000	430,000	750,000	1,000,000
Single Stage					
Excavation and sitework	4,263	7,064	8,161	10,231	11,936
Manufactured equipment	41,732	62,599	83,339	108,353	130,477
Concrete	1,289	2,930	3,750	6,915	8,204
Labor - installation	17,052	22,168	34,104	44,335	53,348
Piping & valves	7,030	14,061	19,063	22,578	62,057
Electrical instrumentation	9,758	14,006	19,516	21,697	30,652
Housing	10,085	18,794	22,691	34,380	37,818
Subtotal	91,209	141,622	190,624	248,489	334,492
Design contingencies	13,681	21,243	28,594	37,273	50,174
TOTAL ***	104,890	162,865	219,218	285,762	384,666

*** based upon labor costs of $13.40 per hour

CONSTRUCTION COST SUMMARY - CENTRAL TREATMENT - LIME SOFTENING

	plant capacity (gallons per day)				
Cost Category	15,000	150,000	430,000	750,000	1,000,000
Two Stage					
Excavation and sitework	7,064	11,327	13,520	17,052	19,975
Manufactured equipment	67,250	100,937	134,499	174,849	210,548
Concrete	2,110	4,922	6,446	11,720	13,830
Labor - installation	28,501	37,027	56,881	73,933	88,914
Piping & valves	14,061	28,257	38,126	44,616	124,114
Electrical instrumentation	17,015	24,682	34,210	37,884	53,841
Housing	17,878	29,796	35,984	50,424	55,008
Subtotal	153,969	236,948	319,666	410,478	566,230
Design contingencies	23,095	35,542	47,950	61,572	84,935
TOTAL ***	177,064	272,490	367,616	472,050	651,165

*** based upon labor costs of $13.40 per hour

OPERATION AND MAINTENANCE COST SUMMARY – CENTRAL TREATMENT – LIME SOFTENING

avg plant flow rate (gpd)	bldng	energy ($/yr) process	total	maintenance material ($/yr)	labor ($/yr)	total cost*** ($/yr)
Single Stage						
15,000	268	1,018	1,286	2,265	14,673	18,224
150,000	549	1,367	1,916	3,457	14,673	20,046
430,000	724	2,090	2,814	4,649	19,564	27,027
750,000	1,313	4,636	5,949	5,841	19,564	31,354
1,000,000	1,568	5,199	6,767	7,271	24,522	38,560
Two Stage						
15,000	523	1,688	2,211	3,814	19,564	25,589
150,000	1,099	2,278	3,377	5,722	19,564	28,663
430,000	1,434	3,484	4,918	7,629	24,522	37,069
750,000	2,613	7,048	9,661	9,655	24,522	43,838
1,000,000	3,136	7,986	11,122	14,662	29,346	55,130

*** based upon labor costs of $13.40 per hour and energy costs of $.134 per kwh

CHEMICAL COST SUMMARY - CENTRAL TREATMENT - LIME SOFTENING

avg plant flow rate (gpd)	lime ($/yr)	soda ash ($/yr)	carbon dioxide ($/yr)	total cost ($/yr)
Single stage				
15,000	195	0	22	217
150,000	1,950	0	220	2,170
Two stage				
15,000	330	390	87	807
150,000	3,300	3,900	870	8,070

DISPOSAL COST SUMMARY - CENTRAL TREATMENT - LIME SOFTENING

avg plant flow rate (gpd)	avg sludge flow rate (gpd)	total cost *** ($/yr)
150	20	19
390	50	38
770	100	88
1,540	200	175
3,850	500	427
7,700	1,000	855
15,400	2,000	1,760
38,500	5,000	4,300
77,000	10,000	8,500
154,000	20,000	17,100

*** assumes suspended solids concentration on the order of 2,000 mg/L

CONSTRUCTION COST SUMMARY - CENTRAL TREATMENT - NANOFILTRATION

plant capacity (gallons per day)

	7,000	40,000	63,000	500,000	1,000,000	2,000,000
TOTAL	10,000	60,000	78,000	475,000*	750,000*	1,250,000

* per reference 89-8; all other data derived from written material and telephone
  conversations with a nanofiltration researcher and his marketing representative

OPERATION & MAINTENANCE / CHEMICAL COST SUMMARY - CENTRAL TREATMENT - NANOFILTRATION

avg plant
flow rate
  (gpd)   total cost ($/yr)

    40,000   14,600   (per nanofiltration researcher/marketing rep)
   500,000   120,450   (per reference 89-8)
 1,000,000   248,200   (per reference 89-8)

DISPOSAL COST SUMMARY - CENTRAL TREATMENT - NANOFILTRATION

avg plant flow rate (gpd)	avg sludge flow rate (gpd)	total cost *** ($/yr)
150	20	19
390	50	38
770	100	88
1,540	200	175
3,850	500	427
7,700	1,000	855
15,400	2,000	1,760
38,500	5,000	4,300
77,000	10,000	8,500
154,000	20,000	17,100

*** assumes suspended solids concentration on the order of 2,000 mg/L

CONSTRUCTION COST SUMMARY - POU - ACTIVATED ALUMINA

cost category	construction cost POU
activated alumina filter canister	251
plastic meter box & 10 in PVC pipe collar	0 - 41
PVC piping to house	0 - 27
faucet & fittings	54
labor - installation	49 - 146
subtotal	354 - 519
contingency	53 - 78
total	407 - 597

OPERATION AND MAINTENANCE COST SUMMARY - POU - ACTIVATED ALUMINA

| | | | total cost ($/yr) *** | |
cost category	labor ($/yr)	materials ($/yr)	specific condition	mid-range condition
sampling/testing frequency				
twice per year	27	24	51	
4 times per year	80	48	128	128
6 times per year	161	72	233	
media regeneration frequency				
twice per year	27	119	146	
once per year	13	60	73	73
once every two years	7	30	37	
repairs				
low	13	12	25	
average	27	24	51	51
high	40	36	76	

TOTAL FOR MID-RANGE CONDITION   252

*** based upon labor cost of $13.40 per hour

CONSTRUCTION COST SUMMARY - POU - REVERSE OSMOSIS

	construction cost
cost category	POU
manufactured equipment	323* - 415
labor - installation	40* - 61
subtotal	363* - 476
contingency	54* - 71
total	417* - 547

* these figures were derived from updating costs associated with the San Ysidro, NM experience;
  see discussion in paragraph entitled MISCELLANEOUS NOTES REGARDING COST CALCULATIONS

OPERATION AND MAINTENANCE COST SUMMARY - POU - REVERSE OSMOSIS

| | | | total cost ($/yr) *** | |
cost category	labor ($/yr)	materials ($/yr)	specific condition	mid-range condition
sampling/testing frequency				
twice per year	27	48	75	
4 times per year	54	95	149	149
6 times per year	80	143	223	
pre-filter and GAC contactor replacement frequency				
once per year	13	24	37	
twice per year	27	48	75	75
RO membrane replacement				
once per year	13	89	102	
once every 2 years	7	45	52	52
once every 3 years	4	30	34	
repairs				
low	13	12	25	
average	27	24	51	51
high	40	36	76	

TOTAL FOR MID-RANGE CONDITION   112* - 327

* derived from San Ysidro, NM experience;
  see discussion in paragraph entitled MISCELLANEOUS NOTES REGARDING COST CALCULATIONS
  of this report

*** based upon labor costs of $13.40 per hour