EPA Cost Evaluation of Small System Compliance Options: Point-of-Use and Point-of-Entry Treatment Units

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ACRONYMS AND ABBREVIATIONS

AA	Activated alumina
Ag	Silver
Al	Aluminum
As	Arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
AWWA	American Water Works Association
AX	Anion exchange
Ba	Barium
BRAA	Bonestroo, Rosene, Anderlik, and Associates
$CaCO_3$	Calcium carbonate
CAM	Cellulose acetate membrane
Cd	Cadmium
CDC	Centers for Disease Control
Cr	Chromium
Cu	Copper
CX	Cation exchange
DBA	Diffuse bubble aeration
DBCP	Dibromochloropropane
DCE	Dichloroethylene
DCP	Dichloropropane
DWRD	Drinking Water Research Division (of U.S. EPA)
EBCT	Empty bed contact time
EDB	Ethyldibromide
EPA	United States Environmental Protection Agency
F	Fluoride
Fe	Iron
GAC	Granulated activated carbon
gpd	Gallons per day
gpm	Gallons per minute
GWCTF	Ground Water Contamination Task Force
Hg	Mercury
HPC	Heterotrophic plate count
IDEM	Indiana Department of Environmental Management
IEPA	Illinois Environmental Protection Agency
IX	Ion exchange
K	Potassium
LCWQID	Lake Carmel Water Quality Improvement District
MCL	Maximum contaminant level
eq	Milliequivalent
mg	Milligram

ACRONYMS AND ABBREVIATIONS (continued)

Mg	Magnesium
Mo	Molybdenum
Na	Sodium
Ni	Nickel
NPL	National Priorities List
NSF	National Sanitation Foundation
O&M	Operation and maintenance
P	Phosphorous
PAC	Powdered activated carbon
Pb	Lead
PCE	Perchloroethylene
pCi	Picocuries
POE	Point-of-entry
POU	Point-of-use
PPI	Producer Price Index
psi	Pounds-per-square-inch
PTA	Packed tower aeration
PVC	Polyvinylchloride
Ra	Radium
Rn	Radon
RIA	Regulatory Impact Analysis
RO	Reverse osmosis
SDWA	Safe Drinking Water Act
Se	selenium
Si	Silicon
SID	Solano Irrigation District
SPC	Standard plate count
TCA	Trichloroethane
TCE	Trichloroethylene
TDS	Total dissolved solids
TFM	Thin film membrane
THA	Tiskillwa Homeowner's Association
TOC	Total organic carbon
WDNR	Wisconsin Department of Natural Resources
WQA	Water Quality Association
Zn	Zinc

EXECUTIVE SUMMARY

To provide small water systems with greater flexibility, the 1996 Amendments to the Safe Drinking Water Act require the Administrator of the United States Environmental Protection Agency to create a list of affordable technologies and treatment techniques that will reduce contaminants in drinking water to meet all maximum contaminant levels established by the National Primary Drinking Water Regulations. The Administrator is required to consider point-of-entry (POE) and point-of-use (POU) treatment devices for inclusion on the list of affordable technologies.

The purpose of this report is to develop broadly applicable cost equations for implementing POE and POU treatment strategies in small communities. Cost equations were developed and verified through a four step process.

1. Information regarding the experiences of small communities that used POE and POU devices to remove contaminants found in their water supply was gathered from the literature and analyzed. Performance data for various POE and POU technologies were also collected.

2. Vendors of household water treatment equipment were contacted to obtain current pricing information and to determine the factors that drive the costs of POE and POU devices.

3. Cost equations were developed for treatment technologies that could be used to reduce the concentration of various contaminants. These cost equations incorporated nationally applicable wholesale pricing information, technical expertise of original equipment manufacturers, and contractor expertise.

4. The cost equations developed in Step 3 were compared with the cost data derived from the case studies and vendors. Any inconsistences were examined and addressed.

POU treatment strategies were determined to be more cost effective than central treatment for the reduction of arsenic (fewer than 75 households), copper (fewer than 30 households), alachlor (fewer than 70 households), and nitrate (fewer than 180 households). POE treatment was determined to be more cost effective than central treatment for the reduction of arsenic (fewer than 50 households), copper (fewer than 15 households), alachlor (fewer than 10 households), and nitrate (fewer than 40 households).

Cost Evaluation of Small System Compliance Options

Point-of-Use and Point-of-Entry Treatment Units

1.0 Background and Introduction

1.1 Regulatory Background

Centralized treatment of drinking water offers many advantages to communities and the water systems that serve them. First, all water supplied to the community is treated to the standards of the National Primary Drinking Water Regulations (NPDWRs). Second, significant economies of scale for both capital and operating costs exist for large communities. Third, central treatment permits comprehensive control of water quality through operation, maintenance, monitoring, and regulatory oversight. Fourth, the size of these operations permits the extension of treatment cycles (decreasing costs) through the blending of water from more than one source. However, the implementation of central treatment presents several problems, especially for small or financially disadvantaged communities and water systems. First, capital costs may prove prohibitive. Second, it may be difficult to retain a trained plant operator. Third, disposal of waste brine or spent media from a central treatment plant may be extremely expensive. Fourth, significantly more water will be treated to drinking water quality than may be necessary for drinking and cooking purposes.

Amended in 1996, section 1412(b)(4)(E)(i) of the Safe Drinking Water Act (SDWA) requires "each national primary drinking water regulation which establishes a maximum contaminant level [MCL]," to "list the technology, treatment techniques, and other means which the Administrator finds feasible for purposes of meeting such maximum contaminant level." Section 1412(b)(4)(E)(ii) requires the Administrator to "include in the list any technology, treatment technique, or other means that is affordable, as determined by the Administrator in consultation with the States, for small public water systems serving —

(I) a population of 10,000 or fewer but more than 3,300;
(II) a population of 3,300 or fewer but more than 500; and
(III) a population of 500 or fewer but more than 25;

and that achieves compliance with the maximum contaminant level or treatment technique, including packaged or modular systems and point-of-entry [POE] or point-of-use [POU] treatment units." Thus, the Administrator is specifically required to consider POE and POU devices as potentially affordable means of achieving compliance.

However, substantial limitations are placed upon the management, operation, and design of POE and POU treatment units used to achieve compliance with an MCL or a treatment technique. Section 1412(b)(4)(E)(ii) stipulates that, "point-of-entry and point-of-use treatment units shall be owned, controlled, and maintained by the public water system or by a person under contract with the public water system to ensure proper operation and maintenance [O&M] and compliance with the maximum contaminant level or treatment technique." In addition, the use of POU devices as a means "to achieve compliance with a maximum contaminant level or treatment technique required for a microbial contaminant (or an indicator of a microbial contaminant)" is explicitly forbidden. Note that the SDWA does not place restrictions on the use POE devices to achieve compliance with a MCL or treatment technique required for a microbial contaminant or an indicator of a microbial contaminant.

Section 1412(b)(4)(E)(ii) also states that no POE or POU unit may be included on the list of affordable technologies, treatment techniques, and other means to achieve compliance with an MCL or treatment technique unless it is "equipped with mechanical warnings to ensure that customers are automatically notified of operational problems. . . . If the American National Standards Institute [ANSI] has issued product standards applicable to a specific type of point-of-entry or point-of-use treatment unit, individual units of that type shall not be accepted for compliance with a maximum contaminant level or treatment technique requirement unless they are independently certified with such standards. In listing any technology, treatment technique, or other means pursuant to this clause, the Administrator shall consider the quality of the source water to be treated."

Despite the restrictions placed on their use as part of an alternative compliance strategy, POU and POE devices offer several advantages over central treatment, especially for small communities. First, costs per customer may be significantly lower. Second, water is selectively treated (e.g., water used to water the lawn is not treated to the same degree as water used for drinking or cooking purposes). Third, some forms of POE and POU treatment may provide greater contaminant reduction than central treatment. This report will further explore some of these advantages in the process of developing nationally applicable cost equations for the implementation of a POE or POU treatment strategy in communities of various size. Disadvantages associated with these treatment strategies (i.e., the greater complexity associated with control of treatment, monitoring, maintenance, and regulatory oversight; higher monitoring costs; and susceptibility to microbial growth) will also be considered in this report and the development of cost equations.

1.2 Point-of-Entry and Point-of-Use Devices

POE and POU technologies may be used to treat a wide variety of contaminants. POE and POU units apply processes similar to those used in central treatment, but on a smaller scale. When properly managed, POE and POU technologies have the potential to be effective and affordable alternatives to central treatment for small communities and water systems. Three practices essential to the successful application of POE and POU technologies are: implementation of appropriate technology, periodic maintenance of POU/POE units, and effective monitoring of water quality.

1.2.1 Point-of-Use Devices

Only water intended for consumption (i.e., drinking or cooking) is treated by POU devices. The technologies used in these devices can be packaged in several different forms: countertop units, faucet-mounted units, in-line units, and line bypass units.

As its name implies, a countertop unit typically is placed on a table or counter next to the tap that supplies water for drinking and cooking. Countertop devices require that water be diverted into the unit directly from the tap, or that water be poured into the device from another container. Since water must be transported between the tap and the countertop device, the potential for accidental bacterial contamination is relatively high. Therefore these units may not suffice as a compliance technology.

Units attached directly to a faucet typically do not allow substantial contact time between the water and the treatment media. These units are more appropriate for controlling taste or odor than for treating contaminants that may cause adverse health impacts because they are not designed to provide a large margin of safety for consumers.

In-line POU units are generally plumbed directly into the piping that connects the cold water supply to the faucet. Thus, the entire cold water supply from the tap is treated by these units.

Line bypass units divert some water from the cold water supply to a treatment device. POU devices of this type are often installed under the kitchen sink. An additional faucet designed to dispense the treated water is frequently installed in conjunction with a line bypass unit. Since these units do not treat the entire cold water supply, they generally last longer than in-line POU units. The purpose of this report is to develop cost equations for in-line and line bypass POU units since they demonstrate the most promise for affordably meeting the requirements of the NPDWRs.

1.2.2 Point-of-Entry Devices

POE units treat all the water that enters a household, providing processed drinking water at every tap. These devices have substantially greater capacity than POU units (i.e., they can treat more water before contaminant breakthrough occurs) and are generally more complex. POE devices require more maintenance than POU devices, but are preferable to POU units when exposure to untreated water poses an acute health risk. The literature reports that the indoor use of contaminated water (particularly water containing volatile organic compounds [VOCs]) can lead to significant human exposure through non-ingestion routes such as inhalation following volatilization (e.g., while showering) or direct contact. Indeed, modeling has shown that when all water uses are considered, an inhabitant's inhalation exposure may be substantially larger than that from direct ingestion. Since all household water must be treated to ensure protection from inhalation and contact exposure, POE units are preferred for the treatment of contaminants that may cause health problems through non-ingestion pathways.

1.3 Treatment Processes Applied at the Point-of-Entry or the Point-of-Use

Many treatment technologies commonly used in central treatment plants have been adapted for use in POE and POU applications. Activated alumina, activated carbon, aeration, ion exchange, reverse osmosis, ultraviolet disinfection, and distillation are commonly incorporated into POE or POU units. While this report focuses on the cost of implementing POE or POU strategies using the first six technologies, all seven are briefly described below. These descriptive pieces were developed using numerous sources, including Point-of-use/Point-of-entry for Drinking Water Treatment (Lykins 1992) and the *WaterReview* Technical Brief (1994).

1.3.1 Activated Alumina

Activated alumina (AA) is a hydrated aluminum oxide (Al_2O_3) that has been heat-treated to a temperature of 300 to 700 degrees Celsius. AA particles are irregular and porous; they are characterized by an extremely high surface area to volume ratio. Treatment with AA may be described as an "exchange/adsorption" process, resulting from electrostatic attraction between the alumina surface and the contaminant, and the sorptive properties of the AA granules.

AA can exchange anions and cations, however it is most commonly used to remove contaminants that manifest as anions in water at standard temperatures and neutral pH. AA technology is principally employed to remove fluoride from drinking water, although it can also be used to remove arsenic, chromium, selenium, and inorganic mercury. The AA media must be prepared (pre-treated) properly take place in order to ensure the effectiveness of this treatment technology. Pretreatment consists of a thorough backwash, followed by rinsing with dilute sulfuric acid. The backwash removes dust and fine particles that may lead to cementation of the AA (destroying its adsorptive capability), while the acid rinse lowers the pH of the AA to about 5.5 — the level at which anion adsorption proceeds most rapidly and efficiently. A partial listing of the anion selectivity sequence (in decreasing order of preference) of AA is presented below:

OH^-, PO_3^{-3}, F^-, $Si(OH)_3O^-$, AsO_4^{-3}, $[Fe(CN)_6]^{-4}$, AsO_3^{-3}, CrO_4^{-2},
SO_4^{-2}, $Cr_2O_7^{-2}$, NO_2^-, Br^-, Cl^-, NO_3^-, MnO_4^-, ClO_4^-, CH_3COO^- (Lake 1987).

As may be seen from the above list, fluoride is preferentially adsorbed by AA over ions containing arsenic. Therefore, the presence of fluoride as a constituent in influent water will reduce this technology's ability to remove arsenic. AA units have also proven effective for the removal of selenium IV. AA does not effectively remove organic contaminants.

1.3.2 Activated Carbon

Activated carbon is the most widely used technology in POE and POU devices. These units are typically the easiest POE and POU systems to use and maintain — operating costs are usually limited to filter replacement. Granular activated carbon (GAC) filters are the most common application for activated carbon, although powdered activated carbon (PAC) filters may also be incorporated in POE and POU treatment units. Either of these filters will remove a broad range of organic contaminants (e.g., pesticides such as aldicarb and solvents such as trichloroethylene [TCE]) and some inorganic contaminants (e.g., radon) from drinking water (Van Dyke 1987).

Activated carbon is characterized by a large surface area to volume ratio. This characteristic enhances its ability to remove contaminants from water by adsorption, the attraction and accumulation of contaminants on the carbon's surface. The adsorption process is influenced by the solubility of the contaminant and its affinity for the carbon surface.

It is important to note that POU GAC units must have their filters changed regularly in order to prevent contaminant breakthrough. A 1987 presentation (Van Dyke 1987) included information on the impact of competitive effects on GAC removal rates for various contaminants. Essentially, GAC has a finite capacity for any one compound. When multiple contaminants occur, they compete to some extent for the available sites on the carbon, reducing the capacity for the less strongly adsorbed compound. In general, chlorinated compounds are more readily adsorbed than non-chlorinated compounds. The presence of double bonds within a compound increases adsorbability. Finally, the more hydrophobic (i.e., the less water soluble) a compound is, the higher its rate of adsorption by GAC. Therefore, the presence of carbon tetrachloride or chloroform in a water source may limit the efficacy of alachlor removal by GAC since it will preferentially adsorb carbon tetrachloride and chloroform over alachlor. Influent water quality should be thoroughly tested prior to application of a carbon system (see section 1.5.3). The performance of activated carbon devices also depends on internal flow patterns, flow rate (or contact time), and raw water quality. Activated carbon is not a generic commodity, and its source (e.g., coal, coconut shell, etc.) and the method in which it is prepared significantly affects its selectivity and capacity.

Activated carbon removes chlorine with great efficiency. In the absence of a chlorine residual, bacteria may quickly multiply, especially in the small, nutrient rich pore spaces of GAC. Numerous studies have documented the colonization of carbon filters by bacteria (Geldereich 1985, Reasoner 1987). While no illness has been attributed to bacterial colonization of POU or POE units, it is generally recommended that carbon filters be replaced frequently (before bacterial populations can build up) or that some sort of post-treatment disinfection be implemented for POE GAC units. See section 1.4 for more information about the potential for bacterial contamination of carbon units.

Silver has been suggested as a means of reducing bacterial colonization of carbon filters. However, while silver has been found to inhibit the growth of bacterial populations after periods of unit disuse, PAC filters impregnated with silver have not reduced bacteria levels more effectively than standard PAC filters during periods of more frequent water use (Regunathan 1987).

1.3.3 Aeration

In a process known as air stripping, contaminants are transferred from water to air. Saturated air is then vented into the atmosphere. The two types of air stripping that are most frequently used are packed tower aeration (PTA) and diffuse bubble aeration (DBA).

1.3.3.1 Packed Tower Aeration

PTA systems rely upon the force of gravity and mass transfer to remove contaminants from water. Water introduced at the top of a column flows down it while air is forced upward by a mechanical blower. The column contains packing (often molded plastic or ceramic) that increases the area of the air-liquid interface and enhances mass transfer. Contaminants are transferred from the water to the air, which is then vented to the atmosphere. PTA has proven effective in removing VOCs and other gases (e.g., radon and methane) from drinking water (Nevada Division of Water Planning 1984). This technology is frequently used in conjunction with activated carbon to reduce particularly high concentrations of VOCs. PTA is not effective in treating inorganic compounds or microbial contaminants.

Water must be repressurized after PTA treatment in order to maintain adequate household pressure. Expensive equipment is required for this process. Repressurization equipment and the blower draw large amounts of electricity and must operate for a substantial part of each day. Thus, electrical costs are high for PTA treatment. In addition, if the PTA unit is not adequately ventilated (e.g., it is housed in an insulated shed without an adequate exhaust fan), contaminant removal efficiency will decrease due to mass transfer constraints (i.e., less of the contaminant will be removed from raw water by feed air already saturated with the contaminant). Therefore it is necessary to provide for adequate dispersal of the exhaust gases.

Due to the size of these units (typically more than nine feet in height), PTA may not be applied as a POU installation. In addition, fan noise may limit the suitability of this technology for use in residential areas. Air quality regulations in certain localities may also prevent the implementation of these units since large quantities of a contaminant are vented into the air.

1.3.3.2 Diffuse Bubble Aeration

DBA is a second generation technology designed to overcome many of the problems associated with the use of PTA for household application. In a DBA system, water flows through an enclosed box while air is bubbled through the box. Contaminants are transferred from the water to the air and then vented outside. The contaminant removal efficiency of DBA systems is comparable to that of PTA systems. Like PTA systems, post-treatment repressurization is required to maintain adequate household pressure for DBA systems. However, efficiencies of DBA technology permit less expensive system operation. Additionally, DBA units are not subject to freezing.

A system suitable for treating up to 18 gallons per minute (gpm) is only 0.6 meters wide, 1.2 meters long, and 0.6 meters in height. Nonetheless, due to the capital cost of DBA units and their accompanying repressurization systems, these systems are only installed for POE applications.

1.3.4 Ion Exchange

Ion exchange (IX) technology relies on the exchange of charged ions in water for similarly charged ions on a resin surface. There are two types of IX: cation exchange (CX) — which replaces positively charged ions, such as calcium, iron, and magnesium with sodium ions; and anion exchange (AX) — which replaces negatively charged ions such as sulfate, nitrate and chloride. The resins are synthetic polymers (polyelectrolytes) and react much as acids, bases, or salts. However, only the cations and anions are free to take part in chemical reactions. Commercially available IX units usually contain a mixture of anion and cation exchange resins.

Although most inorganic compounds can be removed with IX technology, most organic compounds commonly found in drinking water cannot (Gumerman 1984). Moreover, IX units are susceptible to fouling from iron, magnesium, and copper. Channels may develop in the resin bed if the pressure drop across the bed is too high. This may permit water to pass through the unit without adequate contact with the treatment media. Periodic backwashing will help prevent fouling of the media bed and will remove sediment build-up.

CX systems are most often used to remove minerals that contribute to water hardness such as calcium and magnesium. Thus, CX units are commonly referred to as water softeners. Units equipped with CX technology have also been shown to effectively treat barium, cadmium, copper, zinc, manganese, chromium (III), iron (II), lead, mercury, and radium (Gumerman 1984). When the resin bed of a CX system is exhausted, it may be regenerated by flushing the resin with a highly concentrated salt solution (sodium chloride).

Studies conducted at the University of Wisconsin, Madison and the National Sanitation Foundation (NSF) demonstrated that water softeners caused no problems in the operation of anaerobic or aerobic home waste treatment plants. The waste brine was not found to have any negative effect on the biological decomposition action, and the hydrologic load added to the system during regeneration was roughly equivalent to the discharge of a washing machine. This additional discharge is only a problem where the septic field is poorly designed or constructed (COI/WWWebstore 1998a).

Although the use of water softeners has not been found to disrupt the operation of septic tanks, several communities have banned the use of POE CX units. The communities opted to forbid the use of these units due to the high concentrations of salt in water treated by CX technology. Almost all of the salt necessary to recharge the units eventually finds its way into the municipal waste water system. Thus, even small communities may find that the combined discharge from all households would exceed the system's ability to eliminate salt.

It is well known that excessive sodium consumption may result in negative health effects. However, since only about 150 mg of sodium are present in one liter of water softened from 10 grains per gallon (gpg) of hardness, even an individual on a low sodium diet (3,000 mg/day)[1] is unlikely to run into difficulties since he or she would need to drink 20 liters of water in order to exceed the recommended level (COI/WWWebstore 1998b). Nonetheless, people with high blood pressure and/or heart disease are advised to consult with their physician to determine if their maximum allowable intake of sodium will be exceeded by using a home water softener (Michigan State University Extension 1997).

AX is used for dealkalization (bicarbonate removal) and nitrate treatment. AX also has been proven effective for treating arsenic, chromium, selenium, sulfate, and chloride (Gumerman 1984). The resins used in AX systems may be regenerated by passing an acid solution through the resin bed.

Much like AA, AX resins preferentially remove certain contaminants. Therefore, the removal efficiency of an AX system will depend upon the type and concentration of anions in the influent. For example, sulfates are preferentially removed over nitrates. Thus, communities must be especially careful to test influent water quality prior to application of an AX system (see section 1.5.3.

1.3.5 Reverse Osmosis

Reverse osmosis (RO) systems pass water through a synthetic, semipermeable membrane that rejects compounds based on their molecular properties and the characteristics of the RO membrane. The membrane allows water molecules to pass but blocks most dissolved and suspended molecules. Several types of RO membranes are used in POE and POU treatment devices. The most common are cellulose acetate membranes (CAMs) and thin film membranes (TFMs). While CAMs are more resistant to membrane deterioration from chlorine than TFMs, they are not as widely used today. Recent manufacturing and design innovations mean that

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[1] Level recommended by the American Heart Association.

TFMs may now be used to treat water up to 45 degrees Celsius and ranging in pH from 4.0 to 11.0 (Waypa 1997). In addition, TFMs are generally preferred to CAMs due to their superior contaminant removal rates, especially in communities with low system pressure.

RO removes inorganic contaminants such as arsenic, barium, cadmium, chromium, copper, fluoride, lead, mercury, nitrate, radium, selenium, silver, chlorides, and sulfates. Organic compounds with high molecular weights, total dissolved solids (TDS), turbidity, bacteria, and viruses have also been removed by RO units (Gumerman 1984, Van Dyke 1987). Units often have a particulate pre-filter to reduce fouling and extend membrane life. A GAC post-filter is also commonly included in RO units to remove organic compounds of low molecular weight and to improve the taste of treated water. RO membranes that are sensitive to chlorine may require GAC pre-filters. Since RO units treat water at a slow rate, an RO system often includes a pressurized storage tank to ensure the availability of treated water on demand.

RO contaminant removal becomes more physically efficient with increased membrane size. Both POE and central RO units use larger membranes than POU RO units. However, though superior contaminant removal is achieved by the larger units, POE RO poses several problems. The brine waste from these units contains much higher contaminant concentrations. Indeed, this waste may need to be disposed of as hazardous material depending upon State regulations. Additionally, water treated by RO is extremely aggressive and may corrode metal pipes. Thus post-treatment (such as pH adjustment) may be required.

High levels of water hardness tend to reduce membrane efficacy. Moreover, although providing impressive protection in most situations, RO units may not be the optimal treatment technology in arid or water-limited regions since much of the water that is flushed against the RO membrane is wasted in the course of treatment.

1.3.6 Ultraviolet Light

Disinfectants are used to control microbiological contaminants such as algae, bacteria, viruses, and cysts. Common POU and POE disinfectant technologies include ultraviolet light, ozone, chlorine, and silver impregnated carbon. Ultraviolet light (UV) is the simplest and most popular POU/POE disinfection alternative. One of the major advantages of UV technology is that it disinfects without the addition of chemicals. UV light does not expose users to any harmful products, does not impart any taste or odor to water, presents no danger of overdose, and works rapidly. The equipment requires little maintenance, and changes in the system's flow rates do not prevent adequate disinfection. While UV effectively kills most organisms, cysts (such as those of *Cryptosporidium parvium* and *Giardia lambia*) are impervious (Garoll 1988, Lorenzo-Lorenzo 1993). High levels of turbidity in the influent also limits the effectiveness of UV treatment. Therefore, a particulate pre-filter should be incorporated in any UV system.

As mentioned in section 1.1, section 1412(b)(4)(E)(ii) of the SDWA explicitly prohibits the use of POU units for "compliance with a[n] MCL or treatment technique requirement for a microbial contaminant." Therefore, although UV provides effective protection from most microbial contaminants, it must be used in conjunction with a treatment device that employs a different technology to qualify as a POU alternative to central treatment because it is ineffective in treating organic or inorganic contaminants. UV devices are often incorporated in POE GAC units to provide post-treatment disinfection, eliminating the danger of bacterial contamination. See section 1.4 for additional information on this issue.

1.3.7 Distillation

Distillation is a process that uses evaporation to purify water. Unlike the "continuous flow" technologies listed above, distillation treats water in batches. A batch process device treats one batch of water at a time and typically is not connected directly to the household water supply. POU units of this type are frequently installed as countertop units.

The distillation process involves several steps. First, water is poured into a boiling tank. As the water is heated, impurities with low boiling points and dissolved gasses are turned into vapors and are exhausted through a vent. Water then boils, sending steam through a condensing coil. Water is cooled by air or by cold water, condenses, and flows into a container for storage. The majority of contaminants are left behind in the boiling chamber. The boiling chamber is then flushed either manually or automatically. Residential distillation units use either air cooled or water cooled condensers. The air-cooled units waste less water, generally experience fewer service problems, and are typically easier to install and operate. While water-cooled units require 8 to 15 gallons of raw water to produce 1 gallon of treated water, air-cooled units produce almost one gallon of treated water for every gallon of raw water.

Distillation is most effective in removing inorganic contaminants such as metals, minerals, nitrates, and particulates. Cysts, most bacteria, and some viruses can be killed by the high temperatures used in this process. Organisms that survive are separated from the water as steam rises from the tank. Distillation effectiveness in removing an organic compound depends on the compound's physical characteristics such as its water solubility and boiling point.

Like RO units, distillation units frequently include particulate pre-filters (to reduce the sediment introduced into the boiling chamber) and GAC post-filters (to remove any organic contaminants that remain after distillation treatment and to improve the taste of treated water). Even when equipped with particulate pre-filters, distillation units suffer from scale build-up and thus require frequent maintenance to maintain efficacy. Operating costs for distillation units are high due to their high electrical demands (about 3 kilowatt-hours of electricity are required to produce each gallon of treated water). Implementation costs for distillation units are not discussed in this report.

1.4 Bacteriological Contamination

Heterotrophic bacteria, bacteria that rely on organic compounds for their nutrient requirements, have been found to colonize GAC filters (Den Blanken 1982, Rice 1982, Bellen 1985, Geldreich 1985). Densities exceeding hundreds of thousands of bacteria per milliliter have been observed in the effluent of GAC filters (Dufour 1987). The bacterial population in the effluent of POU GAC units was found to be approximately one order of magnitude greater than the bacterial population in untreated water (Regunathan 1987).

The growth of heterotrophic bacteria in treatment devices has caused some concern about the health risk that these bacteria may pose to water users. Some heterotrophic bacteria found in drinking water treated by POE and POU units have been associated with nosocomial infections and illnesses. Infections of this kind usually are caused by bacteria that are avirulent or have limited virulence, which inflict damage on weakened hosts. However, research suggests that ingestion of these bacteria does not have acute health effects on healthy individuals (Mood 1987). Nonetheless, the presence of bacteria may indicate a potential pathway for exposure to pathogenic organisms. Further, since GAC treatment systems are likely to be found in homes where infants, elderly, or other infection-prone persons reside, bacterial colonization is a matter of concern. United States Environmental Protection Agency (EPA) conducted two studies in response to these health concerns. These studies are summarized in the next two sections. One study focused on the effects of ingestion of and dermal exposure to water from POU systems (EPA 1980, Calderon 1987). The second study focused on the health consequences of ingestion and inhalation of water (i.e., steam from showers) treated by POE systems (Bell 1984). Neither of these studies demonstrated a connection between exposure to treated water and an increased incidence of illness.

1.4.1 Bacterial Study of Point-of-Use Systems

Faucet-mounted and line bypass POU GAC filters were tested for the presence of bacteria. The study group consisted of households that had one of these POU filtration systems, while the control group received filters equipped with blank cartridges. Over a 17-month period, water samples were collected and analyzed for signs of an elevated bacteria count. In addition, subjects were asked to keep health diaries. Information on the subjects' health was collected from these diaries, statements by subjects' physicians, and survey responses.

The results of this study showed that line bypass and faucet-mounted POU filters were colonized by heterotrophic plate bacteria. However, there was no evidence of increased levels of skin or gastrointestinal disorders among the study group. The researchers concluded that neither ingestion of, nor skin contact with, water filtered by a POU GAC unit constituted a risk factor for the study population. However, the health effects on sensitive sub-populations such as immuno-compromised individuals, the elderly, and infants were not specifically examined in this study.

1.4.2 Bacterial Study of Point-of-Entry Systems

The second EPA study involved 167 households. Of these, 87 households served as a control group and 80 households comprised the study group. The households in the study group already had POE GAC filtration in place, whereas the households in the control group did not filter their water. Both groups received water from the same central treatment plant. Researchers analyzed hot and cold water samples monthly and took a survey to determine the various ways in which subjects were exposed to filtered water. Exposure was found to result from ingestion, inhalation of steam, and dermal contact. As in the POU study (see section 1.4.1), subjects were asked to keep health diaries. Information on the subjects' health was collected from these diaries, statements by subjects' physicians, and survey responses.

The results of the study indicated that the POE carbon filters were colonized by heterotrophic bacteria. However, no adverse health effects were attributed to the bacteria. The researchers concluded that exposure to POE GAC filtered water through any of the pathways detailed above did not constitute a risk factor for the study population. As with the POU study summarized in section 1.4.1, the health effects on sensitive sub-populations such as immuno-compromised individuals, the elderly, and infants were not specifically examined in this study.

1.4.3 Additional Discussion

It is important to recognize that bacterial colonization of media beds is not unique to POU or POE treatment systems. Central treatment systems, however, normally provide disinfection after treatment. There have been no verified reports of waterborne illness resulting from consumption of contaminated water from GAC or other POU treatment devices. However, it is important to avoid using water of poor or unknown microbiological quality when instituting a POE or POU treatment strategy. If a system must rely on source water that is suspected of containing microbiological organisms, rigorous disinfection should be part of the water system's treatment strategy. Consumers should be instructed to run water at full flow for at least 30 seconds before use after a prolonged period of quiescence to avoid ingesting bacteria easily washed off the filter or treatment media. Periodic backwashing of treatment devices will also reduce levels of bacteria in treated water (those bacteria most easily washed off the filter or media will be removed).

1.5 Management Issues

A water system must address several issues before implementing an alternative compliance strategy. Regardless of the compliance strategy it chooses to pursue, the system remains responsible for providing water that reliably and consistently meets the NPDWRs. The simple installation of POE or POU devices does not absolve the system from this principal responsibility. To ensure that the system meets its responsibility, the SDWA places substantial limitations upon the management, operation, and design of POE and POU treatment units that may be used to achieve compliance with an MCL or a treatment technique.

As mentioned in section 1.1, section 1412(b)(4)(E)(ii) of the SDWA stipulates that, "point-of-entry and point-of-use treatment units shall be owned, controlled, and maintained by the public water system or by a person under contract with the public water system to ensure proper operation and maintenance and compliance with the maximum contaminant level or treatment technique." While this section does not require the water system to perform all maintenance or management functions itself, it does emphasize the requirement that the water system retain ultimate responsibility for the quality of all the water it provides to households within its service area. Water systems are free to subcontract one or more aspects of the day-to-day management of the treatment devices used in a POU or POE strategy, and may provide significant price savings for their customers by doing so, as long as they maintain administrative oversight over all operations. Generally, an established water utility can provide the administrative oversight necessary to implement an alternative treatment strategy safely and responsibly.

Management of Point-of-Use Drinking Water Treatment Systems (Bellen 1985) discusses issues critical to the successful management of a POU treatment system. Although this report focuses on the implementation of a POU treatment strategy, the same issues apply to the implementation of a POE treatment strategy. The principal issues reported by Bellen are discussed in the following five sections, and the management assumptions used in the cost analysis of POE and POU strategies are described briefly. A more detailed discussion of the assumptions used in this report is presented in section 4.

1.5.1 Device Selection

Systems must consider many factors when selecting POE or POU devices. These factors include the microbiological, physical, and chemical characteristics of their source water and the features offered by different manufacturers and technologies. For example, the presence or absence of competing ions (such as sulfate) greatly affects the efficacy of AX treatment for nitrate. Consultation with private water quality consultants, local health departments, and the State agency responsible for water quality is warranted and highly recommended.

Although the use of POU devices "to achieve compliance with a maximum contaminant level or treatment technique required for a microbial contaminant (or an indicator of a microbial contaminant)" is explicitly forbidden by section 1412(b)(4)(E)(ii) of the SDWA, it is important to ensure that neither POE nor POU devices increase the potential risk to public health from microbiological activity (see section 1.4). Since it is difficult to prevent the colonization of treatment devices, even when the central water supply is chlorinated, due to the ubiquitous presence of bacteria, appropriate post-device disinfection should be practiced.

Therefore, the cost of a post-treatment UV disinfection unit was included in the cost of all POE GAC units for the purposes of the cost analysis. Disinfection units were determined to be unnecessary for other POE devices since they are not as readily colonized by bacteria. Moreover, since the GAC filters used in POU units would be changed too frequently to permit the build-up of large bacterial populations, it was determined that no post-device disinfection was necessary for these units. As backwashing has been found to decrease post-device bacterial exposure (see section 1.4.3), all POE GAC units were assumed to be equipped with backwash capabilities. Section 4 provides more information on assumptions used for the cost analysis presented in this report.

SDWA section 1412(b)(4)(E)(ii) stipulates that "if the American National Standards Institute [ANSI] has issued product standards applicable to a specific type of point-of-entry or point-of-use treatment unit, individual units of that type shall not be accepted for compliance with a maximum contaminant level or treatment technique requirement unless they are independently certified with such standards. In listing any technology, treatment technique, or other means pursuant to this clause, the Administrator shall consider the quality of the source water to be treated." Six ANSI/NSF standards have been established for POE and POU drinking water treatment devices. Standards have been set for aesthetic effects (ANSI/NSF 42), health effects (ANSI/NSF 53), CX water softeners (ANSI/NSF 44), RO treatment systems (ANSI/NSF 58), UV microbiological treatment systems (ANSI/NSF 55), and distillation systems (ANSI/NSF 62). The standards are voluntary consensus standards established by representatives of government, user groups, and industry.

Under the standards, the performance of treatment devices is tested against manufacturers' contaminant removal claims. The standards include requirements for materials, design, construction, hydrostatic performance, and product information. All testing evaluations are conducted in accordance with standard protocol. Manufacturing facilities are subject to at least one unannounced inspection annually. Manufacturers are not required to adhere to these standards, but products shown to conform with the requirements of the standard are listed in a publicly available publication and may display the NSF seal.

The Water Quality Association (WQA), an organization representing manufacturers of POU and POE treatment devices, has developed recommended industry standards for household and commercial water filters (S-200-73), as well as RO systems (S-300-84). The American Society of Testing and Materials (ASTM) also provides standard tests that may be used to determine the operating characteristics of RO membranes (D4194-82), GAC (D3922-80), and particulate mixed-bed IX materials (D3375-82). In accordance with the statutory requirement, it was assumed that communities would select only POE or POU devices that were certified under NSF Standard 53 (health effects) and the appropriate technology standard(s) (e.g., ANSI/NSF 58 for RO devices).

To comply with SDWA section 1412(b)(4)(E)(ii), a water system must select POE or POU units that are "equipped with mechanical warnings to ensure that customers are automatically notified of operational problems." To this end, the cost of a water meter equipped with an automatic shut-off valve was included in the price of all treatment devices considered in the cost analysis. RO units were assumed to be equipped with an in-line TDS monitor instead of a water meter since it was demonstrated in the San Ysidro case study (see section 2.1.2) that conductivity could be used to determine the breakthrough of inorganic contaminants such as fluoride and arsenic. All UV elements included as part of POE treatment devices were assumed to be designed with a small peep-hole that permits easy verification that the UV bulbs are operational.

In selecting a treatment device, a system should consider the experience and viability of manufacturers in conjunction with device performance and price. Established vendors may be able to provide significant discounts for volume purchases and product guarantees. Water systems should collect warranty information for each component of a treatment device before committing to a particular technology or manufacturer. Since water systems have generally been held responsible for property damage resulting from leaks due to defective equipment, improper installation, or accidents, the insurance coverage provided by a manufacturer after the device is installed may also affect the lifetime cost of a treatment unit.

1.5.2 Device Installation

Once a particular device is selected, a water system must address the task of installing that device in each household within its service area. Equipment installation may be performed by factory-trained dealers, plumbing contractors (often recommended by equipment dealers), or a water utility employee. Although systems might need to authorize installers to buy additional materials (e.g., fittings) to complete installations, it was assumed for the purposes of this analysis that only water system personnel would install the equipment and that no additional materials would be necessary for proper installation.

Management (Bellen 1985) recommended that a water system contract with vendors to retain responsibility for the performance of the POE and POU devices for at least a short period of time. This contract would allow for minor adjustments and for the training of water system personnel in maintenance procedures. However, the cost associated with this type of extended service was not included in the cost analysis due to the lack of data on the cost of such a service contract. The vendor was assumed to provide water system personnel with the necessary basic training to permit system personnel to service units. By contracting with one vendor for unit purchase and/or installation, a system may be able to reduce costs through a quantity discount. This discount was incorporated in the cost analysis.

When soliciting price quotes from installers, systems should provide them with as much detailed information as possible about the water problems faced by the system and the characteristics of its housing stock. Water systems should also be mindful of local plumbing codes when installing treatment devices. Depending on the size of the treatment device, homeowners may want units installed under-the-sink, at the property line, or in the basement. The latter two options will raise the cost of installation. However, installation at the property line may obviate the necessity of coordinating sampling and maintenance with homeowners. It was assumed that all POU units would be installed under-the-sink, while POE units would be installed in the basement or garage of all households within the community.

1.5.3 Operation and Maintenance

Proper maintenance of POU and POE devices includes timely replacement of media, cartridges, filters, and modules. The timing of these replacements depends on the microbiological, chemical, and physical properties of the community's water supply and the use patterns of water customers. If media, cartridges, filters, or modules are not replaced prior to exhaustion, the device will no longer provide treatment and may, in extreme cases, increase the contaminant level of the treated water as contaminants leach from the media.

To ensure an adequate safety margin for consumers and the timing of replacements in the most cost-efficient manner possible, pilot testing should be performed on one or more units to determine their capacity to treat the community's water. Devices should be tested on the community water supply at a continuous flow to determine the volume of water that a device can treat before breakthrough (i.e., the detection of a contaminant above desired levels [i.e., the MCL] in the treated water) occurs. This test will establish the capacity of a device and typically will take only a few days to perform.

Devices should be monitored for biological contamination, which may result from the installation procedure or from source water contamination. Samples from each device were analyzed for total coliform in addition to the principal contaminant of concern. The sampling regime selected by a water system significantly affects the costs of monitoring. Some tests, are so expensive (e.g., TCE analysis costs $173 per sample) that it is more cost-effective to sample less frequently and replace filters and cartridges more often. Once the capacity of a device is established through pilot testing, monitoring can be curtailed until a device nears its capacity threshold, thus reducing monitoring costs. For this reason, an aggressive replacement strategy was assumed for the purposes of this analysis (typically quarterly for POU and yearly for POE — see section 4). This assumption ensures the protection of public health while limiting the necessity for sampling to once a year. To ensure that estimates of the effective life of treatment devices remain accurate, the quality of the source water must continue to be monitored as part of the water system's treatment strategy.

Water meters may be used by the water system to minimize the chance that breakthrough will occur since water flow through the device will be automatically shut-off when a predetermined amount of water has been treated by the device. While it was assumed that a water meter and shut-off valve were included for all devices, the frequent, periodic replacement of all media, cartridges, and filters was also assumed for the purposes of this cost analysis.

Treatment devices must be monitored to ensure their proper operation. The structure of a monitoring program depends on the community, the number of devices, the type of contaminant being removed, the treatment method, and the logistics of the service area. State laws may dictate the frequency and method of sampling.

Samples could be collected by a circuit rider operator, a vendor representative, staff from a private lab, health department staff, water utility staff, or a local resident. The advantages to having a member of the water system's staff collect the sample is that he or she will be more familiar with the community and the other residents than an out-of-town vendor or circuit rider. For this reason, it was assumed that sampling would be carried out by water system personnel.

All individuals involved in sampling should be trained to ensure that the same procedures are followed for each device to permit comparison of results throughout the community. The water system should consult the appropriate regulatory agency for information on state-approved sampling methods. It is generally considered appropriate to flush a POE or POU system before testing to allow the system to reach a steady state condition before the water sample is drawn. Systems should maintain records of sample collection sites, dates, and analytical results. These administrative tasks were assumed to require one hour of labor for the water system per household per year (see section 4.3.3).

One factor that the water system and the regulatory agency responsible for solid waste disposal should consider in estimating O&M expenses is the type and quantity of waste produced by a POE or POU device. The physical state of the wastewater, the wastewater's toxic or hazardous properties, and the quantity of waste produced are all important considerations. Disposal costs for POU devices were assumed to be zero due to their small size and their rapid replacement (before contaminant build-up); they will not generally constitute a significant contribution of waste to a landfill. In contrast, POE treatment units may require expensive disposal methods. Spent media and waste brines from these units may require disposal as hazardous waste. Media used to treat for radon or other radionuclides may need to be disposed of as low-level radioactive waste. State and local regulatory authorities responsible for solid waste disposal should be contacted by a water system contemplating the use of POE devices. All disposal costs were omitted for the purposes of its cost analysis, since it was not possible to estimate the disposal costs required by the operation of a central treatment plant within the scope of this project (see section 4.3.1).

Systems also should consider other factors that would affect O&M costs of a POU/POE strategy. Examples include price discounts for long-term contracts, the proximity of the supplier, availability of parts and services, and lab fees.

1.5.4 Public Relations and Education

The final key to managing a successful POU treatment system is to promote public involvement and education. While the water system is responsible for maintaining all POU and POE devices it chooses to install within a community, for a POE or POU treatment strategy to be successful, owners must follow the recommended procedures for care of their treatment device. Town meetings — before the treatment device is chosen and then regularly after the household treatment units are installed — are one of the most successful tools for responding to residents' concerns and questions. Aspects of the water system's public education program could be carried out during town meetings by guest speakers or demonstrations. State or local government agencies may be able to assist in these educational activities. A newsletter which informs residents of the fiscal and operating status of the system could be another important public relations tool. This newsletter could be supported through a combination of advertisements, a nominal subscription charge, or a surcharge on water rates.

The effect of the treatment device on the water's taste, odor, or color will have a significant impact on public acceptance of POU or POE technology. In general, water's taste, odor, and color are much more noticeable to the public than the presence of potentially toxic contaminants.

1.5.5 Economic Considerations

Despite the recommendation that POU treatment devices be installed at every faucet dispensing potable water in the community (Bellen 1985), it was assumed that only one tap was equipped with a POU unit for this cost analysis. As previously discussed, the SDWA Amendments of 1996 specifically prohibit the use of POU devices for microbial contaminants. The same rationale could be used for not listing POU devices as a compliance technology for contaminants that cause acute health effects (e.g., nitrate) or contaminants that present a health risk through inhalation (e.g., radon) or dermal contact (e.g., TCE). The cost of additional POU units to provide coverage of all taps would be far greater than the cost of a single POE unit that could provide protection at all taps within the household. An extensive public education campaign could alert consumers to the need to use the treated tap for all drinking or cooking purposes. However, the problems associated with ensuring the implementation of a public education program for an acute contaminant in a small system may still eliminate POU treatment as an option for some contaminants.

A large number of treatment devices would be needed to outfit an entire community. Therefore, it is important for systems to consider their options for equipment ownership and maintenance, and to negotiate with vendors to secure volume discounts. POU devices could be owned and operated by the municipality or district, could be owned publicly and maintained privately, leased by the municipality or district, privately owned, or owned by the water supplier. Because rental costs were higher than purchase costs for the 10-year time frame of the cost analysis, all units were assumed to be owned by the water system. The system must have the right to access all treatment devices to monitor their performance and perform routine maintenance. Further, it was assumed that the water system, in conjunction with local authorities, would be able to pass legislation (similar to that described in the San Ysidro case study in section 2.1.2) requiring homeowners to permit access to the treatment units and prohibiting homeowners from disconnecting or tampering with the units.

Several funding options available to water systems may generate sufficient funds to pay for the initial investment in POE or POU equipment. In many States, water districts and publicly owned water utilities can issue bonds. Local banks, credit unions, and finance companies may make loans to water systems that can demonstrate fiscal responsibility. However, banks, credit unions, and finance companies almost always require the borrower to provide equity (typically an asset with re-sale value) before they will make a loan. Since it is illegal in most states to sell used water treatment equipment, and since few small water systems have substantial assets (e.g., land), many systems may be unable to provide adequate equity to secure a loan from private sources. However, equipment distributors may be able to arrange for funding to purchase equipment and may be able to help systems that lack equity to secure loans. Systems could also consider renting or leasing equipment. Some rental agreements also provide the option to buy the equipment. Water systems might choose to lease treatment devices since vendors frequently include maintenance and monitoring in the lease agreement. However, the water system would need to ensure that the vendor provided adequate maintenance because the system is ultimately liable in cases of inadequate water quality.

A system could recover the costs of capital expenditures and the initial installation of POE or POU devices through property assessment, taxation, or service fees. A successful management plan must also examine water rates and adjust them to cover the full costs of operation, monitoring, and maintenance. To estimate total treatment costs, systems should develop models which amortize capital and installation costs while estimating expected replacement costs. An average effective lifetime of 5 years was assumed for POU devices while an average effective lifetime of 10 years was assumed for POE devices. Therefore, the capital costs for these devices were amortized over 5 and 10 years respectively in the cost analysis. Estimating the lifetime costs (including capital, installation, monitoring, maintenance, spare parts, administrative, and replacement costs) of a technology is also valuable when choosing among different types of POU and POE devices.

A system's monitoring costs depend on several factors, including source water quality, method of treatment, laboratory availability, local regulations, and whether sampling is conducted professionally or by volunteers. Systems can significantly reduce the costs of monitoring by recruiting local volunteers to collect samples or by providing customers with sample bottles which they mail or deliver to the district. For example, according to language in the Lead and Copper Rule, uncertified individuals are permitted to take samples. These costcutting methods are limited by the cooperation of customers, SDWA regulations, and by sampling methods which require special collection or transportation requirements.

A POE and POU management plan needs to incorporate annual administrative costs (e.g., bookkeeping, billing, inventory control, office supplies, etc.) in the system's proposed budget. Administrative costs can be reduced by the use of voluntary labor and/or by active homeowner participation.

2.0 Case Studies

Cost, performance, and administrative data were gathered from field studies and demonstration projects to help develop and corroborate the cost estimates for POE and POU devices presented in this report (see section 4). Few studies or projects were identified despite an extensive literature search. Discussions with Ben Lykins, an EPA expert, and several experts within the industry verified that case studies on the application of POE technologies are especially rare. However, several laboratory studies have recently been published in journals such as the *Journal AWWA*. While these studies did not provide cost data, they did provide useful information on the capabilities of various technologies to treat for different contaminants.

This section summarizes the available field studies and demonstration projects that describe the application of POU and POE technologies in small communities. Other information relevant to the task of developing cost data are also included in the summaries. Table 2.1 presents the cost data taken from these case studies.

Each summary includes information on the following topics, if available:

1. The contaminant(s) of concern (and its concentration in the raw water).
2. The applied treatment technology.
3. The number of households equipped with POE or POU treatment units (i.e., the number of households served by the water system).
4. The administrative strategy used by the water system.
5. The monitoring plan used to ensure adequate protection of public health.
6. The maintenance schedule selected by the water system.
7. Details on the capacity and performance of the treatment units.
8. The capital and O&M costs for each unit.
9. The cost per gallon used.
10. The annual per household cost for implementing a POU or POE treatment strategy. Where possible, estimates for the cost of a central treatment strategy are also included.

Figure 2.1: Study Design

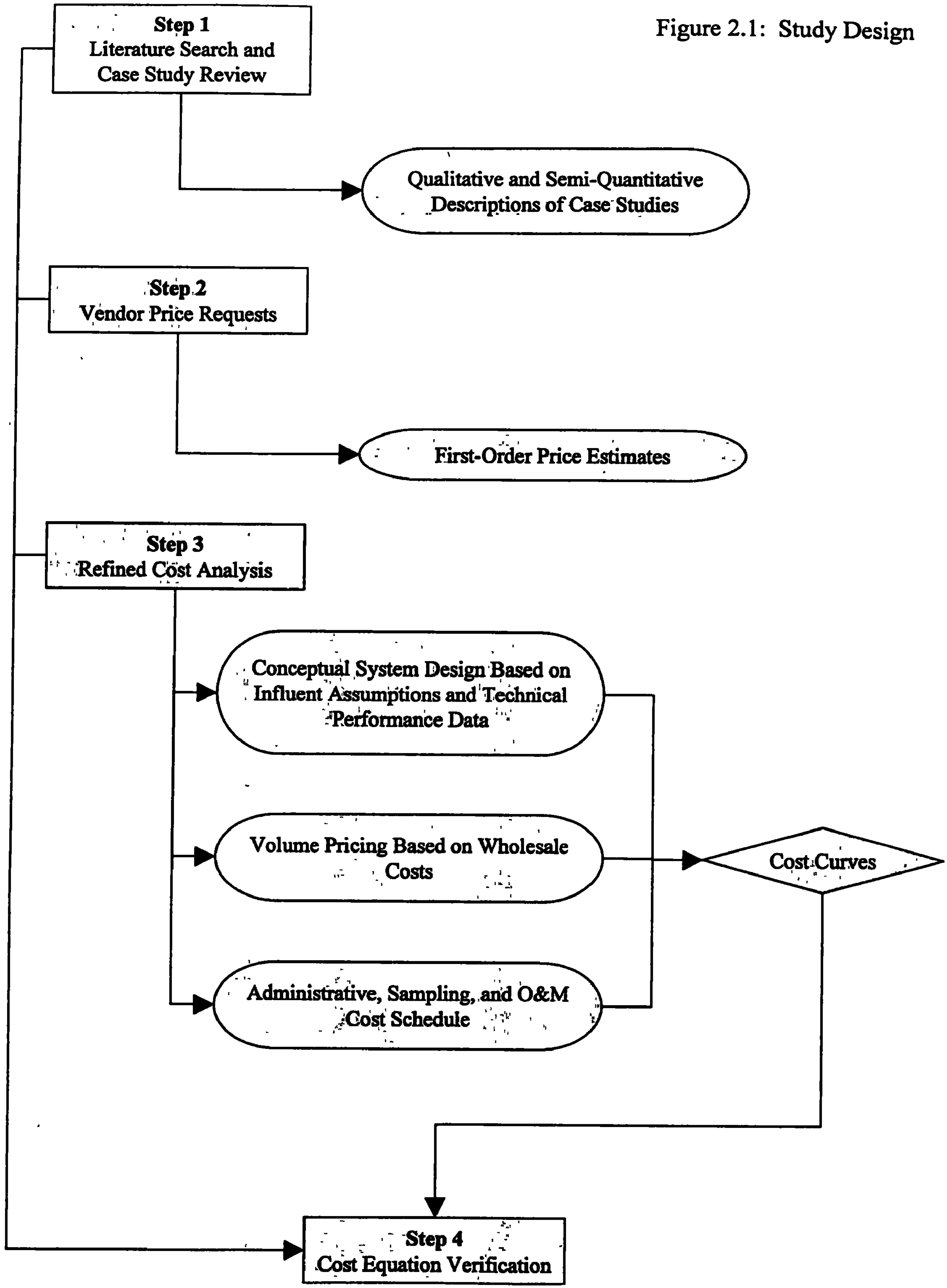


Table 2.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
AA	POU	Fairbanks AK, Eugene OR 1983	Arsenic	4	$250	$19	NA	$382	$95	$365	$32	$15	$411	$506	$462	$4 62
AA	POU	Gumerman (US) 1983	Arsenic	1	$280	$40	$50	$507	$134	$103	$106	$15	$294	$427	$390	$3.90
AA	POU	Gumerman (PL) 1983	Arsenic	1	$330	$120	$70	$712	$188	$103	$106	$15	$294	$482	$440	$4 40
AA	POU	Thunderbird Farms, AZ. 1985	Fluoride/Arsenic	8	$338	$19	NA	$357	$94	$386	$32	$78	$495	$590	$1,154	$5.39
AA	POU	Papago Butte, AZ 1985	Fluoride/Arsenic	1	$501	$19	NA	$520	$137	$369	$32	$15	$415	$552	$82	$5 04
AA	POU	Ruth Fisher Elementary School, AZ 1986	Fluoride/Arsenic	1	$514	$19	NA	$533	$141	$483	$32	$15	$529	$670	$216	$6.72
AA	POU	You and I TP, AZ 1985	Fluoride/Arsenic	1	$345	$19	NA	$364	$96	$413	$32	$15	$459	$555	$276	$5 07
AA	POU	Parkersburg, IL 1985	Fluoride/Arsenic	10	$401	$13	NA	$414	$109	$353	$32	$15	$399	$509	$2,322	$4.84
AA	POU	Bureau Junction, IL 1985	Fluoride/Arsenic	40	$416	$13	NA	$429	$113	$321	$31	$15	$366	$480	$1,642	$4 38
AC	Central	Goodrich 1990	DBCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,628	$16	$14.87
AC	Central	Goodrich 1990	DBCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$786	$8	$7 18
AC	Central	Goodrich 1990	DBCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$468	$5	$4.27
AC	Central	Goodrich 1992	DBCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,507	$16	$13 76
AC	Central	Goodrich 1992	DBCP	15	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,085	$11	$9.91
AC	Central	Goodrich 1992	DBCP	20	NP	NP	NP	NP	NP	NP	NP	NP	NP	$864	$9	$7 89
AC	Central	Goodrich 1992	DBCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$727	$8	$6.64
AC	Central	Goodrich 1992	DBCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$432	$4	$3 95
AC	POE	Goodrich 1990	DBCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$1,043	$5	$9 52
AC	POE	Goodrich 1990	DBCP	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$205	$15	$501	$1,032	$5	$9 43
AC	POE	Goodrich 1990	DBCP	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$258	$194	$15	$467	$999	$5	$9.12
AC	POE	Goodrich 1992	DBCP	10	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$1,341	$14	$12 25
AC	POE	Goodrich 1992	DBCP	15	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$1,341	$14	$12.25
AC	POE	Goodrich 1992	DBCP	20	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$205	$15	$501	$1,331	$14	$12 16
AC	POE	Goodrich 1992	DBCP	25	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$205	$15	$501	$1,331	$14	$12.16
AC	POE	Goodrich 1992	DBCP	50	$2,188	IWP	CpKGT	CpKGT	CpKGT	$258	$194	$15	$467	$1,298	$13	$11 85
AC	POE	Fresno, CA 1990	DBCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$894	$4	$8.17
AC	Central	Goodrich 1990	DCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,756	$17	$16 04
AC	Central	Goodrich 1990	DCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$882	$9	$8.05
AC	Central	Goodrich 1990	DCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$547	$5	$4 99
AC	Central	Goodrich 1992	DCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,542	$16	$14.08
AC	Central	Goodrich 1992	DCP	15	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,120	$12	$10 23
AC	Central	Goodrich 1992	DCP	20	NP	NP	NP	NP	NP	NP	NP	NP	NP	$898	$9	$8 20
AC	Central	Goodrich 1992	DCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$762	$8	$6 96
AC	Central	Goodrich 1992	DCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$466	$5	$4.26
AC	POE	Goodrich 1990	DCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$301	$15	$597	$1,493	$9	$13 63
AC	POE	Goodrich 1990	DCP	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$282	$15	$578	$1,474	$9	$13 46
AC	POE	Goodrich 1990	DCP	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$258	$263	$15	$536	$1,432	$9	$13 08
AC	POE	Goodrich 1992	DCP	10	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$301	$15	$597	$1,561	$16	$14.26
AC	POE	Goodrich 1992	DCP	15	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$301	$15	$597	$1,561	$16	$14 26
AC	POE	Goodrich 1992	DCP	20	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$282	$15	$578	$1,542	$16	$14 09
AC	POE	Goodrich 1992	DCP	25	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$282	$15	$578	$1,542	$16	$14 09
AC	POE	Goodrich 1992	DCP	50	$2,188	IWP	CpKGT	CpKGT	CpKGT	$258	$263	$15	$536	$1,501	$16	$13.70
AC	POE	Florida (Type I) 1987	EDB	1	$1,000	IWP	NA	$1,252	$204	$890	$400	IWS	$1,616	$1,820	$17	$16 62
AC	POE	Florida (Type II) 1987	EDB	1	$1,050	IWP	NA	$1,316	$214	$890	$400	IWS	$1,616	$1,830	$17	$16.71
AC	POE	Various States (GAC 10) 1989	Radon	1	$828	$116	NA	$944	$154	$283	$152	$15	$449	$603	$6	$5 50
AC	POE	Various States (GAC 17) 1989	Radon	1	$1,077	$116	NA	$1,193	$194	$283	$152	$15	$449	$643	$6	$5 88
AC	POE	Various States (GAC 30) 1989	Radon	1	$1,350	$116	NA	$1,466	$239	$283	$152	$15	$449	$688	$6	$6 28

Table 2.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
AC	POU	Gumerman (US) 1983	SOCs	1	$220	$40	$40	$411	$108	$52	$164	$15	$303	$411	$376	$3.76
AC	POU	Gumerman (PL): 1983	SOCs	1	$270	$120	$60	$618	$163	$52	$164	$15	$303	$468	$425	$4.25
AC	POU	Ebbert (var. cap.) 1985	SOCs	1	$260	$19	$42	$321	$85	$211	$121	$15	$347	$432	$394	$3.94
AC	POU	EPA Database (var. cap.): 1989	SOCs	1	$204	$19	$33	$257	$68	$205	$121	$15	$340	$408	$373	$3.73
AC	POU	EPA Study 1988	SOCs	1	$378	$97	$95	$571	$151	$251	$121	$15	$386	$537	$490	$4.90
AC	Central	Lykins (TP w/pipe) 1992	TCE	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$406	$4	$3.71
AC	Central	Lykins (SD w/pipe) 1992	TCE	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$704	$7	$6.43
AC	Central	Lykins (w/o pipe): 1992	TCE	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$202.95	$2	$1.85
AC	Central	Putnam County NY (est.) 1987	TCE	110	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$1,576	$14	$14.40
AC	Central	Goodrich. 1990	TCE	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,640	$16	$14.98
AC	Central	Goodrich 1990	TCE	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$798	$8	$7.29
AC	Central	Goodrich: 1990	TCE	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$480	$5	$4.38
AC	Central	Goodrich 1992	TCE	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,514	$16	$13.83
AC	Central	Goodrich: 1992	TCE	15	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,092	$11	$9.97
AC	Central	Goodrich 1992	TCE	20	NP	NP	NP	NP	NP	NP	NP	NP	NP	$871	$9	$7.95
AC	Central	Goodrich: 1992	TCE	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$734	$8	$6.71
AC	Central	Goodrich 1992	TCE	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$438	$5	$4.00
AC	POE	Lykins: 1992	TCE	150	$2,188	NP	$328	$2,517	$410	$748	$263	$15	$1,026	$1,435	$15	$13.11
AC	POE	Putnam County, NY 1987	TCE	67	$823	$494	NA	$1,650	$268	$320	$263	$15	$678	$947	$10	$8.65
AC	POE	Goodrich: 1990	TCE	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$270	$301	$15	$585	$1,341	$8	$12.25
AC	POE	Goodrich 1990	TCE	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$270	$282	$15	$566	$1,322	$8	$12.08
AC	POE	Goodrich: 1990	TCE	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$253	$263	$15	$530	$1,286	$8	$11.75
AC	POE	Goodrich 1992	TCE	10	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$301	$15	$608	$1,481	$15	$13.53
AC	POE	Goodrich: 1992	TCE	15	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$301	$15	$608	$1,481	$15	$13.53
AC	POE	Goodrich 1992	TCE	20	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$282	$15	$589	$1,462	$15	$13.36
AC	POE	Goodrich: 1992	TCE	25	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$282	$15	$589	$1,462	$15	$13.36
AC	POE	Goodrich 1992	TCE	50	$2,188	IWP	CpKGT	CpKGT	CpKGT	$286	$263	$15	$564	$1,438	$15	$13.13
AC	POU	Rockaway Township, NJ: 1985	TCE	12	$377	IWP	NA	$377	$100	$201	$196	$15	$411	$511	$608	$4.66
AC	POU	Silverdale, PA. 1985	TCE	49	$289	IWP	NA	$289	$76	$206	$179	$15	$399	$475	$1,302	$4.34
AC	POE	Riverhead/Southhold, NY: 1988	VOCs/Radon	1	$2,050	$113	NA	$2,817	$459	$264	$238	$15	$517	$975	$9	$8.91
AC	POE	EPA Database (var. cap.). 1989	VOCs/Radon	1	$940	$112	$158	$1,360	$221	$264	$238	$15	$517	$738	$7	$6.74
AC	POE	EPA Study: 1988	VOCs/Radon	1	$2,531	$123	$531	$3,185	$518	$250	$238	$15	$503	$1,021	$9	$9.32
AC/DBA	POE	Goodrich 1990	TCE	150	$5,623	NP	$843	$6,466	$1,052	$488	$263	$15	$766	$1,818	$19	$16.60
AC/DBA	POE	Elkhart: 1989	TCE	1	$4,685	IWP	NA	$4,685	$762	$646	$301	$15	$962	$1,724	$18	$15.74
Aeration	POE	EPA Database (var. cap.) 1989	VOCs/Radon	1	$1,959	$112	$311	$2,381	$388	$264	$238	$15	$517	$904	$8	$8.26
AX	POU	Fairbanks, AK; Eugene, OR: 1983	Arsenic	4	$350	$19	NA	$499	$132	$365	$32	$15	$411	$542	$495	$4.95
AX	POE	EPA Database (var. cap.): 1989	Arsenic/Nitrate	1	$1,155	$112	$190	$1,457	$237	$264	$122	$15	$400	$637	$6	$5.82
AX	POE	EPA Study: 1988	Arsenic/Nitrate	1	$2,167	$212	$476	$2,855	$465	$250	$122	$15	$386	$851	$8	$7.77
AX	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$350	$40	$60	$616	$163	$78	$124	$15	$284	$447	$408	$4.08
AX	POU	Gumerman (PL): 1983	Arsenic/Nitrate	1	$400	$120	$80	$822	$217	$78	$124	$15	$284	$501	$458	$4.58
AX	POU	EPA Database (var. cap.): 1989	Arsenic/Nitrate	1	$318	$19	$51	$387	$102	$365	$33	$15	$412	$514	$470	$4.70
AX	POU	EPA Study: 1988	Arsenic/Nitrate	1	$288	$97	$77	$461	$122	$411	$33	$15	$458	$580	$529	$5.29
AX	Central	Lykins (TP w/pipe) 1992	Nitrate	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$355	$4	$3.24
AX	Central	Lykins (SD w/pipe): 1992	Nitrate	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$653	$7	$5.96
AX	Central	Lykins (w/o pipe) 1992	Nitrate	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$177	$2	$1.62
AX	POE	Lykins. 1992	Nitrate	150	$2,188	$75	$339	$2,603	$424	$369	$121	$15	$505	$928	$10	$8.48
AX	POE	Riverhead/Southhold, NY 1985	Nitrate	1	$2,325	$175	NA	$2,553	$415	$327	$123	$15	$464	$880	$8	$8.03
AX	POU	Riverhead/Southhold, NY: 1985	Nitrate	1	$306	$80	NA	$410	$108	$365	$34	$15	$413	$521	$476	$4.76
AX	POU	Colorado and New Mexico 1983	Uranium	12	$125	$13	NA	$184	$49	$312	$34	$15	$361	$409	$374	$3.74

Table 2.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
CX	POE	RIA 1987	Copper	25	TCC	TTC	TTC	$1,316	$214	$309	$123	$15	$525	$739	$7	$7 73
CX	POE	RIA 1987	Copper	120	TCC	TTC	TTC	$889	$145	$208	$122	$15	$398	$541	$6	$7.05
CX	POE	RIA 1987	Copper	300	TCC	TTC	TTC	$1,174	$191	$277	$122	$15	$482	$673	$6	$6 56
CX	POE	RIA 1987	Copper	860	TCC	TTC	TTC	$1,046	$170	$248	$122	$15	$444	$614	$6	$6.25
CX	POE	EPA Database (var cap) 1989	Copper	1	$1,155	$112	$190	$1,457	$237	$175	$124	$15	$313	$550	$5	$5 03
CX	POE	EPA Study 1988	Copper	1	$2,167	$212	$476	$2,855	$465	$161	$124	$15	$299	$764	$7	$6 98
CX	POU	Gumerman (US) 1983	Copper	1	$260	$40	$45	$472	$125	$63	$124	$15	$264	$389	$355	$3 55
CX	POU	Gumerman (PL) 1983	Copper	1	$310	$120	$65	$678	$179	$83	$124	$15	$264	$443	$405	$4.05
CX	POU	EPA Database (var cap) 1989	Copper	1	$318	$19	$51	$387	$102	$325	$35	$15	$374	$476	$435	$4 35
CX	POU	EPA Study 1988	Copper	1	$288	$97	$77	$461	$122	$371	$35	$15	$420	$542	$495	$4.95
CX	Central	Bellevue, WI 1989	Radium	1,282	TAC	TAC	TAC	TAC	$118	TAOMC	TAOMC	TAOMC	$75	$193	$2	$1 77
CX	POE	Bellevue WI (w/o Outside Ctrs), 1989	Radium	1,282	$356	$48	$81	$538	$88	TAOMC	TAOMC	TAOMC	$182	$270	$2	$2.47
CX	POE	Bellevue WI (w Outside Ctrs) 1989	Radium	1,282	$1,107	$27	$170	$1,512	$246	TAOMC	TAOMC	TAOMC	$208	$454	$4	$4 15
Disinfection	Central	Gibson Canyon, CA. 1992	Bacteria	140	$11,000	IWP	NA	$11,789	$1,385	TAOMC	TAOMC	TAOMC	$455	$1,840	$17	$16.81
Disinfection	POE	Gibson Canyon CA (Alternative One) 1992	Bacteria	140	$2,657	$75	NA	$2,922	$476	TAOMC	TAOMC	TAOMC	$2,078	$2,554	$23	$23 32
Disinfection	POE	Gibson Canyon, CA (Alternative Two) 1992	Bacteria	140	$3,529	$75	NA	$3,856	$628	TAOMC	TAOMC	TAOMC	$831	$1,459	$13	$13.32
Disinfection	POE	Ephraim WI (Cl and UV) 1994	Bacteria	425	$2,910	IWP	NA	$2,910	$474	$295	$68	$47	$429	$903	$8	$8 24
Disinfection	POE	EPA Database (var cap): 1989	Bacteria	1	$609	$112	$108	$829	$135	$225	$128	$15	$387	$502	$5	$4.58
Disinfection	POU	EPA Database (var cap) 1989	Bacteria	1	$684	$19	$106	$809	$213	$195	$39	$15	$248	$462	$422	$4 22
PTA	Central	Elkhart 1987	TCE	21,667	$115	IWP	NA	$145	$17	TAOMC	TAOMC	TAOMC	$5	$22	$0	$0.20
RO	Central	San Ysidro NM (Univ Houston est) 1986	Arsenic	1	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$536	$199	$4 90
RO	POU	San Ysidro NM (Contract O&M), 1986	Arsenic	78	$290	$36	NA	$415	$110	TAC	TAC	TAC	TAC	$241	$89	$2.20
RO	POU	San Ysidro NM (Village O&M) 1986	Arsenic	78	$290	$36	NA	$415	$110	TAC	TAC	TAC	TAC	$217	$81	$1 99
RO	POU	San Ysidro NM (Capital Costs), 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$191	$71	$1.74
RO	POU	San Ysidro NM (Alternative One w/Capital) 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$217	$81	$1 98
RO	POU	San Ysidro, NM (Alternative Two w/Capital) 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$197	$73	$1.80
RO	POU	San Ysidro, NM 1986	Arsenic	1	$665	IWP	NA	$849	$224	$220	$32	$15	$266	$490	$447	$4 47
RO	POU	Fairbanks AK, Eugene OR 1983	Arsenic	4	$292	$19	NA	$419	$111	$220	$32	$15	$266	$376	$344	$3.44
RO	Central	Emington, IL (est) 1985	Arsenic/Fluoride	47	$2,553	IWP	NA	$3,326	$391	TAOMC	TAOMC	TAOMC	$59	$450	$27	$27 28
RO	Central (Ctn)	King's Point, Suffolk, VA (est.): 1995	Arsenic/Fluoride	57	$14,263	IWP	NA	$14,624	$1,718	Minimal	Minimal	Minimal	Minimal	$1,718	$16	$15 69
RO	POU	King's Point, Suffolk, VA , 1995	Arsenic/Fluoride	1	$1,065	$19	NA	$1,085	$286	$400	AMC	$15	$425	$711	$649	$6 49
RO	POU	Emington, IL 1985	Arsenic/Fluoride	47	$660	$68	NA	$749	$197	$287	$31	$15	$333	$530	$1,815	$4.84
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	25	TAC	TAC	TAC	$1,461	$238	$232	$121	$15	$426	$470	$4	$5 82
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	120	TAC	TAC	TAC	$1,131	$184	$189	$120	$15	$371	$373	$3	$5 31
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	300	TAC	TAC	TAC	$1,496	$243	$252	$120	$15	$450	$495	$5	$4 95
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	860	TAC	TAC	TAC	$1,333	$217	$224	$120	$15	$415	$441	$4	$4 71
RO	POE	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$3,520	$112	$545	$4,177	$680	$657	$122	$15	$793	$1,473	$13	$13 45
RO	POE	EPA Study: 1988	Arsenic/Nitrate	1	$8,836	$364	$1,840	$11,040	$1,797	$591	$122	$15	$727	$2,524	$23	$23 05
RO	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$370	$50	$65	$664	$175	$148	$124	$15	$378	$553	$505	$5 05
RO	POU	Ebbert (var cap) 1985	Arsenic/Nitrate	1	$892	$19	$137	$1,435	$379	$221	$33	$15	$269	$647	$591	$5.91
RO	POU	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$454	$19	$71	$545	$144	$152	$33	$15	$199	$343	$313	$3 13
RO	POU	EPA Study 1988	Arsenic/Nitrate	1	$833	$121	$191	$1,145	$302	$198	$33	$15	$248	$548	$500	$5.00
RO	POE	Riverhead/Southhold NY 1985	Nitrate	1	$9,491	$300	NA	$9,881	$1,608	$643	$123	$15	$781	$2,389	$22	$21 82
RO	POU	Riverhead/Southhold, NY 1985	Nitrate	1	$892	$110	NA	$1,035	$273	$152	$34	$15	$201	$474	$433	$4 33

Table 2.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Assumptions

Number of people per household	3 0
Water consumed per person per day (gpd/per)	1 0
Total water use per person per day (gpd/per)	100 0
Water consumed per household per year (gpy/hh)	1,095 0
Total water use per household per year (gpy/hh)	109,500 0
Hours per workday	8 00
Expected effective life of POU (years)	5 0
Expected effective life of POE (years)	10 0
Expected effective life of Central Plant (years)	20 0
Minimally skilled wage rate ($/hr)	$14 50
Skilled wage rate ($/hr)	$28 00
Installation travel and preparation time (hrs/day)	2 00
POU installation (hrs/unit)	1 00
POE installation (hrs/unit)	3 00
Maintenance travel and preparation time (hrs/day)	2 00
POU maintenance (hrs/unit)	0 75
POE maintenance (hrs/unit)	2 00
Sampling frequency (samples/hh/yr)	1 00
Sampling travel and preparation time (hrs/day)	1 00
POU sampling time (hrs/sample)	0 25
POE sampling time (hrs/sample)	0 50
Sampling and maintenance coordination time (hrs/hh/yr)	1 00
Amortization rate	10 0%
Contingency fee	15 0%

Notes

All italicized entries incorporate assumptions to permit comparison with Cadmus cost curves
- All sampling trips take place at same time as maintenance
- Electrical costs are ignored in the calculation of total annual costs

Replacement Parts

POU Component	Contaminant	Cost	Expected Life
AA Cartridge	Arsenic	$80 00	38
GAC Cartridge	Alachlor	$40 00	38
AX Cartridge	Arsenic/Nitrate	$80 00	38
CX Cartridge	Copper	$70 00	38
RO Membrane	Arsenic	$135 00	150
RO Membrane	Nitrate	$135 00	300
Particulate Filter	Any	$15 00	75
GAC pre-/post-filter	Any	$20 00	75

POE Component	Contaminant	Cost	Treatment Capacity
AA	Arsenic	$85 00	#DIV/0!
GAC	[illegible]	$80 00	82,500
GAC	Radon (300)	$80 00	#DIV/0!
GAC	Radon (1,500)	$80 00	#DIV/0!
AX	Arsenic	$126 00	109,500
AX	Nitrate	$126 00	54,750
CX	Copper	$100 00	109,500
UV Bulb	Microbiologicals	$150 00	109,500

Bulk Discount Rates

Unit Description	Number of Units	Discount
POU	10	15 0%
	50	22 5%
	100+	30 0%
POE (not RO or Rn)	10	15 0%
	50	22 5%
	100+	30 0%
POE RO	10	10 0%
	50	12 5%
	100+	15 0%
POE for Rn	10	10 0%
	50+	20 0%

PPI, Final demand less energy

Year	Level	1997 19XX
1985	96 3	0 00
1986	98 3	0 00
1987	100 2	0 00
1988	103 5	0 00
1989	108 2	0 00
1990	112 5	0 00
1991	115 4	0 00
1992	117 1	0 00
1993	118 9	0 00
1994	120 1	0 00
1995	122 4	0 00
1996	125 0	0 00
1997	125 5	0 00
pre-1985	NA	1 000

PPI, Water and sewer supply construction

Year	Level	1997 19XX
1986	99 5	0 00
1987	101 1	0 00
1988	105 7	0 00
1989	110 2	0 00
1990	113 4	0 00
1991	115 8	0 00
1992	116 8	0 00
1993	118 8	0 00
1994	122 0	0 00
1995	126 8	0 00
1996	130 0	0 00
1997	132 8	0 00
pre-1986	NA	1 00

Key

Acronym	Meaning	Acronym	Meaning
AA	Activated Alumina	NP	Not Provided
AX	Anion Exchange	POE	Point-of-Entry
CpKGT	Included in Cost per 1 000 Gal. Treated	POU	Point-of-Use
CX	Cation Exchange	PPI	Producer Price Index
DBA	Diffuse Bubble Aeration	Rn	Radon
DBCP	Dibromochloropropane	RO	Reverse Osmosis
DCP	Dichloropropane	TAC	Included in Total Annual Cost
EDB	Ethyldibromide	TAOMC	Included in Total Annial O&M Cost
GAC	Activated Carbon	TCE	Trichloroethylene
IWP	Included with Purchase	UV	Ultraviolet Disinfection
NA	Not Applicable		

Lab Fees

Contaminant	Fee
Arsenic	$8 50
Copper	$12 00
Nitrate	$11 00
Radon	$46 50
Alachlor	$98 00
DBCP/EDB	$87 00
TCE/DCP	$173 00
Total Coliform	$16 00

Lab Discount Rates

# of Samples	Discount
20 to 49	10%
50+	20%

Installation Discount Rates

# of Units	Discount
10 +	33%

Conversion Factors

Gallon	Liter	3 785
Grain	Milligram	64 798

Figure 2.1 details the way in which the case study data were included in this cost analysis. Detailed information on "real world" implementation of POE and POU devices was gleaned from documented case studies. However, while these case studies were useful, they were generally too dated or too parochial for use in developing broadly applicable costs. The POE and POU industry has become much more competitive than it was in the early 1980s as more vendors have entered the market. Prices for household water treatment equipment have stabilized and, in some areas, have decreased. Water treatment technology has improved, permitting the fabrication of more durable and more efficient treatment units. Therefore, simply escalating the costs presented in the case studies to 1997 dollars to account for inflation would not provide an accurate picture of the costs small communities would likely incur to purchase, install, and maintain POE and POU devices today.

Nonetheless, the Producer Price Index (PPI) for "final demand less energy" was used to permit comparison between the capital and O&M costs presented in Table 2.1. The case studies were used to verify and support the costs developed in this analysis for the implementation of POE and POU treatment strategies, rather than as the basis for the cost curves presented in section 4. In the event of substantial disagreement between the case study costs and the Cadmus costs, the Cadmus costs and the associated assumptions were revisited to ensure accuracy. In all cases of substantial disagreement a logical explanation for the deviation was found.

The case studies that follow are organized by the contaminant of concern. This organization permits the reader to compare the costs of different POE, POU, and central treatment technologies that may be used to treat a particular contaminant. Note that section 2.11 details the use of POE and POU technology for the treatment of microbiological contaminants. As mentioned in sections 1.1 and 1.4, the SDWA specifically forbids the use of POU devices for the achievement of an MCL for any microbiological contaminant. Great care must also be taken when instituting a POE treatment strategy for microbials. Therefore, these sections should not be read as a recommendation for the implementation of a POU or POE treatment strategy for microbials, but instead as an example of management and sampling strategies that may be used to implement a POU and POE treatment strategy. A community should not select one of the devices described in the case studies simply because the device was used successfully and economically treat the contaminant polluting the community's water. As noted in section 1.5.3, before widespread installation, a treatment device should undergo pilot testing to determine its capacity to treat the contaminant of concern given the nature of the local source water.

2.1 Arsenic Treatment

Arsenic as a free element (As^0) is rarely encountered in natural waters. Soluble inorganic arsenate (As[V]) predominates under normal conditions since it is thermodynamically more stable in water than arsenite (As[III]). Arsenate and arsenite are commonly found in both ground and surface water supplies. Arsenic is frequently used in agricultural chemicals (e.g., herbicides and desiccants) and is often incorporated in semiconductor devices.

Several treatment techniques have proven effective in removing arsenic from water. These include lime softening, electrodialysis, distillation, AA, AX, and RO. However, it is currently only practical to employ the latter four technologies in POU devices (see section 1.3).

AA has proven effective for arsenic removal in several studies (Bellack 1971, Gupta 1978, Clifford 1982, EPA unpublished). The ability of AA to adsorb arsenic is directly dependent on pH. The maximum capacity of AA for arsenic adsorption occurs between pH 5.5 and pH 6.0.

1973 laboratory studies by Shen and Calmon demonstrated that arsenic can be removed by AX resins. As mentioned above, arsenic occurs naturally in ground and surface waters in two valence states, arsenate and arsenite. Arsenate is predominantly encountered as a negatively charged ion. Therefore it is efficiently removed by AX technology. Arsenite occurs predominantly as an uncharged ion (H_3AsO_3) in waters with a pH of less than 9.0 and is not removed as effectively as arsenate by AX (see section 1.3.3). If arsenite is present in source water, oxidation to arsenate is necessary for effective removal by AX.

An unpublished EPA report shows that RO systems can remove more than 90 percent of arsenate and 60 to 70 percent of arsenite. A 1981 study by Huxstep corroborates these results.

2.1.1 Fairbanks, Alaska and Eugene, Oregon

This study investigated the efficacy of AA, AX, and RO devices. Two homes in Eugene, Oregon and two homes in Fairbanks, Alaska were equipped with POU systems designed to treat household drinking water. Each of systems was composed of an AA tank, an AX tank, and an RO system. A water meter was used to measure the true throughput of each unit. The households chosen for study were selected with the cooperation of State organizations and individual homeowners. All relied on private well water that frequently exceeded the MCL for arsenic (0.05 mg/L). This case study was summarized by Fox (1989)

Arsenic concentrations in the source water for the study households ranged from less than 0.005 mg/L to more than 1.1 mg/L during this study. Arsenate was believed to predominate at all four test locations. It is important to note that iron and sulfate concentrations were low in the source water (see Table 2.1.1.1) because these contaminants may interfere with the removal of arsenic. Iron compounds will clog and foul AX resins and the AA media (see sections 1.3.1 and 1.3.3), thereby reducing the removal capabilities of each unit or reducing water throughput. Sulfate is preferentially selected over arsenic by AX resins and also interferes with arsenic removal by AA (see sections 1.3.1 and 1.3.3). In a 1982 study, Clifford and Rosenblum showed that arsenic adsorption was reduced by 50 percent in the presence of 15 milliequivalents (meq) of sulfate per liter in deionized water. The equivalent weight of a substance is its atomic or molecular weight divided by its ionic charge or the number of hydrogen atoms that would be required to replace the cation.[1] During this study, treated water was not consumed by homeowners.

Table 2.1.1.1: Source Water Quality of Surveyed Households in Fairbanks, AK and Eugene, OR

Contaminant	Influent Concentration for Households in Fairbanks		Influent Concentration for Households in Eugene	
	Household One (mg/L)	Household Two (mg/L)	Household One (mg/L)	Household Two (mg/L)
Arsenic (range)	0.25-1.08	0.22-1.16	<0.005-0.28	0.005-0.32
Calcium	22	8.9	18	19
Magnesium	10.6	9.3	5.3	5.5
Sodium	6.0	4.4	40	62
Chloride	<10	<10	<10	<10
Iron	<0.1	0.20	0.24	0.18
Sulfate	<15	<15	<15	<15
Turbidity (NTU)	0.48	0.32	0.43	0.24
Alkalinity	108	56	151	206
pH	8.0	7.4	8.3	8.3

The POU units were operated automatically by a system of solenoid valves and timers. The timers were initially set to open the valves daily at the times when an average family might use water. The system was designed so that each treatment unit would operate separately and no two effluent valves would be open at the same time. The timers actuated the effluent valves nine times a day, permitting the treatment of 1 gallon of water by both the AX and the AA tank, and 0.5 gallons of water by the RO unit each time the valves were opened. After 6 months, the valves were opened 18 times a day to increase flow through the units to speed up arsenic breakthrough.[2]

1 A meq of sulfate (SO_4^{2-}) would equal: (32 + 16*4) / 2 = 48 mg/meq

2 Breakthrough occurs when the concentration of the contaminant of concern exceeds a specified level (generally the local, state, or federal MCL for the contaminant).

Local and State employees performed all sampling of the units. Samples were collected biweekly from the influent and effluent lines of each of the three treatment elements and were sent to EPA in Cincinnati, Ohio for analysis.

2.1.1.1 Activated Alumina

The AA tanks used in this study were 46 inches tall and 9 inches in diameter. Each AA tank was filled with 1 cubic foot of granular activated alumina. The AA medium was designed to be pre-treated in the tank. The pre-treatment process consisted of passing a sodium hydroxide solution through the tank, rinsing the medium with clean water, and then treating the medium with dilute sulfuric acid to lower its pH. At a flow rate of 1 gpm, the surface loading rate of the tank was 2.7 gpm per square foot, and the minimum empty bed contact time (EBCT) was 7.5 minutes. The actual contact time was probably greater because the effluent valves were opened for only 1 minute by the timers, and the water sat undisturbed in the tank (in contact with the AA) until the next valve-opening period.

The three AA units that failed to work as well as expected suffered from inadequate pretreatment. None of the units that failed had been treated with dilute sulfuric acid. Therefore, the pH of the water in the AA units was well above the ideal level for arsenic adsorption (pH 6). Thus, the tanks' capacity to adsorb arsenic was much lower than anticipated. However, the six properly prepared AA units performed extremely well, consistently maintaining arsenic levels well below the MCL until they were taken off line. Three units successfully treated more than 10,000 gallons of water (10,784, 15,427, and 18,557 gallons) while the remaining three AA units each successfully treated more than 6,000 gallons. Based on the results of this study, a capacity of about 1.0 mg of arsenic per gram of AA could probably be expected in future applications of AA if source water concentrations of iron and sulfate are limited and the AA undergoes all appropriate pretreatment.

2.1.1.2 Anion Exchange

The AX tanks used in this study were the same size as the AA tanks. Each AX tank was filled with 1 cubic foot of a strong base AX resin. The resin was chemically treated in the tank into the chlorine form. At a flow of 1 gpm, the surface loading rate of the tank was 2.7 gpm per square foot, providing a minimum EBCT of 7.5 minutes. The actual contact time was probably greater because the effluent valves were only opened for 1 minute by the timers, and the water sat undisturbed in the tank (in contact with the resin) until the next valve-opening period.

Two AX units exhibited erratic removal of arsenic. A third unit performed poorly due to inadequate regeneration practices at the start of the project. However, the remaining four AX units worked extremely well, successfully treating water containing as much as 1.16 mg/L of arsenic to concentrations of less than 0.05 mg/L. Three of the units treated more than 10,000 gallons successfully (11,858, 16,254, and 20,935 gallons) and were disconnected at the end of the project even though the capability of the resin to adsorb arsenic had not been exhausted. Depositions of up to 0.86 mg of arsenic per gram of resin were found in the AX tanks when they were opened at the end of the study.

2.1.1.3 Reverse Osmosis

The RO units studied for this project were designed to produce between 3 and 5 gallons of drinking water per day and to operate with source water pressures ranging from 20 to 100 psi with a reject-to-product water ratio of about 10:1. Each RO unit was equipped with a 5-μm cartridge pre-filter, a carbon post-filter, a cellulose-acetate RO membrane, and a small storage tank. Two years into the study, a second type of RO system was installed at one location. This unit was identical to the old unit, except that a booster pump was added to increase operating pressure to 195 psi. The use of the high-pressure RO system improved the reject-to-product water ratio to 3:1 but also increased electrical costs.

The low-pressure RO systems initially removed 60 to 80 percent of influent arsenic. However, due to the high arsenic concentrations of the source water at the study sites, the RO units rapidly deteriorated and were not always successful in lowering the arsenic concentration below the MCL. On average, the low-pressure RO units provided only a 50 percent removal rate for arsenic over the life of their membranes. For the low-pressure RO system to serve as an effective treatment option given the raw water characteristics observed during this study, the membranes would need to be replaced at least twice a year. The high-pressure RO unit successfully reduced arsenic levels below the MCL for 330 days before it was taken off line at the conclusion of the study. All of the RO systems significantly lowered the level of TDS in the source water.

One potential cause of concern for system administrators who select this treatment technology is the limited production capability of some RO units (less than 3 gallons of treated water each day). The large amount of water wasted by low-pressure RO units may be a source of concern in water-scarce regions. However, since arsenic is not accumulated on the RO membrane, disposal is not a concern as it may be with POU AX and POU AA systems. In areas of high arsenic concentrations in source water, AA units, AX units, or high-pressure RO units may be necessary to ensure adequate protection of public health.

2.1.1.4 Cost Data and Study Conclusions

Costs for the various elements of the pilot systems installed in Alaska and Oregon were provided by Fox (1987). The capital costs reported in the case study were $350, $250, and $292 for the AX element, AA element, and RO element, respectively (1983 dollars).

The author of the study drew several conclusions about the ability of POE and POU devices to treat contaminated water adequately.

1. Any medium used in a POE or POU device must undergo adequate pre-treatment to permit efficient and effective contaminant removal.

2. Sampling should be done immediately after installation and periodically thereafter to confirm adequate contaminant removal.

3. A complete source water analysis is necessary to determine the proper type of POU or POE devices to be used.

4. POE devices should be used when skin adsorption or inhalation of a specific contaminant is of concern.

This study suggests that in areas where centralized treatment is not feasible (e.g., when the cost of a central treatment plant would be prohibitive) the use of POE or POU treatment devices may be acceptable. POE and POU treatment units are easy to install and are relatively inexpensive. POU units provide the added efficiency of treating only water that is actually consumed. However, the use of POE and POU treatment devices requires an extensive monitoring program and substantial educational outreach to the community to ensure the continuous protection of public health. Further, as stated in section 1.5, the installation of POE or POU devices does not eliminate the liability of the local water system. The system is still responsible for the reliable and consistent provision of safe drinking water to all of its customers.

2.1.2 San Ysidro, New Mexico

Rogers (1988) authored the original report detailing the San Ysidro experience from which much of this summary was drawn. Details regarding this case study were also reported by Lykins (1992). The Village of San Ysidro is a rural community of about 200 people located approximately 45 miles north of Albuquerque, New Mexico. Village water is disinfected by a hypochlorination system at the source, a nearby infiltration gallery. The infiltration gallery produces an average of 27,000 gallons per day (gpd) in winter and 36,000 gpd in summer. However, the village uses an average of 30,000 gpd (about 150 gpd per person). To provide the additional capacity the village needs, a 20,000-gallon elevated storage tank was connected to the distribution system. Unfortunately, mechanical and electrical problems have led to difficulty in keeping the tank operational.

The village has a long history of water supply problems, including low water pressure, unpleasant aesthetics (poor taste, color, clarity, and odor), sporadic coliform violations, and arsenic and fluoride contamination. The local ground water has a high mineral content because geothermal activity causes leaching from the area's abundant mineral deposits. At the beginning of the study, the ground water exceeded the primary MCL for arsenic and the recommended standards (secondary MCLs) for fluoride, iron, manganese, chloride, and TDS (0.05 mg/L, 2.0 mg/L, 0.3 mg/L, 0.05 mg/L, 250 mg/L, and 500 mg/L, respectively). The contaminants of primary concern to the village were arsenic and fluoride, each of which exceeded the MCL by three to four times. Arsenic and fluoride concentrations averaged 0.059 mg/L and 2.7 mg/L, respectively, over the course of the study. Of the arsenic found in village water, 35 percent was found to be arsenite.

Four deep test wells were drilled by a local engineering firm to determine if a better water source was available. However, the best of these wells had water merely equal in quality to that of the infiltration gallery. A University of Houston study determined that central treatment of the entire water supply was not feasible for several reasons. First, the village would face an expensive waste disposal problem with either arsenic-contaminated sludge from AA column regeneration or the concentrated reject brine produced by a central RO system. Second, building a central treatment plant would be prohibitively expensive. Third, a central treatment facility was deemed too complicated to be operated efficiently by a community the size of San Ysidro.

Since arsenic and fluoride are harmful only if ingested in excessive quantities for an extended period of time, only water destined for human consumption (i.e., water used for drinking and cooking) needed to be treated in San Ysidro. An analysis of unit removal efficiency, cost, and management requirements led to the identification of POU RO treatment as the best solution to the village's water supply problems. Therefore, EPA, in conjunction with the village, began a study designed to determine whether POU RO units could function satisfactorily in lieu of central treatment to remove arsenic and fluoride from the community's drinking water supply.

The number of units used by the community of San Ysidro ranged from 67 units at the beginning of the study to 78 units at the end. On average, 74 RO units were available for maintenance and testing during the study. The units were each equipped with a particulate pre-filter, a GAC pre-filter, a GAC post-filter, a spiral-wound polyamide RO membrane, a 3-gallon storage tank, and an in-line TDS monitor. Each unit was designed to produce between 5 and 8 gallons of product water per day. The ratio of reject-to-product water for these units ranged from 2:1 to 4:1. Three units were equipped with totalizing (water) meters to measure household water use. Over the course of the study, the units equipped with the meters treated 8.5 to 17 gallons of raw water per day.

Data were collected during the San Ysidro study to evaluate the effectiveness of POU RO units in removing arsenic, fluoride, TDS, and bacteria from the water. Samples were collected from each unit on a bimonthly basis and were analyzed for arsenic and fluoride. Every 4 to 6 months samples were also analyzed for chloride, iron, and manganese. Samples were also collected periodically from a smaller group of 40 units and were analyzed for total coliform organisms. Sample collection usually took 20 hours per month (about 15 minutes per household). A schedule for sample collection was typically placed in a customer's water bill. Each RO unit was numbered for identification purposes. Sampling costs over the course of the study averaged $25 per unit per month. However, post-study testing expenses were virtually eliminated because conductance (determined with the in-line TDS meter) was used as a surrogate test to warn of arsenic and fluoride breakthrough.

The RO units were very effective in removing arsenic and fluoride from the community's water, reducing average influent concentrations of 0.22 mg As/L and 5.2 mg F/L to less than 0.05 mg As/L and 2.0 mg F/L, respectively. The units also reduced chloride, iron, manganese, and TDS to desired levels despite low system pressure (sometimes less than 20 psi). However, as may be seen in Table 2.1.2.1, the removal percentages were approximately 10 percent below those stated in the manufacturer's literature. This was most likely due to the quantity and combination of contaminants in San Ysidro's water. The reduction of TDS resulted in consumer comment on the improved taste of water and the increased clarity of ice cubes. The improved water quality led customers to use treated water for cooking and drinking on a consistent basis.

The study did not generate conclusive findings on the effectiveness of the RO units in removing bacteria from drinking water. In fact, 15 of 131 samples tested positive for bacteria during routine sampling. After the carbon pre-filters were replaced and the system was flushed with chlorine, however, follow-up coliform analyses were negative. No evidence was found that suggested bacterial colonization on the RO membranes.

Table 2.1.2.1: Performance Data for POU RO Devices in San Ysidro, NM

Contaminant	Maximum Influent Concentration (mg/L)	Average Influent Concentration (mg/L)	Observed Removal Rate	Manufacturer's Estimated Removal Rate
Arsenic (total)	0.22	0.059	86%	68% As (III); 96% As (V)
Fluoride	5.2	2.7	87%	82%
Chloride	325.0	91	84%	94%
Iron	2.0	0.58	97%	Not Reported
Manganese	0.2	0.09	87%	97%
Total Dissolved Solids	1,000	780	88%	94%

A competitive bidding process was used to select a POU RO unit for the village. The winning vendor provided the village with a volume discount of 56.5 percent for the purchase of 80 units. Each unit cost the village $325 ($289.50 plus $35.50 for installation) instead of the vendor's standard retail price of $665.00 in 1986 dollars. The vendor maintained all of the treatment units in the community for a monthly service fee of $8.60 per unit. Over the course of the service contract, the village maintenance specialist received field training from the service contractor. The maintenance contract between the village and the vendor remained in effect for 20 months (approximately the duration of the study), after which the village maintenance specialist took over all maintenance and monitoring duties.

The author of the study calculated the anticipated future O&M costs for the residents of San Ysidro based on the village's experience during the study. The following assumptions were used to estimate these future costs:

1. The village would retain ownership of all RO units installed during the course of the study.

2. New units would be purchased by the water customer, but ownership of all RO units would remain with the village. New units were priced at $350 per unit.

3. The village would maintain a small supply of spare parts for routine filter replacement and leak repairs.

4. The frequency of filter and membrane replacement was based on performance during the project period. Replacement costs were $10.60 per particulate filter, $20.10 per carbon pre-filter, $15.60 per carbon post-filter, and $126 per membrane.

5. Damage resulting from customer negligence or misuse would be charged to the customer.

6. Leak repairs and other special service calls would require 8 hours per month.

7. Conductance checks would be performed on 20 units per month to ensure that each unit was checked at least once every 6 months. Checks would require 12 hours per month.

8. A sample from each POU unit would be tested once every 3 years for arsenic. Tests would be staggered over that period and would cost the village $8.50 each.

9. A village maintenance person would perform installation, routine maintenance, and sampling of the units (at $6.00 per hour).

10. Record keeping for all of the units in the community would require 8 hours of the Village Clerk's time each month (at $8.00 per hour).

11. The total estimated monthly charge per customer was based on the universe of 78 POU units installed by the end of the project period. Thus, the estimate was subject to change as the number of installed units increased.

Within the first 6 months, 6 units that were not working properly were replaced. Another 35 units required service due to leaks, TDS monitor malfunction, or water flow problems. Over the 20-month period of the maintenance contract, a total of $3,370 worth of replacement parts were required to repair the RO units. To estimate future repair costs, the village adjusted the figure in several ways. First, since the units had a pro-rated warranty of 24 months, a partial refund could be obtained if a unit was found to be defective. Over the 20-month period, $656 was refunded to San Ysidro by the vendor for premature breakage. Second, because customers were expected to pay for any damage to their RO units that resulted from their own negligence, the village could expect to avoid paying the repair costs associated with freeze damage ($136). Third, since it was determined that all future POU units would be disinfected prior to installation and installed with an air gap to prevent cross contamination with the household septic systems, the $1,034 worth of parts that needed to be replaced due to bacterial contamination could be ignored in the calculation of future costs. Thus, the future cost for replacement parts was estimated at $77.21 per month for the entire town. Since an average of 74 households were equipped with POU RO units while the maintenance contract was in effect, the estimated cost for replacement parts was determined to be $1.04 per household per month.

Incorporating the assigned and assumed costs for parts, labor, lab work, and insurance, the total cost per month per customer was estimated to be $7.04. This compares favorably to the monthly household charge ($30 to $40) estimated by the University of Houston for the installation of central treatment in San Ysidro. Further, the $30 to $40 monthly charge does not include the potential costs associated with disposal of the brine produced by the RO process. It is important to note that the estimate for central treatment included costs for capital expenditures, whereas the estimate for RO treatment did not include the initial purchase price of the unit. According to the report, if the cost of the units were included in the monthly charge, the monthly total cost for POU treatment would rise to $12.45.

Although the monthly cost for POU treatment was less than half that estimated for central treatment, the cost of each gallon treated by POU devices was approximately six times greater. Central treatment was estimated to cost approximately $0.01 per gallon treated (including capital costs). The POU treatment option cost approximately $0.06 per gallon treated (including the cost of the unit), based on a production level of seven gallons of treated water per day. Excluding unit capital costs for the POU treatment strategy would result in a cost of $0.03 per gallon treated. However, the cost per gallon used in households equipped with POU devices remains much lower than that of central treatment because POU units treat only a small portion of the water used by the household and do not require large fixed costs.

The costs of two alternative POU maintenance regimes were estimated by Rogers in the EPA report describing the San Ysidro study. The cost estimates for both alternatives were based on 78 units. Alternative One assumed that all carbon pre-filters would be changed annually. The purchase and installation of 78 carbon pre-filters would be required for this scenario (75 more than the base scenario each year). A quarter-hour of extra time was allotted for the village maintenance person to install the extra filter on each unit. This resulted in an additional charge of $1,620 per year, which translated into an additional cost of $1.73 per unit per month. Alternative Two assumed a higher cost for replacement polyamide membranes ($170 instead of $126 per membrane). Since the study assumed that 10 percent of membranes would need to be replaced each year (an implicit 10-year lifetime), Alternative Two would result in an additional charge of $352 per year. This translated into an additional monthly cost to customers of $0.38 per unit. Note that a much shorter 1- or 2-year lifetime was assumed for RO membranes for the purposes of the POU cost analysis (see section 4.3.1). Table 2.1.2.2 presents the costs of various treatment options examined for San Ysidro.

Table 2.1.2.2: Cost of POU and Central Treatment Options for San Ysidro, NM(1986$)

Treatment	Cost per Household per Month ($/month)	Gallons Treated (gal)	Cost per Thousand Gallons Treated ($/Kgal)
POU treatment (excluding cost of unit)	$7.04	225	$31.29
POU treatment (including cost of unit)	$12.45	225	$55.33
POU treatment Alternative 1 (including cost of unit)	$14.18	225	$63.02
POU treatment Alternative 2 (including cost of unit)	$12.83	225	$57.02
Central treatment (University of Houston estimate)	$30-$40	3,000	$10-$13

To meet its responsibilities under section 1412(b)(4)(E)(ii) of the SDWA, San Ysidro passed an ordinance making the use of village water contingent upon the installation of a POU device in the home. The ordinance was deemed necessary because POU treatment cannot be considered a viable alternative to central treatment if the water system does not supply safe (i.e., treated) drinking water to all of its customers.

The successful operation of a community-wide POU treatment strategy requires that the responsibilities of water users and the water utility be clearly identified. The village council of

San Ysidro outlined six responsibilities for water users and three for the water utility (the village). Each water user was required to:

1. Allow access to their unit.
2. Protect their unit from damage.
3. Assume liability for damage to their unit.
4. Refrain from tampering with or disconnecting their unit.
5. Allow periodic inspection of their unit.
6. Report any problems with their unit to the water utility in a timely fashion.

The village was required to provide:

1. Unit maintenance.
2. Periodic monitoring.
3. Liability insurance to cover any damage caused to a resident's home by a treatment device.

To fulfill the consumer requirements, each water customer was required to sign a permission form allowing a village designee to enter his or her home for installation and for periodic testing and maintenance. Customers were also required to accept liability for their treatment device in the event of negligence or tampering.

The village clerk played a vital role in managing the installation, maintenance, and monitoring of the units (fulfilling the village's first two requirements). As the contact person for water customers, the clerk made arrangements with customers for unit installation and all necessary maintenance work. The clerk coordinated this effort with the contractor's service manager during the 20-month service contract and with the village maintenance specialist after the contract expired.

To fulfill its third requirement, the village of San Ysidro secured a liability policy designed to cover water damage resulting from improper installation or device malfunction. The policy cost the community $400 per year.

The village made special provisions for commercial establishments. Although the primary responsibility for providing safe drinking water lies with the water utility operator, the village decided to transfer this responsibility to the commercial water user through a new ordinance. This served two purposes. First, the village was relieved of the burden of trying to coordinate the leasing, purchasing, and maintenance of RO units of various sizes. Second, the ordinance allowed commercial water users some flexibility in selecting the most economical way to provide safe drinking water to their customers. Note that this transfer of responsibility and liability may not be legal in all localities.

Several conclusions were drawn as a result of the San Ysidro study:

- POU treatment served as an effective and economically sound alternative to central treatment in San Ysidro for the removal of arsenic, fluoride, and other contaminants.

- POU treatment of drinking water can be a reliable and effective means of contaminant removal in a small community, as long as public acceptance and cooperation are achieved.

- Because of the increased record keeping required to monitor individual devices, adopting a POU treatment strategy in a small community requires more oversight and administrative labor than the implementation of central treatment.

- POU strategies require special regulations specifying customer responsibilities, water utility responsibilities, and the requirement of device installation in each home obtaining water from the utility.

- POU strategies require special consideration from regulatory agencies to determine appropriate methods for record keeping, monitoring, and testing frequencies, which may be contrary to existing regulations.

The following recommendations were drawn from the San Ysidro experience:

- Since combinations of contaminants may alter the removal efficiencies of POU devices, a pilot test of potential treatment devices should be undertaken using the community's source water before approval of the device for community-wide use.

- Public acceptance is more vital to the success of a POU treatment strategy than for a central treatment strategy. For example, new water customers must be educated in the procedures and requirements of the POU system. Existing customers should also be periodically reminded of these responsibilities.

- Routine maintenance and sampling operations are best carried out by local water utility employees or members of the immediate community once they have received sufficient training. In this way, travel expenses will be minimized, coordination with customers will be streamlined, and better quality control procedures may be implemented.

- Monitoring costs may be minimized by using conductance as a means to test for breakthrough of inorganic contaminants such as fluoride or arsenic.

- Pre-assembly of POU units may drastically reduce on-site installation time and associated labor costs.

2.2 Fluoride Treatment

Fluorine is the most electronegative element and the most reactive non-metal. Due to its high reactivity, fluorine is rarely, if ever, encountered in the elementary state. Instead it is encountered in the ionic form or as a variety of inorganic and organic fluorides. Like arsenic, inorganic fluoride is commonly found in both ground and surface water supplies. While low concentrations of fluoride in drinking water may prevent dental cavities, concentrations exceeding 2.0 μg/L may result in mottled enamel. Both RO and AA may be used to treat water contaminated with fluoride.

2.2.1 Suffolk, Virginia

The King's Point subdivision in Suffolk, Virginia was chosen by EPA and the State of Virginia as a demonstration site to evaluate the feasibility of POU RO treatment for fluoride. Lykins, Jr., et al. (1995) provided a summary for this case.

The water available to King's Point contained fluoride in the range of 5.0 to 6.1 mg/L, which exceeds both the federal secondary MCL of 2.0 mg/L and the primary MCL of 4.0 mg/L. When the site was chosen for study, the King's Point water system served 39 connections; by the end of the project period it served 57 connections.

Due to the high concentration of fluoride in the drinking water system, Suffolk received two notices of violation, one from the Virginia Department of Health in 1989 and one from EPA in 1991. After examining its options, the city chose POU treatment as the most attractive option based on cost, timeliness, and O&M requirements. In 1993, the city and State agreed to the POU demonstration project as part of the city's compliance plan.

The project team included EPA, the Virginia Department of Health, the City of Suffolk, and three manufacturers of consumer drinking water products. The POU units used in the study consisted of a sediment pre-filter, a high-flow TFM, a storage tank, and an activated carbon post-filter. The units were installed in all homes in April 1992. Soon after project implementation, it was discovered that the RO-treated water showed an elevated HPC. In July 1992, the treatment system was reconfigured by centrally chlorinating the source water for King's Point, replacing the chlorine-sensitive high-flow TFMs with CAMs, and removing the activated carbon post-filters.

All homeowners in the King's Point subdivision were required to participate in the study before the State and EPA would accept the POU alternative. The homeowners were also required to sign a home access agreement that relieved the city of liability for damages caused by the treatment units. The subdivision was divided into three regions, each served by a different manufacturer of POU RO units.

The initial monitoring and O&M plan called for two residents from each region to volunteer their homes as distribution sampling sites, where chemical and microbiological samples would be collected monthly by a city official. The analyses were performed and recorded by the Suffolk Department of Public Utilities. A representative of the manufacturer was called if the unit required routine service. In the event of high HPC or fluoride levels, a manufacturer's service representative scheduled necessary maintenance with the homeowner. Data were collected from these distribution sampling sites for 2 years.

A new plan was developed in 1994 to monitor all of the RO units and to demonstrate typical maintenance. The manufacturers were responsible for scheduling and collecting samples from residences in their respective regions on a quarterly basis. In a routine service call, pre- and post-device free chlorine, total chlorine, and conductivity were recorded. Membranes were replaced as needed, and additional service calls were made when lab analyses indicated maintenance was necessary. In March 1995, the project was completed.

Fluoride levels in tap water were maintained below 2.0 mg/L in all households in the subdivision. Variations in fluoride concentrations from month-to-month or residence-to-residence were explained by membrane degradation. The life expectancy of the membranes depended upon environmental conditions. High temperatures, bacteria, and high pH all shortened the useful life of the membranes. Rejection rates of the membranes were monitored, and membranes were replaced when their rejection rates fell below 70 percent, as measured by post-device conductivity. Table 2.2.1.1 shows the data for treated water collected from one residence and the raw feed during a quarterly sample collection.

The authors of the study estimated costs for the three compliance options considered by the city: 1) using POU RO units; 2) connecting to Suffolk central treatment; and 3) installing central treatment at King's Point. The total annual cost per household of the POU treatment strategy was 55 percent of the estimated annual cost per household of connecting to Suffolk central treatment. Table 2.2.1.2 shows the cost estimates for each option. The third option was found to be infeasible due to local discharge regulations. Although estimates of cost per gallon treated were not available in the literature, one of the participating manufacturers estimated the cost at $0.49 per gallon treated in their region. The capacity of the device offered by this manufacturer was 4 to 6 gpd.

Table 2.2.1.1: Performance Data for a Typical POU RO Unit in Suffolk, VA

Contaminant	Influent (1/12/95)	Effluent (1/9/95)
Total Coliform (coliform organisms/100 mL)	<1	<1
Heterotrophic Plate Count (cfu/mL)	12	5
Fluoride (mg/L)	5.62	0.352
Sodium (mg/L)	207	18.0
Total Dissolved Solids (mg/L)	474	36
Turbidity (NTU)	0.18	0.08
Conductivity (μmho/cm)	768	62.5

The capital cost of the POU option is based on a leasing agreement that charges households $25 per month per unit for rental and routine service. The City of Suffolk was given the option of purchasing or leasing the equipment. The city chose to lease so that the distributor would maintain responsibility for routine service and O&M activities. The purchase price of the POU RO units used in this study was $995.

Table 2.2.1.2: Cost Estimates of Compliance Options for Suffolk, VA (1995$)

Compliance Option	Capital Costs ($/year)	O&M Costs ($/year/unit)	Total Costs ($/year/household)
POU RO	$300 per household[1]	$80 (parts) $320 (labor, sample analyses)	$700
Connection to Suffolk central treatment	$1,267 per household[2]	Minimal	$1,267

1. POU equipment rental at $25/month/unit. Assumes one unit per household.
2. The total cost of connection to the community distribution system for 57 households was $813,000. These costs were amortized at 8 percent for 30 years.

2.2.2 Various Sites in Arizona and Illinois

AA POU devices designed for fluoride reduction were installed in several communities in Arizona and Illinois to determine their effectiveness. This summary draws from reports written by Bellen (1986) and Lykins (1992).

A portion of domestic water was treated with AA for drinking and cooking purposes at Thunderbird Farms, Arizona and Papago Butte Ranch, Arizona. The Ruth Fisher Elementary School (Tonopah, Arizona) was also equipped with AA units to reduce fluoride levels in drinking water. The You and I Trailer Park (Wintersburg, Arizona) and the communities of Parkersburg, Illinois and Bureau Junction, Illinois tested the effectiveness of POU AA devices in reducing influent concentrations of arsenic as well as fluoride. The well water of the Illinois communities was characterized by high levels of fluoride, alkalinity, and TDS.

Eight sites were equipped with POU units in the Thunderbird Farms project. Several devices reduced fluoride concentrations below the local MCL of 1.4 mg/L for over 2 years. Other devices had a shorter service life, due to media cementing or short-circuiting. Influent arsenic and silica concentrations at these sites were reduced to non-detectable levels beyond fluoride breakthrough. The unit installed at the You & I Trailer Park successfully treated 2,500 gallons of raw water with arsenic and fluoride concentrations of 15.7 mg/L and 0.086 mg/L, respectively. Performance and cost data for the Arizona studies are given in Table 2.2.2.1.

Table 2.2.2.1: Performance and Cost Data for POU AA Devices in Arizona (1985$)

Study Location	Number of Sites at Each Location	Service Area Type	Influent Fluoride (mg/L)	Influent Alkalinity (mg/L as $CaCO_3$)	Mean Treated Water Use	Volume to Breakthrough (gallons)[1]	Total Household Cost per Month[2]
Thunderbird Farms	8	Central system with single family homes	2.6	200	1.4 gpd	>1,540	$4.44
Papago Butte	1	Subsystem for several families	2.6	200	18.5 gpd	9,500	$4.60
Ruth Fisher Elementary School	1	Institution	4.4	80	8.5 gpd	1,000	$12.00
You and I Trailer Park	1	Institution	15.7	40	5.5 gpd	2,500	$6.27

1. Defined as the point at which post-device fluoride concentration first exceeds the local MCL for fluoride.
2. Capital costs of $225, $350, $360, and $230, respectively, amortized at 10 percent for 20 years plus maintenance

Records from Thunderbird Farms indicate that 200 hours per month were required by the water quality district to maintain 1,500 records for 643 customers. This translates to about 20 minutes per household per month. Telephone, postage, and miscellaneous supplies for the 643 customers were $1,275 per year in 1985 dollars. This translates to about $2 per customer per year. Administrative costs could be reduced through voluntary labor and/or more active homeowner participation.

In Illinois, 10 units were installed in Parkersburg and 40 units were installed in Bureau Junction. These sites relied on public water systems that supplied ground water with high levels of fluoride, alkalinity, and dissolved solids. The effect of raw water alkalinity on the performance of AA POU devices is demonstrated in the data from the two Illinois sites. The higher alkalinity of Parkersburg water resulted in fluoride breakthrough (fluoride concentrations above 1.8 mg/L) after treating only 400 gallons of water. In contrast, fluoride breakthrough did not occur at Bureau Junction until the unit had treated 1,300 gallons of water. Performance and cost data for the units used in Parkersburg and Bureau Junction are listed in Table 2.2.2.2. The maintenance costs outlined below were based on replacing the alumina cartridge as soon as the fluoride concentration of treated water exceeded the local MCL.

Analysis of treated water indicated microbial colonization of the AA bed. However, this colonization was not as extensive as that frequently found in activated carbon beds. Further, the study did not provide evidence of AA colonization by coliform bacteria. Flushing the system for several minutes and disinfecting taps before sampling was found to reduce post-device standard plate counts (SPCs) by an order of magnitude in the Parkersburg study. See section 1.4 for further discussion of bacterial colonization of POE and POU treatment devices.

Table 2.2.2.2: Performance and Cost Data for POU AA Devices in Illinois (1985$)

Study Location	Number of Sites at Each Location	Service Area Type	Influent Fluoride (mg/L)	Influent Alkalinity (mg/L as $CaCO_3$)	Mean Treated Water Use	Volume to Breakthrough[1]	Total Household Cost per Month[2]
Parkersburg	10	Central system with single family homes	6.6	1,000	0.6 gpd	400; >110	$6.23
Bureau Junction	40	Central system with single family homes	6.0	540	0.8 gpd	1,300; 350	$4.25

1. Defined as the point at which post-device fluoride concentration first exceeds the local MCL for fluoride.
2. Capital costs of $273 and $285, respectively, amortized at 10 percent for 20 years plus maintenance.

2.2.3 Emington, Illinois

This case is summarized from Bellen (1986) and Lykins (1992). In Emington, Illinois 47 low-pressure RO units were installed by equipment dealers and monitored for 8 months. The primary target contaminants were fluoride and TDS. The RO systems consisted of a 5-μm particulate pre-filter, a GAC pre-filter, a pressurized 2-gallon tank, a GAC post-filter, and a TFM. Treated water was stored in the tank and passed through the GAC post-filter before being dispensed.

The POU units were effective in reducing fluoride contamination. An average rejection rate of 86 percent from source water concentrations of 4.5 mg/L was observed in this study. TDS rejection averaged 79 percent from source water concentrations of 2,620 mg/L. Wide variation in rejection rates were observed. Most of the variation was attributed to a pressure drop across the pre-filter assembly. As noted in section 1.3.5, RO membranes (especially CAMs) are more effective for contaminant removal in high water pressure environments.

The capital cost for POU RO in Emington ($540 in 1985 dollars) was calculated by averaging several manufacturer's quotes for devices, both with and without pressurizing pumps, based on purchases of 40 to 50 units. The average installation cost charged by the manufacturers ($68 per unit) is included in this cost. While the POU RO units operated satisfactorily, a significant drawback was their low water output—approximately three gpd. To supplement their needs, many homeowners purchased up to 30 gallons of bottled water per month at a cost of $1 per gallon.

Costs for RO central treatment in Emington were estimated by soliciting a quote. The quoted cost of building and maintaining a central RO treatment plant in Emington was $60,000 (in 1985 dollars). The cost of a concrete block building to house the system was estimated at $60,000. Operating costs were based upon a design flow of 16,500 gpd and totaled $0.66 per 1,000 gallons of water treated. Total operating costs included the cost of treatment chemicals ($0.10/1,000 gallons), electrical power ($0.36/1,000 gallons), membrane replacement every 5 years ($0.18/1,000 gallons), and pre-filter cartridge replacement ($0.02/1,000 gallons). Table 2.2.3.1 tabulates the performance and cost data for the Emington POU project and compares POU costs to the estimated costs developed for central treatment.

The SPC of treated water was found to be an order of magnitude higher than that of untreated water. Controlled sampling from various stages of the RO unit established that most bacterial growth occurred in the GAC polishing unit (i.e., post-filter). Coliforms were found in 4 pre-device and 11 post-device samples (16 percent of all samples).

Table 2.2.3.1: Performance and Cost Data for POU RO Devices in Emington, IL (1985$)

Number of Participating Sites	47
Service Area Type	Central system with single family homes
Mean Treated Water Use (gpd)	0.8
Mean Flow Rates (gpd) Product Water Reject Water	 2.9 22.5
Fluoride (mean mg/L) Influent Effluent	 4.5 0.6
Total Dissolved Solids (mean mg/L) Influent Effluent	 2,530 520
POU Treatment Costs Average Cost per POU Unit[1] Total Cost per Household per Month[2]	 $540 $12.48
Estimated Central Treatment Costs Total Capital Costs Total Cost per Household per month[2]	 $120,000 $28.80

1. Average of six manufacturers; includes equipment plus installation costs.
2. Capital, amortized at 10 percent for 20 years plus maintenance.

2.3 Radium Treatment: Bellevue, Wisconsin

Radium, one of the alkaline-earth group metals, is present in all uranium minerals. It decomposes in water and is somewhat more volatile than barium. Radium emits gamma rays as well as alpha and beta particles. The half-life of radium-226, the most common isotope of radium, is 1,599 years. A single gram of radium produces about 0.0001 mL of radon gas per day. Inhalation, ingestion, or dermal exposure to radium may lead to cancer and other disorders.

The Wisconsin Department of Natural Resources (WDNR) established Plan Approval Criteria (PA Criteria) for the use of POE systems to remove radium. These PA Criteria establish the issues that need to be considered in proposals to the WDNR for the use of POE treatment. The PA Criteria focus on five areas:

1. Legal and Economic Liabilities: The water system owner is responsible for the quality of the water provided at each customer's tap. Therefore, the plan must provide treatment and monitoring protection equivalent to central treatment.

2. Effective Technology: Pilot plant/field testing is required to provide WDNR with assurance that equipment proposed for use in a water system will effectively remove radium. The requirements for inspection and testing after installation are delineated.

3. O&M: The system owner must ensure that appropriate O&M is carried out for every unit in the system. The system must ensure that treatment is provided when owners object to equipment installation or tamper with the treatment device.

4. Monitoring: Annual monitoring for radium is required, along with monthly inspections of every installation in the system. Allowances are made for use of surrogate monitoring devices. Specifics for the monthly inspections are outlined.

5. Departmental Approval: Comparison with other possible radium removal techniques is required prior to approval of a POE system.

In March 1988, the Town of Bellevue provided service to 1,248 residential users, 11 commercial users, 11 industrial users, and 2 municipal services. The water supply for the town contains radium (both Ra-226 and Ra-228) in excess of the MCL established by EPA (20 pCi/L). It is important to note that this summary was based on a feasibility study, not on a demonstration project.

Bellevue draws its water from three wells. The raw water characteristics of each well are presented in Table 2.3.1. The centrally supplied water is subjected only to chlorination prior to distribution to the community.

The purpose of the study in Bellevue was to determine the feasibility of achieving compliance with radium regulations using POE CX units. Radium levels can be reduced efficiently with the IX softening technique, with reduction occurring beyond the point where the resin ceases to remove calcium and magnesium ions. The study addressed the issues identified by EPA, the WDNR, and the Wisconsin Department of Industrial, Labor and Human Resources that need to be considered in approving plans for the use of POE systems to reduce radium concentrations in household water.

Table 2.3.1: Source Water Quality of Wells in Bellevue, WI

Contaminant	Well Number One (1/4/72)	Well Number Two (10/2/75)	Well Number Three (12/24/80)
Total Alkalinity (mg/L as $CaCO_3$)	164	150	180
Total Hardness (mg/L as $CaCO_3$)	452	372	344
Total Iron (mg/L)	1.0	0.74	0.14
Total Dissolved Solids (mg/L)	848	680	614
Calcium (mg/L)	124	98	92
Magnesium (mg/L)	35	30	28
Sodium (mg/L)	90	70	57
pH	7.8	7.6	7.8
Radium-226 (pCi/L)	10.0	8.0	15.0
Radium-228 (pCi/L)	5.5	6.0	3.9

Water softener vendors servicing Bellevue were contacted to characterize the softeners already installed in the town. Seventy-eight percent of all customers already had water softeners because of the extreme hardness of the water. Typical characteristics included:

- A capacity of 10,000 to 40,000 grains.
- An effective resin life of about 20 years. Some installations in Bellevue had been in service for 13 or more years.
- A timer to ensure periodic regeneration.

The water softeners typically treated the entire household water supply (hot and cold taps), with the exception of outside connections. The most common maintenance problems were overflow of the softener's brine tank, malfunction of the timer mechanism, and the inaccessibility of the treatment units. Therefore, maintenance had to be completed at the customer's convenience. One company had over 200 house keys for service access.

The majority of treatment units used in Bellevue were purchased. Vendors did not rent treatment devices to the owners of mobile homes because of the high potential for property damage due to overflow of the brine tank.

The feasibility study developed a detailed cost evaluation for POE CX treatment. Cost data were obtained from two local manufacturers/distributors of softening equipment and from residential and commercial surveys conducted by the authors. Cost estimates were developed for the implementation of two different POE treatment strategies: 1) providing softeners that would not treat outside connections; and 2) providing softeners that would treat all household connections (including outside connections).

The evaluation was completed assuming that softeners would be provided to all residences and businesses that did not already have softening equipment, with sizing based on water use. For those households already equipped with softeners, plumbing modifications for treating outside hose connections and for treating all indoor water were estimated. A complete inspection of each system would have been required to establish these costs individually. Hardness monitors were installed with all treatment units. A post-installation inspection, including microbiological analysis of a sample of the treated water, was also assumed. Residential and commercial survey results were used to estimate the percentage of sites where installation would be difficult because pipes were not exposed or only a portion of the hot or cold water supply was treated.

To permit inter-scenario comparison, capital costs were amortized and added to the annual O&M costs to arrive at the annual average cost of each treatment alternative. For this analysis, an annual interest rate of nine percent and an amortization period of 20 years were used.

Water billing data from town records for 1987 were evaluated to provide water use information. Other parameters used to evaluate costs included influent water hardness, media exchange capacity, regeneration interval, and salt requirements. These data are available in the full NSF report.

Treating water dispensed at outside connections significantly increases the cost of treatment because additional equipment is required to ensure that all residences have a constant supply of treated water. To meet the additional demand, two softeners would be required for each system. The replacement of all existing softeners was considered for this alternative because of the difficulty associated with retrofitting.

The results of the cost evaluation are summarized in Tables 2.3.2 and 2.3.3.

Table 2.3.2: Cost Data for POE CX Devices (No Outside Connections) in Bellevue, WI (1989$)

Item	Cost
Equipment and "standard" installation costs:	
New softeners - residential	$76,100
New softeners - commercial	$42,700
Perret Mobile Home Park	$9,200
Parkview Mobile Home Park	$37,000
Monitors/dialers with central station	$265,500
"Special" installation and repair costs:	
Residential	$48,600
Commercial	$2,900
Mobile Home Parks	$9,500
Microbiological Analysis (first year)	$25,600
Contingencies (15% of capital cost)	$77,600
Total capital costs	$594,700
Annual capital costs (9%, 20 yrs.)	$65,100
Annual O&M and monitoring costs	$201,700
Total annual cost	**$266,800**
Cost per connection (1,282 connections)	*$238.92*

Table 2.3.3: Cost Data for POE CX Devices (With Outside Connections) in Bellevue, WI (1989$)

Item	Cost
Equipment and "standard" installation costs	
New softeners - residential	$1,027,500
New softeners - commercial	$42,700
Perret M.H. Park	$9,200
Parkview M.H. Park	$37,000
Monitors/dialers w/ central station	$265,500
Backflow preventers	$36,500
Salvage value for old softeners (1,013 units, $25/unit)	($25,300)
"Special" installation and repair costs	
Residential	$23,800
Commercial	$1,500
Mobile home parks	$9,500
Microbiological analysis (first year)	$25,600
Contingencies (15% of capital cost)	$218,000
Total capital costs	$1,671,500
Annual capital costs (9%, 20 yrs.)	$18,300
Annual O&M and monitoring costs	$230,300
Total annual cost	**$413,300**
Cost per connection (1,282 connections)	*$322.39*

The authors of this feasibility study compared the annual cost of implementing a POE treatment strategy with the cost of several alternative treatment strategies available to the town. The costs used for the alternative treatment options were obtained from an engineering report prepared by Bellevue's engineers in December 1987. The costs presented in the engineering report were escalated by the authors of the study by 5 percent per year for comparison with the POE costs developed in 1989. A summary comparison is offered in Table 2.3.4.

Table 2.3.4: Costs of Compliance Options for Bellevue, WI (1989$)

Compliance Option	Capital Costs[1]	Annual O&M Costs	Total Annual Costs	Cost per Connection[2]
Manganese greensand treatment by town[3]	$134,100	$39,000	$173,100	$135.02
Central CX treatment by town[3]	$130,400	$83,300	$213,700	$166.69
Service from Green Bay[3]	$168,400	$95,100[4]	$263,500	$205.54
POE softening:				
Without hose bibs (no outside connection)	$65,100	$201,700	$306,300	$238.92
With hose bibs (outside connection)	$183,000	$230,300	$413,300	$322.39

1. Capital costs are annualized at 9 percent over 20 years.
2. 1,282 connections.
3. Costs for these alternatives were obtained from a December 1987 engineering report. The costs presented in this table were increased by 5 percent per year for comparison with the POE costs developed in 1989.
4. O&M cost includes $124,500 for purchase of water from Green Bay and an allowance of $46,000 for cost savings due to reduced power consumption at wells.

2.4 Uranium Treatment: Various Sites in Colorado and New Mexico

Uranium occurs in numerous minerals such as pitchblende, uraninite, carnotite, autunite, uranophane, davidite, and tobernite; it is believed to be as abundant as arsenic. Uranium has 23 isotopes, all of which are radioactive. Naturally occurring uranium consists primarily of U-238. The half-life of uranium-238 is 4.46×10^9 years. Uranium is of great importance as a nuclear fuel used to generate electrical power.

Uranium and its compounds are highly toxic, both chemically and radiologically. High U-235 content increases irradiation risk. Uranium concentrations in ground waters at U.S. Department of Energy sites indicate that uranium is highly sorbed. Uranium sorption is likely due to its reduction from the hexavalent state, where it is introduced via surface waters, to the tetravalent state found in confined aquifers. The natural presence of uranium in many soils has recently become a concern to homeowners because the decay of uranium may lead to the build-up of radon gas in nearby homes and to the contamination of ground water supplies.

EPA's Drinking Water Research Division (DWRD) in Cincinnati, Ohio conducted a uranium removal study in Colorado and New Mexico (Lassovsky 1983). Twelve AX tanks, each containing 0.25 cubic feet of a strong base anion resin, were involved in the study. Six units were set to operate intermittently to simulate typical household consumption patterns. The remaining six were operated in a continuous flow setting. Flow restrictors limited flow to 0.25 gpm. All units were routinely sampled and were equipped with flow meters to measure the volume of water treated. The influent uranium concentration ranged from 22 to 104 μg of total uranium/L. After approximately two years of operation, effluent levels of uranium were below 1 μg total uranium/L for all but three of the units. Uranium breakthrough for these units occurred after 8,000, 10,000, and 13,000 bed volumes had been successfully treated. The AX tanks used in this study cost $125 each (in 1983 dollars). Although units were installed by EPA personnel and field contractors, the installation costs were not available.

2.5 Various Inorganic Compounds: Cincinnati, Ohio

A POU RO unit identical to those used in San Ysidro, New Mexico was installed in an EPA DWRD laboratory in Cincinnati, Ohio. This system consisted of a 5-μm pre-filter, an activated carbon pre-filter, a GAC post-filter, a spiral wound polyamide membrane, and a 3-gallon storage tank. The installed cost of the RO unit was $325 ($289.50 for the unit, $35.50 for installation in 1986 dollars). Test water was pumped at a pressure of 42 ± 2 psi and consisted of Cincinnati tap water spiked with a specific contaminant. Fourteen contaminants were successfully treated by the RO unit and TDS levels were substantially reduced as detailed in Table 2.5.1. While this study did not determine the life of the RO membrane for any single water supply, it did demonstrate that RO systems generally provide good removal of most inorganic contaminants.

Table 2.5.1: Performance Data for POU RO Device in Laboratory Testing — Cincinnati, OH

Contaminant	Influent Concentration (mg/L)	Removal Rate (%)	Contaminant	Influent Concentration (mg/L)	Removal Rate (%)
Arsenic (III)	0.101	73.3	Mercury (inorganic)	0.017	> 97.1
Beryllium	0.043	> 97.7	Nickel	0.239	> 95.0
Cadmium	0.045	> 95.6	Selenium (IV)	0.075	> 99.3
Chromium (II)	0.19	> 97.4	Selenium (VI)	0.083	> 94.0
Chromium (III)	0.202	> 97.5	Uranium (total)	0.0692	> 99.0
Copper (II)	4.81	> 98.0	Uranium (total)	0.1825	> 99.0
Fluoride	5.95	98.3	Zinc (II)	5.42	> 99.0
Lead	0.28	> 98.3			

2.6 Nitrate Treatment

Primary sources of organic nitrates in natural waters include human sewage and livestock manure, especially from feedlots. The inorganic nitrates that most often contaminate drinking water are potassium nitrate and ammonium nitrate. Potassium and ammonium nitrates are used primarily as fertilizers, though they are also used in explosives. According to the Toxics Release Inventory (TRI), over 112 million pounds of inorganic nitrates were released from 1991 to 1993. The largest releases occurred in Georgia and California.

Because they are highly soluble and poorly retained by soil, nitrates are very mobile. They move at approximately the same rate as water and are likely to migrate into ground and surface water supplies.

Ingestion of nitrates may lead to acute health problems for children less than 6 months old. Nitrates are converted to nitrites by bacteria within the mouth and stomach. In adults, the acidity of the stomach is usually great enough that bacterial growth and the consequent conversion of nitrate to nitrite are negligible. Nitrites react with hemoglobin, producing methemoglobin. This interferes with the oxygen-carrying capacity of blood and may lead to the onset of methemoglobinemia, or "blue-baby syndrome." Methemoglobinemia is an acute condition that may result in asphyxiation and death. Chronic exposure to high levels of nitrates may lead to diuresis, increased starchy deposits, and hemorrhaging of the spleen. A 1990 EPA publication (EPA 1990) provides a thorough review of the literature available on the occurrence of methemoglobinemia in infants, children, and adults.

2.6.1 Suffolk County, New York

A 1983 study evaluated various water supply options for the towns of Riverhead and Southhold, both located in the predominantly rural North Fork of Suffolk County. This case was summarized from Lykins (1992). Due to the size and demographics of the communities, it was determined that the development of public water supplies throughout the contaminated areas would be prohibitively expensive. Individual POU/POE units were recommended for these contaminated areas. Eighteen units, provided by 10 manufacturers, were installed in Riverhead and Southhold homes that received contaminated water. The performance of the units was monitored through sampling and analysis of the raw and treated waters.

POE devices along with countertop and line bypass POU units were demonstrated in this study. Several treatment technologies were tested, including GAC, IX, RO, and aeration. All units demonstrated the ability to remove the contaminants of concern to the necessary levels, and consumers were satisfied with the performance of the units. Table 2.6.1.1 summarizes the water quality problems, the types of POU/POE devices used to treat the problems, and the performance of each unit.

Table 2.6.1.1: Performance Data for POU and POE Devices in Suffolk County, NY

Unit Number	Water Quality Problem	Type of Device	Average Nitrate		Average Organics	
			Influent (mg/L)	Effluent (mg/L)	Influent (µg/L)	Effluent (µg/L)
1	Nitrate	Countertop (GAC+IX)	9.2	3.3	NA	NA
2	Nitrate	Countertop (GAC+IX)	7.7	2.4	NA	NA
3	Nitrate, chloride	Line bypass (RO+GAC)	10.8	4.6	NA	NA
4	Nitrate	Line bypass (RO+GAC)	9.9	4.3	NA	NA
5	Nitrate, chloride	Line bypass (RO+GAC)	0.4	<0.2	NA	NA
6	Nitrate, VOC	Countertop (Distiller)	12.2	<0.2	12	<2
7	Nitrate	Line bypass (RO+GAC)	11.1	0.3	NA	NA
8	Nitrate	Line bypass (RO+GAC)	7.7	0.2	NA	NA
9	VOC	POE (GAC–1.0 cu. ft.)	NA	NA	58	<2
10	Nitrate	Line bypass (RO+GAC)	11.2	0.3	NA	NA
11	VOC	POE (GAC–0.5 cu. ft.)	NA	NA	53	<2
12	Nitrate	Batch (distiller)	9.3	0.2	NA	NA
13	Iron, carbofuran	Countertop (filter+GAC)	2.3[1]	0.1[1]	13[2]	<2[2]
14	Manganese	Line bypass (RO+GAC)	1.7[3]	0.07[3]	NA	NA
15	Nitrate	Line bypass (RO+GAC)	8.6	0.8	NA	NA
16	Iron	POE (aeration+GAC+filter)	0.96[1]	0.1[1]	NA	NA
17	Nitrate	Line bypass (RO+GAC)	11.5	0.3	NA	NA
18	Nitrate	POE (IX)	12.1	0.6	NA	NA

1. Average values for iron
2. Average values for carbofuran
3. Average values for manganese

Despite the success of the units, the sampling results during the study revealed several problems that could be traced to improper installation or inadequate maintenance. Several units developed plumbing leaks that required repair. Organic contaminants were found to be leaching into treated water from three units due to solvents used during manufacturing or assembly processes. High levels of copper were found in the effluent of two units that used copper discharge lines. Once these units were replaced, all units functioned satisfactorily for the duration of the study.

Bacteria were present in samples from all of the treatment units that included a carbon filter. These data confirm the observations of other researchers that bacteria will grow on GAC (see section 1.4). However, no evidence of pathogenic bacteria growth was isolated, even in samples that exhibited elevated plate counts.

The effluent of three units tested positive for coliform after installation, though follow-up samples were satisfactory. Two of the contaminated units were countertop models, which are more susceptible to cross-contamination by homeowner activity (see section 1.2.1). Additional disinfection procedures should be followed before and after installation of these models if they are selected by the water system for use in a compliance strategy.

RO units #3 and #4 exhibited much lower efficiencies than RO units #7 and #8. This was probably due to the lower efficiency of the CAMs used in units #3 and #4 relative to the thin film composite membranes used in units #7 and #8 (see section 1.3.6).

The authors provide representative cost ranges for the various types of POU/POE treatment units demonstrated during this study. Table 2.6.1.2 outlines the initial capital and installation costs, but does not incorporate annual O&M costs for these units. Total average annual costs per home for all the POU equipment evaluated are summarized in Table 2.6.1.3. These data were developed from a survey of 1,650 households in Riverhead and 2,250 households in Southhold. Total average annual costs include amortized initial capital costs, annual O&M costs, and annual costs for monitoring and administering the POU program. Capital and O&M costs were estimated from manufacturers' literature. The study proposes that bulk purchase of treatment units would result in lower (discounted) per-unit costs. The cost ranges represent units of different capacities.

Table 2.6.1.2: Representative Cost Data for POU and POE Devices (1985$)

Treatment Technology	Single Tap (POU)		Whole Tap (POE)	
	Capital Cost	Installation Cost	Capital Cost	Installation Cost
Distillation	$200-$800	$100-$150	$9,500-$11,000	$200-$300
GAC	$200-$350	$60-$100	$1,100-$3,000	$75-$150
IX	$100-$300	$60-$100	$1,500-$2,000	$150-$200
Filtration	$150-$200	$80-$100	$1,500-$2,000	$150-$200
RO	$500-$800	$70-$150	$6,000-$8,500[1]	$250-$350

1. This cost includes the RO unit, a storage tank, and a dispenser pump.

A detailed description of the monitoring plan, the capacity of the POU units, a full discussion of the division of responsibilities, and the cost per gallon of water treated were not provided in the literature reviewed. However, the study did emphasize the need for conservative design of POU/POE treatment devices to preclude premature contaminant breakthrough due to interactions between multiple contaminants (and from contaminants as yet undiscovered in the area).

Table 2.6.1.3: Average Annual Cost of POU Treatment for Riverhead and Southhold, NY (1985$)

Cost Description	Cost
Amortized Start-up Cost[1]	$160-$170
O & M Costs	$50-$100
Monitoring and Administrative Costs	$15-$20
Total Annual Costs	**$225-$290**

1. A 15-percent and a 5-percent surcharge were assessed to the initial purchase and installation costs (start-up costs) to cover contingency and associated costs, respectively. Total start-up costs were amortized at 12 percent over an 8 year period.

2.6.2 POE and Central Treatment Cost Comparison

Lykins (1992) compared the costs of POE and central treatment units using AX technology designed to remove 95 percent of influent nitrate. The analysis compares the costs of the treatment alternatives for two communities with different demographics: a trailer park and a subdivision. Each residential area has 150 households (approximately 500 consumers) requiring 40 gpm. The trailer park, which is densely populated, was assumed to require only 3,400 feet of pipe. However, the more sparsely populated subdivision would require 15,840 feet of pipe to connect all households to a central plant. Eight-inch diameter polyvinylchloride (PVC) pipe was used to estimate distribution system costs. Additional costs for trenching, embedment, backfill, paving, and variable connection costs (given different population densities) were also incorporated. Cost data for these items were taken from *Standardized Costs for Water Distribution Systems* (Gumerman 1992). The use of ductile iron pipe instead of PVC pipe would double the cost of the distribution system.

The central AX treatment system considered in this study consisted of a 25-cubic foot resin bed that provides a minimum of 4.7 minutes of EBCT. The resin bed was assumed to be regenerated daily. The entire unit was assumed to be purchased with 10 percent financing for 20 years. The POE AX unit was priced at $2,000 with 10 percent financing for 10 years. The resin in the POE unit was assumed to be auto-regenerated. O&M for the POE unit was assumed to be covered by a service professional at a cost of $15 per month. Table 2.6.2.1 compares the cost of the POE and central treatment alternatives given the assumption that the distribution system is constructed of PVC pipe.

Table 2.6.2.1: Costs of AX Compliance Options for Communities of Differing Density I (1990$)

Residential Area	Central Treatment Cost[1]	POE Treatment Cost[2]
Trailer Park	$312/house/year $3.24/1,000 gallons	$480/house/year $4.98/1,000 gallons
Subdivision	$574/house/year $5.96/1,000 gallons	

1. Central treatment costs include the cost of constructing a distribution system using PVC pipe. The central treatment system was amortized at 10 percent for 20 years.
2. Outfitting the entire community requires 150 POE units. POE units were amortized at 10 percent for 10 years.

The one-unit central treatment alternative would be the most cost-effective option for the trailer park. However, even though the distribution system was constructed from relatively inexpensive PVC pipe, the POE alternative would be more cost-effective than central treatment for the subdivision. Table 2.6.2.2 presents the costs of the treatment alternatives assuming the use of ductile iron pipe instead of PVC pipe for the distribution system.

Table 2.6.2.2: Costs of AX Compliance Options for Communities of Differing Density II (1990$)

Residential Area	Central Treatment Cost[1]	POE Treatment Cost[2]
Trailer Park	$468/house/year $4.86/1,000 gallons	$480/house/year $4.98/1,000 gallons
Subdivision	$861/house/year $8.94/1,000 gallons	

1. Central treatment costs include the cost of constructing a distribution system using ductile iron pipe. The central treatment system was amortized at 10 percent for 20 years.
2. Outfitting the entire community requires 150 POE units. POE units were amortized at 10 percent for 10 years.

Again, a central treatment system would be less expensive than equipping each household in the trailer park with a POE unit. However, the cost differential is much smaller than that presented in Table 2.6.2.1. The POE treatment alternative would be much less expensive than the central treatment alternative for the subdivision if ductile iron pipe were used for the distribution system.

2.7 Radon Treatment: Various States

Radon is a naturally occurring radionuclide that gained high visibility in the 1980s when extraordinary levels were found in new, well-insulated houses. However, radon may also be found in groundwater and can have a severe impact on human health when high concentrations are ingested over a long period of time. The most common isotope of radon, radon-222, has a half-life of 3.823 days and is an alpha emitter. EPA has recently withdrawn a proposed rule that would create a primary MCL for radon of 300 pCi/L. However, the Agency must submit another proposed rule for regulation of radon by August 1999. Therefore, many water systems will need to develop a means of lowering the radon levels found in the water distributed to their consumers.

A report completed by EPA in 1989 evaluated the effectiveness of full-scale (i.e., central treatment) GAC and aeration (diffused bubble and packed tower) treatment of small community groundwater supplies contaminated with very high levels of radon (Kinner 1989). Two low-technology treatment options, radon loss in the central distribution system and modified atmospheric storage tanks (e.g., coarse bubble aeration), were also evaluated. Since the focus of this report is on POU and POE treatment, only the evaluation of POE technology will be summarized in this section.

To determine the effectiveness of POE GAC units in removing radon from drinking water, 121 POE GAC units in 12 states were monitored to varying degrees over seven years. Each house was equipped with a separate POE GAC system consisting of fiberglass vessels filled with either 1.0, 1.7, or 3.0 cubic feet of GAC, supported on a bed of gravel. The units were installed downstream of the existing pressure tank and operated in the downflow mode. Sixty percent of the installations were done by the homeowner without outside assistance.

Most units underwent initial sampling and analysis 3 weeks after installation to confirm the success of the installation. Sampling and analyses were conducted every 6 months thereafter for a period of 2 years. Samples were collected by homeowners and mailed to the Radon Research Laboratory at the University of Maine for liquid scintillation analysis. Some units were selected for long-term or monthly monitoring. The monitoring protocol used either direct syringe scintillation vials or glass septum capped vials (VOC type).

The GAC units in this study treated water supplies with a wide variety of radon levels, ranging from 2,576 pCi/L to more than 1,000,000 pCi/L. Average household water use was estimated at 157 gpd for purposes of determining performance. Performance data for the POE GAC devices observed in this study are presented in Table 2.7.1.

In most cases, O&M costs were negligible. In a very few instances, GAC beds had to be replaced at a cost of $130 per cubic foot of GAC. Moreover, if standards are set for the accumulation of lead-210, bed changes may be necessary as often as every few months, making POE GAC treatment prohibitively expensive. The cost of radon analyses was reported to be $40 per year in this study. Gamma emissions from POE GAC units used to treat for radon may lead to negative health effects. Exposure to gamma radiation depends upon the level of radon in the raw water and the location and shielding of the GAC unit. Therefore the need for shielding or other protective measures must be evaluated for each specific site. Cost data for the POE GAC devices observed in this study are presented in Table 2.7.2.

Table 2.7.1: Performance Data for POE GAC Devices

GAC Device	Flow (gpd)	Average EBCT (hrs)	Expected Removal Rate	Observed Removal Rate
GAC 10	157	1.14	96.7%	90.7%
GAC 17	157	1.94	99.7%	92.5%
GAC 30	157	3.43	> 99.99%	98.6%

Table 2.7.2: Cost Data for POE GAC Devices

GAC Device	Cost of GAC Unit	Cost of Sediment Filter	Cost of Water Shield	Installation Cost	Total Cost
GAC 10	$600	$50	$25	$100	$775
GAC 17	$750	$50	$90	$100	$990
GAC 30	$950	$50	$125	$100	$1,225

Note: shipping costs (averaging $30 per unit) were paid by the installer.

2.8 Aldicarb Treatment

Aldicarb is a pesticide used on a variety of crops in nearly all areas of the nation. This organic contaminant acts as a cholinesterase inhibitor. Symptoms of exposure include sweating, muscular weakness, headaches, vomiting, and nausea. Available evidence suggests that the neuro-behavioral effects associated with exposure to aldicarb are short-lived and that no accumulation effects occur over time. Aldicarb was not found to cause statistically significant increases in tumor incidence in mice or rats in feeding studies or in mice in a skin painting study. Available assays are inadequate to assess the carcinogenic potential of aldicarb (IRIS 1993a).

Since the effects of aldicarb exposure on humans are acute rather than chronic, POE devices are more appropriate for the treatment of this contaminant than POU devices because they provide a greater margin of safety. GAC devices have proven effective in removing aldicarb from raw water in several communities.

2.8.1 Suffolk County, New York

Historically, Suffolk County has been an area characterized by heavy agricultural activity. Fertilization practices and extensive pesticide and herbicide use have led to widespread contamination of local ground water by nitrate and various organic chemicals. Local geology and hydrology allow these contaminants to percolate unchanged through the coarse sand and gravel of the upper geological formation directly to the groundwater table.

Since 1978, Suffolk County has monitored ground water for agricultural contaminants. During monitoring, nitrate was detected at levels exceeding 15 mg/L. Further, four agricultural compounds — aldicarb, carbofuran, 1,2-dichloropropane (1,2-DCP), and 1,2,3-trichloropropane (1,2,3-TCP) — were found at levels greater than 100 μg/L. Between April and June 1980, approximately 15 percent of sampled wells were found to have aldicarb concentrations that exceeded the level considered safe for consumption (i.e., the New York State guideline for aldicarb of 7 μg/L. After this discovery, the manufacturer of aldicarb prohibited its sale in Suffolk County. In 1985, 11.7 percent of 2,000 wells sampled exceeded the State guideline for aldicarb. Despite the fact that carbofuran was available both before and after aldicarb, only 1.8 percent of the same 2,000 wells exceeded the State guideline for carbofuran. 1,2-DCP testing began in 1980. In one Suffolk County community, DCP was found in 17 of 33 wells. Two of these wells had 1,2-DCP levels of approximately 50 μg/L (the New York State guideline for 1,2-DCP).

From 1983 to 1987, more than 3,000 GAC units were used in Suffolk County to treat water with an average aldicarb concentration of 87 μg/L. Based on this experience, it was determined that a GAC filter composed of 1 cubic foot of activated carbon could treat 170,325 L of water with an influent concentration of 100 μg aldicarb/L before breakthrough (an aldicarb concentration greater than 7 μg aldicarb/L) occurred.

Five GAC treatment units were tested to determine their capacity to remove aldicarb from Long Island ground water. Two POU units, with 1.04 and 0.94 pounds of carbon, respectively, treated less than 1,000 gallons of water before the effluent exceeded the New York State guidelines for aldicarb. However, all three POE units (15.0 to 17.5 pounds of 12×40 or 20×40 mesh carbon) proved effective in removing aldicarb from household water. In June 1980, equivalent GAC systems were provided free of charge by the manufacturer of aldicarb to all households dependent upon Suffolk County water sources that exceeded the New York State guideline level.

More than 100 GAC POE units were eventually monitored on a bimonthly basis in association with this program. Units lasted for 37 percent to 158 percent of their advertised lifetime. Over 93 percent of all monitored units operated satisfactorily as designed. Premature breakthrough of aldicarb occurred primarily as a result of improper installation or O&M difficulties such as an inadequate backwashing cycle or homeowner negligence.

Concerns were raised regarding the possibility of bacterial colonization of the GAC media. However, testing for total coliform, SPC, and *pseudomonas* did not reveal large-scale microbial activity on the GAC. Two reasons for the lack of microbial activity were presented.

First, Long Island ground waters are characterized by a general absence of bacteria. Most bacteria are effectively removed by the soils. Second, each POE unit was equipped with a backwash system. Backwashing tends to mitigate bacterial growth while removing sediments, such as iron, that may hamper GAC performance. Due to the lack of evidence of bacterial colonization of the POE GAC units, disinfection was not necessary for units used in Suffolk County. See section 1.4 for additional information on the potential for microbial colonization of GAC treatment units.

Used carbon was shipped out of state to a carbon manufacturer, where it was regenerated via a high temperature (1,000 degrees Celsius) process. The regenerated carbon was recycled for use in industrial applications. Only virgin carbon was used in the treatment units provided under the manufacturer-sponsored program.

2.8.2 Various Sites in Florida

Several of Florida's public water supplies were analyzed early in the organic quality testing work done by EPA. EPA efforts and testing by the state's laboratories revealed widespread contamination of Florida's ground water. Leaking underground petroleum storage tanks had released benzene and other hydrocarbons into the ground water. The agricultural chemicals aldicarb and ethyldibromide (EDB) were also found in samples taken from many private wells. Of the 12,400 wells analyzed for EDB through October 1987, 1,530 were found to have EDB concentrations greater than the then-current MCL of 0.02 μg/L.

Florida's Ground Water Contamination Task Force (GWCTF) determined that protection from EDB would need to be afforded to the entire household. Therefore, POE treatment options were investigated for those homes for which connection to a central treatment system would be prohibitively expensive. GAC was found to remove EDB and hydrocarbons from ground water. In light of this finding and the need to provide whole-house protection, POE GAC units were determined to be the best method to treat the water from contaminated private wells. Since the volume of water, usage habits, and other important parameters that influence the effectiveness of GAC were typically unknown, two very conservative filter designs were devised by the GWCTF. Type I POE GAC units consisted of a 5-μm pre-filter, a 2-cubic foot GAC filter, a UV disinfection element, and a water meter. Type II POE GAC units were installed when higher contamination was found. Type II units were identical to the Type I units, except that they incorporated additional GAC filters to ensure adequate contaminant removal. If expected water consumption exceeded 10 gpm, larger GAC units were provided to handle the increased flow.

By October 1987, 780 Type I and 62 Type II units were installed. Seven larger GAC units (with between 50 gpm and 200 gpm capacity) and three municipal systems (with capacities greater than 3,000 gpm) were also installed by October 1987 as part of the overall corrective effort for EDB. The installed cost of each Type I unit was $1,000, and the installed cost of each Type II unit was $1,050. Carbon filters were replaced twice each year, while the UV bulb was replaced annually. The annual cost of annual carbon and bulb replacement was estimated to be approximately $890 per POE unit. To ensure that public health concerns were not compromised, an additional annual cost of $400 for sampling and lab analyses was included.

2.9 Trichloroethylene Treatment

The VOC TCE is a commonly used industrial solvent. TCE is often used as a chemical building block to synthesize other chemicals. It has been found in at least 460 of 1,179 hazardous waste sites on the Superfund National Priorities List (NPL). Various federal and state surveys indicate that between 9 percent and 34 percent of the water supply sources in the United States may be contaminated with TCE.

Individuals that have been exposed to TCE may suffer from dizziness, headaches, slowed reaction time, sleepiness, and facial numbness. Irritation of the eyes, nose, and throat can also occur under these conditions. More severe effects on the central nervous system, such as unconsciousness and death, can occur from drinking or breathing high levels of TCE. In general, the health effects associated with exposure to TCE dissipate when exposure ends. However, several animal studies have shown that ingesting or breathing levels of TCE that are higher than typical background levels can produce nervous system changes; liver and kidney damage (especially among those who drink alcohol); tumors of the liver, kidney, lung, and male sex organs; and possibly leukemia (ATSDR 1989).

Since the effects of TCE exposure on humans may be acute and severe, and since TCE is a volatile chemical, POE devices are more appropriate for the treatment of this contaminant than POU devices because they provide a greater margin of safety and protect against inhalation exposure. GAC devices have proven effective in removing TCE from raw water in several communities.

2.9.1 Byron, Illinois

This case is summarized from a paper presented by Bianchin at the 1987 Conference on Point-of-Use Treatment of Drinking Water. Byron Johnson is a 20-acre salvage yard located in a rural area of northern Illinois. In the 1960s the salvage yard was operated as a junk yard. From 1970 to 1972, the Illinois Environmental Protection Agency (IEPA) conducted periodic inspections to identify operating deficiencies. In 1972, the IEPA ordered the yard closed, and in 1974 the salvage yard ceased operation. In December 1982, the site was placed on the Superfund NPL. A remedial investigation/feasibility study (RI/FS) was begun by IEPA. The study focused on contamination directly on or below the site. Both major aquifers in the area were found to be contaminated by VOCs. In addition, cyanide and some inorganic compounds were found in the ground water beneath the salvage yard.

From 1983 through 1985, contamination levels in nearby (down-gradient) wells were monitored by EPA, IEPA, and the Illinois Department of Public Health. Private wells were found with TCE levels of up to 710 μg/L. In July 1984, EPA placed residents in areas adjacent to the salvage yard (i.e., the Dirk Farm area), whose water was characterized by concentrations greater than 200 μg TCE/L, on bottled water as a temporary measure. POU and POE devices may be used much like bottled water to alleviate the immediate danger of contaminated drinking water. Therefore, in May 1986, EPA installed POU GAC treatment devices for residents using bottled water as an interim measure. In July 1986, EPA initiated a monthly sampling program of these units to monitor the effectiveness of the POE devices.

In October 1985, EPA undertook a phased feasibility study to investigate the health threat posed to another nearby development from exposure to the contaminated water supply. Rock River Terrace Subdivision is located 1.5 miles down gradient of the salvage yard along the Rock River. Wells in the subdivision were contaminated with up to 48 μg TCE/L. Three treatment alternatives were analyzed for their potential to solve the subdivision's contamination problem. First, all residences could be connected to the Byron Municipal Treatment Facility. This alternative would cost approximately $900,000 (in 1986 dollars) and would take 1 to 2 years to implement. Second, all affected homes could be supplied with bottled water. This alternative was estimated to cost $91,150 per year and could be implemented almost immediately. However, since the water entering local households is not treated, and since bottled water would only be used for drinking or cooking, this alternative would provide no protection from inhalation of or direct contact with contaminated water. Third, each household could be equipped with a POU treatment unit. This alternative would cost $26,000 and installation would take about 3 months. However, as with the bottled water option, since all taps would not be treated, residents would not be completely protected from any health problems resulting from inhalation or direct contact with contaminated water. Fourth, each household could be equipped with a POE treatment unit. This alternative would cost $115,000 and, like the third option, would require about 3 months unit installation within the community. The fourth alternative would provide treated water at all taps within the household.

The fourth alternative was selected as the strategy most protective of public health and the most economically feasible. Beginning in September 1986, EPA installed POE GAC systems in the basement of residences or in insulated, outdoor sheds throughout the subdivision. Each system consisted of a 5-μm pre-filter and two GAC tanks in series. Each GAC tank was 54 inches tall and contained 110 pounds of GAC. The system was designed for a flow of 7.5 gpm. Since carbon replacement rates depend on many factors including the level of contamination, water temperature, pH, water usage, and the presence of other constituents, periodic monitoring was conducted to ensure that contaminants were being effectively removed. Samples collected on a monthly basis before and after the carbon tanks were sent to a local lab for analysis. The carbon was scheduled to be replaced upon breakthrough. However, a year after installation, no analysis revealed that breakthrough had occurred.

2.9.2 POE and Central Treatment Cost Comparison

Lykins (1992) completed a cost comparison of POE GAC and central GAC treatment alternatives for TCE contamination in a trailer park and a subdivision. Each residential area was assumed to consist of 150 homes (approximately 500 residents). This translates into a water requirement of approximately 40 gpm for each community. The trailer park was assumed to be much more densely populated than the subdivision.

Since this analysis assumed that there was no pre-existing distribution system in either community, more piping would be required to connect the households of the subdivision to the central plant (15,840 feet) than would be required to connect the households of the trailer park (3,400 feet). Piping costs were based upon the use of 8-inch PVC pipe and incorporate the additional costs of trenching, embedment, backfill, and paving. Cost data for these items were taken from *Standardized Costs for Water Distribution Systems*. Distribution system costs account for about 70 percent of the total central system costs for the subdivision and about 50 percent for the trailer park. If ductile iron pipe were used instead of PVC pipe, the costs for the distribution system would double.

The central treatment system and the POE devices were designed to remove at least 95 percent of influent TCE (assumed to be 100 μg/L for the purposes of this study). Costs for the central GAC treatment unit incorporated the need to maintain a 10-minute EBCT to ensure adequate TCE removal, a carbon service life of 165 days, 30-percent excess capacity (to provide an additional margin of safety), and 10-percent financing for 20 years. The POE units consisted of 2 GAC tanks in series, each filled with 2 cubic feet of F-400 carbon. These units were designed to provide 4.1 minutes of EBCT with a loading rate of 4 gpm per square foot. Each POE unit was priced at $2,000 and assumed to be financed at 10 percent for 10 years. Annual carbon replacement (2 cubic feet per year) was assumed to cost $420 in addition to a $15 per month maintenance charge. A PTA unit could be installed before the GAC tanks in the POE system. The aerator would cost approximately $3,000 and would require a continuous electrical supply. However, the aeration unit would also extend the lifetime of the GAC by as much as 80 percent by removing a large part of the TCE prior to GAC adsorption. Thus, because the carbon tanks would need to be replaced less frequently, the addition of the aeration unit would probably reduce the total lifetime cost of the POE system.

Another alternative to central treatment was also studied for the two communities. This alternative incorporates 4 GAC units, each of which could produce 10 gpm. This may save on the amount of piping needed given certain demographics. Twenty-five percent less piping was assumed necessary in the analysis of this alternative. Table 2.9.2.1 presents the costs of the various treatment alternatives.

Table 2.9.2.1: Costs of GAC Compliance Options for Communities of Differing Density I (1990$)

Residential Area	Central Treatment Cost[1]		POE Treatment Cost[2]
	1 Unit (40 gpm)	4 Units (10 gpm each)	
Trailer Park	$357/household/year $3.70/1,000 gallons	$636/household/year $6.60/1,000 gallons	$690/household/year $7.16/1,000 gallons
Subdivision	$619/household/year $6.42/1,000 gallons	$837/household/year $8.68/1,000 gallons	

1. Central treatment costs include the cost of constructing a distribution system using PVC pipe.
2. Outfitting the entire community requires 150 POE units.

Central treatment would be the most cost-effective alternative for both communities if the distribution system was constructed from PVC pipe. Table 2.9.2.2 presents the cost estimates developed for the various treatment alternatives assuming the use of ductile iron pipe instead of PVC pipe for the distribution system.

While it would still be less expensive to install a single central treatment system rather than multiple POE units for the trailer park, the POE alternative would be significantly less expensive for the more dispersed subdivision.

Table 2.9.2.2: Costs of GAC Compliance Options for Communities of Differing Density II (1990$)

Residential Area	Central Treatment Cost[1]		POE Treatment Cost[2]
	1 Unit (40 gpm)	4 Units (10 gpm each)	
Trailer Park	$536/household/year $5.55/1,000 gallons	$770/household/year $7.99/1,000 gallons	$690/household/year $7.16/1,000 gallons
Subdivision	$929/household/year $9.63/1,000 gallons	$1,069/household/year $11.09/1,000 gallons	

1. Central treatment costs include the cost of constructing a distribution system using ductile iron pipe.
2. Outfitting the entire community requires 150 POE units.

2.9.3 Elkhart, Indiana

Elkhart is located in north central Indiana at the confluence of the Saint Joseph and Elkhart Rivers. The population of the Elkhart metropolitan area is approximately 65,000. A large number of industries in the Elkhart area use or have used TCE or other organic solvents in their processes.

The surface geology of Elkhart consists of a typical glacial deposit created from various types of sand and gravel that forms an extensive outwash aquifer permeating up to 175 feet. An intermediate, non-permeable clay bed confines a deeper aquifer.

Through routine monitoring, ground water in 9 of the 17 wells at the municipal treatment facility were found to be contaminated with approximately 95 μg/L TCE. The site was added to the Superfund NPL in December 1982. EPA and the Indiana Department of Environmental Management (IDEM) decided to install PTA units at the municipal water utility to meet the drinking water standard. In the fall of 1987, a nationally known water treatment company constructed 3 concurrent flow, 17-meter air-stripping towers under the supervision of the US Army Corps of Engineers. The towers were 3 meters in diameter and each contained 9 cubic meters of polypropylene packing media. These units were designed to treat between 5 million and 6 million gallons of water per day. The air towers cost $2.5 million (in 1987 dollars) to construct. The annual O&M cost for the towers was estimated to be between $81,000 and $106,000.

In the fall of 1984, it was found that private wells in the East Jackson area of Elkhart were contaminated by several VOCs including carbon tetrachloride, trichloroethane (TCA), dichloroethylene (DCE), perchloroethylene (PCE), and TCE. The levels of contamination were as high as 19,380 μg/L of TCE. Drinking water from these wells constituted an immediate and significant health threat to the residents of the affected households. In addition, according to the Centers for Disease Control (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR), inhalation and absorption of water contaminated with TCE above 1,500 μg/L is also a health danger.

In 1985, EPA initiated a city-wide sampling program that identified more than 80 wells in East Jackson that were contaminated by TCE at levels in excess of 200 μg/L. Fifteen of these wells had TCE concentrations in excess of 1,500 μg/L. Carbon tetrachloride contamination was also found in this area of the city. More than 800 residents were temporarily placed on bottled water delivery, while 14,500 feet of water main were installed to connect the affected areas (301 homes and 7 businesses) to city water. In addition, 11 homes with minor contamination problems were given POU devices since they were not adjacent to a water main.

In June 1986, severe contamination by TCE (800 μg/L) and carbon tetrachloride (488 μg/L) was detected in a well in the County 1 area of Elkhart. EPA again instituted a sampling program, this time covering 88 wells. Significant levels of TCE (5,000 μg/L) and carbon tetrachloride (7,500 μg/L) contamination were detected in this effort (Bianchin 1987). EPA immediately provided bottled water to all affected residents and advised those with the most contaminated wells not to use their water for any reason. Due to the time required to extend the city's water mains, EPA decided to install POE GAC and POU GAC units at private residences. Fifty-four POE GAC and 22 POU GAC units were installed. IDEM agreed to sample the affected homes periodically to ensure the continued efficiency of the treatment units.

The POE GAC units were 13 inches in diameter and permitted the use of up to 3.8 cubic feet of carbon (50 inches of carbon depth). Each POE unit contained 110 pounds of 20 x 50 mesh size GAC. Carbon replacement costs were approximately $510 per tank (in 1989 dollars), while the sediment pre-filters cost $40 each to replace.

Two residences in East Jackson were equipped with treatment systems consisting of a PTA element connected to two GAC tanks in series. These units were located in the basement and were vented outside. The air strippers had a 40:1 air-to-water ratio and operated at a rate of 5 gpm. The air strippers were packed with 1-inch diameter polypropylene cylinders. Although no microbiological problems have been encountered, a UV light may be installed in the POE system for post-GAC disinfection. The installed cost of the entire unit (one air stripper and two GAC tanks) was about $4,000 (in 1989 dollars). The installer recommended flushing the system any time that water had to stand unused for more than a day. Special monitoring was undertaken to test the effectiveness of these POE systems. The results of this monitoring showed that the units effectively reduced the levels of carbon tetrachloride and TCE in the water.

The authors evaluated the performance of the POE GAC units in Elkhart. GAC isotherm calculations, sometimes used to estimate breakthrough for GAC media, proved unreliable in accurately predicting breakthrough in this instance. The time to breakthrough was significantly over- and under-estimated. The number of gallons successfully treated before breakthrough has ranged from 25,000 to over 300,000 gallons. Competitive effects were evident in a dual GAC unit in Elkhart that was monitored for a special EPA study. In this case, isotherm data predicted breakthrough for chloroform at approximately 225,000 gallons, but chloroform was estimated to have actually broken through after about 130,000 gallons were treated by the unit. Over the course of the study, methylene chloride concentrations of 115 μg/L were consistently lowered below detection levels. Table 2.9.3.1 summarizes data from homes in Elkhart that experienced breakthrough and provides an illustration of GAC capabilities.

Table 2.9.3.1: Performance Data for POE GAC Devices in Elkhart, IN

Site	Average influent concentrations (μg/L)			Gallons treated	Months	Possible Cause for CCL_4 Breakthrough
	TCE	CCl_4	$CHCl_3$			
1	170	291	15	30,500	25	Competitive effects; bacterial colonization
2	60	2,864	ND	120,000	22	High influent levels
3	418	2,188	ND	150,000	24	High influent levels
4	331	135	10	135,000	16	Competitive effects; TCE concentration
5	1,686	348	50	140,000	18	TCE concentration

2.9.4 Rockaway Township, New Jersey

This case is summarized from Bellen (1986). Rockaway Township is located 18 miles northwest of Newark, in Morris County, New Jersey. The township has a population of about 20,000 people and covers approximately 45 square miles. In 1980, two ether compounds, di-isopropyl ether and tert-butyl ether, were found in the township's water at concentrations of 70 to 100 μg/L and 25 ro 40 μg/L, respectively.

The 320-acre Lake Telemark subdivision is located in the northern section of Rockaway Township within the Hibernia Brook River Drainage Basin. The subdivision is primarily residential, consisting of approximately 310 private homes and a small commercial district. Fourteen of 50 wells tested in the subdivision tested positive for VOC contamination. 1,1-dichloroethane, TCA, DCE, PCE, TCE, 1,2-DCP, and trichlorofluoromethane were found in detectable concentrations. These contaminants and their respective concentrations varied considerably from site to site; most probably, the individual wells tapped different aquifers. It was also concluded that there was more than one source of these contaminants in the area.

Ten wells had such high levels of contamination that the township health department recommended the use of bottled water. A pilot demonstration of POU GAC technology was begun in the subdivision in October, 1981. The township installed POU units and monitoring devices in 12 homes in the subdivision which relied on private wells. Each well was contaminated with a variety of organic compounds. Flow meters were not installed on the POU devices used in the Lake Telemark Subdivision. On average, it was estimated that 2.3 gallons of water were treated daily by each POU unit.

All 12 POU devices were purchased from the same manufacturer. Each consisted of a two-cartridge treatment system. One cartridge contained GAC, while the other contained PAC and filterable materials. The units held 765 grams of carbon and provided 62 seconds of contact time based upon the manufacturer's specified maximum flow rate. The units were installed using the line bypass approach to POU treatment. The township received a price discount on the units used in the pilot study and was not required to pay until the units had proven effective in removing the contaminants. Homeowners not selected for the study were also permitted to purchase POU units for the reduced price negotiated by the community. The manufacturer agreed to arrange and pay for all installation and maintenance costs (including cartridge replacement) for 1 year. In addition, 50 percent of the analytical costs incurred to demonstrate the efficacy of the POU devices were covered by the vendor. Sampling costs and the remaining analytical costs were covered by the Health Department of Rockaway Township. All participants in the pilot study were required to sign documents indemnifying the health department for any negative effects resulting from the use of the POU devices.

At the start of the EPA study in October 1982, the devices had been in operation for approximately 1 year and had treated approximately 800 gallons of water. The POU GAC units demonstrated VOC removal rates of greater than 99 percent.

Water sample collectors were selected and trained by the NSF, which managed the project. Water sample collection, preservation, and analysis were conducted according to prescribed EPA methods. Sample collectors were instructed to let water run for 1 to 2 minutes before taking a sample to provide a post-treatment sample that was representative of water subject to the minimal carbon contact time. Water samples were frequently delivered with a small headspace (air bubble) in the sampling container. Headspace of less than 0.5 ml was not found to significantly alter the results of VOC analyses.

From October 1982 through October 1983, only 1 of 21 post-device samples contained detectable levels of VOCs (4 μg/L TCE and 2 μg/L PCE). Eight sites were sampled during the 24 months of operation with no detectable VOCs in effluent samples (<1 μg/L). Total organic carbon (TOC) concentrations were low in Rockaway Township. This low level of organic loading may have improved the capacity of carbon to remove PCE and TCE, the contaminants of concern. Communities that depend on surface water supplies must be especially alert to high TOC levels.

SPCs and coliform analyses were performed on pre- and post-device water samples collected at 10 sites in the Lake Telemark Subdivision. Mean plate counts were higher in post-device samples than in pre-device samples. Although the difference was significant, it was not as great as that reported in Silverdale, Pennsylvania (see section 2.9.5). As in Silverdale, flushing the system before sampling significantly reduced the post-device SPC. No coliform organisms were detected in any post-device samples collected in the subdivision.

Total capital costs for POU GAC units in Lake Telemark included a housing, appropriate cartridges, connective fittings, and installation. Each unit was also equipped with a shut-off flow meter. The purchase price was negotiated by the community. Based upon the manufacturer's rated treatment capacity of 2,000 gallons and an estimated use rate of 2.3 gallons per household per day, the GAC cartridge life was calculated to be 2.4 years. Total estimated replacement costs were $1.77 per device per month. No maintenance was reported on any unit during the 2-year demonstration period. Table 2.9.4.1 outlines unit performance and costs. Cost information was supplied by equipment manufacturers and the township. Maintenance costs were calculated using manufacturers' rated service volumes and the average volume of treated water in the project since no maintenance was reported during the study.

The authors of the study recommend that communities selecting POU treatment conduct a pilot study by operating a device on the community water supply at continuous flow until breakthrough occurs. This pilot study will establish the device's capacity for the quality of water and could be completed in less than 3 days for most devices. Raw water quality must also be monitored during normal (post-pilot study) operation to ensure that the quality has not changed and that the pilot study results are still valid.

Table 2.9.4.1: Performance and Cost Data for POU GAC Devices in Rockaway Township, NJ (1985$)

Number of Units	12
Service area type	Private wells at single family homes
Mean treated water use (gpd)	2.3 (est.)
Trichlorethylene (mean mg/L)[1] Influent Effluent	 0.125 <0.001
1,1,1-Trichloroethane (mean mg/L)[1] Influent Effluent	 0.092 <0.001
Average Cost per POU Unit[2] Total Cost per Household per Month[3]	$255 $4.23

1. Samples containing <0.001 mg/L were assigned a value of 0.0009 mg/L for calculation of the mean.
2. Average of five manufacturers; includes equipment plus installation costs.
3. Capital, amortized at 10 percent for 20 years plus maintenance.

2.9.5 Silverdale, Pennsylvania

This case is summarized from Bellen (1986) and Lykins (1992). The Village of Silverdale is located 30 miles north of Philadelphia and lies within the Pleasant Springs Creek Drainage Basin in central Bucks County, Pennsylvania. Silverdale has a population of about

550. Approximately 200 residences and 15 commercial establishments are located within the community. Individual septic tanks were used for wastewater treatment within the community until 1981.

The principal VOCs contaminating Silverdale's water supply were TCE and PCE. Concentrations of up to 65 μg/L of TCE and 12 μg/L of PCE were found in October 1980. Chloroform and carbon tetrachloride were also consistently found in local water samples, but generally at concentrations of less than 10 μg/L.

Line bypass POU GAC units from five manufacturers (thus five different designs) were tested in Silverdale. All the devices demonstrated greater than 95 percent reduction of halogenated organics in laboratory and field studies directed by the Gulf South Research Institute between 1979 and 1981. The device manufacturers were required to certify that their products met NSF Standard 53, Section 3 for structural integrity, corrosion resistance, nontoxicity, etc. The units held between 300 and 1,708 grams of carbon and provided estimated contact times of 6 to 78 seconds based on the manufacturers' specified maximum flow rate. Two of the five designs used silver-impregnated activated carbon.

Forty-nine POU GAC units were installed and monitored for 14 months of operation for control of VOCs. All of these devices used the line bypass approach to treatment. POU devices were purchased from the manufacturers and installed by licensed plumbing contractors.

The average capital cost of a POU GAC treatment unit in Silverdale was $289 (in 1985 dollars). The systems included a housing, all appropriate cartridges, a flow meter, a tap, and all connective fittings. The cost of the POU devices reflected the discount provided by the manufacturers for purchases of 10 or more units.

Installation and maintenance was subcontracted to the local water company at a rate of $20 an hour. Installation generally required between 0.75 and 1.5 hours of labor per device. Maintenance costs averaged $1.43 per site per month. The estimated effective life of the GAC cartridges ranged from two to five years. These estimates were developed using each manufacturer's rated capacity and the observed treated water usage rate of 1 gpd. Particulate pre-filters were assumed to be replaced annually. Thus, an average replacement cost of $1.72 per device per month was developed. Model-specific replacement costs ranged from $0.48 to $3.11 per device per month. Since replacement parts needed for unit repair were provided by the manufacturers free of charge, this figure represents only labor costs. Sampling and microbiological analysis in Silverdale cost $20 per sample. VOC analyses cost $50 per sample. All cost information is based on actual cost data gathered during the project. Table 2.9.5.1 outlines unit performance and costs.

Table 2.9.5.1: Performance and Cost Data for POU GAC Devices in Silverdale, PA (1985$)

Number of Units	49
Service area type	Central system with single family homes
Mean treated water use (gpd)	1.0
Trichlorethylene (mean mg/L)[1] Influent Effluent	 0.080 <0.001
1,1,1-Trichloroethane (mean mg/L)[1] Influent Effluent	 0.001 <0.001
Average Cost per POU Unit[2] Total Cost per Household per Month[3]	$289 $5.98

1. Samples containing <0.001 mg/L were assigned a value of 0.0009 mg/L for calculation of the mean.
2. Average of five manufacturers; includes equipment plus installation costs.
3. Capital, amortized at 10 percent for 20 years plus maintenance.

Water sample collectors were selected and trained by the NSF, which managed the project. Collection, preservation, and analysis of water samples were conducted according to prescribed EPA methods.

Properly sized and installed GAC POU units reduced PCE and TCE concentrations to less than 1.0 μg/L throughout the 14-month study period (in 95.0 percent and 97.7 percent of samples, respectively). Other VOCs were detected in only 61 of 715 post-device analyses (8.5 percent) during the study. In no case was a VOC detected in a concentration greater than 24.3 μg/L. Table 2.9.5.2 summarizes the contaminants and influent concentrations successfully treated over the study period. While the total quantity of compound adsorbed may differ from unit to unit, the relative capacities, or the order of breakthrough of the compounds, remain the same.

While the number of microorganisms measured by the SPC method was substantially higher in post-device than in pre-device water, no evidence of coliform bacteria colonization was found in any of the POU devices. Samples taken after 2 minutes of flushing the system were found to have SPCs comparable to those of the distribution system itself. Silver impregnation of GAC did not appear to affect microbial density under the conditions of this study. Measures of microbial density such as the SPC had a negative correlation with the weight of carbon used in a device (i.e., units that contained more GAC produced water with lower bacterial concentrations). The study concluded that variation in sampling technique will significantly alter results of microbiological testing of water passing through POU devices. An experiment specifically designed to study the correlation between SPC densities and carbon quantity would be required to confirm this finding. Once a sampling method has been chosen, it should be consistently followed to ensure comparable results.

Table 2.9.5.2: Source Water Quality of Surveyed Houses in Silverdale, PA

Contaminant	Mean Pre-device Concentration (μg/L)	Contaminant	Mean Pre-device Concentration (μg/L)
Trichloroethylene	80.4	1,2—dichloroethane	< 1.0
Tetrachloroethylene	20.6	Bromodichloromethane	1.5
Carbon Tetrachloride	8.0	Dibromochloromethane	1.4
Chloroform	6.7	Bromoform	< 1.0
1,1,1-Trichloroethane	1.1		

The study also concluded that all water quality districts that choose to install POU technology should conduct periodic monitoring. For most cases involving VOC contamination, premature replacement of carbon cartridges is more cost effective than frequent sampling and analysis due to the high lab fees charged for VOC analyses. Relatively consistent raw water quality is necessary to ensure the efficacy of periodically replacing POU cartridges as a treatment method. As with central treatment, routine maintenance must be provided after installation. Homeowners must also be made aware of how and when to request maintenance and monitoring. The study found that many homeowners did not report operational problems immediately.

Leaking caused $250 and $300 worth of damage in two homes. Although these costs were covered by the manufacturer's liability insurance, reimbursement took several months.

The authors of the study recommend that communities selecting POU treatment conduct a pilot study by operating a device on the community water supply at continuous flow until breakthrough occurs. This pilot study will establish the device's capacity for the quality of water and could be completed in less than 3 days for most devices. Raw water quality must also be monitored during normal (post-pilot study) operation to ensure that the quality has not changed and that the pilot study results are still valid.

2.9.6 Putnam County, New York

Lake Carmel is located approximately 50 miles north of New York City in Putnam County. During the 1930s, the hills surrounding the small lake were extensively developed with seasonal residences. Most of these residences were recently converted to year-round housing. Each residence has its own well and septic system. Petroleum leaks and spills and the chemicals residents flushed into septic systems contaminated local ground water. TCA, PCE, TCE, benzene, toluene, xylene, and carbon tetrachloride were all detected at relatively high concentrations. Elevated nitrate and high coliform levels were also discovered at some wells. Approximately 40 percent of bacteriological samples exceeded the standard of 1 coliform organism/100 mL. However, coliform levels varied considerably from well to well and in the same well over time. Table 2.9.6.1 provides a summary of local contamination problems.

Residents hired an engineering consultant to conduct a feasibility study for central treatment. The study found that installing a public water system would cost more than $1,200 per household per year. The majority of this projected cost was due to the need for extensive excavation in rocky terrain to install the distribution system. The U.S. Department of Housing and Urban Development provided $165,000 to design, purchase and install POE treatment systems under an imminent threat grant. Sixty-seven of the 110 eligible households opted to install POE units.

Table 2.9.6.1: Source Water Quality of Surveyed Households in Putnam County, NY

Contaminant	Mean Concentration (μg/L)	Contaminant	Mean Concentration (μg/L)
Benzene	67.7 ± 176.3	Barium	0.115 ± 0.122
Bromodichloromethane	2.90 ± 1.15	Boron	0.212 ± 0.425
Carbon Tetrachloride	4.50 ± 1.98	Calcium	30.27 ± 16.04
Chloroform	5.03 ± 4.81	Chromium	0.001 ± 0.002
Ethylbenzene	38.3 ± 62.1	Copper	0.033 ± 0.039
Tetrachloroethylene	100.2 ± 215.3	Iron (Fe)	0.100 ± 0.097
Toluene	8.5 ± 88.0	Lead (Pb)	0.008 ± 0.015
1,1,1-Trichloroethane	6.91 ± 5.10	Magnesium (Mg)	10.47 ± 5.45
Trichloroethylene	5.48 ± 3.86	Molybdenum (Mo)	0.081 ± 0.126
Trichlorofluoromethane	1.25 ± 0.50	Nickel (Ni)	0.005 ± 0.007
Vinyl Chloride	2 ± 0	Phosphorous (P)	0.002 ± 0.005
Xylene	108.4 ± 178.1	Potassium (K)	2.18 ± 2.42
Total Coliform (coliform organisms/100 mL)	< 1 to 245	Silicon (Si)	4.69 ± 2.75
Bis-(2-ethylhexyl)-phthalate	23 ± 17.0	Sodium (Na)	85.28 ± 73.49
Aluminum	0.095 ± 0.155	Zinc (Zn)	0.033 ± 0.038
Arsenic	0.015 ± 0.030	Nitrate	5.65 ± 3.47

Each POE unit included a water meter, two 5-μm cartridge pre-filters in parallel, two GAC filters in series, pressure gauges before and after the treatment system, and a UV light disinfection system. The GAC filters were composed of a 10-inch diameter fiberglass tank containing 40 pounds of virgin activated carbon. Bed depth was 36 inches, and each cylinder provided for an EBCT of about 2.5 minutes at a flow rate of 5 gpm. The UV light element was equipped with a light sensor and visual alarm to inform the homeowner of proper operation. A valve system was designed to allow water use even when the GAC cylinders were being changed. Costs for this system are detailed in Table 2.9.6.2. Based upon a benzene concentration of 244 μg/L (the mean observed benzene concentration plus one standard deviation), the theoretical useful life of this POE unit was 36 months. Although the theoretical lifetime of each individual tank was 18 months, the lead cylinder was replaced annually. Thus, each year the lag tank was moved to the lead position and a newly charged tank was placed in the lag position.

Table 2.9.6.2: Cost Data for POE GAC Devices in Putnam County, NY (1987$)

<table>
<tr><th>Item</th><th>Cost</th></tr>
<tr><td>Water Meter</td><td rowspan="5">$150.60</td></tr>
<tr><td>Gate Valves (8)</td></tr>
<tr><td>Check Valve</td></tr>
<tr><td>Sampling Taps (3)</td></tr>
<tr><td>Pressure Gauges (2)</td></tr>
<tr><td>Cartridge Pre-filters (2)</td><td>$67.84</td></tr>
<tr><td>GAC tanks (2)</td><td>$140.60</td></tr>
<tr><td>GAC (80 pounds)*</td><td>$72.00</td></tr>
<tr><td>UV Disinfection Unit</td><td>$392.00</td></tr>
<tr><td>Installation</td><td>$494.00</td></tr>
<tr><td>Total System Cost</td><td>$1,317.04</td></tr>
</table>

Initially, O&M of the POE units was to be carried out by personnel of the nearby Town of Kent. However, the town turned responsibility for O&M over to the homeowners. They formed a not-for-profit corporation, the Lake Carmel Water Quality Improvement District (LCWQID), which consists of the homeowners who installed POE treatment systems in their homes.

The maintenance requirements of these units consists of changing one of the GAC tanks every year, replacing the UV bulb every 9 months, and changing the pre-filters when necessary. The GAC tank is recharged at a town-provided workshed where the used GAC is replaced with 18 pounds of virgin GAC. The spent carbon is disposed of at a nearby landfill. Maintenance staff make house calls to repair leaks and to clean the quartz tube housing the UV bulb. They are paid on a per-item basis.

The LCWQID attempted to sample 10 percent of the POE units each year. From 1984 through 1986, 21 paired samples were collected and analyzed for coliform organisms. Three untreated samples had high coliform counts. However, only one treated sample had a detectable level of coliforms (2/100 mL). The LCWQID did not have enough money to adequately monitor organic chemicals. Only 10 units were sampled and analyzed for benzene, toluene, and xylene in 1984. None of these chemicals were found either in untreated or treated water at concentrations exceeding the guideline levels of 5 μg/L for benzene and 50 μg/L for toluene and xylene. Limited testing continued from 1985 to 1987. The test results were not comprehensive enough to make a definitive statement on the POE systems' efficacy in the removal of organic contaminants, but they did provide evidence that the units were performing satisfactorily (at no point was any contaminant detected at levels greater than 5μg/L).

In the first 4 years of operation, the annual costs of O&M have been $250 per household. By 1987, the annual cost had been raised by LCWQID to $320 per household. This fee was paid quarterly.

2.9.7 POU and Central Treatment Cost Comparison I

Economies of scale frequently result in central treatment systems being less costly to operate than a network of POU or POE devices, especially for larger communities. For example, a study by Goodrich (1990) compared the cost of upgrading an established central treatment system with the cost of installing POE devices in every household of communities of different sizes. For this study, water use was assumed to be 275 gpd per house. Both the central system and the POE units were designed to remove of at least 95 percent of dibromochloropropane (DBCP), TCE, and 1,2-DCP. In each case, when a community is larger than 25 households, and has a pre-existing distribution system, central treatment becomes economically preferable to POE treatment. The absence of a pre-existing distribution system will result in the POE treatment strategy becoming less expensive to implement than a central treatment strategy for a larger number of households.

Table 2.9.7.1: Costs of GAC Compliance Options for Communities of Differing Size 1 (1990$)

Number of Households	Contaminant	Influent Concentration (μg/L)[1]	Central System Cost per 1,000 Gallons[2]	Average POE Cost per 1,000 Gallons
10	DBCP	50	$13.85	
25	DBCP	50	$6.69	$4.75
50	DBCP	50	$3.98	
10	TCE	100	$13.95	
25	TCE	100	$6.79	$6.75
50	TCE	100	$4.08	
10	1,2-DCP	100	$14.94	
25	1,2-DCP	100	$7.50	$8.00
50	1,2-DCP	100	$4.65	

1. Systems must remove more than 95 percent of contaminant.
2. Distribution system (i.e., pipes, valves, etc.) already in place.

2.9.8 POE and Central Treatment Cost Comparison II

Goodrich completed a similar study to that reported in section 2.9.7 in 1992. It was assumed that a small community had a central treatment plant and distribution system. GAC treatment was to be used to address organic chemical contamination. Water use was assumed to be 80 gpd per person; a household was considered to be 3.3 persons. Three contaminants were considered: DBCP, 1,2-DCP, and TCE. Both the POE system and the central plant were designed to remove 95 to 99 percent of these contaminants.

The POE system consisted of two GAC contactors in series; each had approximately 2 cubic feet of GAC, providing 4.1 minutes EBCT with a design loading of 4 gpm per square foot. The carbon in the POE system was replaced every one to two years. POE costs included a capital cost of $2,000, paid over 10 years at 8 percent interest. Costs for routine maintenance, sampling, and analysis were estimated at $350 per year. Carbon replacement costs varied by contaminant.

Costs associated with GAC central treatment varied with system capacity and type of contaminant. Replacement of spent carbon with virgin carbon was assumed. Capital costs were amortized at 8 percent for 20 years. Table 2.9.8.1 compares the costs of POE and central treatment employing GAC technology as a function of the number of households involved.

Table 2.9.8.1: Costs of GAC Compliance Options for Communities of Differing Size II (1992$)

Number of Households	Annual Cost for Each Household					
	DBCP		TCE		1,2-DCP	
	Central	*POE*	*Central*	*POE*	*Central*	*POE*
10	$1,325	$775	$1,332	$815	$1,356	$900
15	$954		$960		$985	
20	$760		$766		$790	
25	$639		$646		$670	
50	$380		$385		$410	

2.10 Dibromochloropropane Treatment: Fresno, California

The provision of safe drinking water to areas of low population density is an increasing problem in California's San Joaquin Valley. A survey indicated that 99 of 231 sampled wells (42.9 percent) tested positive for organic contamination in Fresno County, while 41.2 percent of sampled wells tested positive for contamination by organic compounds in Los Angeles County. Hundreds of homes in the area were sold POE GAC units to treat for DBCP because of its previous widespread application to control nematode infestations of grapes and other crops. Typically, these units were equipped with flow totalizers, pressure gauges at the inlets and outlets, a flow-restriction mechanism to maintain a minimum contact time of 1.5 minutes, and facilities to backwash the carbon to control head loss. Local firms sell and lease POE GAC units. Vendors typically service the units themselves.

Ten POE GAC units were selected for study in an intensively farmed area southeast of Fresno. Both pre- and post-device water was sampled for DBCP every 4 to 8 weeks for 2 years. GAC treatment, when properly applied, proved to be extremely effective in removing DBCP from the household water supply. However, the effectiveness of individual units depended upon the quality of the GAC media. Monitoring results showed that the performance of these units could change markedly over short periods of time. Thus, safe use of these units requires conscientious, periodic monitoring. This level of monitoring may be difficult to achieve, since owners generally lack the expertise to monitor the units they buy, and vendors have no contractual authority or responsibility to monitor the POE units they sell.

Several models for achieving the desired degree of supervision and control over individual or small private water systems were presented. These included using existing districts or similar entities that have an adequate physical system and sufficient personnel, or creating a special water quality district through legislative action. Counties, towns, public or private water service districts, irrigation districts, community service districts, and sanitation districts would all be suitable jurisdictional bodies for administering POU and POE unit programs.

Test results for bacteriological growth in the carbon beds of the 10 units were scattered and inconclusive. However, the data seem to suggest that the number of organisms generally increased in the product waters relative to the feed waters. Because of the potential for colonization on GAC by some primary and opportunistic pathogens, the study concludes that POE GAC devices are best used on waters that meet the bacteriological standards for drinking water.

Representative costs for GAC treatment using POE devices were found to range from $3 to $4 per 1,000 gallons treated (in January 1990 dollars). The authors emphasize that the costs associated with all aspects of POU and POE unit operation must be considered to permit an accurate comparison with central treatment options.

2.11 Microbiological Treatment

Although the SDWA explicitly forbids the use of POU treatment devices to meet the MCL for a microbiological contaminant, several case studies identified during the literature search describe the strategies selected by small communities to address microbial contamination. Even though POU units may not be used to address microbiological contamination, valuable insight into potentially useful management techniques for the use of both POU and POE treatment devices may be gleaned from the following case studies.

2.11.1 Ephraim, Wisconsin

This case is summarized from reports provided by Bonestroo, Rosene, Anderlik and Associates, Inc. Ephraim, Wisconsin is a village of 260 permanent residents and an additional 1,000 to 2,000 seasonal residents. The village has endured bacterial contamination of its ground water for many years. In 1987, the village improved the quality of the ground water in the area by installing a wastewater treatment facility that serves about 40 percent of the population, though the majority still rely upon household septic systems.

Improved wastewater treatment did not eliminate the bacterial contamination of village wells. Testing showed the presence of coliform in 48.5 percent of non-community public wells and 39.5 percent of private wells tested in the village. In 1993, due to the high incidence of coliform in the village wells, the WDNR issued a boil water advisory for the entire village and suggested that Ephraim build a municipal water system. The village contracted with a consulting firm to evaluate the possible alternatives for addressing the water quality problem. The firm of

Bonestroo, Rosene, Anderlik and Associates (BRAA) studied the alternatives and placed the cost of a municipal system at approximately $13 million. In contrast, they determined the cost of installing and maintaining POE treatment at all of the 425 residences in the village to be approximately $3.3 million.

The cost of constructing the municipal system was driven by several factors. The shallow bedrock in the area made it very expensive to put in pipelines, while underlying rock formations made construction difficult and risky. Because of the unique characteristics of the trenches used for the wastewater treatment facility, WDNR determined that the same trenches could not be used for the municipal water system. The scattering of residences on the outskirts of the village necessitated long underground pipelines. In addition, the water contamination problems in Ephraim are site-specific; the water quality at a well in the south end of the village has little to do with water quality at a well in the north end.

In August 1994, the WDNR, the Village of Ephraim, and the WQA formed an informal partnership to conduct a POE pilot study. Eight wells were selected for the pilot study, and two types of POE systems were installed. Chlorine disinfection systems were installed in two wells and UV was installed in five wells. One well was used as a control site. The chlorine systems also included a GAC post-filter to remove chlorine odor and taste and a 1-μm pre-filter to remove *Cryptosporidium*. The UV systems included a 5-μm pre-filter for the removal of iron before water went through the UV disinfection compartment and a 1-μm filter after the UV element to remove *Cryptosporidium* and *Giardia*.

During the 3-month study, coliform bacteria were found in untreated water at three of the five POE UV sites. For all three of the POE UV sites where pre-device samples tested positive for coliform, UV treatment rendered the water 100 percent coliform-negative. A total of 50 "valid pairs" of samples were taken from the UV sites over the 3 month study period. A valid pair indicates that the untreated water tested coliform-positive and the treated water tested coliform-negative. The combination of technologies used in these POE systems also effectively reduced the level of TDS in treated water.

Positive pre-device samples for coliform were found at only one of the two POE chlorine sites during the testing period. A total of 17 "valid pairs" of samples were taken during the period. The results showed that the chlorine system removed 100 percent of the coliform bacteria.

Both POE systems were found to be 100-percent effective in eliminating coliform from the village water. The study emphasizes that the UV systems, while as effective as the chlorine systems, were much simpler to operate and monitor. Researchers also found that the chlorine systems were difficult to apply when household water use was low and that consistent chlorine levels were tedious to maintain.

The responsibility for monitoring during this study was shared by a contract service hired by the village, village officials, and individual homeowners. After the study ended, monitoring became the responsibility of the homeowner. Homeowners could fulfill this responsibility themselves, or hire a contract service to monitor their POE system on a regular basis.

BRAA estimated installation and yearly O&M costs for installing POE units at all Ephraim wells. The POE strategy combined the use of several POE technologies. BRAA assumed for the purposes of their cost analysis that chlorine disinfection systems would be installed at all public non-community wells, while UV disinfection systems would be installed in most private residences. It was further assumed that UV disinfection systems equipped with an air-injected iron pre-filter would be installed in private residences that had severe iron contamination problems. By making assumptions about the volume of water use and by amortizing the purchase and installation costs over the service life of the treatment units, the cost per gallon treated could be estimated. The costs calculated by BRAA are presented in Table 2.11.1.1.

Table 2.11.1.1: Cost Estimate for POE Treatment in Ephraim, WI (1994$)

Item	Unit	Cost	Number	Total Cost
PUBLIC WELLS				
Chlorine disinfection system with GAC post-filter	each	$12,000	32	$384,000
O&M				
Chlorine addition	per year	$90	32	$2,880
Carbon filter replacement (every 3 years)	per year	$45	32	$1,440
Inspection and maintenance of chlorine injector and feed pump	per year	$40	32	$1,280
Valve and pressure gauge replacement (every 10 years)	per year	$6	32	$192
Total O&M cost				*$5,792*
PRIVATE WELLS				
Ultraviolet light disinfection system with 1-μm post-filter	each	$1,500	295	$442,500
O&M				
Replacement of UV Lamp (twice per year)	per year	$160	295	$47,200
Replacement of cartridge filter (every 3 months)	per year	$20	295	$5,900
Valve and pressure gauge replacement (every 10 years)	per year	$6	295	$1,770
Electrical costs	per year	$60	295	$17,700
Total O&M cost				*$72,570*
UV disinfection system with air-injected iron pre-filter	each	$3,100	98	$303,800
O&M				
Replacement of UV lamp (twice per year)	per year	$160	98	$15,680
Maintenance of air-injection filter (once per month)	per year	$240	98	$23,520
Valve and pressure gauge replacement (every 10 years)	per year	$6	98	$588
Electrical costs	per year	$75	98	$7,350
Total O&M cost				*$47,138*
Bacteria Sampling				
PUBLIC (twice per month)	per year	$600	32	$19,200
PRIVATE (once per year)	per year	$25	393	$9,825
Pilot Study for DNR Approval	L.S.	$35,000	1	$35,000
Ongoing Testing and Administration of System	per year	$20,000	1	$20,000
Subtotal				
Initial Installation				$1,165,300
Annual O&M				$174,525
Total Cost of POE Option				**$1,339,825**

2.11.2 Gibson Canyon, California

Gibson Canyon, California is a development of 140 homeowners northwest of San Francisco. Gibson Canyon has long used POE devices to solve bacteria and turbidity problems in the water supplied to them by the Solano Irrigation District (SID). Residential water use was considered incidental to the SID's primary function of providing water for agriculture. At the community's request, the SID completed a feasibility study to explore the option of implementing POE treatment instead of central treatment.

The feasibility study compared the implementation costs of two different POE strategies to the cost of implementing central treatment. The two POE options differed in their assumptions regarding the extent of the required pilot study and the frequency of system-wide sampling. Alternative One, the higher cost option, employed a more extensive pilot study and continuous turbidity monitoring for each home. Alternative Two reduced the scope of the pilot study and assumes that monitoring requirements would be reduced to representative monitoring. This would be accomplished through the use of continuous turbidity meters and recorders equipped with alarms located at five representative sites within the water system's service area. The sites would be rotated over time so that all POE devices would be monitored. It was assumed that bacteriological testing would also be reduced to representative monitoring. The costs used below for central treatment were based on a two-pipe central system that would provide raw water for irrigation and potable water for household use. A comparison of the costs associated with Alternative One, Alternative Two, and central treatment is presented in Table 2.11.2.1.

Table 2.11.2.1: Cost Data for Compliance Options in Gibson Canyon, CA (1992$)

Compliance Option	Capital Cost	Annual Repayment of Capital[1]	Annual Operating Cost	Total Annual Cost	Annual Cost Per Connection[2]
POE Alternative One	$372,000	$38,000	$271,500	$309,500	$2,211
POE Alternative Two	$494,000	$50,000	$108,600	$158,600	$1,133
Central Treatment	$1,540,000	$157,000	$59,500	$216,500	$1,546

1. Amortization at 8 percent over 20 years.
2. Based on 140 connections.

Additional cost data were provided for Alternative Two. The author of the feasibility study included an estimate of the cost associated with retrofitting existing POE devices and an estimate of the cost of maintaining the POE devices. Table 2.11.2.2 outlines the estimated cost of retrofitting existing POE devices, and Table 2.11.2.3 presents the estimated cost of maintaining the existing POE devices.

Table 2.11.2.2: Cost Data for Retrofit of Existing POE Devices (1992$)

Item	Cost
Install UV devices on 69 units without UV (of 136 total units) 69 POE x $800	$55,200
Install cartridge filters 136 POE x 2 filters x $100 Installation: 136 x $50	 $27,200 $6,800
Install ceramic media filters 136 existing POE x $1,350	$183,600
Modify to allow Solano Irrigation District access 136 existing POE x $500	$68,000
Subtotal	*$340,800*
Contingencies (25%)	$85,200
Total	**$426,000**

Table 2.11.2.3: Cost Data for Maintenance of Existing POE Devices (1992$)

Item	Cost
Replacement of filter cartridges 136 POE devices x 3 changes per year = 408 visits at 30 minutes 30 min. each = 12 per day; 408 ÷ 12 = 34 days 34 – 165 x $30,000 per year Cartridges; 136 POE units x 2 filters/unit x 3 times/year = 816 cartridges x $25/cartridge	 $3,000 $20,400
Monitoring Turbidity at 5 continuous stations; ½ person/year x $30,000 Bacteria at 12 samples/month x $25/sample (labor included in above)	 $15,000 $3,600
Maintenance of POE devices at ½ person/year x $30,000	$15,000
Replacement of UV lights at 136 POE devices x 1/year 136 lights x $100 each	$13,600
Total	**$70,600**

2.12 POU Treatment Devices

Several articles identified during the literature search provided generic pricing information for POU treatment devices. Although these articles do not provide performance data, they do provide additional points of reference that were used to verify the cost data provided by other case studies and the cost curves presented in section 4.4.

2.12.1 Gumerman (1984)

Gumerman (1984) presents cost data for unit processes capable of removing contaminants in small water systems. Included is a discussion of POU treatment that provides information on treatment capabilities, construction costs, and O&M costs for five POU treatment technologies: AA, GAC, AX, CX, and RO. Cost estimates are provided for two types of POU installations: under-sink and at the property line.

Much like the POU line bypass units described in section 1.2.1, the under-sink installations described by Gumerman tapped into the cold water line under the kitchen sink. These units also included a shutoff-valve between the cold water line and the treatment device. Treated water would be dispensed from a dedicated faucet mounted on the sink. For installations at the property line, the treatment unit was assumed to be housed in a meter box at the edge of the resident's property. The meter box was designed to permit easy access for unit maintenance. A copper tube connected the unit to the household's main water supply. A shutoff-valve was provided upstream of the treatment unit, and a sampling tap was provided downstream; both were designed to be accessible at the meter box. A half-inch PVC pipeline connecting the treatment unit to a dedicated kitchen tap was also specified.

Under-sink installations cost less than property line installations and provide greater protection from adverse weather conditions, particularly freezing. However, under-sink installations do not permit the water system to access the treatment unit for sample collection and replacement of exhausted treatment devices without first coordinating its activities with homeowners.

Location of a treatment device at the property line ensures access for the water utility or its designee for servicing and sample collection. However, in locations where winter freezing occurs, an outdoor location would probably not be practical. In addition, POU RO units may not be located at the property line if there is no readily available sewer connection for the discharge of the aggressive waste brine produced by such devices.

Gumerman emphasized that the water utility is responsible for the installation and maintenance of POU treatment devices designed to remove contaminants regulated under the NPDWRs. According to Gumerman, these responsibilities include: purchasing treatment units, proper installation of treatment units, routine monitoring to ensure compliance with MCLs, maintenance of the units, and periodic replacement of all filters and cartridges. Any or all of these responsibilities may be subcontracted to a firm that specializes in such work. However, the public water utility remains ultimately responsible (and liable) for the safety of all water supplied to the community (see section 1.1).

2.12.1.1 Activated Alumina

AA systems were reported to be effective in the removal of arsenate (99 percent removal at pH 5-6 and an influent concentration of 5.0 mg As(V)/L), fluoride (99 percent removal at pH 5-6 and an influent concentration of more than 140 mg F/L), and selenium (IV) (70 percent at an influent concentration of 0.033 mg Se (IV)/L).

Construction costs for AA filtration units are presented in Table 2.12.1.1.1 for under-sink installations and for installations at the property line. For both locations, the AA canister was described as a 14.2-liter fiberglass cylinder. The cost of PVC piping can vary for installation at the property line. For homes close to the curb with a grass lawn, the cost estimate is reasonable. For homes with extensive landscaping, the estimate may be low. Particular attention should be given to this cost for each installation.

Table 2.12.1.1: Capital Cost Data for POU AA Devices (1983$)

Cost Category	Cost for Under Sink Installation	Cost for Installation at the Property Line
AA filter canister	$200	$200
Water meter	$40	$40
Plastic meter box and 10-inch PVC pipe collar	–	$30
PVC piping to house	–	$20
Faucet, copper or plastic tubing, and fittings	$40	$40
Labor, installation	$40	$120
Subtotal	$320	$450
Contingency	$50	$70
Total	**$370**	**$520**

O&M costs for POU AA treatment are limited to the cost of labor and materials because the AA units do not require electrical power. The O&M costs are divided into three categories: sampling/testing, media regeneration, and repairs. A summary of O&M costs is shown in Table 2.12.1.1.2. A range of costs is presented for each category to illustrate the sensitivity of O&M costs to various assumptions.

Table 2.12.1.1.2: Operation and Maintenance Cost Data for POU AA Devices (1983$)

Cost Category	Labor (hr/yr)	Annual Material Cost[1]	Total Annual Cost[2]	Average Total Annual Cost
Sampling/testing frequency				
2/yr	$2	$20	$41	
4/yr	$6	$40	$106	$106
6/yr	$12	$60	$192	
Media regeneration frequency[3]				
2/yr	$2	$100	$122	
1/yr	$1	$50	$61	$61
0.5/yr	$0.5	$25	$30	
Repairs				
Low	$1	$10	$21	
Average	$2	$20	$42	$42
High	$3	$30	$63	
Total cost for mid-range condition				**$209/yr**

1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.
3. Materials costs for regeneration assume that the alumina is regenerated locally.

2.12.1.2 Granular Activated Carbon

Gumerman reports that GAC units can remove 80 percent of inorganic mercury (influent concentration of 0.01 mg Hg (inorganic)/L) and 60 percent of organic mercury (influent concentration of 0.005 mg Hg (organic)/L). POU GAC units also effectively remove most organic compounds.

Construction costs for POU GAC units are presented in Table 2.12.1.2.1 for under-sink installations and for installations at the property line. The cost of a POU GAC unit are based on the use of a quality plastic or stainless steel housing and a replaceable carbon cartridge. The amount of carbon in the POU unit would range from 0.002 to 0.003 cubic meters. The theoretical water treatment capacity for the units ranges between 1,000 and 3,000 gallons, based on the carbon volumes given above. Actual capacity would depend on the quality of the raw water to be treated.

O&M costs for POU GAC treatment are limited to labor and materials because the GAC units do not require electrical power. The O&M costs are divided into three categories: sampling/testing, carbon cartridge replacement, and repairs. A summary of O&M costs is presented in Table 2.12.1.2.2. A range of costs is shown for each category to illustrate the sensitivity of O&M costs to various assumptions.

Table 2.12.1.2.1: Capital Cost Data for POU GAC Devices (1983$)

Cost Category	Cost for Under Sink Installation	Cost for Installation at the Property Line
GAC unit	$140	$140
Plastic meter box and 10-inch PVC pipe collar	–	$30
Water meter	$40	$40
PVC piping to house	–	$20
Faucet, copper or plastic tubing, and fittings	$40	$40
Labor, installation	$40	$120
Subtotal	$260	$390
Contingency	$40	$60
Total	$300	$450

Table 2.12.1.2.2: Operation and Maintenance Cost Data for POU GAC Devices (1983$)

Cost Category	Labor (hr/yr)	Annual Material Cost[1]	Total Annual Cost[2]	Average Total Annual Cost
Sampling/testing frequency				
2/yr	2	$60	$82	
4/yr	4	$120	$164	$164
6/yr	6	$180	$246	
Carbon cartridge replacement interval[3]				
1 yr	1	$10	$21	
2 yr	0.5	$5	$10	$10
3 yr	0.3	$3	$6	
Repairs				
Low	1	$10	$21	
Average	2	$20	$42	$42
High	3	$30	$63	
Total cost for mid-range condition				$216

1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.
3. This read as "Frequency" and "1/yr, 2/yr, 3/yr" in the original, but the cost and labor figures decreased as the frequency per year increased. Since this seemed illogical, the heading was changed to "Interval" for this report.

2.12.1.3 Anion Exchange

AX units have demonstrated their ability to remove arsenate (90 percent removal for influent waters with 0.5 mg As(V)/L), barium (95 percent removal for influent waters with 20 mg Ba/L), nitrate (90 percent removal for influent waters with 100 mg NO_3/L), selenium (IV) (90 percent removal for influent waters with 0.1 mg Se(IV)/L), and selenium (VI) (97 percent removal for influent waters with 0.33 mg Se (VI)/L). However, it is important to note that sulfate is preferentially removed over arsenate and selenium (IV) by AX. Preference for selenium (VI) is approximately equal to that of sulfate. Therefore, use of AX to remove selenium (VI) may be possible even in the presence of low concentrations of sulfate.

Construction costs for POU AX units are presented in Table 2.12.1.3.1 for under-sink installations and for installations at the property line. The cost of the unit is based on using a fiberglass housing and a replaceable resin cartridge. The housing is 6¼ inches in diameter, 23 inches long, and has a resin capacity of 0.008 m^3. The quantity of water that can be treated depends on the contaminant being removed.

Table 2.12.1.3.1: Capital Cost Data for POU AX Devices (1983$)

Cost Category	Cost for Under Sink Installation	Cost for Installation at the Property Line
AX canister and resin	$270	$270
Water meter	$40	$40
Plastic meter box and 10-inch PVC pipe collar	–	$30
PVC piping to house	–	$20
Faucet, copper or plastic tubing, and fittings	$40	$40
Labor, Installation	$40	$120
Subtotal	*$390*	*$520*
Contingency	$60	$80
Total	**$450**	**$600**

O&M costs for POU AX treatment are limited to the cost of labor and materials since the AA units do not require electrical power for effective operation. The O&M costs are divided into three categories: sampling/testing, AX resin regeneration, and repairs. A summary of O&M costs for POU AX treatment is shown in Table 2.12.1.3.2. A range of costs is presented for each category to illustrate the sensitivity of O&M costs to various assumptions.

Table 2.12.1.3.2: Operation and Maintenance Cost Data for POU AX Devices (1983$)

Cost Category	Labor (hr/yr)	Annual Material Cost[1]	Total Annual Cost[2]	Average Total Annual Cost
Sampling/testing frequency				
2/yr	2	$40	$62	
4/yr	4	$80	$124	$124
6/yr	6	$120	$186	
Resin regeneration interval[3]				
1 yr	1	$60	$71	
2 yr	0.5	$30	$36	$36
3 yr	0.3	$20	$23	
Repairs				
Low	1	$10	$21	
Average	2	$20	$42	$42
High	3	$30	$63	
Total cost for mid-range condition				$202

1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.
3. This read as "Frequency" and "1/yr, 2/yr, 3/yr" in the original, but the cost and labor figures decreased as the frequency per year increased. Since this seemed illogical, the heading was changed to "Interval" for this report.

2.12.1.4 Cation Exchange

CX units effectively remove 98 percent of cadmium from influent waters with 0.5 mg Cd/L and 85 percent of silver from influent waters with 0.33 mg Ag/L. Barium, chromium (III), lead, and radium contamination may also be ameliorated by the use of CX technology.

Construction costs for POU CX systems are presented in Table 2.12.1.4.1 for under-sink installations and for installations at the property line. Costs include a CX canister and resin, a water meter, a special faucet, and all required tubing, fittings, and adapters. The canister is approximately 6 inches in diameter and 23 inches in length and contains an effective resin volume of 0.008 m^3. The quantity of water that can be treated prior to regeneration depends on the quality of the water being treated.

O&M costs for POU CX units are limited to labor and materials because CX devices do not require electrical power. The O&M costs are divided into three categories: sampling/testing, resin regeneration, and repairs. A summary of O&M costs is presented in Table 2.12.1.4.2. A range of costs is shown for each category to illustrate the sensitivity of O&M costs to various assumptions.

Table 2.12.1.4.1: Capital Cost Data for POU CX Devices (1983$)

Cost Category	Cost for Under Sink Installation	Cost for Installation at the Property Line
Cation Exchange Canister and Resin	$180	$180
Water meter	$40	$40
Plastic meter box and 10-inch PVC pipe collar	–	$30
PVC piping to house	–	$20
Faucet, copper or plastic tubing, and fittings	$40	$40
Labor, installation	$40	$120
Subtotal	*$300*	*$430*
Contingency	$45	$65
Total	**$345**	**$495**

Table 2.12.1.4.2: Operation and Maintenance Cost Data for POU CX Devices (1983$)

Cost Category	Labor (hr/yr)	Annual Material Cost[1]	Total Annual Cost[2]	Average Total Annual Cost
Sampling/testing frequency				
2/yr	2	$40	$62	
4/yr	4	$80	$124	$124
6/yr	6	$120	$186	
Resin regeneration interval[3]				
1 yr	1	$30	$41	
2 yr	0.5	$15	$21	$21
3 yr	0.3	$10	$13	
Repairs				
Low	1	$10	$21	
Average	2	$20	$42	$42
High	3	$30	$63	
Total cost for mid-range condition				**$187**

1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.
3. This read as "Frequency" and "1/yr, 2/yr, 3/yr" in the original, but the cost and labor figures decreased as the frequency per year increased. Since this seemed illogical, the heading was changed to "Interval" for this report.

2.12.1.5 Reverse Osmosis

Gumerman reported that RO systems removed:

- 80 percent of arsenite from influent waters with 0.25 mg As(III)/L;
- 90 percent of arsenate from influent waters with 0.5 mg As(V)/L;
- 97 percent of barium from influent waters with 33 mg Ba/L;
- 90 percent of cadmium from influent waters with 0.1 mg Cd/L;
- 90 percent of both chromium (III) and chromium (VI) from influent waters with 0.5 mg Cr(III or VI)/L;
- 85 percent of fluoride from influent waters with more than 9.3 mg F/L;
- 99 percent of lead from influent waters with more than 5 mg Pb/L and a pH between 8.8 and 11.0; 95 percent of inorganic mercury from influent waters with 0.04 mg Hg(inorganic)/L;
- 60 percent of organic mercury from influent waters with 0.005 mg Hg(organic)/L;
- 85 percent of nitrate from influent water levels of 66.7 mg NO_3/L;
- 97 percent of selenium (IV) and selenium (VI) from influent waters of 0.33 mg Se(IV or VI)/L; and
- 93 percent of silver from influent water levels of 0.71 mg Ag/L.

RO technology has also proven capable of removing radium, uranium, and some beta emitting radionuclides.

Construction costs for POU RO units installed under the kitchen sink are presented in Table 2.12.1.5.1. Costs included an RO membrane unit, a 5-μm pre-filter, a pressure reservoir, a small GAC post-filter, a dedicated faucet, a water meter, and all required tubing, fittings, and adapters. The RO membrane unit has the capacity to produce up to 5 gallons of water per day. The pressure reservoir has a 3.2 gallon storage capacity. In 1983, virtually all commercially available RO membranes were composed of cellulose acetate due to its resistance to chlorine. However, with the development of more reliable GAC pre-filters and better chlorine removal, the more efficient TFMs have become more popular. See Section 1.3.5 for additional discussion of CAMs and TFMs.

Table 2.12.1.5.1: Capital Cost Data for POU RO Devices (1983$)

Cost Category	Construction Cost
RO element	$330
Water meter	$40
Labor installation	$50
Subtotal	$420
Contingency	$65
Total	**$485**

O&M costs for POU RO units are limited to labor and materials because RO units do not require electrical power for operation. Costs are separated into four categories: sampling/testing, pre-filter and GAC contactor replacement, RO membrane replacement, and repairs. A range of O&M costs is shown in Table 2.12.1.5.2 to illustrate the sensitivity of O&M costs to various assumptions.

Table 2.12.1.5.2: Operation and Maintenance Cost Data for POU RO Devices (1983$)

Cost Category	Labor (hr/yr)	Annual Material Cost[1]	Total Annual Cost[2]	Average Total Annual Cost
Sampling/testing frequency				
2/yr	2	$40	$62	
4/yr	4	$80	$124	$124
6/yr	6	$120	$186	
Pre-filter and GAC contactor replacement frequency				
1/yr	1	$20	$31	
2/yr	2	$40	$62	$62
RO membrane replacement interval				
1 yr	1	$75	$86	
2 yr	0.5	$38	$44	$44
3 yr	0.3	$25	$28	
Repairs				
Low	1	$10	$21	
Average	2	$20	$42	$42
High	3	$30	$63	
Total Cost for Mid-range Condition				$272

1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.

2.12.2 Ebbert (1985)

Ebbert provided cost estimates for POU GAC and RO treatment units in a 1985 report. The typical capital and replacement costs of both types of units are presented in Table 2.12.2.1

Table 2.12.2.1: Cost Data for POU Devices from Ebbert (1985$)

POU Device	Initial Capital Cost	Replacement Costs
GAC	$30-$300	$4-$60
RO	$450-$850	$70-$140

The cost ranges in Table 2.12.2.1 represent units of different capacities. For example, flow-through GAC units that attach directly to the faucet are significantly less expensive, and contain significantly less carbon than under-sink GAC units plumbed directly into the cold water line. The price of POU RO units varies directly with membrane surface area. As the surface area of the membrane increases, so does the price of the unit.

2.12.3 Tiskillwa, New York

EPA conducted a POU demonstration project in Tiskillwa, New York designed to address the microbiological water quality problems facing the town's public water system. EPA intervention became necessary since no one, neither the town nor private companies, claimed ownership of the system. As a result, EPA could not identify a party to be held responsible.

EPA directed the town to organize a homeowner's association that would have the authority to negotiate a contract with a water service products company to install and maintain POU UV units. Each homeowner was required to sign an agreement providing the Tiskillwa Homeowner's Association (THA) with access to their home for monitoring and maintenance. The contractor hired by the THA was responsible for all monitoring and maintenance of the POU units. No additional information could be gathered for this case study, despite follow-up efforts with the involved parties.

2.13 POE Treatment Devices: Regulatory Impact Analysis (1987)

Section 5.6 of the 1987 Regulatory Impact Analysis (RIA) details the estimated costs of various alternatives to central treatment for water systems serving small communities of various populations (i.e., 25-100, 101-500, 501-1,000, and 1,001-3,300). Costs for the purchase, installation, and maintenance of POE RO and POE IX devices are presented in section 5.6.1 of the RIA. Several assumptions were made in order to arrive at these cost estimates. The water utility or community was assumed to be responsible for the selection and purchase of all POE devices, their installation, and all regularly scheduled maintenance. A single type of device was selected for all residences and buildings in the community to ensure that all customers would receive equal protection and maintenance.

The water system was assumed to purchase a number of treatment units equal to the median number of households in each size of community. The median number of households was determined by dividing the median service population by the number of people per household (assumed to be 2.5 for the RIA). A single unit was assumed to be installed at each household. POE units were not installed with pre-filters. However, filters could be installed for $50 per unit (in September 1987 dollars) to extend the service life of the POE units. Replacement cartridges for these units were priced at $5 each. The RIA recommended annual replacement of all pre-filters included in POE treatment units. The RIA did not assume any additional labor costs for filter replacement because the filter cartridges could be changed at the same time as the POE device cartridge (RO membrane or IX resin cartridge).

While bulk purchase of POE treatment units probably would have resulted in some reduction in unit costs, especially in the larger size categories (see section 1.5), this was not considered in the RIA. Neither administrative nor monitoring costs were included in the analysis' total cost calculation. Actual costs for small systems would likely be higher than those reported in this analysis, while those of the largest systems would likely be lower. The RIA cost estimates are summarized in Table 2.13.1

Table 2.13.1: Cost Data for POE Devices from 1987 RIA

Number of Households Served	Reverse Osmosis			Ion Exchange		
	Total Capital Cost ($)	Annual O&M Cost ($/yr)	Cost per Gallon Used ($/Kgal)	Total Capital Cost ($)	Annual O&M Cost ($/yr)	Cost per Gallon Used ($/Kgal)
25	$31,500	$5,800	$4.645	$30,000	$9,100	$6.165
120	$123,200	$22,700	$4.241	$117,300	$35,600	$5.631
300	$410,700	$75,600	$3.945	$390,900	$118,500	$5.238
860	$1,045,900	$192,500	$3.757	$995,500	$301,800	$4.988

2.14 POU and POE Treatment Devices: U.S. EPA (1988, 1989)

The information in this section was drawn from Lykins (1992). A 1988 EPA in-house study compared the costs of four types of POU and POE systems. Manufacturers were contacted for current costs, and the following analysis was produced using a pre-defined set of assumptions, including: $50 per year for O&M costs, a 15-percent contingency cost, a 5-percent outlay to cover any associated costs, and amortization at 12 percent over 8 years. Tables 2.14.1 and 2.14.2 outline the costs developed in this study.

Table 2.14.1: Cost Data for POU Devices from EPA In-House Study (1988$)

Treatment Technology	Capital Costs	Installation Costs	Amortized Start-up Costs[1]	Annual O&M Costs	Total Annual Cost
GAC	$275	$80	$86	$50	$136
RO	$650	$100	$184	$50	$234
IX	$200	$80	$68	$50	$118
Distillation	$500	$125	$151	$50	$201

1. Total amortized start-up costs include 15-percent and 5-percent surcharges to cover contingencies and associated costs. These costs are amortized at 12 percent over 8 years.

Table 2.14.2: Cost Data for POE Devices from EPA In-House Study (1988$)

Treatment Technology	Capital Costs	Installation Costs	Amortized Start-up Costs[1]	Annual O&M Costs	Total Annual Cost
GAC	$2,050	$115	$523	$50	$573
RO	$7,250	$300	$1,824	$50	$1,874
IX	$1,750	$175	$465	$50	$515
Distillation	$10,250	$250	$2,536	$50	$2,586

1. Total amortized start-up costs include 15 percent and 5 percent surcharges to cover contingency and associated costs. These costs are amortized at 12 percent over 8 years.

In 1989, EPA requested information from POU/POE manufacturers, suppliers, and regulators on: 1) the types of POU/POE devices used at that time; 2) the types of contaminants removed by these devices; 3) the effectiveness of these devices; and 4) the cost of these devices. A total of 164 responses were received from industry sources. The initial capital costs of the devices are listed in Table 2.14.1.

Table 2.14.1: POU and POE Capital costs from EPA database (1989$)

Technology	POU Devices		POE Devices	
	Cost Range[1]	Average Cost	Cost Range[1]	Average Cost
Aeration	NA	NA	$1,650.00	$1,650.00
Chlorine	NA	NA	$235.85-$246.95	$241.40
Distillation	$214.38-$1,749.00	$817.38	$640.43	$640.43
Filtration	$13.75-$899.00	$258.63	$48.75-$852.20	$359.22
GAC	$4.54-$822.25	$136.62	$539.00-$1,329.85	$939.71
Ion exchange	$195.00-$275.00	$235.00	$415.00-$1,250.00	$956.67
Neutralization	NA	NA	$335.00-$395.00	$368.33
RO	$39.95-$999.00	$353.10	$79.00-$6,340.00	$2,996.02
Softening	NA	NA	$425.00-$1,200.00	$731.67
UV	$254.00-$732.00	$550.67	$317.00-$637.00	$486.00

1. The cost range represents units of different capacity in addition to standard price variation within the industry.
2. Any of the above technologies in series (e.g., filtration/GAC/RO, etc.)

3.0 Model System Scenarios

Unit cost, unit ownership, concentration of contaminant(s), liability, monitoring, maintenance, administrative requirements, and the reliable and consistent maintenance of adequate public health protection must be thoroughly explored by a community, water district, or water utility before it opts to use POU or POE technology to comply with the SDWA. The case studies presented in section 2 detail the experiences of communities that have wrestled with these and other issues. However, most of the case studies and cost analyses reported in section 2 are based on projects that took place 5 to 15 years ago.

The POU and POE industry has matured over the past decade. Prices have stabilized, and the entry of major hardware and department stores into the POU and POE market has exerted downward pressure on prices. POU and POE technology also has advanced. Over the past few years, superior unit design and improved manufacturing techniques have improved the reliability and treatment capability of POU and POE devices. For example, as discussed in section 1.3.5, TFMs, once expensive and fragile, have become much less expensive and more resistant to temperature and pH variations. The efforts of the NSF and the WQA have greatly improved the awareness of consumers and vendors to variations in product capabilities and to their proper implementation. In response to greater consumer demand for safety, many manufacturers have chosen to test their products under the noncompulsory standards developed by the NSF (see section 1.5.1). These standards assure consumers that certified units have passed stringent testing and will perform as advertised. In summary, POU and POE technology has become a more attractive compliance option for small, financially-disadvantaged communities since most of the case studies took place.

Cost and performance data were gathered from four firms in June 1997 to review current costs of POU and POE treatment devices. Two of the firms are well-known national providers with franchised vendors, one is a local distributor of POU and POE devices, and one is a national hardware chain that sells water treatment equipment. These four different sources were contacted to capture the likely pricing variation that communities would encounter.

The vendors were provided the following information for each of nine model scenarios developed by EPA: the number of households vulnerable to contamination; the principal contaminant; and the desired effluent level for the contaminant (see Table 3.0.1). Each vendor was asked to estimate the cost of providing the appropriate POU or POE device to all households within each model community.

Table 3.0.1: Model System Scenarios

Scenario	Type of Water System	Service Population (number of people; number of required units)	Contaminant	Desired Effluent (mg/L)	Treatment Options
Scenarios One	Community Water System (CWS)	375; 150	Arsenic	0.05	RO
Scenario Two	CWS	375; 150	Arsenic	0.0.5	AA, AX
Scenario Three	Nontransient, Noncommunity Water System	80; 10	Copper	1.0	CX
Scenario Four	CWS	230; 92	Alachlor	0.02	GAC
Scenario Five	CWS	50; 16	Radon	300[1]	GAC
Scenario Six	CWS	250; 100	Radon	300[1]	DBA
Scenario Seven	CWS	250; 100	Radon	1,500[1]	GAC
Scenario Eight	CWS	150; 60	Trichloroethylene	0.05	GAC
Scenario Nine	CWS	100; 40	Nitrate	10.0	AX, RO

1. Desired effluent levels for radon are measured in pCi/L.

3.1 Arsenic Treatment

As presented in Table 3.0.1, Model Scenarios One and Two both considered a community attempting to reduce arsenic concentrations to less than 50.0 μg/L, the current MCL. Scenario One called for POU RO units, while Scenario Two sought to generate price quotes for either AX or AA units.

One vendor expressed concern over the use of POU technology to deal with arsenic because all taps would not be protected. Section 2.1 provides a brief overview of the health risks associated with drinking water contaminated by arsenic. It is incumbent upon water utilities to check local regulations because some communities do not permit the use of POU technology for arsenic treatment. None of the vendors sold POU AX or POU AA units specifically designed for arsenic removal. However, three vendors recommended the use of POU RO units to deal with arsenic contamination. The vendor-estimated costs of these units are presented in Table 3.1.1.

Table 3.1.1: Cost Data for POU RO Devices from Model Scenario One (1997$)

Unit Costs and Characteristics	Vendor One	Vendor Two	Vendor Four
Type of System	POU RO	POU RO	POU RO
Capital[1]	$799	$300-$600	$700
Installation	$125	$75-100	Included with Purchase
Replacement Membrane	$135	$135-$175	$155
Replacement Pre- and Post-Filter	Not Provided (NP)	$50	$75[3]
Rental	$30/month + membrane replacement	$15-$25/month + filter and membrane replacement	NP
Expected Unit Life	> 10 years	18-25 years[2]	NP
Expected Membrane Life	3-5 years	5 years	5 years
Expected Filter Life (gallons)	NP	500	NP
Yield (gpd)	15	14-15	NP
Notes	Triple membrane; Separate tap	Automatic shutoff after 500 gallons treated	GAC post-filter; 3-gallon storage tank; Separate tap

1. Includes all required membranes and filters.
2. Unit is guaranteed for 7 years.
3. Includes all labor required to replace filters and a water test.

Vendor Two proposed the use of a POE AA system to reduce arsenic concentrations in household water within the community. Vendor Three sells a two-cartridge countertop filtration system that includes an AA canister. The system consists of a combination polypropylene pre-filter and GAC module, followed by the AA canister equipped with an integral polypropylene filter. Although this POU unit was designed for lead removal, and while no claims were made as to its ability to treat arsenic contamination, it may be able to remove arsenic. The vendor-provided costs for Scenario Two are listed in Table 3.1.2.

Table 3.1.2: Cost Data for POE and POU AA Devices from Model Scenario Two (1997$)

Costs and Characteristics	Vendor Two Twin-tank System	Vendor Two Single-tank System	Vendor Three
Type of System	POE AA	POE AA	POU AA
Capital[1]	$1,800-$2,500	$1,200-$1,800	$65
Installation	NP	NP	Installed by Homeowner
Replacement Media	$166 per year[2]	$166 per year[2]	approximately $76
Replacement Filter	Not Applicable (NA)	NA	$38
Rental	NP	$35-$45 per month + salt, maintenance and AA	NP
Expected Unit Life	NP	NP	NP
Expected Resin Life	NP[3]	NP[3]	NP
Expected Filter Life	NA	NA	500 gallons
Notes	Twin tank	Single tank	None

1. Includes fully charged media and all required filters.
2. Replacement media costs include salt required for backwashing ($60 per year), and maintenance ($66 per year). A system test is conducted as part of annual maintenance.
3. Resin is guaranteed for 7 years.

3.2 Copper Treatment

Model Scenario Three challenged vendors to provide a POU system that would reduce copper concentrations in a NTNCWS. The model system supplies water to 10 kitchen and bathroom taps in different buildings. Approximately 80 people use the facility each day. Vendors were asked to ensure that the concentration of copper in the effluent not exceed 1.0 mg/L. This concentration is below the secondary MCL of 1.3 mg Cu/L.

Copper is an essential nutrient, but at high doses it has been shown to cause stomach and intestinal distress, liver and kidney damage, and anemia. Individuals suffering from Wilson's disease may be at a higher risk of adverse health effects due to copper.

Copper levels above 1.3 mg/L are rarely found in raw drinking water supplies or in distributed water. EPA estimates that only 66 water systems have copper in their source water at levels that exceed the secondary MCL. In some cases, a water system may add copper to control algal growth in drinking water. Smelting operations and municipal incineration may also produce copper. Water resources located near copper mines and smelters have been found to be contaminated with copper. The primary source of copper in drinking water is the corrosion of copper pipes used for interior plumbing of residences and other buildings by acidic source water.

Table 3.2.1: Cost Data for POE and POU Devices from Model Scenario Three (1997$)

Costs and Characteristics	Vendor One	Vendor Two	Vendor Two	Vendor One	Vendor Two	Vendor Four
Type of System	POE CX	POE CX	POE Sac. Filter	POU RO	POU RO	POU RO
Capital[1]	$1,200-$1,400	$1,600	$500-$1,200	$799	$300-$600	$700
Installation	$225	NP	NP	$125	$75-100	Included with Purchase
Replacement Media	$80-100[2]	NP	NA	NA	NA	NA
Replacement Membrane	NA	NA	NA	$135	$135-$175	$155
Replacement Filter	NA	NP	$86-$96 per year[3]	NP	$50	$75[5]
Rental	$32/month + salt	NP	NP	$30/month + membrane replacement	$15-$25/month + filter and membrane replacement	NP
Expected Unit Life	> 10 years	NP	NP	> 10 years	18-25 years[4]	NP
Expected Resin or Membrane Life	10-20 years	NP	NP	3-5 years	5 years	5 years
Expected Filter Life	NA	NP	NP	NP	500	NP
Notes	None	None	None	Triple membrane; Separate tap	Automatic shutoff after 500 gallons treated	GAC post-filter; 3-gallon storage tank; Separate tap

1. Includes fully charged media and all required membranes and filters.
2. This represents the cost of the salt required for backwashing.
3. Replacement filter costs include $66 for maintenance and $20-$30 for sacrificial mineral filters each year. A system test is conducted as part of annual maintenance.
4. Unit is guaranteed for 7 years.
5. Includes all labor required to replace filters and a water test.

Vendor Two recommended a POE sacrificial mineral filter to raise the pH of household water. If the source of copper is not the pipes of the residence, either an RO or a CX unit can lower copper concentrations. Vendors One and Two provided price information on POE CX units, while Vendors One, Two, and Four provided costs for POU RO units. The RO units were identical to those the particular vendor had recommended for arsenic removal (see section 3.1). Table 3.2.1 provides pricing information for Model Scenario Three.

3.3 Alachlor Treatment

Model Scenario Four required vendors to provide an estimate for POU GAC devices to reduce alachlor levels in a community water system to less than 2.0 μg/L, the current MCL. All four vendors were confident that GAC could treat an organic compound like alachlor. However, carbon pore size significantly affects the removal efficiency and overall performance of a GAC unit. Thus, while the units the vendors recommended should be adequate to lower alachlor concentrations, any unit selected by a community should be subjected to a pilot study using water from the community supply before being placed in households. This will permit determination of the break-through point of the GAC filter and allow system administrators to adopt a replacement regime that provides an adequate margin of safety for their customers.

Alachlor is a herbicide used for pre-emergent control of annual grasses and broadleaf weeds in crops. It is the second most widely used herbicide in the United States, with particularly heavy use on corn and soybeans in Illinois, Indiana, Iowa, Minnesota, Nebraska, Ohio, and Wisconsin. Alachlor was detected in rural domestic wells by EPA's National Survey of Pesticides in Drinking Water Wells. EPA's Pesticides in Ground Water Database reports detections of alachlor in ground water at concentrations above the MCL in at least 15 States.

EPA has found that acute exposure to alachlor may lead to skin and eye irritation. Long - term exposure to high levels of alachlor may result in damage to the liver, kidney, spleen, nasal mucosa, and eyes. Animal studies confirm these findings (IRIS 1993b). In addition, there is some evidence that alachlor may have the potential to cause cancer from a lifetime exposure at levels above the MCL.

Three vendors offered price information on their standard POU under-sink GAC units. Vendor Four does not carry a POU GAC device and recommended the use of a POU RO unit to treat for alachlor. The pricing information provided by the vendors is presented in Table 3.3.1.

Table 3.3.1: Cost Data for POU GAC and POU RO Devices from Model Scenario Four (1997$)

Costs and Characteristics	Vendor One	Vendor One	Vendor Two	Vendor Three	Vendor Four
Type of System	POU GAC	POU GAC	POU GAC	POU GAC	POU RO
Capital[1]	$250	$150	$150-$200	$100	$700
Installation	Included with Purchase	Homeowner Installation	Included with Purchase	Homeowner Installation	Included with Purchase
Replacement Media	NA	NA	NA	NA	NA
Replacement Membrane	NA	NA	NA	NA	$155
Replacement Filter	$49	$45	$10-$25	$17	$75[2]
Rental	NP	NP	NP	NP	NP
Expected Unit Life	> 10 years	NP	> 10 years	NP	NP
Expected Membrane Life	NA	NA	NA	NA	5 years
Expected Filter Life	1,000 gallons	1,500 gallons	Variable	1,000 gallons	NP
Daily Yield	15 gallons	1 gpm	Unlimited	1 gpm	NP
Notes	None	Single GAC cartridge	Backwashable filter	Dual GAC cartridges	GAC post-filter; 3-gallon storage tank; Separate tap

1. Includes all required membranes and filters.
2. Includes all labor required to replace filters and a water test.

3.4 Radon Treatment

Model Scenario Five asked vendors to supply pricing information for providing 16 POE GAC units to reduce radon in household water below 300 pCi/L. Model Scenario Six asked vendors to supply pricing information for a community water system serving 100 households. Vendors were asked to provide unit prices for at least 100 units capable of treating radon to less than 1,500 pCi/L for Model Scenario Seven.

While none of the vendors had extensive experience with radon removal, three had a preferred system for removing radon. None had design specifications sensitive to effluent concentrations, and none recommended different equipment or provided a different unit price for any of the three scenarios.

Vendors One and Two provided price information for POE GAC units. Vendor One specified a unit designed to be submerged in 6 inches of water to shield the household from alpha and beta radiation. Vendor Two provided information for a back-washable POE GAC filter system. Vendor Two also provided cost information for an aeration tank that could be installed in conjunction with the GAC unit. Adding an aeration tank in a POE system would remove more radon, but might not be necessary to reduce radon levels to 1,500 pCi/L. Vendor Four recommended the use of an open, direct-vented aeration system followed by a GAC element to reduce radon contamination. A UV element (or another form of disinfection) would be appropriate for these systems due to the potential for bacteriological colonization of the GAC media (see section 1.4). However, the quoted prices for the recommended units did not include post-treatment disinfection. The pricing data provided by the vendors for the specified systems are presented in Table 3.4.1.

Table 3.4.1: Cost Data for POE GAC Devices from Model Scenarios Five, Six, and Seven (1997$)

Costs and Characteristics	Vendor 1	Vendor 2	Vendor 2	Vendor 4
Type of System	POE GAC	POE GAC	POE GAC with Aeration	POE GAC with Aeration
Capital[1]	$2,000	$800-$2,500	$1200-$2,900	$2,000
Installation	$225	Included with Purchase	Included with Purchase	Included with Purchase
Replacement Media	$300 per year	NP	NP	$150 per year[2]
Replacement Filter	NP	$20-$30 per year	$20-$30 per year	NP
Rental	NP	NP	NP	NP
Expected Unit Life	NP	> 10 years	> 10 years	NP
Expected Filter Life	NP	Variable	Variable	NP
Daily Yield	NP	Unlimited	Unlimited	NP
Notes	Water shielding	Back-washable filter	Aeration tank; Back-washable filter	Direct vented aeration

1. Includes fully charged carbon bed and all required filters.
2. Includes all necessary labor.

3.5 Trichloroethylene Treatment

Model Scenario Eight asked vendors to provide unit pricing information for 60 units designed to reduce TCE concentrations below the current MCL of 5.0 μg/L. Section 2.9 provides a brief overview of the health risks associated with exposure to water contaminated by TCE.

TCE is a VOC and may gasify at relatively low temperatures. Because TCE may be absorbed through the skin, a POE system would be required to treat for TCE contamination (see section 1.2.2).

Vendor Two recommended the same back-washable POE GAC unit for Scenario Eight as recommended for radon removal in Scenarios Five, Six, and Seven. Neither Vendor Three nor Vendor Four provided pricing information for Scenario Eight. However, the unit recommended for radon removal by Vendor Four would most likely remove TCE as well. The aeration elements incorporated in the systems for radon removal offered by Vendor Two and Vendor Four would be appropriate (and potentially necessary) to remediate high influent concentrations of TCE. Due to the potential for bacteriological colonization of the GAC media, UV radiation or another form of disinfection would be appropriate. However, none of the recommended units came equipped with post-treatment disinfection. The pricing information for Model Scenario Eight is identical to that presented above in Table 3.4.1 for Scenarios Five, Six, and Seven.

3.6 Nitrate Treatment

Model Scenario Nine asked vendors to recommend and provide pricing information for treatment systems designed to reduce nitrate concentrations in household water for a community of about 100 people or about 40 households. Vendors were asked to base their estimates on the maintenance of an effluent nitrate concentration of no more than 10 mg/L, the current MCL.

Section 2.6 provides a brief overview of the health risks associated with drinking nitrate-contaminated water. While relatively innocuous to the majority of the population even in relatively high concentrations, nitrate may cause severe acute health effects in children under 6 months. To prevent inadvertent poisoning, a water utility that opted for a POU treatment strategy for nitrate would need to undertake an educational effort targeted at expectant mothers and the mothers of young children. The program would emphasize that only water from the treated tap should be used for drinking or cooking. The successful implementation of such a program may be beyond the managerial capacity of many small water systems. Therefore, a POE treatment strategy would probably provide more complete protection of the public health than a POU treatment strategy (even one that included an educational campaign).

Table 3.6.1: Cost Data for POU and POE Devices from Model Scenario Nine (1997$)

Unit Costs and Characteristics	Vendor 1	Vendor 2	Vendor 2	Vendor 2	Vendor 4	Vendor 4
Type of System	POU RO	POU RO	POE AA	POE AA	POE AX	POE RO
Capital[1]	$799	$300-$600	$1,800-$2,500	$1,200-$1,800	$1,500	$10,000-$15,000
Installation	$125	$75-100	NP	NP	Included with Purchase	Included with Purchase
Replacement Media	NA	NA	$166 per year[2]	$166 per year[2]	$80-100 per year[3]	NA
Replacement Membrane	$135	$135-$175	NA	NA	NA	$500 per year
Replacement Pre- and Post-Filter	Not Provided (NP)	$50	NA	NA	NP	$250 per year
Rental	$30/month + membrane replacement	$15-$25/month + filter and membrane replacement	NP	$35-$45 per month + salt, maintenance and AA	NP	NP
Expected Unit Life	> 10 years	18-25 years[2]	NP	NP	NP	NP
Expected Media Life	NA	NA	NP[3]	NP[3]	NP	NA
Expected Membrane Life	3-5 years	5 years	NA	NA	NA	NP
Expected Filter Life	NP	500 gallons	NA	NA	NP	NP
Yield (gpd)	15 gallons	14-15 gallons	NP	NP	NP	250 gpd (By custom design)
Notes	Triple membrane; Separate tap	Automatic shutoff after 500 gallons treated	Twin tank	Single tank	None	None

1. Includes fully charged media and all required membranes and filters.
2. Replacement media costs include salt required for backwashing ($60 per year) and maintenance ($66 per year). A system test is conducted as part of annual maintenance.
3. This represents the cost of the salt required for backwashing and resin recharge.

Vendor One claimed that its POU RO unit would remove 91 percent to 96 percent of nitrate. The POU units detailed by Vendors One and Two for Scenario Nine were identical to the units they recommended for arsenic removal in Scenarios One and Two. The vendors provided the same unit prices for all three scenarios.

Vendor Two also provided pricing information for two POE AA systems that would remove nitrate. The AX unit sold by Vendor Four and recommended for nitrate removal is identical to Vendor Four's water softening units, except that an AX resin is substituted for a CX resin. Vendor Four provided an approximate cost for a POE RO system, based on a single installation. The vendor indicated that these applications were extremely rare because they are very expensive and because in many localities the water treated by an RO unit cannot, by law, be run through copper pipe due to its corrosivity without post-treatment pH adjustment. Vendor Four installed polybutyl pipes to every point in the home within which it installed the POE RO unit. Post-treatment pH adjustment is probably a more cost-efficient way to neutralize the corrosivity of water treated by POE RO devices. Pricing information for Model Scenario Nine is presented in Table 3.6.1.

3.7 Conclusions

To examine the costs of POU and POE units, we contacted three local and franchise vendors of water treatment equipment and requested system prices based on model cases. The price requests were not bids and vendors were not asked to custom design units based on characteristics presented in the model case. Equipment from a fourth vendor, a national hardware chain, was priced to determine the prices a system would pay if it chose to have system personnel install equipment.

The prices obtained from the vendors provide a first-order estimate of the capital and O&M costs associated with each of the major POU and POE technology types, including CX, AX, AA, RO, aeration, and activated carbon. In general, costs were roughly consistent between vendors in those cases in which the vendor-recommended equipment was similar. When vendor-recommended approaches differed (e.g., CX versus pH adjustment for copper control), greater pricing variation resulted.

Requesting general pricing from local and franchise vendors has limitations. The pricing supplied by the vendors is most likely relevant only for small purchases of 10 units or less. The pricing information received from vendors was further limited because we did not provide the vendor with detailed information regarding source water characteristics, nor did we request a custom design based on source water characteristics. Because of this, the pricing information received was general. To refine our costs and to better reflect purchases of larger numbers of units, an approach (described in section 4) was developed that incorporated hypothetical influent concentrations, examined the effect of competing contaminants, developed conceptual unit designs (including filter sizes and media capacities), and used known wholesale costs to develop large-order pricing schedules.

4.0 Cost Analysis

Four steps were involved in developing cost equations to estimate the cost of implementing POU and POE treatment in small communities. Figure 2.1 outlines the process by which the cost estimates were developed for the use of AA, GAC, aeration, IX, and RO devices to reduce concentrations of specified contaminants to the levels set by the NPDWRs and the National Secondary Drinking Water Regulations (NSDWRs).

First, a literature search was conducted on the capabilities of POU and POE devices and the experience of communities that had installed such treatment. Summaries of the field and laboratory studies identified through the literature search are presented in section 2. The literature search revealed that important changes had taken place since the case studies were published in the 1980s and early 1990s. The POE and POU industry had matured, and manufacturing techniques and system designs had improved. Therefore, adjusting the costs presented in the case studies to account for inflation would not accurately estimate the costs small communities would likely face for the purchase, installation, and maintenance of POE and POU devices today.

To supplement the data drawn from the case studies, vendors were contacted to obtain current pricing information for POE and POU treatment units. The results of the vendor survey are reported in section 3. As discussed in section 3.7, requesting general pricing from local or franchise vendors has limitations. The costs provided by the vendors are most likely relevant only for the purchase of 10 units or less. The pricing information from vendors was further limited because we did not request a custom designed system based on specific source water characteristics.

The third step of the cost development process was to develop cost equations for the implementation of the five technologies considered in this report. This step had three goals. The first was to determine a realistic discounting schedule for volume purchases. The second was to ensure that appropriate technology, at the appropriate point of application, was used to address the various contaminants. The third goal was to combine capital costs with the cost of O&M required of water systems that elect to implement a POE or POU strategy to achieve compliance with the SDWA.

Nationally applicable wholesale pricing information was obtained for POU and POE units to develop a realistic schedule for volume discounts. The technical expertise of original equipment manufacturers (OEMs) was also tapped in step three of the cost development process. To further investigate pricing and discounting of POU and POE systems, components for each of the systems were conceptually designed; parts were specified and suggested retail and wholesale prices were noted. OEMs of GAC and AA media were able to detail the removal capabilities of their products. This information enabled the design of treatment units engineered to remove a specified contaminant with a precise degree of efficiency. The total cost of implementing a

POE or POU treatment strategy may be disaggregated into capital and O&M costs. Design parameters, treatment claims, and pricing schedules used by numerous firms were researched. To ensure a reasonable and current estimate for the cost of implementing a POU or POE treatment strategy in a small community, several assumptions were developed within each of these cost categories. These assumptions were based on vendor experience, case study information, information from OEMs, and contractor expertise. Each assumption used in estimating the total annual cost of each POU or POE treatment strategy is presented, along with its underlying rationale, in the following sections.

In the fourth and final step of the development process the case studies and the data gathered from the vendor survey were compared to the cost equations presented in section 4. When the case study or vendor costs were substantially different than the Cadmus costs, the Cadmus costs and associated assumptions were revisited to ensure accuracy. In all cases of substantial disagreement a logical explanation for the deviation was found. In general, Cadmus' cost estimates were in good agreement with the updated costs from the case studies and the vendor reported data (see Figures in section 4.4).

4.1 General Assumptions

This analysis was designed to include costs incurred by a water system over a 10-year period. This time frame was selected to take into account the long planning horizons frequently adopted by water utilities.

It was assumed that an average household size of three individuals based on the current average household size in the United States, and that each individual would consume an average of 1 gallon of water per day for drinking and cooking, or a yearly household water requirement of 1,095 gallons. Each individual was assumed to use 100 gallons of water each day for all purposes (e.g., drinking, washing, etc.). This assumption is consistent with the findings of the 1997 Community Water System Survey. Therefore, the total annual water requirement of each household was determined to be 109,500 gallons.

According to the above assumptions, a POU device would need to treat 1,095 gallons of water each year to meet the drinking and cooking needs of a household. In contrast, since POE devices treat all water that enters a household, they were assumed to treat 109,500 gallons of water per year. For the purposes of this cost analysis, central treatment facilities were assumed to treat the same quantity of water (i.e., 109,500 gallons) for each household served by the water system.

It was assumed that a water authority would have staff members that could perform simple tasks such as sample collection and filter cartridge replacement. If a water authority had expertise in POU and POE systems, projected costs could be reduced substantially depending on the cost of that in-house expertise. An authority willing to assume the burden of installation and the risk of liability could reduce costs further.

The standard work week consists of 40 hours. Therefore, the average workday was assumed to consist of 8 hours for this cost analysis. The fully loaded wage rate for minimally skilled individuals employed by the water utility was set at $14.50 per hour. The fully loaded wage for skilled laborers was set at $28.00 per hour. These rates were used for systems serving fewer than 3,300 individuals, and systems serving 3,300 or more individuals, respectively, in the Information Collection Request (ICR) for the Public Water System Supervision Program submitted to EPA in July 1997. This ICR has been submitted to the Office of Management and Budget (OMB) and is still under their review. It was concluded that minimally skilled laborers could effectively perform administrative duties, install POU units, sample for contaminants, and replace filters, membranes, and other basic parts on POU units because these are all relatively simple tasks. The installation and maintenance of POE treatment units was assumed to require the use of skilled laborers due to the sophistication of these devices.

It was assumed that a central distribution system was in place in all communities for the purposes of this cost analysis. In the absence of this assumption, the costs for the implementation of central treatment would be significantly greater.

4.2 Capital Costs

The purchase and installation of treatment devices are included in the total capital cost for POU and POE devices. To ensure the provision of adequately treated water, it was assumed that the water system would supply a POU or POE unit capable of addressing the contaminant of concern to each household in the service community (see sections 1.3, 2, 3).

Water treatment dealers frequently guaranteed their products for 10 years and often claim their useful life to be far longer. However, since POU devices are typically small, relatively inexpensive, pieces of equipment, the average effective life for a POU unit was assumed to be 5 years. Since POE units are generally larger, carry longer warranties, and are located in more protected areas (i.e., the basement rather than underneath the kitchen sink), these units were assumed to have an average effective life of 10 years. Therefore, given the 10-year time frame of this cost analysis (see section 4.1), the capital cost for a POU treatment strategy must include the purchase of two POU units per household, while the capital cost for POE treatment must include the purchase of only one treatment unit per household.

The cost of a water meter and automatic shut-off valve was included in the capital cost of all POU and POE devices to ensure that units would comply with the requirements of section 1412(b)(4)(E)(ii) SDWA. A local vendor (or by the local branch of a national vendor) was assumed to provide all necessary treatment equipment. Thus, no shipping and handling costs would be incurred by a community that opted to implement a POU or POE compliance strategy.

In step three of the cost development process, wholesale prices were reviewed. Based on these data and conversations with industry sources, a volume discount schedule was developed for the purchase of POU and POE units. Because the wholesale prices are available nationally, this method gives a good indication of the discounts a "typical" small community could expect to receive for large purchases. It was determined that a vendor would charge retail price for a single POU unit, would allow a 15-percent discount for 10 units, and retain a 30 percent profit margin for 100 or more POU units. Prices were interpolated between these data points. An identical discount was applied for the majority of POE units. However, vendors professed very limited knowledge of POE RO systems and reported installing very few of these systems. Therefore, a 10-percent discount was assumed for purchases of 10 units and a 15-percent discount was assumed for the purchase of 100 or more units. Again, prices were interpolated between these data points. Due to liability concerns associated with radon removal, aeration and GAC units used to treat for radon were discounted according to the following schedule: 10 percent for 10 units and 20 percent for 50 or more units.

POU installations were assumed to require 1 hour per unit and POE installations were assumed to require 3 hours per unit due to their greater size and complexity. As noted in section 4.1, the use of skilled labor was assumed for POE installations, while it was assumed that all POU devices would be installed with unskilled labor. All units would be tested for proper operation as part of the installation procedure. The time required to travel between households was assumed to be included in total installation time.

Daily preparation (preparation of all necessary parts and fittings, completion of appropriate paperwork, etc.) and travel to and from the community was assumed to require 2 hours. Therefore, an installer would actually spend only 6 hours of his or her day installing treatment devices assuming an 8 hour workday (see section 4.1). Given these assumptions, two POE units or six POU units may be installed per employée per day.

It was assumed that the installation process would become more efficient once installers became accustomed to the units and could pre-fabricate units to speed the installation procedure. Therefore, installation time was assumed to decrease by two-thirds if more than 10 units were installed in a community. Under this assumption (e.g., for a community of 25 households) would permit up to nine POU units or three POE units could be installed each day. No additional efficiency was assumed for larger installation projects.

To compare the capital costs of equipment with different effective service lifetimes, permit the comparison of capital costs for equipment with different effective service lifetimes, purchase, installation and any included contingency costs for POU and POE units were amortized over their expected effective lifetimes (five and 10 years, respectively) at 10-percent. In keeping with general practice used to calculate the costs for large construction projects, a 20-year amortization period was adopted to determine the annual cost of central treatment plants. The capital costs of central treatment systems were amortized at 10 percent. The 10 percent amortization rate was frequently mentioned in the literature (Gumerman 1984; Bellen 1985).

Cost data for the purchase and installation of POE and POU treatment devices are provided in Tables 4.2.1, 4.2.2, and 4.2.3. These exhibits present the derived capital costs along side pricing information from all appropriate case studies. All pricing information from the case studies that is presented in the exhibits was updated to 1997 dollars using the PPI. In addition, a 15-percent contingency fee was applied to initial capital and installation costs to cover unexpected costs that arise due to the unique characteristics of each site.

4.3 Operation and Maintenance Costs

O&M costs may be divided into three types: maintenance, sampling and lab analysis, and administrative. Maintenance costs vary greatly depending upon community size, the contaminant of concern, treatment technology, and where the treatment technology is applied. Sampling and lab costs depend only upon the size of the community and the contaminant of concern. Administrative costs vary according to community size. These costs are discussed in the following three sections. O&M cost data for the implementation of POE and POU strategies are presented in Tables 4.3.1, 4.3.2, and 4.3.3.

4.3.1 Maintenance Costs

Without periodic servicing, POU and POE units cannot be depended upon to provide adequate protection of public health. Not only is periodic maintenance necessary for the treatment strategy to reduce the level of a particular contaminant, appropriate maintenance of all household treatment units is the legal responsibility of a water system that installs them as apart of a compliance strategy (see sections 1 and 1.5.3).

All maintenance was assumed to be performed by trained water system personnel because the POU or POE units must be "owned, controlled, and maintained by the public water system or by a person under contract with the public water system." POU maintenance (e.g., tightening joints, replacing filters, etc.) was assumed to require 45 minutes per unit while POE maintenance was assumed to require 2 hours per unit. All units would be tested for proper operation and all water meters would be calibrated as part of the maintenance procedure. The time required to travel between households within the community was also assumed to be included in total installation time for this cost analysis.

Table 4.2.1: Capital Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)
AA	POU	Fairbanks, AK, Eugene, OR 1983	Arsenic	4	$250	$19	NA	$362	$95
AA	POU	Gumerman (US): 1983	Arsenic	1	$280	$40	$50	$507	$134
AA	POU	Gumerman (PL) 1983	Arsenic	1	$330	$120	$70	$712	$188
AA	POU	Thunderbird Farms, AZ: 1985	Fluoride/Arsenic	8	$338	$19	NA	$357	$94
AA	POU	Papago Butte, AZ 1985	Fluoride/Arsenic	1	$501	$19	NA	$520	$137
AA	POU	Ruth Fisher Elementary School, AZ 1985	Fluoride/Arsenic	1	$514	$19	NA	$533	$141
AA	POU	You and I TP, AZ 1985	Fluoride/Arsenic	1	$345	$19	NA	$364	$96
AA	POU	Parkersburg, IL: 1985	Fluoride/Arsenic	10	$401	$13	NA	$414	$109
AA	POU	Bureau Junction, IL 1985	Fluoride/Arsenic	40	$416	$13	NA	$429	$113
AC	Central	Goodrich: 1990	DBCP	10	NP	NP	NP	NP	NP
AC	Central	Goodrich 1990	DBCP	25	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1990	DBCP	50	NP	NP	NP	NP	NP
AC	Central	Goodrich 1992	DBCP	10	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DBCP	15	NP	NP	NP	NP	NP
AC	Central	Goodrich. 1992	DBCP	20	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DBCP	25	NP	NP	NP	NP	NP
AC	Central	Goodrich 1992	DBCP	50	NP	NP	NP	NP	NP
AC	POE	Goodrich: 1990	DBCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1990	DBCP	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1990	DBCP	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	DBCP	10	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1992	DBCP	15	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	DBCP	20	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1992	DBCP	25	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	DBCP	50	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Fresno, CA: 1990	DBCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	Central	Goodrich 1990	DCP	10	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1990	DCP	25	NP	NP	NP	NP	NP
AC	Central	Goodrich 1990	DCP	50	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DCP	10	NP	NP	NP	NP	NP
AC	Central	Goodrich 1992	DCP	15	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DCP	20	NP	NP	NP	NP	NP
AC	Central	Goodrich 1992	DCP	25	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DCP	50	NP	NP	NP	NP	NP
AC	POE	Goodrich 1990	DCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1990	DCP	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1990	DCP	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1992	DCP	10	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	DCP	15	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	DCP	20	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	DCP	25	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1992	DCP	50	$2,188	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Florida (Type I) 1987	EDB	1	$1,000	IWP	NA	$1,252	$204
AC	POE	Florida (Type II): 1987	EDB	1	$1,050	IWP	NA	$1,316	$214
AC	POE	Various States (GAC 10) 1989	Radon	1	$828	$116	NA	$944	$154
AC	POE	Various States (GAC 17) 1989	Radon	1	$1,077	$116	NA	$1,193	$194
AC	POE	Various States (GAC 30) 1989	Radon	1	$1,350	$116	NA	$1,466	$239

Table 4.2.1: Capital Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)
AC	POU	Gumerman (US) 1983	SOCs	1	$220	$40	$40	*$411*	*$108*
AC	POU	Gumerman (PL) 1983	SOCs	1	$270	$120	$80	*$616*	*$163*
AC	POU	Ebbert (var cap) 1985	SOCs	1	*$260*	*$19*	*$42*	*$321*	*$85*
AC	POU	EPA Database (var. cap): 1989	SOCs	1	*$204*	*$19*	*$33*	*$257*	*$68*
AC	POU	EPA Study. 1988	SOCs	1	*$378*	*$97*	$95	*$571*	*$151*
AC	Central	Lykins (TP w/pipe): 1992	TCE	150	NP	NP	NP	NP	NP
AC	Central	Lykins (SD w/pipe) 1992	TCE	150	NP	NP	NP	NP	NP
AC	Central	Lykins (w/o pipe): 1992	TCE	150	NP	NP	NP	NP	NP
AC	Central	Putnam County, NY (est.) 1987	TCE	110	TAC	TAC	TAC	TAC	TAC
AC	Central	Goodrich: 1990	TCE	10	NP	NP	NP	NP	NP
AC	Central	Goodrich 1990	TCE	25	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1990	TCE	50	NP	NP	NP	NP	NP
AC	Central	Goodrich. 1992	TCE	10	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1992	TCE	15	NP	NP	NP	NP	NP
AC	Central	Goodrich 1992	TCE	20	NP	NP	NP	NP	NP
AC	Central	Goodrich: 1992	TCE	25	NP	NP	NP	NP	NP
AC	Central	Goodrich 1992	TCE	50	NP	NP	NP	NP	NP
AC	POE	Lykins. 1992	TCE	150	*$2,188*	NP	*$328*	*$2,517*	*$410*
AC	POE	Putnam County, NY 1987	TCE	67	$823	$494	NA	*$1,650*	*$268*
AC	POE	Goodrich: 1990	TCE	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1990	TCE	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1990	TCE	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	TCE	10	*$2,188*	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1992	TCE	15	*$2,188*	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	TCE	20	*$2,188*	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich: 1992	TCE	25	*$2,188*	IWP	CpKGT	CpKGT	CpKGT
AC	POE	Goodrich 1992	TCE	50	*$2,188*	IWP	CpKGT	CpKGT	CpKGT
AC	POU	Rockaway Township, NJ: 1985	TCE	12	*$377*	IWP	NA	*$377*	*$100*
AC	POU	Silverdale, PA 1985	TCE	49	$289	IWP	NA	*$289*	*$76*
AC	POE	Riverhead/Southold, NY: 1985	VOCs/Radon	1	$2,050	$113	NA	*$2,817*	*$459*
AC	POE	EPA Database (var cap) 1989	VOCs/Radon	1	$940	*$112*	*$158*	*$1,360*	*$221*
AC	POE	EPA Study: 1988	VOCs/Radon	1	*$2,531*	*$123*	$531	*$3,185*	*$518*
AC/DBA	POE	Goodrich 1990	TCE	150	*$5,623*	NP	*$843*	*$6,466*	*$1,052*
AC/DBA	POE	Elkhart: 1989	TCE	1	*$4,685*	IWP	NA	*$4,685*	*$762*
Aeration	POE	EPA Database (var cap) 1989	VOCs/Radon	1	*$1,959*	*$112*	*$311*	*$2,381*	*$388*
AX	POU	Fairbanks, AK, Eugene, OR: 1983	Arsenic	4	$350	*$19*	NA	*$499*	*$132*
AX	POE	EPA Database (var cap) 1989	Arsenic/Nitrate	1	*$1,155*	*$112*	*$190*	*$1,457*	*$237*
AX	POE	EPA Study: 1988	Arsenic/Nitrate	1	*$2,167*	*$212*	*$476*	*$2,855*	*$465*
AX	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$350	$40	$60	*$616*	*$163*
AX	POU	Gumerman (PL): 1983	Arsenic/Nitrate	1	$400	$120	$80	*$822*	*$217*
AX	POU	EPA Database (var cap) 1989	Arsenic/Nitrate	1	*$318*	*$19*	*$51*	*$387*	*$102*
AX	POU	EPA Study: 1988	Arsenic/Nitrate	1	*$288*	*$97*	*$77*	*$461*	*$122*
AX	Central	Lykins (TP w/pipe). 1992	Nitrate	150	NP	NP	NP	NP	NP
AX	Central	Lykins (SD w/pipe): 1992	Nitrate	150	NP	NP	NP	NP	NP
AX	Central	Lykins (w/o pipe) 1992	Nitrate	150	NP	NP	NP	NP	NP
AX	POE	Lykins: 1992	Nitrate	150	*$2,188*	*$75*	*$339*	*$2,603*	*$424*
AX	POE	Riverhead/Southold, NY 1985	Nitrate	1	*$2,325*	$175	NA	*$2,553*	*$415*
AX	POU	Riverhead/Southold, NY. 1985	Nitrate	1	*$306*	$80	NA	*$410*	*$108*
AX	POU	Colorado and New Mexico 1983	Uranium	12	$125	*$13*	NA	*$184*	*$49*

Table 4.2.1: Capital Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)
CX	POE	RIA. 1987	Copper	25	TCC	TTC	TTC	*$1,316*	*$214*
CX	POE	RIA: 1987	Copper	120	TCC	TTC	TTC	*$889*	*$145*
CX	POE	RIA 1987	Copper	300	TCC	TTC	TTC	*$1,174*	*$191*
CX	POE	RIA: 1987	Copper	860	TCC	TTC	TTC	*$1,046*	*$170*
CX	POE	EPA Database (var cap) 1989	Copper	1	*$1,155*	*$112*	*$190*	*$1,457*	*$237*
CX	POE	EPA Study: 1988	Copper	1	*$2,167*	*$212*	*$476*	*$2,855*	*$465*
CX	POU	Gumerman (US) 1983	Copper	1	$260	$40	$45	*$472*	*$125*
CX	POU	Gumerman (PL): 1983	Copper	1	$310	$120	$65	*$678*	*$179*
CX	POU	EPA Database (var cap) 1989	Copper	1	*$318*	*$19*	*$51*	*$387*	*$102*
CX	POU	EPA Study: 1988	Copper	1	*$288*	*$97*	*$77*	*$461*	*$122*
CX	Central	Bellevue, WI 1989	Radium	1,282	TAC	TAC	TAC	TAC	*$118*
CX	POE	Bellevue, WI (w/o Outside Ctns): 1989	Radium	1,282	$358	$48	$61	*$538*	*$88*
CX	POE	Bellevue WI (w Outside Ctns) 1989	Radium	1,282	$1,107	$27	$170	*$1,512*	*$246*
Disinfection	Central	Gibson Canyon, CA: 1992	Bacteria	140	$11,000	IWP	NA	*$11,789*	*$1,385*
Disinfection	POE	Gibson Canyon, CA (Alternative One) 1992	Bacteria	140	$2,657	*$75*	NA	*$2,922*	*$476*
Disinfection	POE	Gibson Canyon, CA (Alternative Two): 1992	Bacteria	140	$3,529	*$75*	NA	*$3,856*	*$628*
Disinfection	POE	Ephraim, WI (Cl and UV) 1994	Bactena	425	*$2,910*	IWP	NA	*$2,910*	*$474*
Disinfection	POE	EPA Database (var. cap.): 1989	Bacteria	1	*$609*	*$112*	*$108*	*$829*	*$135*
Disinfection	POU	EPA Database (var cap) 1989	Bactena	1	*$684*	*$19*	*$106*	*$809*	*$213*
PTA	Central	Elkhart: 1987	TCE	21,867	$115	IWP	NA	*$145*	*$17*
RO	Central	San Ysidro, NM (Univ Houston est.): 1986	Arsenic	1	TAC	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM (Contract O&M): 1986	Arsenic	78	$290	$36	NA	*$415*	*$110*
RO	POU	San Ysidro, NM (Village O&M): 1986	Arsenic	78	$290	$36	NA	*$415*	*$110*
RO	POU	San Ysidro, NM (Capital Costs): 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM (Alternative One w/Capital) 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM (Alternative [illegible] w/o Capital): 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM 1986	Arsenic	1	$665	IWP	NA	*$849*	*$224*
RO	POU	Fairbanks, AK; Eugene, OR: 1983	Arsenic	4	$292	*$19*	NA	*$419*	*$111*
RO	Central	Emington, IL (est.): 1985	Arsenic/Fluoride	47	$2,553	IWP	NA	*$3,326*	*$391*
RO	Central (Ctn)	King's Point, Suffolk, VA (est.): 1986	Arsenic/Fluoride	57	$14,263	IWP	NA	*$14,624*	*$1,718*
RO	POU	King's Point, Suffolk, VA. 1995	Arsenic/Fluoride	1	*$1,065*	*$19*	NA	*$1,085*	*$286*
RO	POU	Emington, IL: 1985	Arsenic/Fluoride	47	*$660*	$68	NA	*$749*	*$197*
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	25	TAC	TAC	TAC	*$1,461*	*$238*
RO	POE	RIA (RO): 1987	Arsenic/Nitrate	120	TAC	TAC	TAC	*$1,131*	*$184*
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	300	TAC	TAC	TAC	*$1,496*	*$243*
RO	POE	RIA (RO): 1987	Arsenic/Nitrate	860	TAC	TAC	TAC	*$1,333*	*$217*
RO	POE	EPA Database (var cap) 1989	Arsenic/Nitrate	1	*$3,520*	*$112*	*$545*	*$4,177*	*$680*
RO	POE	EPA Study: 1988	Arsenic/Nitrate	1	*$8,836*	*$364*	*$1,840*	*$11,040*	*$1,797*
RO	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$370	$50	$65	*$664*	*$175*
RO	POU	Ebbert (var. cap.): 1985	Arsenic/Nitrate	1	*$892*	*$19*	*$137*	*$1,435*	*$379*
RO	POU	EPA Database (var cap) 1989	Arsenic/Nitrate	1	*$454*	*$19*	*$71*	*$545*	*$144*
RO	POU	EPA Study: 1988	Arsenic/Nitrate	1	*$833*	*$121*	*$191*	*$1,145*	*$302*
RO	POE	Riverhead/Southhold, NY 1985	Nitrate	1	*$9,491*	$300	NA	*$9,881*	*$1,608*
RO	POU	Riverhead/Southhold, NY: 1985	Nitrate	1	*$892*	$110	NA	*$1,035*	*$273*

Table 4.2.2: Capital Cost Data -- Vendor Survey

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)
AA	POE	Vendor Two (Single tank)	Arsenic	150	$1,545	*$112*	*$249*	*$1,906*	*$310*
AA	POE	Vendor Two (Dual tank)	Arsenic	150	$2,195	*$112*	*$346*	*$2,653*	*$432*
AA	POU	Vendor Three	Arsenic	150	$110	*$19*	*$19*	*$149*	*$39*
AA	POE	Vendor Two (Single tank)	Nitrate	40	$1,545	*$112*	*$249*	*$1,906*	*$310*
AA	POE	Vendor Two (Dual tank)	Nitrate	40	$2,195	*$112*	*$346*	*$2,653*	*$432*
AC	POU	Vendor One	Alachlor	92	$295	IWP	*$44*	*$339*	*$89*
AC	POU	Vendor One	Alachlor	92	$195	*$19*	*$32*	*$246*	*$65*
AC	POU	Vendor Two	Alachlor	92	$220	IWP	*$33*	*$253*	*$67*
AC	POU	Vendor Three	Alachlor	92	$145	*$19*	*$25*	*$189*	*$50*
AC	POE	Vendor One	Radon (1,500)	100	$2,045	$225	*$341*	*$2,611*	*$425*
AC	POE	Vendor Two	Radon (1,500)	100	$1,695	IWP	*$254*	*$1,949*	*$317*
AC	POE	Vendor One	Radon (300)	16	$2,045	$225	*$341*	*$2,611*	*$425*
AC	POE	Vendor Two	Radon (300)	16	$1,695	IWP	*$254*	*$1,949*	*$317*
AC	POE	Vendor One	Radon (300)	100	$2,045	$225	*$341*	*$2,611*	*$425*
AC	POE	Vendor Two	Radon (300)	100	$1,695	IWP	*$254*	*$1,949*	*$317*
AC	POE	Vendor One	TCE	60	$2,045	$225	*$341*	*$2,611*	*$425*
AC	POE	Vendor Two	TCE	60	$1,695	IWP	*$254*	*$1,949*	*$317*
AC/DBA	POE	Vendor Two	Radon (1,500)	100	$2,095	IWP	*$314*	*$2,409*	*$392*
AC/DBA	POE	Vendor Four	Radon (1,500)	100	$2,045	IWP	*$307*	*$2,352*	*$383*
AC/DBA	POE	Vendor Two	Radon (300)	16	$2,095	IWP	*$314*	*$2,409*	*$392*
AC/DBA	POE	Vendor Four	Radon (300)	16	$2,045	IWP	*$307*	*$2,352*	*$383*
AC/DBA	POE	Vendor Two	Radon (300)	100	$2,095	IWP	*$314*	*$2,409*	*$392*
AC/DBA	POE	Vendor Four	Radon (300)	100	$2,045	IWP	*$307*	*$2,352*	*$383*
AC/DBA	POE	Vendor Two	TCE	60	$2,095	IWP	*$314*	*$2,409*	*$392*
AC/DBA	POE	Vendor Four	TCE	60	$2,045	IWP	*$307*	*$2,352*	*$383*
AX	POE	Vendor Four	Nitrate	40	$1,545	IWP	*$232*	*$1,777*	*$289*
CX	POE	Vendor One	Copper	10	$1,345	$225	*$236*	*$1,806*	*$294*
CX	POE	Vendor Two	Copper	10	$1,645	*$112*	*$264*	*$2,021*	*$329*
pH	POE	Vendor Two	Copper	10	$895	*$112*	*$151*	*$1,158*	*$188*
RO	POU	Vendor Four	Alachlor	92	$745	IWP	*$112*	*$857*	*$226*
RO	POU	Vendor One	Arsenic	150	$844	$125	*$145*	*$1,114*	*$294*
RO	POU	Vendor Two	Arsenic	150	$495	$88	*$87*	*$670*	*$177*
RO	POU	Vendor Four	Arsenic	150	$745	IWP	*$112*	*$857*	*$226*
RO	POU	Vendor One	Copper	10	$844	$125	*$145*	*$1,114*	*$294*
RO	POU	Vendor Two	Copper	10	$495	$88	*$87*	*$670*	*$177*
RO	POU	Vendor Four	Copper	10	$745	IWP	*$112*	*$857*	*$226*
RO	POE	Vendor Four	Arsenic/Nitrate	40	$12,545	IWP	*$1,882*	*$14,427*	*$2,348*
RO	POU	Vendor One	Nitrate	40	$844	$125	*$145*	*$1,114*	*$294*
RO	POU	Vendor Two	Nitrate	40	$495	$88	*$87*	*$670*	*$177*

Table 4.2.3: Capital Cost Data -- Cadmus

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)
AA	POU	Cadmus	Arsenic	1	$239	$19	$39	$297	$78
AA	POU	Cadmus	Arsenic	10	$203	$13	$32	$248	$66
AA	POU	Cadmus	Arsenic	50	$185	$13	$30	$228	$60
AA	POU	Cadmus	Arsenic	100	$167	$13	$27	$207	$55
AC	POE	Cadmus	Alachlor	1	$2,554	$112	$400	$3,066	$499
AC	POE	Cadmus	Alachlor	10	$2,171	$75	$337	$2,582	$420
AC	POE	Cadmus	Alachlor	50	$1,979	$75	$308	$2,362	$384
AC	POE	Cadmus	Alachlor	100	$1,788	$75	$279	$2,142	$349
AC	POE	Cadmus	Radon (1500)	1	$1,682	$112	$269	$2,063	$336
AC	POE	Cadmus	Radon (1500)	10	$1,514	$75	$238	$1,827	$297
AC	POE	Cadmus	Radon (1500)	50	$1,346	$75	$213	$1,633	$266
AC	POE	Cadmus	Radon (1500)	100	$1,346	$75	$213	$1,633	$266
AC	POE	Cadmus	Radon (300)	1	$4,110	$112	$633	$4,855	$790
AC	POE	Cadmus	Radon (300)	10	$3,699	$75	$566	$4,340	$706
AC	POE	Cadmus	Radon (300)	50	$3,288	$75	$504	$3,867	$629
AC	POE	Cadmus	Radon (300)	100	$3,288	$75	$504	$3,867	$629
AC	POE	Cadmus	TCE	1	$2,554	$112	$400	$3,066	$499
AC	POE	Cadmus	TCE	10	$2,171	$75	$337	$2,582	$420
AC	POE	Cadmus	TCE	50	$1,979	$75	$308	$2,362	$384
AC	POE	Cadmus	TCE	100	$1,788	$75	$279	$2,142	$349
AX	POE	Cadmus	Arsenic	1	$1,345	$112	$219	$1,676	$273
AX	POE	Cadmus	Arsenic	10	$1,143	$75	$183	$1,401	$228
AX	POE	Cadmus	Arsenic	50	$1,042	$75	$168	$1,285	$209
AX	POE	Cadmus	Arsenic	100	$942	$75	$152	$1,169	$190
AC	POU	Cadmus	Alachlor	1	$199	$19	$33	$251	$66
AC	POU	Cadmus	Alachlor	10	$169	$13	$27	$209	$55
AC	POU	Cadmus	Alachlor	50	$154	$13	$25	$192	$51
AC	POU	Cadmus	Alachlor	100	$139	$13	$23	$175	$46
AX	POU	Cadmus	Arsenic	1	$239	$19	$39	$297	$78
AX	POU	Cadmus	Arsenic	10	$203	$13	$32	$248	$66
AX	POU	Cadmus	Arsenic	50	$185	$13	$30	$228	$60
AX	POU	Cadmus	Arsenic	100	$167	$13	$27	$207	$55
AX	POE	Cadmus	Nitrate	1	$1,345	$112	$219	$1,676	$273
AX	POE	Cadmus	Nitrate	10	$1,143	$75	$183	$1,401	$228
AX	POE	Cadmus	Nitrate	50	$1,042	$75	$168	$1,285	$209
AX	POE	Cadmus	Nitrate	100	$942	$75	$152	$1,169	$190
AX	POU	Cadmus	Nitrate	1	$239	$19	$39	$297	$78
AX	POU	Cadmus	Nitrate	10	$203	$13	$32	$248	$66
AX	POU	Cadmus	Nitrate	50	$185	$13	$30	$228	$60
AX	POU	Cadmus	Nitrate	100	$167	$13	$27	$207	$55

Table 4.2.3: Capital Cost Data -- Cadmus

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)
CX	POE	Cadmus	Copper	1	$1,345	$112	$219	$1,676	$273
CX	POE	Cadmus	Copper	10	$1,143	$75	$183	$1,401	$228
CX	POE	Cadmus	Copper	50	$1,042	$75	$168	$1,285	$209
CX	POE	Cadmus	Copper	100	$942	$75	$152	$1,169	$190
CX	POU	Cadmus	Copper	1	$229	$19	$37	$286	$75
CX	POU	Cadmus	Copper	10	$195	$13	$31	$239	$63
CX	POU	Cadmus	Copper	50	$177	$13	$29	$219	$58
CX	POU	Cadmus	Copper	100	$160	$13	$26	$199	$53
DBA	POE	Cadmus	Radon (300)	1	$4,345	$112	$669	$5,126	$834
DBA	POE	Cadmus	Radon (300)	10	$3,911	$75	$598	$4,583	$746
DBA	POE	Cadmus	Radon (300)	50	$3,476	$75	$533	$4,083	$665
DBA	POE	Cadmus	Radon (300)	100	$3,476	$75	$533	$4,083	$665
RO	POE	Cadmus	Arsenic	1	$8,445	$448	$5,336	$14,229	$2,316
RO	POE	Cadmus	Arsenic	10	$7,601	$299	$4,740	$12,639	$2,057
RO	POE	Cadmus	Arsenic	50	$7,389	$299	$4,613	$12,301	$2,002
RO	POE	Cadmus	Arsenic	100	$7,178	$299	$4,486	$11,963	$1,947
RO	POU	Cadmus	Arsenic	1	$730	$19	$112	$862	$227
RO	POU	Cadmus	Arsenic	10	$621	$13	$95	$728	$192
RO	POU	Cadmus	Arsenic	50	$566	$13	$87	$665	$176
RO	POU	Cadmus	Arsenic	100	$511	$13	$79	$602	$159
RO	POE	Cadmus	Nitrate	1	$8,445	$448	$5,336	$14,229	$2,316
RO	POE	Cadmus	Nitrate	10	$7,601	$299	$4,740	$12,639	$2,057
RO	POE	Cadmus	Nitrate	50	$7,389	$299	$4,613	$12,301	$2,002
RO	POE	Cadmus	Nitrate	100	$7,178	$299	$4,486	$11,963	$1,947
RO	POU	Cadmus	Nitrate	1	$730	$19	$112	$862	$227
RO	POU	Cadmus	Nitrate	10	$621	$13	$95	$728	$192
RO	POU	Cadmus	Nitrate	50	$566	$13	$87	$665	$176
RO	POU	Cadmus	Nitrate	100	$511	$13	$79	$602	$159

Table 4.3.1: Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)
AA	POU	Fairbanks, AK, Eugene, OR 1983	Arsenic	4	$365	$32	$15	$411
AA	POU	Gumerman (US): 1983	Arsenic	1	$103	$106	$15	$294
AA	POU	Gumerman (PL) 1983	Arsenic	1	$103	$106	$15	$294
AA	POU	Thunderbird Farms, AZ 1985	Fluoride/Arsenic	8	$386	$32	$78	$495
AA	POU	Papago Butte, AZ 1985	Fluonde/Arsenic	1	$369	$32	$15	$415
AA	POU	Ruth Fisher Elementary School, AZ 1985	Fluoride/Arsenic	1	$483	$32	$15	$529
AA	POU	You and I TP, AZ 1985	Fluoride/Arsenic	1	$413	$32	$15	$459
AA	POU	Parkersburg, IL 1985	Fluoride/Arsenic	10	$353	$32	$15	$399
AA	POU	Bureau Junction, IL 1985	Fluoride/Arsenic	40	$321	$31	$15	$366
AC	Central	Goodrich: 1990	DBCP	10	NP	NP	NP	NP
AC	Central	Goodrich 1990	DBCP	25	NP	NP	NP	NP
AC	Central	Goodrich: 1990	DBCP	50	NP	NP	NP	NP
AC	Central	Goodrich 1992	DBCP	10	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DBCP	15	NP	NP	NP	NP
AC	Central	Goodrich 1992	DBCP	20	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DBCP	25	NP	NP	NP	NP
AC	Central	Goodrich 1992	DBCP	50	NP	NP	NP	NP
AC	POE	Goodrich: 1990	DBCP	10	$281	$215	$15	$511
AC	POE	Goodnch 1990	DBCP	25	$281	$205	$15	$501
AC	POE	Goodrich: 1990	DBCP	50	$258	$194	$15	$467
AC	POE	Goodnch: 1992	DBCP	10	$281	$215	$15	$511
AC	POE	Goodrich: 1992	DBCP	15	$281	$215	$15	$511
AC	POE	Goodnch 1992	DBCP	20	$281	$205	$15	$501
AC	POE	Goodrich: 1992	DBCP	25	$281	$205	$15	$501
AC	POE	Goodrich 1992	DBCP	50	$258	$194	$15	$467
AC	POE	Fresno, CA: 1990	DBCP	10	$281	$215	$15	$511
AC	Central	Goodrich 1990	DCP	10	NP	NP	NP	NP
AC	Central	Goodrich: 1990	DCP	25	NP	NP	NP	NP
AC	Central	Goodnch. 1990	DCP	50	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DCP	10	NP	NP	NP	NP
AC	Central	Goodnch 1992	DCP	15	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DCP	20	NP	NP	NP	NP
AC	Central	Goodnch 1992	DCP	25	NP	NP	NP	NP
AC	Central	Goodrich: 1992	DCP	50	NP	NP	NP	NP
AC	POE	Goodnch 1990	DCP	10	$281	$301	$15	$597
AC	POE	Goodrich: 1990	DCP	25	$281	$282	$15	$578
AC	POE	Goodnch 1990	DCP	50	$258	$263	$15	$536
AC	POE	Goodrich: 1992	DCP	10	$281	$301	$15	$597
AC	POE	Goodnch 1992	DCP	15	$281	$301	$15	$597
AC	POE	Goodrich: 1992	DCP	20	$281	$282	$15	$578
AC	POE	Goodrich 1992	DCP	25	$281	$282	$15	$578
AC	POE	Goodrich: 1992	DCP	50	$258	$263	$15	$536
AC	POE	Flonda (Type I) 1987	EDB	1	$890	$400	IWS	$1,616
AC	POE	Florida (Type II): 1987	EDB	1	$890	$400	IWS	$1,616
AC	POE	Vanous States (GAC 10) 1989	Radon	1	$283	$152	$15	$449
AC	POE	Various States (GAC 17) 1989	Radon	1	$283	$152	$15	$449
AC	POE	Vanous States (GAC 30) 1989	Radon	1	$283	$152	$15	$449

Table 4.3.1: Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)
AC	POU	Gumerman (US) 1983	SOCs	1	$52	$164	$15	$303
AC	POU	Gumerman (PL): 1983	SOCs	1	$52	$164	$15	$303
AC	POU	Ebbert (var cap): 1985	SOCs	1	$211	$121	$15	$347
AC	POU	EPA Database (var. cap): 1989	SOCs	1	$205	$121	$15	$340
AC	POU	EPA Study 1988	SOCs	1	$251	$121	$15	$386
AC	Central	Lykins (TP w/pipe) 1992	TCE	150	NP	NP	NP	NP
AC	Central	Lykins (SD w/pipe) 1992	TCE	150	NP	NP	NP	NP
AC	Central	Lykins (w/o pipe): 1992	TCE	150	NP	NP	NP	NP
AC	Central	Putnam County, NY (est.) 1987	TCE	110	TAC	TAC	TAC	TAC
AC	Central	Goodrich: 1990	TCE	10	NP	NP	NP	NP
AC	Central	Goodrich. 1990	TCE	25	NP	NP	NP	NP
AC	Central	Goodrich: 1990	TCE	50	NP	NP	NP	NP
AC	Central	Goodrich 1992	TCE	10	NP	NP	NP	NP
AC	Central	Goodrich: 1992	TCE	15	NP	NP	NP	NP
AC	Central	Goodrich 1992	TCE	20	NP	NP	NP	NP
AC	Central	Goodrich: 1992	TCE	25	NP	NP	NP	NP
AC	Central	Goodrich 1992	TCE	50	NP	NP	NP	NP
AC	POE	Lykins: 1992	TCE	150	$748	$263	$15	$1,026
AC	POE	Putnam County, NY 1987	TCE	67	$320	$263	$15	$678
AC	POE	Goodrich: 1990	TCE	10	$270	$301	$15	$585
AC	POE	Goodrich 1990	TCE	25	$270	$282	$15	$566
AC	POE	Goodrich: 1990	TCE	50	$253	$263	$15	$530
AC	POE	Goodrich 1992	TCE	10	$292	$301	$15	$608
AC	POE	Goodrich: 1992	TCE	15	$292	$301	$15	$608
AC	POE	Goodrich 1992	TCE	20	$292	$282	$15	$589
AC	POE	Goodrich: 1992	TCE	25	$292	$282	$15	$589
AC	POE	Goodrich 1992	TCE	50	$286	$263	$15	$564
AC	POU	Rockaway Township, NJ: 1985	TCE	12	$201	$196	$15	$411
AC	POU	Silverdale, PA 1985	TCE	49	$206	$179	$15	$399
AC	POE	Riverhead/Southhold, NY: 1985	VOCs/Radon	1	$264	$238	$15	$517
AC	POE	EPA Database (var cap) 1989	VOCs/Radon	1	$264	$238	$15	$517
AC	POE	EPA Study: 1988	VOCs/Radon	1	$250	$238	$15	$503
AC/DBA	POE	Goodrich 1990	TCE	150	$488	$263	$15	$766
AC/DBA	POE	Elkhart 1989	TCE	1	$646	$301	$15	$962
Aeration	POE	EPA Database (var cap) 1989	VOCs/Radon	1	$264	$238	$15	$517
AX	POU	Fairbanks, AK, Eugene, OR. 1983	Arsenic	4	$365	$32	$15	$411
AX	POE	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$264	$122	$15	$400
AX	POE	EPA Study: 1988	Arsenic/Nitrate	1	$250	$122	$15	$386
AX	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$78	$124	$15	$284
AX	POU	Gumerman (PL): 1983	Arsenic/Nitrate	1	$78	$124	$15	$284
AX	POU	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$365	$33	$15	$412
AX	POU	EPA Study: 1988	Arsenic/Nitrate	1	$411	$33	$15	$458
AX	Central	Lykins (TP w/pipe) 1992	Nitrate	150	NP	NP	NP	NP
AX	Central	Lykins (SD w/pipe) 1992	Nitrate	150	NP	NP	NP	NP
AX	Central	Lykins (w/o pipe) 1992	Nitrate	150	NP	NP	NP	NP
AX	POE	Lykins: 1992	Nitrate	150	$389	$121	$15	$505
AX	POE	Riverhead/Southhold, NY 1985	Nitrate	1	$327	$123	$15	$464
AX	POU	Riverhead/Southhold, NY: 1985	Nitrate	1	$365	$34	$15	$413
AX	POU	Colorado and New Mexico 1983	Uranium	12	$312	$34	$15	$361

Table 4.3.1: Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)
CX	POE	RIA 1987	Copper	25	$309	$123	$15	$525
CX	POE	RIA: 1987	Copper	120	$208	$122	$15	$396
CX	POE	RIA 1987	Copper	300	$277	$122	$15	$482
CX	POE	RIA: 1987	Copper	880	$246	$122	$15	$444
CX	POE	EPA Database (var cap) 1989	Copper	1	$175	$124	$15	$313
CX	POE	EPA Study: 1988	Copper	1	$161	$124	$15	$299
CX	POU	Gumerman (US) 1983	Copper	1	$63	$124	$15	$264
CX	POU	Gumerman (PL): 1983	Copper	1	$63	$124	$15	$264
CX	POU	EPA Database (var cap) 1989	Copper	1	$325	$35	$15	$374
CX	POU	EPA Study: 1988	Copper	1	$371	$35	$15	$420
CX	Central	Bellevue, WI 1989	Radium	1,282	TAOMC	TAOMC	TAOMC	$75
CX	POE	Bellevue, WI (w/o Outside Cons): 1989	Radium	1,282	TAOMC	TAOMC	TAOMC	$182
CX	POE	Bellevue, WI (w Outside Cons) 1989	Radium	1,282	TAOMC	TAOMC	TAOMC	$208
Disinfection	Central	Gibson Canyon, CA: 1992	Bacteria	140	TAOMC	TAOMC	TAOMC	$455
Disinfection	POE	Gibson Canyon, CA (Alternative One) 1992	Bacteria	140	TAOMC	TAOMC	TAOMC	$2,078
Disinfection	POE	Gibson Canyon, CA (Alternative Two): 1992	Bacteria	140	TAOMC	TAOMC	TAOMC	$831
Disinfection	POE	Ephraim, WI (Cl and UV) 1994	Bacteria	425	$295	$68	$47	$429
Disinfection	POE	EPA Database (var. cap.), 1989	Bacteria	1	$225	$128	$15	$367
Disinfection	POU	EPA Database (var cap) 1989	Bacteria	1	$195	$39	$15	$248
PTA	Central	Elkhart: 1987	TCE	21,667	TAOMC	TAOMC	TAOMC	$5
RO	Central	San Ysidro NM (Univ Houston est) 1986	Arsenic	1	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM (Contract O&M): 1986	Arsenic	78	TAC	TAC	TAC	TAC
RO	POU	San Ysidro NM (Village O&M) 1986	Arsenic	78	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM (Capital Costs): 1986	Arsenic	78	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM (Alternative One w/Capital) 1986	Arsenic	78	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM (Alternative Two w/Capital) 1986	Arsenic	78	TAC	TAC	TAC	TAC
RO	POU	San Ysidro, NM 1986	Arsenic	1	$220	$32	$15	$266
RO	POU	Fairbanks, AK, Eugene, OR: 1983	Arsenic	4	$220	$32	$16	$266
RO	Central	Emington, IL (est) 1985	Arsenic/Fluoride	47	TAOMC	TAOMC	TAOMC	$59
RO	Central (Ctn)	King's Point, Suffolk, VA (est.): 1995	Arsenic/Fluoride	57	Minimal	Minimal	Minimal	Minimal
RO	POU	King's Point, Suffolk, VA 1995	Arsenic/Fluoride	1	$400	AMC	$15	$425
RO	POU	Emington, IL: 1985	Arsenic/Fluoride	47	$287	$31	$15	$333
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	25	$232	$121	$15	$426
RO	POE	RIA (RO): 1987	Arsenic/Nitrate	120	$189	$120	$15	$371
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	300	$252	$120	$15	$450
RO	POE	RIA (RO): 1987	Arsenic/Nitrate	880	$224	$120	$15	$415
RO	POE	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$657	$122	$15	$793
RO	POE	EPA Study: 1988	Arsenic/Nitrate	1	$591	$122	$15	$727
RO	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$148	$124	$15	$378
RO	POU	Ebbert (var. cap): 1985	Arsenic/Nitrate	1	$221	$33	$15	$269
RO	POU	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$152	$33	$15	$199
RO	POU	EPA Study 1988	Arsenic/Nitrate	1	$198	$33	$15	$246
RO	POE	Riverhead/Southhold, NY 1985	Nitrate	1	$643	$123	$15	$781
RO	POU	Riverhead/Southhold, NY 1985	Nitrate	1	$152	$34	$15	$201

Table 4.3.2: Operation and Maintenance Cost Data -- Vendor Survey

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)
AA	POE	Vendor Two (Single tank)	Arsenic	150	$166	$121	$15	$301
AA	POE	Vendor Two (Dual tank)	Arsenic	150	$166	$121	$15	$301
AA	POU	Vendor Three	Arsenic	150	$121	$32	$15	$167
AA	POE	Vendor Two (Single tank)	Nitrate	40	$241	$123	$15	$378
AA	POE	Vendor Two (Dual tank)	Nitrate	40	$241	$123	$15	$378
AC	POU	Vendor One	Alachlor	92	$98	$121	$15	$234
AC	POU	Vendor One	Alachlor	92	$77	$121	$15	$213
AC	POU	Vendor Two	Alachlor	92	$115	$121	$15	$250
AC	POU	Vendor Three	Alachlor	92	$63	$121	$15	$199
AC	POE	Vendor One	Radon (1,500)	100	$525	$159	$15	$698
AC	POE	Vendor Two	Radon (1,500)	100	$250	$159	$15	$423
AC	POE	Vendor One	Radon (300)	16	$525	$159	$15	$698
AC	POE	Vendor Two	Radon (300)	16	$250	$159	$15	$423
AC	POE	Vendor One	Radon (300)	100	$525	$159	$15	$698
AC	POE	Vendor Two	Radon (300)	100	$250	$159	$15	$423
AC	POE	Vendor One	TCE	60	$525	$285	$15	$824
AC	POE	Vendor Two	TCE	60	$250	$285	$15	$549
AC/DBA	POE	Vendor Two	Radon (1,500)	100	$250	$159	$15	$423
AC/DBA	POE	Vendor Four	Radon (1,500)	100	$300	$159	$15	$473
AC/DBA	POE	Vendor Two	Radon (300)	16	$250	$159	$15	$423
AC/DBA	POE	Vendor Four	Radon (300)	16	$300	$159	$15	$473
AC/DBA	POE	Vendor Two	Radon (300)	100	$250	$159	$15	$423
AC/DBA	POE	Vendor Four	Radon (300)	100	$300	$159	$15	$473
AC/DBA	POE	Vendor Two	TCE	60	$250	$285	$15	$549
AC/DBA	POE	Vendor Four	TCE	60	$300	$285	$15	$600
AX	POE	Vendor Four	Nitrate	40	$165	$123	$15	$302
CX	POE	Vendor One	Copper	10	$165	$124	$15	$303
CX	POE	Vendor Two	Copper	10	$165	$124	$15	$303
pH	POE	Vendor Two	Copper	10	$91	$124	$15	$230
RO	POU	Vendor Four	Alachlor	92	$181	$121	$15	$317
RO	POU	Vendor One	Arsenic	150	$123	$32	$15	$169
RO	POU	Vendor Two	Arsenic	150	$146	$32	$15	$192
RO	POU	Vendor Four	Arsenic	150	$181	$32	$15	$227
RO	POU	Vendor One	Copper	10	$123	$35	$15	$173
RO	POU	Vendor Two	Copper	10	$146	$35	$15	$195
RO	POU	Vendor Four	Copper	10	$181	$35	$15	$231
RO	POE	Vendor Four	Arsenic/Nitrate	40	$825	$123	$15	$962
RO	POU	Vendor One	Nitrate	40	$123	$34	$15	$172
RO	POU	Vendor Two	Nitrate	40	$146	$34	$15	$194

Table 4.3.3: Operation and Maintenance Cost Data -- Cadmus

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)
AA	POU	Cadmus	Arsenic	1	$365	$32	$15	$411
AA	POU	Cadmus	Arsenic	10	$312	$32	$15	$358
AA	POU	Cadmus	Arsenic	50	$286	$30	$15	$330
AA	POU	Cadmus	Arsenic	100	$260	$30	$15	$304
AC	POE	Cadmus	Alachlor	1	$304	$191	$15	$510
AC	POE	Cadmus	Alachlor	10	$270	$191	$15	$475
AC	POE	Cadmus	Alachlor	50	$253	$168	$15	$435
AC	POE	Cadmus	Alachlor	100	$235	$168	$15	$418
AC	POE	Cadmus	Radon (1500)	1	$305	$140	$15	$459
AC	POE	Cadmus	Radon (1500)	10	$282	$140	$15	$436
AC	POE	Cadmus	Radon (1500)	50	$259	$127	$15	$400
AC	POE	Cadmus	Radon (1500)	100	$259	$127	$15	$400
AC	POE	Cadmus	Radon (300)	1	$309	$140	$15	$463
AC	POE	Cadmus	Radon (300)	10	$285	$140	$15	$439
AC	POE	Cadmus	Radon (300)	50	$262	$127	$15	$403
AC	POE	Cadmus	Radon (300)	100	$262	$127	$15	$403
AC	POE	Cadmus	TCE	1	$304	$266	$15	$585
AC	POE	Cadmus	TCE	10	$270	$266	$15	$550
AC	POE	Cadmus	TCE	50	$253	$228	$15	$495
AC	POE	Cadmus	TCE	100	$235	$228	$15	$478
AX	POE	Cadmus	Arsenic	1	$201	$86	$15	$301
AX	POE	Cadmus	Arsenic	10	$182	$86	$15	$282
AX	POE	Cadmus	Arsenic	50	$172	$84	$15	$271
AX	POE	Cadmus	Arsenic	100	$163	$84	$15	$261
AC	POU	Cadmus	Alachlor	1	$205	$121	$15	$340
AC	POU	Cadmus	Alachlor	10	$176	$121	$15	$312
AC	POU	Cadmus	Alachlor	50	$162	$102	$15	$278
AC	POU	Cadmus	Alachlor	100	$148	$102	$15	$264
AX	POU	Cadmus	Arsenic	1	$365	$32	$15	$411
AX	POU	Cadmus	Arsenic	10	$312	$32	$15	$358
AX	POU	Cadmus	Arsenic	50	$286	$30	$15	$330
AX	POU	Cadmus	Arsenic	100	$260	$30	$15	$304
AX	POE	Cadmus	Nitrate	1	$327	$88	$15	$429
AX	POE	Cadmus	Nitrate	10	$289	$88	$15	$391
AX	POE	Cadmus	Nitrate	50	$270	$86	$15	$370
AX	POE	Cadmus	Nitrate	100	$251	$86	$15	$351
AX	POU	Cadmus	Nitrate	1	$365	$34	$15	$413
AX	POU	Cadmus	Nitrate	10	$312	$34	$15	$361
AX	POU	Cadmus	Nitrate	50	$286	$32	$15	$332
AX	POU	Cadmus	Nitrate	100	$260	$32	$15	$306

Table 4.3.3: Operation and Maintenance Cost Data -- Cadmus

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)
CX	POE	Cadmus	Copper	1	*$175*	*$89*	*$15*	*$278*
CX	POE	Cadmus	Copper	10	*$160*	*$89*	*$15*	*$263*
CX	POE	Cadmus	Copper	50	*$152*	*$87*	*$15*	*$253*
CX	POE	Cadmus	Copper	100	*$145*	*$87*	*$15*	*$246*
CX	POU	Cadmus	Copper	1	*$325*	*$35*	*$15*	*$374*
CX	POU	Cadmus	Copper	10	*$278*	*$35*	*$15*	*$328*
CX	POU	Cadmus	Copper	50	*$255*	*$33*	*$15*	*$302*
CX	POU	Cadmus	Copper	100	*$232*	*$33*	*$15*	*$279*
DBA	POE	Cadmus	Radon (300)	1	*$375*	*$140*	*$15*	*$529*
DBA	POE	Cadmus	Radon (300)	10	*$210*	*$140*	*$15*	*$364*
DBA	POE	Cadmus	Radon (300)	50	*$195*	*$127*	*$15*	*$336*
DBA	POE	Cadmus	Radon (300)	100	*$195*	*$127*	*$15*	*$336*
RO	POE	Cadmus	Arsenic	1	*$703*	*$121*	*$15*	*$838*
RO	POE	Cadmus	Arsenic	10	*$648*	*$121*	*$15*	*$783*
RO	POE	Cadmus	Arsenic	50	*$634*	*$119*	*$15*	*$767*
RO	POE	Cadmus	Arsenic	100	*$620*	*$119*	*$15*	*$754*
RO	POU	Cadmus	Arsenic	1	*$220*	*$32*	*$15*	*$266*
RO	POU	Cadmus	Arsenic	10	*$189*	*$32*	*$15*	*$235*
RO	POU	Cadmus	Arsenic	50	*$173*	*$30*	*$15*	*$218*
RO	POU	Cadmus	Arsenic	100	*$158*	*$30*	*$15*	*$203*
RO	POE	Cadmus	Nitrate	1	*$528*	*$123*	*$15*	*$666*
RO	POE	Cadmus	Nitrate	10	*$490*	*$123*	*$15*	*$628*
RO	POE	Cadmus	Nitrate	50	*$481*	*$121*	*$15*	*$616*
RO	POE	Cadmus	Nitrate	100	*$471*	*$121*	*$15*	*$607*
RO	POU	Cadmus	Nitrate	1	*$152*	*$34*	*$15*	*$201*
RO	POU	Cadmus	Nitrate	10	*$131*	*$34*	*$15*	*$180*
RO	POU	Cadmus	Nitrate	50	*$121*	*$32*	*$15*	*$168*
RO	POU	Cadmus	Nitrate	100	*$111*	*$32*	*$15*	*$157*

Before maintenance staff can service a unit, they must have all necessary replacement parts and they must travel to the household in which the unit is installed. As with device installation, it was assumed that daily preparation (preparation of all necessary parts and fittings, completion of appropriate paperwork, etc.) and travel to and from the community would require 2 hours. Therefore, maintenance personnel would actually spend only 6 hours of her day servicing treatment devices given the assumption of an eight hour workday (see section 4.1).

Given the assumptions presented in the preceding paragraph, three POE units can be serviced per employee per day while a single employee could service eight POU devices per day.

The costs and estimated effective life of various replacement parts for POU devices are presented in Table 4.3.1.1. A substantial margin of safety is included in the minimum effective life determined for these components. It was assumed that all parts would be available from local vendors. Therefore, no shipping and handling costs were included in this cost analysis.

Table 4.3.1.1: Cost Data for POU Replacement Components (1997$)

Component	Contaminant	Cost	Minimum Effective Life
AA Cartridge	Arsenic	$80	275 gallons
GAC Cartridge	Alachlor	$40	275 gallons
AX Cartridge	Arsenic/Nitrate	$80	275 gallons
CX Cartridge	Copper	$70	275 gallons
RO Membrane	Arsenic	$135	1,100 gallons
RO Membrane	Nitrate	$135	2,200 gallons
Particulate filter (5-μm)	NA	$15	550 gallons
GAC pre- or post-filter	NA	$20	550 gallons

For the purposes of this cost analysis, it was determined that all POU units would be charged for replacement of a particulate pre-filter and the appropriate cartridge (i.e., an AA cartridge for a POU AA device). The cost of replacing GAC pre- and post-filters were included in the maintenance costs for all POU RO devices.

Cost estimates for replacement components and media used in POE devices are presented in Table 4.3.1.2.

Table 4.3.1.2: Cost Data for POE Replacement Components (1997$)

Media/Component	Contaminant	Cost per Cubic Foot	Minimum Effective Life
AA (cubic foot)	Arsenic	$65	33,500 gallons
GAC (cubic foot)	Alachlor, TCE	$60	85,000 gallons
GAC (cubic foot)	Radon (300)	$60	Not Applicable
GAC (cubic foot)	Radon (1,500)	$60	Not Applicable
AX Salt	Arsenic	$126	110,000 gallons
AX Salt	Nitrate	$126	55,000 gallons
CX Salt	Copper	$100	110,000 gallons
UV Bulb	Microbiologicals	$150	110,000 gallons

All prices were derived from the data provided by the vendor survey (see section 3), the information provided by the contacted OEMs, and contractor expertise. Volume discounts identical to those provided for the purchase of treatment devices were incorporated into the cost of replacement parts and media.

Although UV units draw electrical power, no reliable data on their yearly energy requirements were available. However, the additional electrical requirement is expected to be small and would be dwarfed by the electrical demands of other household appliances (e.g., water heater or dishwasher). Therefore, electrical costs were ignored in this cost analysis.

Disposal costs for spent media should be incorporated in any cost analysis to reflect the true cost of a particular technology to the water system and the water system's customers. Disposal costs for POU devices are negligible due to their small size (and therefore small contribution to the total waste stream) and to their low level of contamination. However, due to their greater size, the installation and use of POE units may result in significant disposal costs. For example, the waste brines from POE RO units may not be accepted by the local wastewater treatment plant. While the brine could be stored in a tank and discharged at a slow rate (via a bleed valve), this would result in an additional cost for the water system. In addition, as noted in sections 1.3.4 and 1.3.5, the use of IX units may face legal restrictions in certain areas. Spent GAC contaminated with radon or the products of radon's decay may require disposed as low-level radioactive waste. This would greatly increase the costs of this treatment alternative. While central treatment plants face even more daunting waste disposal issues, sufficient information was not available to accurately determine the disposal costs for central treatment plants of various sizes. Therefore, to prevent unfair bias in the cost analysis, all disposal costs were ignored.

4.3.2 Sampling and Lab Analysis

While monitoring is essential to maintaining POU and POE systems, sampling and lab analyses are expensive. Indeed, lab fees can drive the implementation costs of a POU or POE treatment strategy, especially because these units are relatively inexpensive.

Water systems were assumed to test water from each household's treatment device annually to ensure that all customers are provided with water that meets the NPDWRs. It was not necessary to include the costs of more frequent monitoring, since all replacement schedules used in this cost analysis include built in safety margins of at least 100 percent as detailed in section 4.3.1.

As discussed in section 1.4, bacterial colonization of GAC filters has been documented. Therefore, a fecal coliform analysis will also be performed on samples taken from all treatment devices that use GAC technology. Since EPA will continue to regulate the water provided by the water system, it was assumed that no additional analyses would be required of the water systems that implement POU or POE treatment strategies. Nonetheless, water systems would still be subject to the sampling requirements of the Standard Monitoring Framework (e.g., they would still need to monitor contaminant concentrations at the point-of-entry to the distribution system). The sampling would ensure that the water systems could continue to use POE or POU strategies to meet the NPDWRs.

To provide an extra measure of safety, this cost analysis assumed that sampling would be done by trained water system personnel. It also assumed that sampling would occur at the same time as device maintenance in order to reduce travel costs. Since maintenance occurs at least twice a year for all POE and POU treatment units (see section 4.3.1), no separate trips for sampling were determined to be necessary. All travel time would be covered under maintenance costs. Nonetheless, 1 extra hour of preparation (e.g., for labeling sample bottles, sample drop-off, etc.) was incorporated in the cost analysis for each workday required to sample the service community to ensure that appropriate protocols would be followed.

Since the sampling process is relatively simple, consisting of filling a small vial with water from a tap that dispenses treated water, it was assumed that sampling (e.g., running water for two minutes, taking samples, etc.) would require only 15 minutes for each POU unit. Thus, servicing and sampling for a POU unit would require 1 hour per unit (45 minutes for maintenance plus 15 minutes for sampling). Sampling was assumed to require 30 minutes for each POE unit. Thus, servicing and sampling a POE unit would require 2.5 hours (2 hours for maintenance plus 30 minutes for sampling). Therefore, since 5 hours would be available for sampling and maintenance per 8-hour workday (3 hours for preparation and travel), five POU units and two POE units could be sampled and serviced each workday by a single employee.

The fees assigned to lab analyses for this cost analysis are presented in Table 4.3.2.1.

Table 4.3.2.1: Cost Data for Lab Analyses (1997$)

Contaminant	Cost of Analysis	Source
Arsénic	$8.50	Independent Laboratories
Copper	$12.00	1997 Lead and Copper Rule
Nitrate	$11.00	1997 Drinking Water Program Information Request (DW ICR)
Radon	$46.50	Independent Laboratories
Alachlor	$98.00	DW ICR
Trichloroethylene	$173.00	DW ICR
Total Coliform	$16.00	DW ICR

All costs taken from the Lead and Copper Rule and the 1997 Drinking Water Program Information Request were corroborated by contacted laboratories. Most of these laboratories publicized the availability of discounts for large orders. Therefore, it was assumed that a 10-percent discount would be provided to a water system for 20 to 49 sample analyses and that a 20-percent discount would be provided for 50 or more sample analyses. Since several of the contacted laboratories advertised free pick-up and delivery via messenger service, it was assumed that the water system would not incur any shipping or handling charges. Since all of the devices for which costs were developed were designed with ample capacity and since provisions had been made for frequent maintenance and cartridge/filter/membrane replacement, it was assumed that no contaminant analyses would return positive (necessitating additional sampling).

4.3.3 Administrative Costs

Effective administration is necessary for a water system that relies on POU or POE technology, because each unit must be maintained in working order. Administrative costs for office supplies, record keeping, and other administrative activities were reported in several case studies (see sections 2.1.2, 2.2.2, and 2.6.1). When adjusted for inflation using the PPI, these costs amounted to $14.13 per year for each household equipped with a POU and POE unit. As noted in section 4.1, it was assumed that all administrative duties would be undertaken by a minimally skilled worker (wage rate of $14.50 per hour). Therefore, it was determined that a water system employee would need to spend 1 hour per household per year to coordinate device sampling and maintenance with homeowners and vendors. Central treatment plants were not charged administrative costs since these were assumed to be incorporated in the cost of maintaining the plant. Therefore the administrative portion of O&M costs was determined to be zero for all central treatment projects.

4.4 Total Costs

Given the assumptions presented in section 4.1, a household would use 100 gallons of water per day for all purposes (e.g., drinking, washing, cleaning, etc.). By dividing the total annual household cost of the POU or POE treatment option by the volume of water used by each household for *all* purposes, it was possible to calculate a per-gallon-used cost for implementation of a POE or POU strategy. Since POE units treat all household water, cost per-gallon-used for these devices is equivalent to cost-per-gallon treated. However, POU units treat only water used for drinking and cooking purposes (1 percent of total water usage). Therefore, the cost-per-gallon treated for these devices will be significantly (about 100 times) greater than the cost-per-gallon used. The examination of cost-per-gallon used (hereafter referred to as "costs") permits comparison of the costs associated with different alternatives for achieving compliance with the SDWA. Tables 4.4.1, 4.4.2, 4.4.3, and 4.4.4 present the total costs associated with the provision of various POE and POU treatment devices.

The results of the cost analysis are presented in the following sections. As noted in section 4.1, the final stage of the cost development process was the verification of the Cadmus cost estimates. The concentration of several contaminants could be successfully reduced in household water by the application of more than one technology (e.g., arsenic concentrations may be reduced by AA, AX, or RO).

The costs provided by the case studies and the surveyed vendors are presented along with the Cadmus cost curve (and the associated cost equation) for comparison. As previously detailed, case study and vendor cost data were adjusted to ensure the comparison of comparable systems (e.g., the cost of a water meter was added to the purchase price of those systems that did not come equipped with one) in comparable terms (i.e., 1997 dollars). However, when component replacement schedules were provided by a vendor or in a case study, these nominal schedules were used in calculating total costs even when they differed with the replacement regime developed for this cost analysis.

After the cost curves for the POU application of each appropriate treatment technology are presented individually (with case study and vendor data), the implementation costs for all potential POU treatment strategies are compared. This permits the determination of the least-cost POU treatment technology for the contaminant of concern.

Table 4.4.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
AA	POU	Fairbanks AK, Eugene, OR 1983	Arsenic	4	$250	$19	NA	$362	$95	$365	$32	$15	$411	$506	$482	$4.62
AA	POU	Gumerman (US) 1983	Arsenic	1	$280	$40	$50	$507	$134	$103	$106	$15	$294	$427	$390	$3.90
AA	POU	Gumerman (PL) 1983	Arsenic	1	$330	$120	$70	$712	$188	$103	$106	$15	$294	$482	$440	$4.40
AA	POU	Thunderbird Farms, AZ 1985	Fluoride/Arsenic	8	$338	$19	NA	$357	$94	$388	$32	$78	$495	$590	$1,164	$5.39
AA	POU	Papago Butte, AZ 1985	Fluoride/Arsenic	1	$501	$19	NA	$520	$137	$369	$32	$15	$415	$552	$82	$5.04
AA	POU	Ruth Fisher Elementary School, AZ 1985	Fluoride/Arsenic	1	$514	$19	NA	$533	$141	$483	$32	$15	$529	$670	$216	$6.12
AA	POU	You and I TP, AZ 1985	Fluoride/Arsenic	1	$345	$19	NA	$364	$96	$413	$32	$15	$459	$555	$276	$5.07
AA	POU	Parkersburg, IL 1985	Fluoride/Arsenic	10	$401	$13	NA	$414	$109	$353	$32	$15	$399	$509	$2,322	$4.64
AA	POU	Bureau Junction, IL 1985	Fluoride/Arsenic	40	$416	$13	NA	$429	$113	$321	$31	$15	$366	$480	$1,642	$4.38
AC	Central	Goodrich 1990	DBCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,628	$18	$14.87
AC	Central	Goodrich 1990	DBCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$786	$8	$7.18
AC	Central	Goodrich 1990	DBCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$488	$5	$4.27
AC	Central	Goodrich 1992	DBCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,507	$16	$13.76
AC	Central	Goodrich 1992	DBCP	15	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,085	$11	$9.91
AC	Central	Goodrich 1992	DBCP	20	NP	NP	NP	NP	NP	NP	NP	NP	NP	$864	$9	$7.89
AC	Central	Goodrich 1992	DBCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$727	$8	$6.64
AC	Central	Goodrich 1992	DBCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$432	$4	$3.95
AC	POE	Goodrich 1990	DBCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$1,043	$5	$9.52
AC	POE	Goodrich 1990	DBCP	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$205	$15	$501	$1,032	$5	$9.43
AC	POE	Goodrich 1990	DBCP	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$258	$194	$15	$467	$999	$5	$9.12
AC	POE	Goodrich 1992	DBCP	10	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$1,341	$14	$12.25
AC	POE	Goodrich 1992	DBCP	15	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$1,341	$14	$12.25
AC	POE	Goodrich 1992	DBCP	20	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$205	$15	$501	$1,331	$14	$12.16
AC	POE	Goodrich 1992	DBCP	25	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$205	$15	$501	$1,331	$14	$12.16
AC	POE	Goodrich 1992	DBCP	50	$2,188	IWP	CpKGT	CpKGT	CpKGT	$258	$194	$15	$467	$1,298	$13	$11.85
AC	POE	Fresno, CA 1990	DBCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$215	$15	$511	$894	$4	$8.17
AC	Central	Goodrich 1990	DCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,756	$17	$16.04
AC	Central	Goodrich 1990	DCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$882	$9	$8.05
AC	Central	Goodrich 1990	DCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$547	$5	$4.99
AC	Central	Goodrich 1992	DCP	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,542	$16	$14.08
AC	Central	Goodrich 1992	DCP	15	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,120	$12	$10.23
AC	Central	Goodrich 1992	DCP	20	NP	NP	NP	NP	NP	NP	NP	NP	NP	$898	$9	$8.20
AC	Central	Goodrich 1992	DCP	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$762	$8	$6.96
AC	Central	Goodrich 1992	DCP	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$466	$5	$4.28
AC	POE	Goodrich 1990	DCP	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$301	$15	$597	$1,493	$9	$13.63
AC	POE	Goodrich 1990	DCP	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$281	$282	$15	$578	$1,474	$9	$13.48
AC	POE	Goodrich 1990	DCP	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$258	$263	$15	$536	$1,432	$9	$13.08
AC	POE	Goodrich 1992	DCP	10	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$301	$15	$597	$1,561	$16	$14.26
AC	POE	Goodrich 1992	DCP	15	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$301	$15	$597	$1,561	$16	$14.26
AC	POE	Goodrich 1992	DCP	20	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$282	$15	$578	$1,542	$16	$14.09
AC	POE	Goodrich 1992	DCP	25	$2,188	IWP	CpKGT	CpKGT	CpKGT	$281	$282	$15	$578	$1,542	$16	$14.09
AC	POE	Goodrich 1992	DCP	50	$2,188	IWP	CpKGT	CpKGT	CpKGT	$258	$263	$15	$536	$1,501	$16	$13.70
AC	POE	Florida (Type I) 1987	EDB	1	$1,000	IWP	NA	$1,252	$204	$890	$400	IWS	$1,616	$1,820	$17	$16.62
AC	POE	Florida (Type II) 1987	EDB	1	$1,050	IWP	NA	$1,315	$214	$890	$400	IWS	$1,616	$1,830	$17	$16.71
AC	POE	Various States (GAC 10) 1989	Radon	1	$828	$116	NA	$944	$154	$283	$152	$15	$449	$603	$6	$5.50
AC	POE	Various States (GAC 17) 1989	Radon	1	$1,077	$116	NA	$1,193	$194	$283	$152	$15	$449	$643	$6	$5.88
AC	POE	Various States (GAC 30) 1989	Radon	1	$1,350	$116	NA	$1,466	$239	$283	$152	$15	$449	$688	$6	$6.28

Table 4.4.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
AC	POU	Gumerman (US) 1983	SOCs	1	$220	$40	$40	$411	$108	$52	$164	$15	$303	$411	$376	$3.76
AC	POU	Gumerman (PL) 1983	SOCs	1	$270	$120	$80	$616	$163	$52	$164	$15	$303	$466	$425	$4.25
AC	POU	Ebbert (var cap) 1985	SOCs	1	$260	$19	$42	$321	$85	$211	$121	$15	$347	$432	$394	$3.94
AC	POU	EPA Database (var cap.) 1989	SOCs	1	$204	$19	$33	$257	$68	$205	$121	$15	$340	$408	$373	$3.73
AC	POU	EPA Study 1988	SOCs	1	$378	$97	$95	$571	$151	$251	$121	$15	$386	$537	$490	$4.90
AC	Central	Lykins (TP w/pipe) 1992	TCE	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$406	$4	$3.71
AC	Central	Lykins (SD w/pipe) 1992	TCE	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$704	$7	$6.43
AC	Central	Lykins (w/o pipe) 1992	TCE	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$202.95	$2	$1.85
AC	Central	Putnam County NY (est.) 1987	TCE	110	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$1,576	$14	$14.40
AC	Central	Goodrich 1990	TCE	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,640	$16	$14.98
AC	Central	Goodrich 1990	TCE	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$798	$8	$7.29
AC	Central	Goodrich 1990	TCE	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$480	$5	$4.38
AC	Central	Goodrich 1992	TCE	10	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,514	$16	$13.83
AC	Central	Goodrich 1992	TCE	15	NP	NP	NP	NP	NP	NP	NP	NP	NP	$1,092	$11	$9.97
AC	Central	Goodrich 1992	TCE	20	NP	NP	NP	NP	NP	NP	NP	NP	NP	$871	$9	$7.95
AC	Central	Goodrich 1992	TCE	25	NP	NP	NP	NP	NP	NP	NP	NP	NP	$734	$8	$6.71
AC	Central	Goodrich 1992	TCE	50	NP	NP	NP	NP	NP	NP	NP	NP	NP	$438	$5	$4.00
AC	POE	Lykins: 1992	TCE	150	$2,188	NP	$328	$2,517	$410	$748	$263	$15	$1,026	$1,435	$15	$13.41
AC	POE	Putnam County, NY 1987	TCE	67	$823	$494	NA	$1,650	$268	$320	$263	$15	$678	$947	$10	$8.65
AC	POE	Goodrich 1990	TCE	10	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$270	$301	$15	$585	$1,341	$8	$12.25
AC	POE	Goodrich 1990	TCE	25	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$270	$282	$15	$566	$1,322	$8	$12.08
AC	POE	Goodrich: 1990	TCE	50	CpKGT	CpKGT	CpKGT	CpKGT	CpKGT	$253	$263	$15	$530	$1,286	$8	$11.75
AC	POE	Goodrich 1992	TCE	10	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$301	$15	$608	$1,481	$15	$13.53
AC	POE	Goodrich 1992	TCE	15	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$301	$15	$608	$1,481	$15	$13.53
AC	POE	Goodrich 1992	TCE	20	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$282	$15	$589	$1,462	$15	$13.36
AC	POE	Goodrich: 1992	TCE	25	$2,188	IWP	CpKGT	CpKGT	CpKGT	$292	$282	$15	$589	$1,462	$15	$13.36
AC	POE	Goodrich 1992	TCE	50	$2,188	IWP	CpKGT	CpKGT	CpKGT	$286	$263	$15	$564	$1,438	$15	$13.13
AC	POU	Rockaway Township, NJ, 1985	TCE	12	$377	IWP	NA	$377	$100	$201	$196	$15	$411	$511	$608	$4.68
AC	POU	Silverdale, PA 1985	TCE	49	$289	IWP	NA	$289	$76	$206	$179	$15	$399	$475	$1,302	$4.34
AC	POE	Riverhead/Southhold, NY, 1985	VOCs/Radon	1	$2,050	$113	NA	$2,617	$459	$264	$238	$15	$517	$975	$9	$8.91
AC	POE	EPA Database (var cap) 1989	VOCs/Radon	1	$940	$112	$158	$1,360	$221	$264	$238	$15	$517	$738	$7	$6.74
AC	POE	EPA Study. 1988	VOCs/Radon	1	$2,531	$123	$531	$3,185	$518	$250	$238	$15	$503	$1,021	$9	$9.32
AC/DBA	POE	Goodrich 1990	TCE	150	$5,623	NP	$843	$6,466	$1,052	$488	$263	$15	$766	$1,818	$19	$18.60
AC/DBA	POE	Elkhart 1989	TCE	1	$4,685	IWP	NA	$4,685	$762	$646	$301	$15	$962	$1,724	$18	$15.74
Aeration	POE	EPA Database (var cap) 1989	VOCs/Radon	1	$1,959	$112	$311	$2,381	$388	$264	$238	$15	$517	$904	$8	$8.26
AX	POU	Fairbanks AK, Eugene, OR; 1983	Arsenic	4	$350	$19	NA	$499	$132	$365	$32	$15	$411	$542	$495	$4.95
AX	POE	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$1,155	$112	$190	$1,457	$237	$264	$122	$15	$400	$637	$6	$5.82
AX	POE	EPA Study: 1988	Arsenic/Nitrate	1	$2,167	$212	$476	$2,855	$465	$250	$122	$15	$386	$851	$8	$7.77
AX	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$350	$40	$60	$616	$163	$78	$124	$15	$284	$447	$408	$4.08
AX	POU	Gumerman (PL): 1983	Arsenic/Nitrate	1	$400	$120	$80	$822	$217	$78	$124	$15	$284	$501	$458	$4.58
AX	POU	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$318	$19	$51	$387	$102	$365	$33	$15	$412	$514	$470	$4.70
AX	POU	EPA Study 1988	Arsenic/Nitrate	1	$288	$97	$77	$461	$122	$411	$33	$15	$458	$580	$529	$5.29
AX	Central	Lykins (TP w/pipe) 1992	Nitrate	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$355	$4	$3.24
AX	Central	Lykins (SD w/pipe): 1992	Nitrate	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$653	$7	$5.96
AX	Central	Lykins (w/o pipe) 1992	Nitrate	150	NP	NP	NP	NP	NP	NP	NP	NP	NP	$177	$2	$1.62
AX	POE	Lykins 1992	Nitrate	150	$2,188	$75	$339	$2,603	$424	$369	$121	$15	$505	$928	$10	$8.48
AX	POE	Riverhead/Southhold NY 1985	Nitrate	1	$2,325	$175	NA	$2,553	$415	$327	$123	$15	$464	$880	$8	$8.03
AX	POU	Riverhead/Southhold, NY 1985	Nitrate	1	$306	$80	NA	$410	$108	$365	$34	$15	$413	$521	$476	$4.76
AX	POU	Colorado and New Mexico 1983	Uranium	12	$125	$13	NA	$184	$49	$312	$34	$15	$361	$409	$374	$3.74

Table 4.4.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
CX	POE	RIA 1987	Copper	25	TCC	TTC	TTC	$1,316	$214	$309	$123	$15	$525	$739	$7	$7 73
CX	POE	RIA 1987	Copper	120	TCC	TTC	TTC	$889	$145	$208	$122	$15	$396	$541	$5	$7.05
CX	POE	RIA 1987	Copper	300	TCC	TTC	TTC	$1,174	$191	$277	$122	$15	$482	$673	$6	$6 56
CX	POE	RIA 1987	Copper	860	TCC	TTC	TTC	$1,046	$170	$246	$122	$15	$444	$614	$6	$6.25
CX	POE	EPA Database (var cap) 1989	Copper	1	$1,155	$112	$190	$1,457	$237	$175	$124	$15	$313	$550	$5	$5 03
CX	POE	EPA Study 1988	Copper	1	$2,167	$212	$476	$2,855	$465	$161	$124	$15	$299	$764	$7	$6 98
CX	POU	Gumerman (US) 1983	Copper	1	$260	$40	$45	$472	$125	$63	$124	$15	$264	$389	$355	$3 55
CX	POU	Gumerman (PL) 1983	Copper	1	$310	$120	$85	$678	$179	$63	$124	$15	$264	$443	$405	$4.05
CX	POU	EPA Database (var cap) 1989	Copper	1	$318	$19	$51	$387	$102	$325	$35	$15	$374	$476	$435	$4 35
CX	POU	EPA Study 1988	Copper	1	$288	$97	$77	$461	$122	$371	$35	$15	$420	$542	$495	$4 95
CX	Central	Bellevue, WI 1989	Radium	1,282	TAC	TAC	TAC	TAC	$118	TAOMC	TAOMC	TAOMC	$75	$193	$2	$1 77
CX	POE	Bellevue WI (w/o Outside Ctns.) 1989	Radium	1,282	$356	$48	$81	$538	$88	TAOMC	TAOMC	TAOMC	$182	$270	$2	$2.47
CX	POE	Bellevue WI (w Outside Ctns) 1989	Radium	1,282	$1,107	$27	$170	$1,512	$246	TAOMC	TAOMC	TAOMC	$208	$454	$4	$4 15
Disinfection	Central	Gibson Canyon, CA. 1992	Bacteria	140	$11,000	IWP	NA	$11,789	$1,385	TAOMC	TAOMC	TAOMC	$455	$1,840	$17	$16.81
Disinfection	POE	Gibson Canyon CA (Alternative One) 1992	Bacteria	140	$2,657	$75	NA	$2,922	$476	TAOMC	TAOMC	TAOMC	$2,078	$2,554	$23	$23 32
Disinfection	POE	Gibson Canyon, CA (Alternative Two) 1992	Bacteria	140	$3,529	$75	NA	$3,856	$628	TAOMC	TAOMC	TAOMC	$831	$1,459	$13	$13.32
Disinfection	POE	Ephraim WI (Cl and UV) 1994	Bacteria	425	$2,910	IWP	NA	$2,910	$474	$295	$68	$47	$429	$903	$8	$8 24
Disinfection	POE	EPA Database (var cap.) 1989	Bacteria	1	$609	$112	$108	$829	$135	$225	$128	$15	$367	$502	$5	$4 58
Disinfection	POU	EPA Database (var cap) 1989	Bacteria	1	$684	$19	$106	$809	$213	$195	$39	$15	$248	$462	$422	$4 22
PTA	Central	Elkhart 1987	TCE	21,667	$115	IWP	NA	$145	$17	TAOMC	TAOMC	TAOMC	$5	$22	$0	$0.20
RO	Central	San Ysidro NM (Univ Houston est) 1986	Arsenic	1	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$536	$199	$4 90
RO	POU	San Ysidro NM (Contract O&M) 1986	Arsenic	78	$290	$36	NA	$415	$110	TAC	TAC	TAC	TAC	$241	$89	$2.20
RO	POU	San Ysidro NM (Village O&M) 1986	Arsenic	78	$290	$36	NA	$415	$110	TAC	TAC	TAC	TAC	$217	$81	$1 99
RO	POU	San Ysidro, NM (Capital Costs) 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$191	$71	$1.74
RO	POU	San Ysidro NM (Alternative One w/Capital) 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$217	$81	$1 98
RO	POU	San Ysidro, NM (Alternative Two [illegible]) 1986	Arsenic	78	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	TAC	$197	$73	$1.80
RO	POU	San Ysidro, NM 1986	Arsenic	1	$665	IWP	NA	$849	$224	$220	$32	$15	$266	$490	$447	$4 47
RO	POU	Fairbanks AK, Eugene, OR 1983	Arsenic	4	$292	$19	NA	$419	$111	$220	$32	$15	$266	$376	$344	$3 44
RO	Central	Emington, IL (est.) 1985	Arsenic/Fluoride	47	$2,553	IWP	NA	$3,326	$391	TAOMC	TAOMC	TAOMC	$59	$450	$27	$27 28
RO	Central (Ctn)	King's Point, Suffolk, VA (est.) 1995	Arsenic/Fluoride	57	$14,263	IWP	NA	$14,624	$1,718	Minimal	Minimal	Minimal	Minimal	$1,718	$18	$15.69
RO	POU	King's Point, Suffolk VA 1995	Arsenic/Fluoride	1	$1,065	$19	NA	$1,085	$286	$400	AMC	$15	$425	$711	$649	$6 49
RO	POU	Emington, IL 1985	Arsenic/Fluoride	47	$860	$68	NA	$749	$197	$287	$31	$15	$333	$530	$1,815	$4.84
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	25	TAC	TAC	TAC	$1,461	$238	$232	$121	$15	$426	$470	$4	$5 82
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	120	TAC	TAC	TAC	$1,131	$184	$189	$120	$15	$371	$373	$3	$5.31
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	300	TAC	TAC	TAC	$1,496	$243	$252	$120	$15	$450	$495	$5	$4 95
RO	POE	RIA (RO) 1987	Arsenic/Nitrate	860	TAC	TAC	TAC	$1,333	$217	$224	$120	$15	$415	$441	$4	$4.71
RO	POE	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$3,520	$112	$545	$4,177	$680	$657	$122	$15	$793	$1,473	$13	$13 45
RO	POE	EPA Study 1988	Arsenic/Nitrate	1	$8,836	$364	$1,840	$11,040	$1,797	$591	$122	$15	$727	$2,524	$23	$23.05
RO	POU	Gumerman (US) 1983	Arsenic/Nitrate	1	$370	$50	$65	$664	$175	$148	$124	$15	$378	$553	$505	$5 05
RO	POU	Ebbert (var cap) 1985	Arsenic/Nitrate	1	$892	$19	$137	$1,435	$379	$221	$33	$15	$269	$647	$591	$5.91
RO	POU	EPA Database (var cap) 1989	Arsenic/Nitrate	1	$454	$19	$71	$545	$144	$152	$33	$15	$199	$343	$313	$3 13
RO	POU	EPA Study 1988	Arsenic/Nitrate	1	$833	$121	$191	$1,145	$302	$198	$33	$15	$246	$548	$500	$5 00
RO	POE	Riverhead/Southhold NY 1985	Nitrate	1	$9,491	$300	NA	$9,881	$1,608	$643	$123	$15	$781	$2,389	$22	$21 82
RO	POU	Riverhead/Southhold, NY 1985	Nitrate	1	$892	$110	NA	$1,035	$273	$152	$34	$15	$201	$474	$433	$4.33

Table 4.4.1: Capital and Operation and Maintenance Cost Data -- Case Studies

Assumptions

Number of people per household	3 0
Water consumed per person per day (gpd/pgr)	1 0
Total water use per person per day (gpd/per)	100 0
Water consumed per household per year (gpy/hh)	1,095 0
Total water use per household per year (gpy/hh)	109,500 0
Hours per workday	8 00
Expected effective life of POU (years)	5 0
Expected effective life of POE (years)	10 0
Expected effective life of Central Plant (years)	20 0
Minimally skilled wage rate ($/hr)	$14 50
Skilled wage rate ($/hr)	$28 00
Installation travel and preparation time (hrs/day)	2 00
POU installation (hrs/unit)	1 00
POE installation (hrs/unit)	3 00
Maintenance travel and preparation time (hrs/day)	2 00
POU maintenance (hrs/unit)	0 75
POE maintenance (hrs/unit)	2 00
Sampling frequency (samples/hh/yr)	1 00
Sampling travel and preparation time (hrs/day)	1 00
POU sampling time (hrs/sample)	0 25
POE sampling time (hrs/sample)	0 50
Sampling and maintenance coordination time (hrs/hh/yr)	1 00
Amortization rate	10 0%
Contingency fee	15 0%

Notes

- All italicized entries incorporate assumptions to permit comparison with Cadmus cost curves
- All sampling trips take place at same time as maintenance

Electrical costs are ignored in the calculation of total annual costs

Replacement Parts

POU Component	Contaminant	Cost	Expected Life
AA Cartridge	Arsenic	$80 00	38
GAC Cartridge	Alachlor	$40 00	38
AX Cartridge	Arsenic/Nitrate	$80 00	38
CX Cartridge	Copper	$70 00	38
RO Membrane	Arsenic	$135 00	150
RO Membrane	Nitrate	$135 00	300
Particulate Filter	Any	$15 00	75
GAC pre-/post-filter	Any	$20 00	75

POE Component	Contaminant	Cost	Treatment Capacity
AA	Arsenic	$85 00	#DIV/0!
GAC	[illegible]	$80 00	82,500
GAC	Radon (300)	$80 00	#DIV/0!
GAC	Radon (1,500)	$80 00	#DIV/0!
AX	Arsenic	$128 00	109,500
AX	Nitrate	$128 00	54,750
CX	Copper	$100 00	109 500
UV Bulb	Microbiologicals	$150 00	109 500

Bulk Discount Rates

Unit Description	Number of Units	Discount
POU	10	15 0%
	50	22 5%
	100+	30 0%
POE (not RO or Rn)	10	15 0%
	50	22 5%
	100+	30 0%
POE RO	10	10 0%
	50	12 5%
	100+	15 0%
POE for Rn	10	10 0%
	50+	20 0%

PPI. Final demand less energy

Year	Level	1997 19XX
1985	98 3	0 00
1986	98 3	0 00
1987	100 2	0 00
1988	103 5	0 00
1989	108 2	0 00
1990	112 5	0 00
1991	115 4	0 00
1992	117 1	0 00
1993	118 9	0 00
1994	120 1	0 00
1995	122 4	0 00
1996	125 0	0 00
1997	125 5	0 00
pre-1985	NA	1 000

PPI. Water and sewer supply construction

Year	Level	1997 19XX
1986	99 5	0 00
1987	101 1	0 00
1988	105 7	0 00
1989	110 2	0 00
1990	113 4	0 00
1991	115 8	0 00
1992	116 8	0 00
1993	118 8	0 00
1994	122 0	0 00
1995	126 8	0 00
1996	130 0	0 00
1997	132 8	0 00
pre-1986	NA	1 00

Key

Acronym	Meaning	Acronym	Meaning
AA	Activated Alumina	NP	Not Provided
AX	Anion Exchange	POE	Point-of-Entry
CpKGT	Included in Cost per 1 000 Gal Treated	POU	Point-of-Use
CX	Cation Exchange	PPI	Producer Price Index
DBA	Diffuse Bubble Aeration	Rn	Radon
DBCP	Dibromochloropropane	RO	Reverse Osmosis
DCP	Dichloropropane	TAC	Included in Total Annual Cost
EDB	Ethyldibromide	TAOMC	Included in Total Annial O&M Cost
GAC	Activated Carbon	TCE	Trichloroethylene
IWP	Included with Purchase	UV	Ultraviolet Disinfection
NA	Not Applicable		

Lab Fees

Contaminant	Fee
Arsenic	$8 50
Copper	$12 00
Nitrate	$11 00
Radon	$48 50 -
Alachlor	$98 00
DBCP/EDB	$87 00
TCE/DCP	$173 00
Total Coliform	$16 00

Lab Discount Rates

# of Samples	Discount
20 to 49	10%
50+	20%

Installation Discount Rates

# of Units	Discount
10 +	33%

Conversion Factors

Gallon	Liter	3 785
Grain	Milligram	64 798

Table 4.4.2: Capital and Operation and Maintenance Cost Data -- Vendor Survey

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
AA	POE	Vendor Two (Single tank)	Arsenic	150	$1,545	$112	$249	$1,906	$310	$166	$121	$15	$301	$611	$5 58	$5 58
AA	POE	Vendor Two (Dual tank)	Arsenic	150	$2,195	$112	$346	$2,653	$432	$166	$121	$15	$301	$733	$6.69	$6 69
AA	POU	Vendor Three	Arsenic	150	$110	$19	$19	$149	$39	$121	$32	$15	$167	$206	$188	$1 88
AA	POE	Vendor Two (Single tank)	Nitrate	40	$1,545	$112	$249	$1,906	$310	$241	$123	$15	$378	$688	$6.29	$6.29
AA	POE	Vendor Two (Dual tank)	Nitrate	40	$2,195	$112	$346	$2,653	$432	$241	$123	$15	$378	$810	$7 40	$7 40
AC	POU	Vendor One	Alachlor	92	$295	IWP	$44	$339	$89	$98	$121	$15	$234	$323	$295	$2.95
AC	POU	Vendor One	Alachlor	92	$195	$19	$32	$246	$65	$77	$121	$15	$213	$278	$254	$2 54
AC	POU	Vendor Two	Alachlor	92	$220	IWP	$33	$253	$67	$115	$121	$15	$250	$317	$289	$2.89
AC	POU	Vendor Three	Alachlor	92	$145	$19	$25	$189	$50	$63	$121	$15	$199	$249	$227	$2 27
AC	POE	Vendor One	Radon (1,500)	100	$2,045	$225	$341	$2,611	$425	$525	$159	$15	$698	$1,123	$10.25	$10.25
AC	POE	Vendor Two	Radon (1,500)	100	$1,695	IWP	$254	$1,949	$317	$250	$159	$15	$423	$740	$6 76	$6 76
AC	POE	Vendor One	Radon (300)	16	$2,045	$225	$341	$2,611	$425	$525	$159	$15	$698	$1,123	$10.25	$10.25
AC	POE	Vendor Two	Radon (300)	16	$1,695	IWP	$254	$1,949	$317	$250	$159	$15	$423	$740	$6 76	$6 76
AC	POE	Vendor One	Radon (300)	100	$2,045	$225	$341	$2,611	$425	$525	$159	$15	$698	$1,123	$10.25	$10.25
AC	POE	Vendor Two	Radon (300)	100	$1,695	IWP	$254	$1,949	$317	$250	$159	$15	$423	$740	$6 76	$6 76
AC	POE	Vendor One	TCE	60	$2,045	$225	$341	$2,611	$425	$525	$285	$15	$824	$1,249	$11.41	$11.41
AC	POE	Vendor Two	TCE	60	$1,695	IWP	$254	$1,949	$317	$250	$285	$15	$549	$866	$7 91	$7.91
AC/DBA	POE	Vendor Two	Radon (1,500)	100	$2,095	IWP	$314	$2,409	$392	$250	$159	$15	$423	$815	$7.44	$7.44
AC/DBA	POE	Vendor Four	Radon (1,500)	100	$2,045	IWP	$307	$2,352	$383	$300	$159	$15	$473	$856	$7 81	$7 81
AC/DBA	POE	Vendor Two	Radon (300)	16	$2,095	IWP	$314	$2,409	$392	$250	$159	$15	$423	$815	$7.44	$7.44
AC/DBA	POE	Vendor Four	Radon (300)	16	$2,045	IWP	$307	$2,352	$383	$300	$159	$15	$473	$856	$7 81	$7 81
AC/DBA	POE	Vendor Two	Radon (300)	100	$2,095	IWP	$314	$2,409	$392	$250	$159	$15	$423	$815	$7.44	$7.44
AC/DBA	POE	Vendor Four	Radon (300)	100	$2,045	IWP	$307	$2,352	$383	$300	$159	$15	$473	$856	$7 81	$7 81
AC/DBA	POE	Vendor Two	TCE	60	$2,095	IWP	$314	$2,409	$392	$250	$285	$15	$549	$941	$8.60	$8.60
AC/DBA	POE	Vendor Four	TCE	60	$2,045	IWP	$307	$2,352	$383	$300	$285	$15	$600	$982	$8 97	$8 97
AX	POE	Vendor Four	Nitrate	40	$1,545	IWP	$232	$1,777	$289	$165	$123	$15	$302	$591	$5.40	$5.40
CX	POE	Vendor One	Copper	10	$1,345	$225	$236	$1,806	$294	$165	$124	$15	$303	$597	$5 45	$5 45
CX	POE	Vendor Two	Copper	10	$1,645	$112	$264	$2,021	$329	$165	$124	$15	$303	$632	$5.77	$5.77
pH	POE	Vendor Two	Copper	10	$895	$112	$151	$1,158	$188	$91	$124	$15	$230	$418	$3 82	$3 82
RO	POU	Vendor Four	Alachlor	92	$745	IWP	$112	$857	$226	$181	$121	$15	$317	$543	$496	$4.96
RO	POU	Vendor One	Arsenic	150	$844	$125	$145	$1,114	$294	$123	$32	$15	$169	$463	$423	$4 23
RO	POU	Vendor Two	Arsenic	150	$495	$88	$87	$670	$177	$146	$32	$15	$192	$369	$338	$3.38
RO	POU	Vendor Four	Arsenic	150	$745	IWP	$112	$857	$226	$181	$32	$15	$227	$453	$414	$4 14
RO	POU	Vendor One	Copper	10	$844	$125	$145	$1,114	$294	$123	$35	$15	$173	$467	$426	$4.26
RO	POU	Vendor Two	Copper	10	$495	$88	$87	$670	$177	$146	$35	$15	$195	$372	$340	$3 40
RO	POU	Vendor Four	Copper	10	$745	IWP	$112	$857	$226	$181	$35	$15	$231	$457	$417	$4.17
RO	POE	Vendor Four	Arsenic/Nitrate	40	$12,545	IWP	$1,882	$14,427	$2,348	$825	$123	$15	$962	$3,310	$30 23	$30 23
RO	POU	Vendor One	Nitrate	40	$844	$125	$145	$1,114	$294	$123	$34	$15	$172	$466	$425	$4.25
RO	POU	Vendor Two	Nitrate	40	$495	$88	$87	$670	$177	$146	$34	$15	$194	$371	$339	$3 39

Table 4.4.2: Capital and Operation and Maintenance Cost Data -- Vendor Survey

Assumptions

Number of people per household	3 0
Water consumed per person per day (gpd/per)	1 0
Total water use per person per day (gpd/per)	100 0
Water consumed per household per year (gpy/hh)	1 095 0
Total water use per household per year (gpy/hh)	109 500 0
Hours per workday	8 00
Expected effective life of POU (years)	5 0
Expected effective life of POE (years)	10 0
Expected effective life of Central Plant (years)	20 0
Minimally skilled wage rate ($/hr)	$14 50
Skilled wage rate ($/hr)	$28 00
Installation travel and preparation time (hrs/day)	2 00
POU installation (hrs/unit)	1 00
POE installation (hrs/unit)	3 00
Maintenance travel and preparation time (hrs/day)	2 00
POU maintenance (hrs/unit)	0 75
POE maintenance (hrs/unit)	2 00
Sampling frequency (samples/hh/yr)	1 00
Sampling travel and preparation time (hrs/day)	1 00
POU sampling time (hrs/sample)	0 25
POE sampling time (hrs/sample)	0 50
Sampling and maintenance coordination time (hrs/hh/yr)	1 00
Amortization rate	10 0%
Contingency fee	15 0%

Notes

- All italicized entries incorporate assumptions to permit comparison with Cadmus cost curves
- All sampling trips take place at same time as maintenance
  Electrical costs are ignored in the calculation of total annual costs

Replacement Parts

POU Component	Contaminant	Cost	Expected Life
AA Cartridge	Arsenic	$80 00	0
GAC Cartridge	Alachlor	$40 00	0
AX Cartridge	Arsenic/Nitrate	$80 00	0
CX Cartridge	Copper	$70 00	0
RO Membrane	Arsenic	$135 00	0
RO Membrane	Nitrate	$135 00	0
Particulate Filter	Any	$15 00	0
GAC pre-/post filter	Any	$20 00	0

POE Component	Contaminant	Cost	Treatment Capacity
AA	Arsenic	$85 00	#DIV/0!
GAC	[illegible]	$80 00	82,500
GAC	Radon (300)	$80 00	#DIV/0!
GAC	Radon (1,500)	$80 00	#DIV/0!
AX	Arsenic	$126 00	109 500
AX	Nitrate	$126 00	54,750
CX	Copper	$100 00	109,500
UV Bulb	Microbiologicals	$150 00	109,500

Bulk Discount Rates

Unit Description	Number of Units	Discount
POU	10	15 0%
	50	22 5%
	100+	30 0%
POE (not RO or Rn)	10	15 0%
	50	22 5%
	100+	30 0%
POE RO	10	10 0%
	50	12 5%
	100+	15 0%
POE for Rn	10	10 0%
	50+	20 0%

PPI, Final demand less energy

Year	Level	1997 19XX
1985	96 3	0 00
1986	98 3	0 00
1987	100 2	0 00
1988	103 5	0 00
1989	108 2	0 00
1990	112 5	0 00
1991	115 4	0 00
1992	117 1	0 00
1993	118 9	0 00
1994	120 1	0 00
1995	122 4	0 00
1996	125 0	0 00
1997	125 5	0 00
pre-1985	NA	1 000

PPI, Water and sewer supply construction

Year	Level	1997 19XX
1986	99 5	0 00
1987	101 1	0 00
1988	105 7	0 00
1989	110 2	0 00
1990	113 4	0 00
1991	115 8	0 00
1992	116 8	0 00
1993	118 8	0 00
1994	122 0	0 00
1995	126 8	0 00
1996	130 0	0 00
1997	132 8	0 00
pre-1986	NA	1 00

Key

Acronym	Meaning	Acronym	Meaning
AA	Activated Alumina	NP	Not Provided
AX	Anion Exchange	POE	Point-of-Entry
CpKGT	Included in Cost per 1 000 Gal Treated	POU	Point-of-Use
CX	Cation Exchange	PPI	Producer Price Index
DBA	Diffuse Bubble Aeration	Rn	Radon
DBCP	Dibromochloropropane	RO	Reverse Osmosis
DCP	Dichloropropane	TAC	Included in Total Annual Cost
EDB	Ethyldibromide	TAOMC	Included in Total Annial O&M Cost
GAC	Activated Carbon	TCE	Trichloroethylene
IWP	Included with Purchase	UV	Ultraviolet Disinfection
NA	Not Applicable		

Lab Fees

Contaminant	Fee
Arsenic	$8 50
Copper	$12 00
Nitrate	$11 00
Radon	$48 50
Alachlor	$98 00
DBCP/EDB	$87 00
TCE/DCP	$173 00
Total Coliform	$16 00

Lab Discount Rates

# of Samples	Discount
20 to 49	10%
50+	20%

Installation Discount Rates

# of Units	Discount
10 +	33%

Conversion Factors

Gallon	Liter	3 785
Grain	Milligram	64 798

Table 4.4.3: Capital and Operation and Maintenance Cost Data -- Cadmus

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
AA	POU	Cadmus	Arsenic	1	$239	$19	$39	$297	$78	$365	$32	$15	$411	$489	$447	$4 47
AA	POU	Cadmus	Arsenic	10	$203	$13	$32	$248	$66	$312	$32	$15	$358	$424	$387	$3.87
AA	POU	Cadmus	Arsenic	50	$185	$13	$30	$228	$60	$286	$30	$15	$330	$390	$356	$3 56
AA	POU	Cadmus	Arsenic	100	$167	$13	$27	$207	$55	$260	$30	$15	$304	$359	$328	$3.28
AC	POE	Cadmus	Alachlor	1	$2,554	$112	$400	$3,066	$499	$304	$191	$15	$510	$1,009	$9	$9 21
AC	POE	Cadmus	Alachlor	10	$2,171	$75	$337	$2,582	$420	$270	$191	$15	$475	$896	$8	$8.18
AC	POE	Cadmus	Alachlor	50	$1,979	$75	$308	$2,362	$384	$253	$168	$15	$435	$820	$7	$7 49
AC	POE	Cadmus	Alachlor	100	$1,788	$75	$279	$2,142	$349	$235	$168	$15	$418	$767	$7	$7.00
AC	POE	Cadmus	Radon (1500)	1	$1,682	$112	$269	$2,063	$336	$305	$140	$15	$459	$794	$7	$7 26
AC	POE	Cadmus	Radon (1500)	10	$1,514	$75	$238	$1,827	$297	$282	$140	$15	$436	$733	$7	$6.69
AC	POE	Cadmus	Radon (1500)	50	$1,346	$75	$213	$1,633	$266	$259	$127	$15	$400	$666	$6	$6 08
AC	POE	Cadmus	Radon (1500)	100	$1,346	$75	$213	$1,633	$266	$259	$127	$15	$400	$666	$6	$6.08
AC	POE	Cadmus	Radon (300)	1	$4,110	$112	$633	$4,855	$790	$309	$140	$15	$463	$1,253	$11	$11 44
AC	POE	Cadmus	Radon (300)	10	$3,699	$75	$566	$4,340	$706	$285	$140	$15	$439	$1,146	$10	$10.46
AC	POE	Cadmus	Radon (300)	50	$3,288	$75	$504	$3,867	$629	$262	$127	$15	$403	$1,033	$9	$9 43
AC	POE	Cadmus	Radon (300)	100	$3,288	$75	$504	$3,867	$629	$262	$127	$15	$403	$1,033	$9	$9 43
AC	POE	Cadmus	TCE	1	$2,554	$112	$400	$3,066	$499	$304	$266	$15	$585	$1,084	$10	$9 90
AC	POE	Cadmus	TCE	10	$2,171	$75	$337	$2,582	$420	$270	$266	$15	$550	$971	$9	$8.86
AC	POE	Cadmus	TCE	50	$1,979	$75	$308	$2,362	$384	$253	$228	$15	$495	$880	$8	$8 03
AC	POE	Cadmus	TCE	100	$1,788	$75	$279	$2,142	$349	$235	$228	$15	$478	$827	$8	$7.55
AX	POE	Cadmus	Arsenic	1	$1,345	$112	$219	$1,676	$273	$201	$86	$15	$301	$573	$5	$5 24
AX	POE	Cadmus	Arsenic	10	$1,143	$75	$183	$1,401	$228	$182	$86	$15	$282	$510	$5	$4.65
AX	POE	Cadmus	Arsenic	50	$1,042	$75	$168	$1,285	$209	$172	$84	$15	$271	$480	$4	$4 38
AX	POE	Cadmus	Arsenic	100	$942	$75	$152	$1,169	$190	$163	$84	$15	$261	$451	$4	$4.12
AC	POU	Cadmus	Alachlor	1	$199	$19	$33	$251	$66	$205	$121	$15	$340	$406	$371	$3 71
AC	POU	Cadmus	Alachlor	10	$169	$13	$27	$209	$55	$176	$121	$15	$312	$367	$335	$3.35
AC	POU	Cadmus	Alachlor	50	$154	$13	$25	$192	$51	$162	$102	$15	$278	$329	$300	$3 00
AC	POU	Cadmus	Alachlor	100	$139	$13	$23	$175	$46	$148	$102	$15	$264	$310	$283	$2.83
AX	POU	Cadmus	Arsenic	1	$239	$19	$39	$297	$78	$365	$32	$15	$411	$489	$447	$4 47
AX	POU	Cadmus	Arsenic	10	$203	$13	$32	$248	$66	$312	$32	$15	$358	$424	$387	$3.87
AX	POU	Cadmus	Arsenic	50	$185	$13	$30	$228	$60	$286	$30	$15	$330	$390	$356	$3 56
AX	POU	Cadmus	Arsenic	100	$167	$13	$27	$207	$55	$260	$30	$15	$304	$359	$328	$3.28
AX	POE	Cadmus	Nitrate	1	$1,345	$112	$219	$1,676	$273	$327	$88	$15	$429	$702	$6	$6 41
AX	POE	Cadmus	Nitrate	10	$1,143	$75	$183	$1,401	$228	$289	$88	$15	$391	$619	$6	$5.66
AX	POE	Cadmus	Nitrate	50	$1,042	$75	$168	$1,285	$209	$270	$86	$15	$370	$579	$5	$5 29
AX	POE	Cadmus	Nitrate	100	$942	$75	$152	$1,169	$190	$251	$86	$15	$351	$542	$5	$4.95
AX	POU	Cadmus	Nitrate	1	$239	$19	$39	$297	$78	$365	$34	$15	$413	$492	$449	$4 49
AX	POU	Cadmus	Nitrate	10	$203	$13	$32	$248	$66	$312	$34	$15	$361	$426	$389	$3.89
AX	POU	Cadmus	Nitrate	50	$185	$13	$30	$228	$60	$286	$32	$15	$332	$392	$358	$3 58
AX	POU	Cadmus	Nitrate	100	$167	$13	$27	$207	$55	$260	$32	$15	$306	$361	$329	$3.29

Table 4.4.3: Capital and Operation and Maintenance Cost Data -- Cadmus

Type of Unit	Point of Application	Source	Contaminant	Number of Households (hh)	Purchase Price ($/hh)	Installation Cost ($/hh)	Contingency Cost ($/hh)	Total Capital Cost (1997$/hh)	Amortized Capital Costs (1997$/hh/yr)	Annual Maintenance Cost ($/hh/yr)	Annual Sampling Cost ($/hh/yr)	Annual Administrative Cost ($/hh/yr)	Total Annual O&M Cost (1997$/hh/yr)	Total Annual Costs (1997$/hh/yr)	Cost per 1,000 Gallons Treated (1997$/Kgal)	Cost per 1,000 Gallons Used (1997$/Kgal)
CX	POE	Cadmus	Copper	1	$1,345	$112	$219	$1,676	$273	$175	$89	$15	$278	$551	$5	$5 03
CX	POE	Cadmus	Copper	10	$1,143	$75	$183	$1,401	$228	$160	$89	$15	$263	$491	$4	$4.49
CX	POE	Cadmus	Copper	50	$1,042	$75	$168	$1,285	$209	$152	$87	$15	$253	$462	$4	$4 22
CX	POE	Cadmus	Copper	100	$942	$75	$152	$1,169	$190	$145	$87	$15	$246	$436	$4	$3.98
CX	POU	Cadmus	Copper	1	$229	$19	$37	$286	$75	$325	$35	$15	$374	$450	$411	$4 11
CX	POU	Cadmus	Copper	10	$195	$13	$31	$239	$63	$278	$35	$15	$328	$391	$357	$3.57
CX	POU	Cadmus	Copper	50	$177	$13	$29	$219	$58	$255	$33	$15	$302	$360	$329	$3 29
CX	POU	Cadmus	Copper	100	$160	$13	$26	$199	$53	$232	$33	$15	$279	$331	$303	$3.03
DBA	POE	Cadmus	Radon (300)	1	$4,345	$112	$669	$5,126	$834	$375	$140	$15	$529	$1,363	$12	$12 45
DBA	POE	Cadmus	Radon (300)	10	$3,911	$75	$598	$4,583	$746	$210	$140	$15	$364	$1,110	$10	$10.13
DBA	POE	Cadmus	Radon (300)	50	$3,476	$75	$533	$4,083	$665	$195	$127	$15	$336	$1,001	$9	$9 14
DBA	POE	Cadmus	Radon (300)	100	$3,476	$75	$533	$4,083	$665	$195	$127	$15	$336	$1,001	$9	$9.14
RO	POE	Cadmus	Arsenic	1	$8,445	$448	$5,336	$14,229	$2,316	$703	$121	$15	$838	$3,154	$29	$28 80
RO	POE	Cadmus	Arsenic	10	$7,601	$299	$4,740	$12,639	$2,057	$648	$121	$15	$783	$2,840	$26	$25.93
RO	POE	Cadmus	Arsenic	50	$7,389	$299	$4,613	$12,301	$2,002	$634	$119	$15	$767	$2,769	$25	$25 29
RO	POE	Cadmus	Arsenic	100	$7,178	$299	$4,486	$11,963	$1,947	$620	$119	$15	$754	$2,700	$25	$24.66
RO	POU	Cadmus	Arsenic	1	$730	$19	$112	$862	$227	$220	$32	$15	$266	$493	$450	$4 50
RO	POU	Cadmus	Arsenic	10	$621	$13	$95	$728	$192	$189	$32	$15	$235	$427	$390	$3.90
RO	POU	Cadmus	Arsenic	50	$566	$13	$87	$665	$176	$173	$30	$15	$218	$393	$359	$3 59
RO	POU	Cadmus	Arsenic	100	$511	$13	$79	$602	$159	$158	$30	$15	$203	$361	$330	$3.30
RO	POE	Cadmus	Nitrate	1	$8,445	$448	$5,336	$14,229	$2,316	$528	$123	$15	$666	$2,982	$27	$27 23
RO	POE	Cadmus	Nitrate	10	$7,601	$299	$4,740	$12,639	$2,057	$490	$123	$15	$628	$2,685	$25	$24.52
RO	POE	Cadmus	Nitrate	50	$7,389	$299	$4,613	$12,301	$2,002	$481	$121	$15	$616	$2,618	$24	$23 91
RO	POE	Cadmus	Nitrate	100	$7,178	$299	$4,486	$11,963	$1,947	$471	$121	$15	$607	$2,554	$23	$23.32
RO	POU	Cadmus	Nitrate	1	$730	$19	$112	$862	$227	$152	$34	$15	$201	$428	$391	$3 91
RO	POU	Cadmus	Nitrate	10	$621	$13	$95	$728	$192	$131	$34	$15	$180	$372	$340	$3.40
RO	POU	Cadmus	Nitrate	50	$566	$13	$87	$665	$176	$121	$32	$15	$168	$343	$313	$3 13
RO	POU	Cadmus	Nitrate	100	$511	$13	$79	$602	$159	$111	$32	$15	$157	$316	$289	$2.89

Table 4.4.3: Capital and Operation and Maintenance Cost Data -- Cadmus

Assumptions

Number of people per household	3 0
Water consumed per person per day (gpd/per)	1 0
Total water use per person per day (gpd/per)	100 0
Water consumed per household per year (gpy/hh)	1,095 0
Total water use per household per year (gpy/hh)	109,500 0
Hours per workday	8 00
Expected effective life of POU (years)	5 0
Expected effective life of POE (years)	10 0
Expected effective life of Central Plant (years)	20 0
Minimally skilled wage rate ($/hr)	$14 50
Skilled wage rate ($/hr)	$28 00
Installation travel and preparation time (hrs/day)	2 00
POU installation (hrs/unit)	1 00
POE installation (hrs/unit)	3 00
Maintenance travel and preparation time (hrs/day)	2 00
POU maintenance (hrs/unit)	0 75
POE maintenance (hrs/unit)	2 00
Sampling frequency (samples/hh/yr)	1 00
Sampling travel and preparation time (hrs/day)	1 00
POU sampling time (hrs/sample)	0 25
POE sampling time (hrs/sample)	0 50
Samping and maintenance coordination time (hrs/hh/yr)	1 00
Amortization rate	10 0%
Contingency fee	15 0%

Notes

- All italicized entries incorporate assumptions to permit comparison with Cadmus cost curves
- All sampling trips take place at same time as maintenance

Electrical costs are ignored in the calculation of total annual costs

Replacement Parts

POU Component	Contaminant	Cost	Expected Life
AA Cartridge	Arsenic	$80 00	0
GAC Cartridge	Alachlor	$40 00	0
AX Cartridge	Arsenic/Nitrate	$80 00	0
CX Cartridge	Copper	$70 00	0
RO Membrane	Arsenic	$135 00	1
RO Membrane	Nitrate	$135 00	2
Particulate Filter	Any	$15 00	1
GAC pre-/post-filter	Any	$20 00	1

POE Component	Contaminant	Cost	Treatment Capacity
AA	Arsenic	$65 00	#DIV/0!
GAC	[illegible]	$80 00	82,500
GAC	Radon (300)	$80 00	#DIV/0!
GAC	Radon (1,500)	$80 00	#DIV/0!
AX	Arsenic	$126 00	109 500
AX	Nitrate	$126 00	54,750
CX	Copper	$100 00	109 500
UV Bulb	Microbiologicals	$150 00	109,500

Bulk Discount Rates

Unit Description	Number of Units	Discount
POU	10	15 0%
	50	22 5%
	100+	30 0%
POE (not RO or Rn)	10	15 0%
	50	22 5%
	100+	30 0%
POE RO	10	10 0%
	50	12 5%
	100+	15 0%
POE for Rn	10	10 0%
	50+	20 0%

PPI, Final demand less energy

Year	Level	1997.19XX
1985	96 3	0 00
1986	98 3	0 00
1987	100 2	0 00
1988	103 5	0 00
1989	108.2	0 00
1990	112 5	0 00
1991	115 4	0 00
1992	117 1	0 00
1993	118 9	0 00
1994	120 1	0 00
1995	122 4	0 00
1996	125 0	0 00
1997	125 5	0 00
pre-1985	NA	1 000

PPI, Water and sewer supply construction

Year	Level	1997-19XX
1986	99 5	1 19
1987	101 1	1 18
1988	105 7	1 12
1989	110 2	1 08
1990	113 4	1 05
1991	115 8	1 03
1992	116 8	1 02
1993	118 8	1 00
1994	122 0	0 97
1995	126 8	0 94
1996	130 0	0 91
1997	132 8	0 90
pre-1986	NA	1 03

Key

Acronym	Meaning	Acronym	Meaning
AA	Activated Alumina	NP	Not Provided
AX	Anion Exchange	POE	Point-of-Entry
CpKGT	Included in Cost per 1 000 Gal Treated	POU	Point-of-Use
CX	Cation Exchange	PPI	Producer Price Index
DBA	Diffuse Bubble Aeration	Rn	Radon
DBCP	Dibromochloropropane	RO	Reverse Osmosis
DCP	Dichloropropane	TAC	Included in Total Annual Cost
EDB	Ethyldibromide	TAOMC	Included in Total Annial O&M Cost
GAC	Activated Carbon	TCE	Trichloroethylene
IWP	Included with Purchase	UV	Ultraviolet Disinfection
NA	Not Applicable		

Lab Fees

Contaminant	Fee
Arsenic	$8 50
Copper	$12 00
Nitrate	$11 00
Radon	$46 50
Alachlor	$98 00
DBCP/EDB	$87 00
TCE/DCP	$173 00
Total Coliform	$16 00

Lab Discount Rates

# of Samples	Discount
20 to 49	10%
50+	20%

Installation Discount Rates

# of Units	Discount
10 +	33%

Conversion Factors

Gallon	Liter	3 785
Grain	Milligram	64 798

In identical processes, the least-cost POE and least-cost central treatment technologies are determined. To determine the least-cost treatment strategy for small communities of different sizes (i.e., the community size at which POE becomes less expensive than POU treatment and at which central treatment becomes less expensive than POE treatment and POU treatment), the least-cost treatment options for POU, POE, and central treatment of the contaminant of concern are compared.

Cost curves for central treatment with each technology were derived from data provided by Gumerman (1984) for the capital and O&M costs of central treatment plants of varying capacity. In order to account for inflation and changes within the industry over the last 15 years, the costs provided by Gumerman were adjusted using the Producer Price Index for "water and sewer supply construction." The water supply and construction sub-Index was chosen to reflect pricing developments within the water treatment industry. Because the current series begins in 1986, a pre-1986 index was derived from the average yearly rate of increase in the Index from 1986 to 1997. Central treatment costs provided by Gumerman were not otherwise adjusted.

The caveats noted for each treatment technology in section 1.3 and the particular treatment requirements noted for each contaminant in sections 2 and 3 remain in effect (e.g., the use of POE RO units may be illegal in certain localities).

4.4.1 Treatment for Arsenic

As detailed in section 2.1, arsenic may be successfully removed from drinking water by several treatment technologies. AA, AX, and RO all may lower arsenic concentrations to below the MCL of 5 μg/L. In evaluating the cost of arsenic treatment by the three technologies, an influent concentration of 100 μg/L, or twice the MCL, was assumed.

4.4.1.1 Point-of-Use Treatment for Arsenic

The cost estimate for the implementation of a POU AA strategy for the treatment of arsenic is presented in Figure 4.4.1.1.1. The Cadmus curve is consistent with the case study data. The vendor that supplied data for a POU AA system was a national hardware chain. This firm frequently provides deep discounts for water treatment equipment. However, little technical support is provided. Thus, although the vendor-supplied cost for the use of a POU AA system is less than that derived from this cost analysis, the discrepancy resulted from a trade-off (price versus service and technical expertise) rather than a skewed cost estimate.

Figure 4.4.1.1.2 presents the cost estimate for the application of a POU AX treatment strategy for arsenic. As with POU AA, the Cadmus cost curve for POU AX is consistent with the case study data. Vendors did not supply information on POU AX treatment units.

The Cadmus cost curve for POU RO treatment for arsenic is provided in Figure 4.4.1.1.3. The curve is straddled by the vendor-supplied data and also matches well with the case study costs. The schedule for membrane replacement in the San Ysidro case study was less frequent than that assumed for the purposes of this cost analysis. This may explain why the Cadmus cost estimate is somewhat higher for communities of 80 households than the case study data.

The cost curves for the implementation of POU AA, POU AX, and POU RO treatment strategies are provided in Figure 4.4.1.1.4. All three of these treatment technologies have similar costs regardless of community size. This similarity resulted from the fact that O&M labor costs drove the total costs for these devices due to their low purchase price and since lab analyses for arsenic are inexpensive (the three devices required the same number of service visits each year). However, since AX technology is not frequently found in POU applications, and since RO systems require somewhat more technical expertise to operate and maintain, AA was determined to be the least-cost treatment technology at the POU.

4.4.1.2 Point-of-Entry Treatment for Arsenic

Contacted vendors indicated that they had not installed or sold AA units for POE application. Nonetheless, POE AA and POE AX devices are identical except for the treatment media. Since the capital and O&M costs for AX resins are similar to that of AA, the total cost for POE AA and POE AX systems are nearly identical. The cost curve developed for POE AA and POE AX treatment for arsenic is presented in Figure 4.4.1.2.1. Higher costs were provided for the implementation of a POE AA or AX treatment strategy in the case studies and by the vendors. One of the vendor-supplied devices consisted of a twin-tank (rather than a single tank) AA system. Cadmus' costs are within 15 percent of those provided by the vendor for a single tank POE AA unit.

POE RO treatment is extremely expensive since POE RO devices have high capital and O&M costs. The Cadmus cost curve was based on actual POE RO installation with appropriate post-treatment and a large storage tank. While the Cadmus cost estimates presented in Figure 4.4.1.2.2 for POE RO exceed those developed by theoretical cost studies found in the literature, they were in close agreement with the cost provided by the only vendor that had experience with the installation and maintenance of a such a system. The costs for POE RO found in the literature were estimates rather than actual case studies and did not include details regarding the line-items included in the O&M of POE RO devices, the replacement schedule for device components, or the inclusion of a storage tank for treated water.

Figure 4.4.1.2.3 illustrates that POE AX treatment is significantly more cost-effective than POE RO treatment for arsenic, regardless of community size.

4.4.1.3 Central Treatment for Arsenic

Central treatment costs are provided in Figure 4.4.1.3.1. Although central AX is less expensive for smaller communities, the least-cost technology for central treatment of arsenic is AA for all communities of more than about 30 households.

4.4.1.4 Least-Cost Treatment for Arsenic

The least-cost POU, POE, and central treatment options for arsenic are presented in Figure 4.4.1.4.1. According to the Cadmus cost equations, POU application of AA technology is the least expensive treatment alternative for communities of less than about 75 households. Larger communities would be served more cost-effectively by the application of AA technology in a central treatment plant. Central treatment with AA becomes less expensive than POE (AX) treatment for arsenic for communities of more than about 50 households. POE treatment for arsenic is more expensive than POU treatment for arsenic for all studied communities.

Since both the POE and POU cost curves are relatively flat at their point of intersection with the central treatment cost curve, a small change in the price of either treatment option would result in a sizeable change in the community population at which central treatment becomes the most cost effective method of reducing arsenic concentrations in household water. For example, a 10 percent decrease in the cost of POU technology would result in central treatment becoming more cost-effective for communities of more than 85 households rather than communities of more than 75 households. In contrast, a 10 percent increase in the cost of POU technology would result in central treatment becoming more cost-effective for communities of more than 60 households rather than communities of more than 75 households.

Figure 4.4.1.1.1
POU Treatment for Arsenic with Activated Alumina

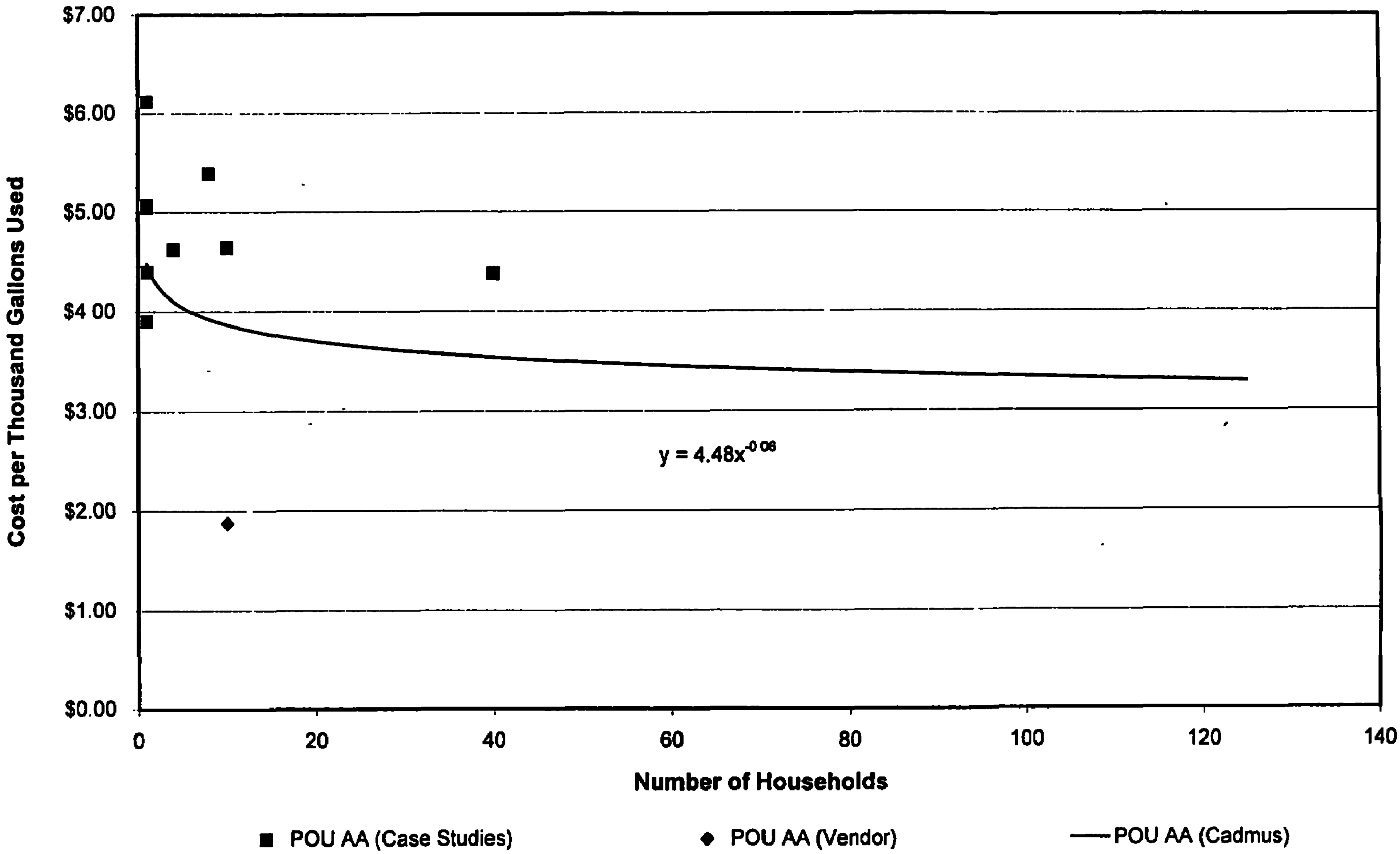


Figure 4.4.1.1.2
POU Treatment for Arsenic with Anion Exchange

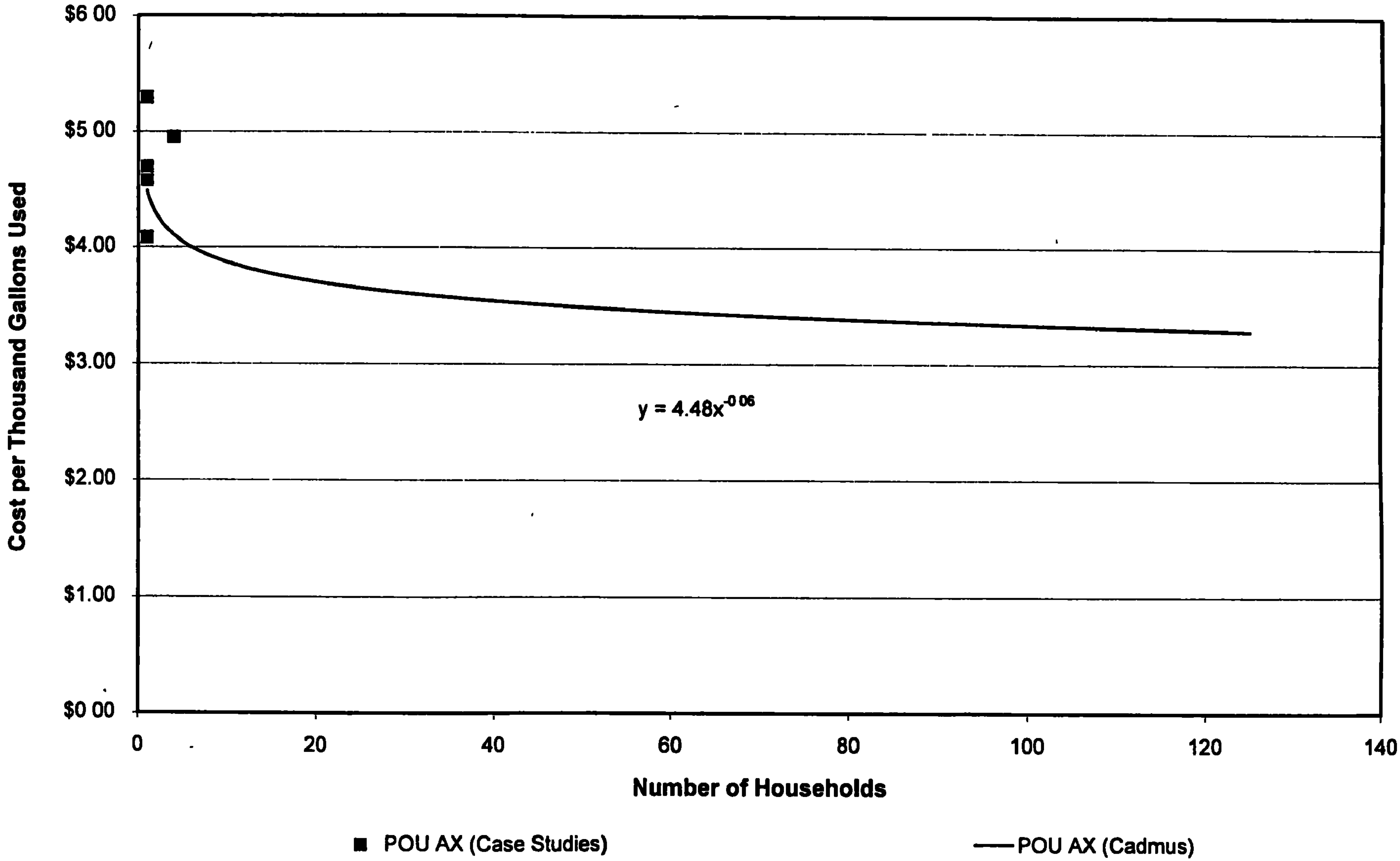


Figure 4.4.1.1.3
POU Treatment for Arsenic with Reverse Osmosis

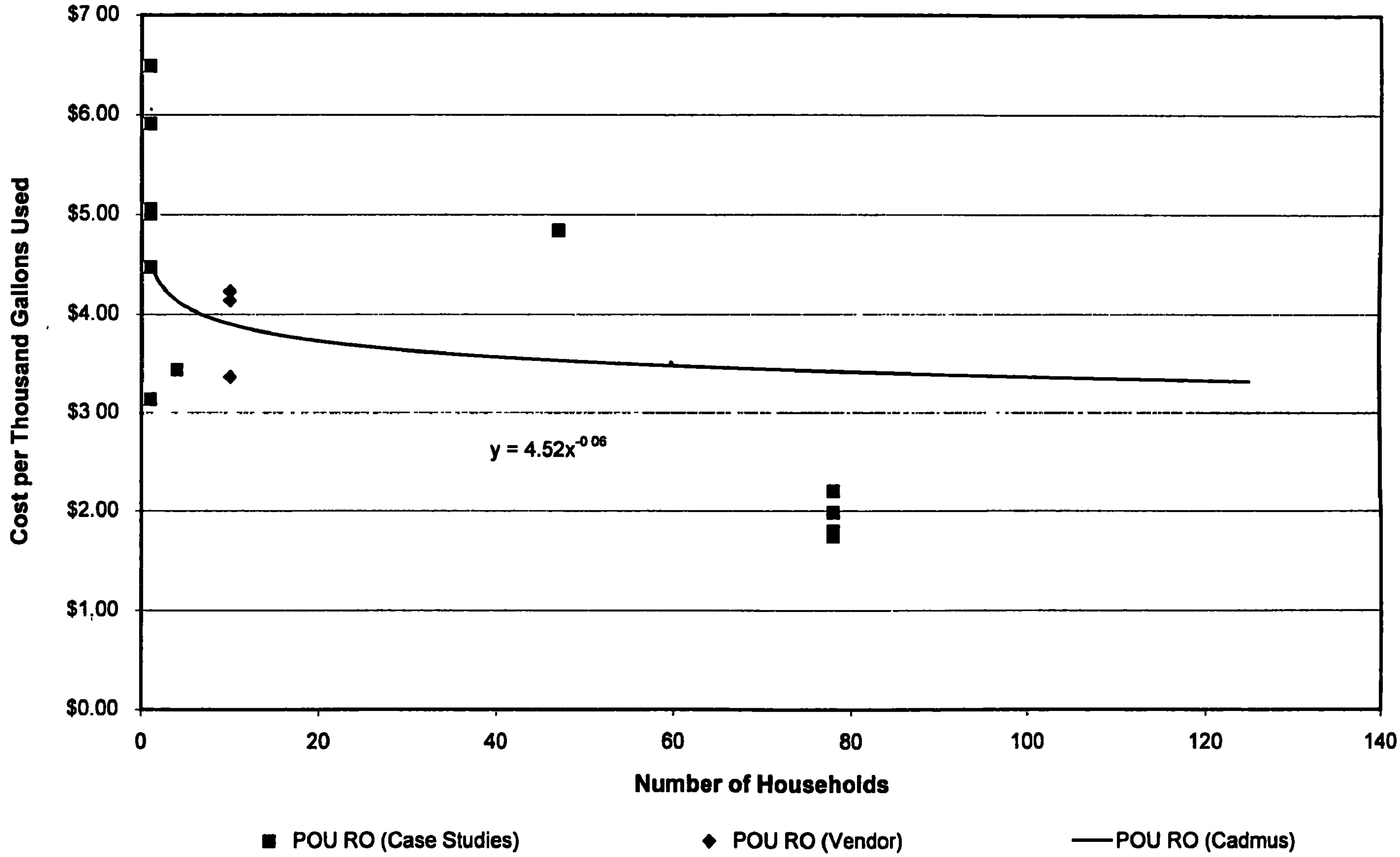


Figure 4.4.1.1.4
POU Treatment for Arsenic

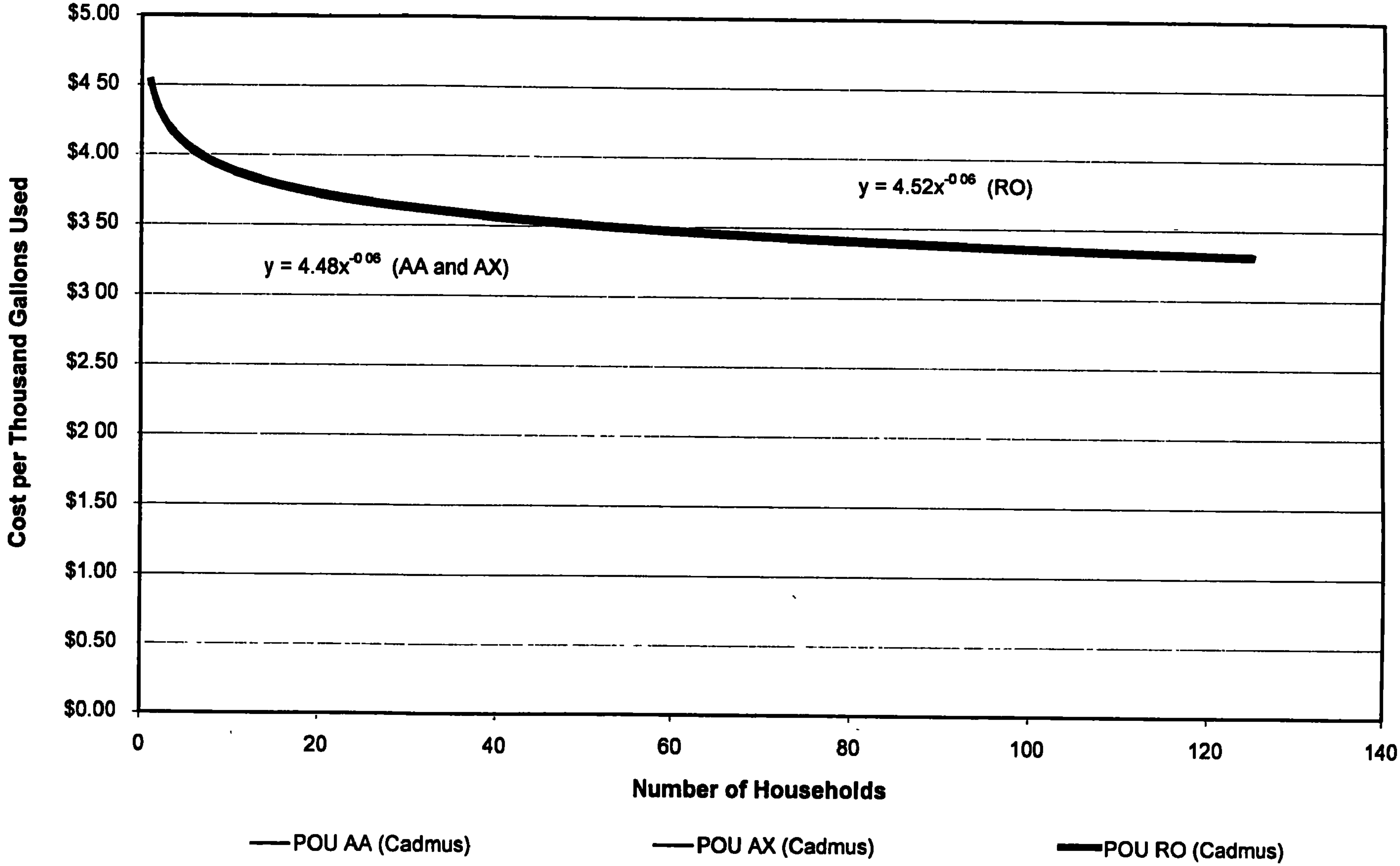


Figure 4.4.1.2.1
POE Treatment for Arsenic with Activated Alumina and Anion Exchange

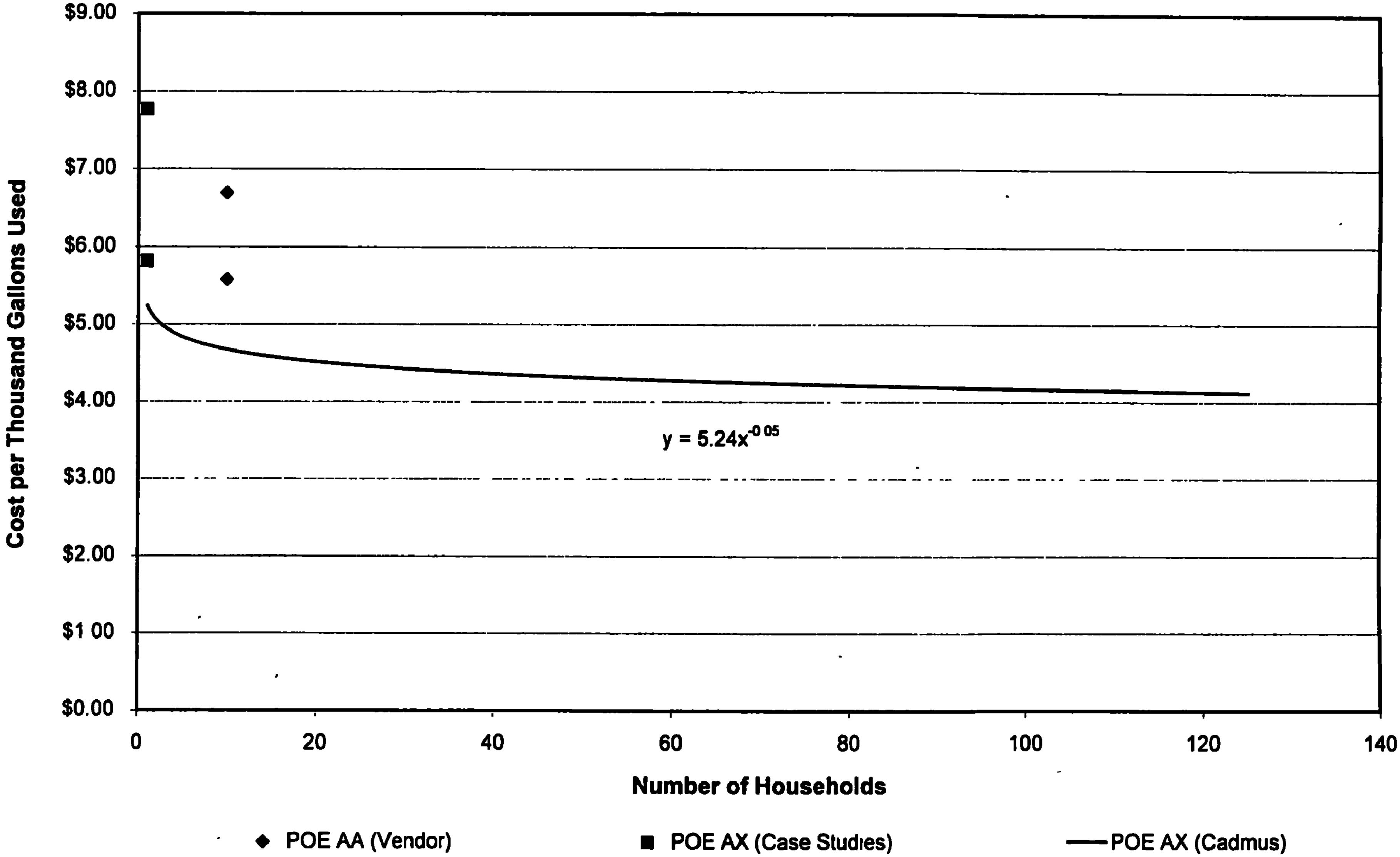
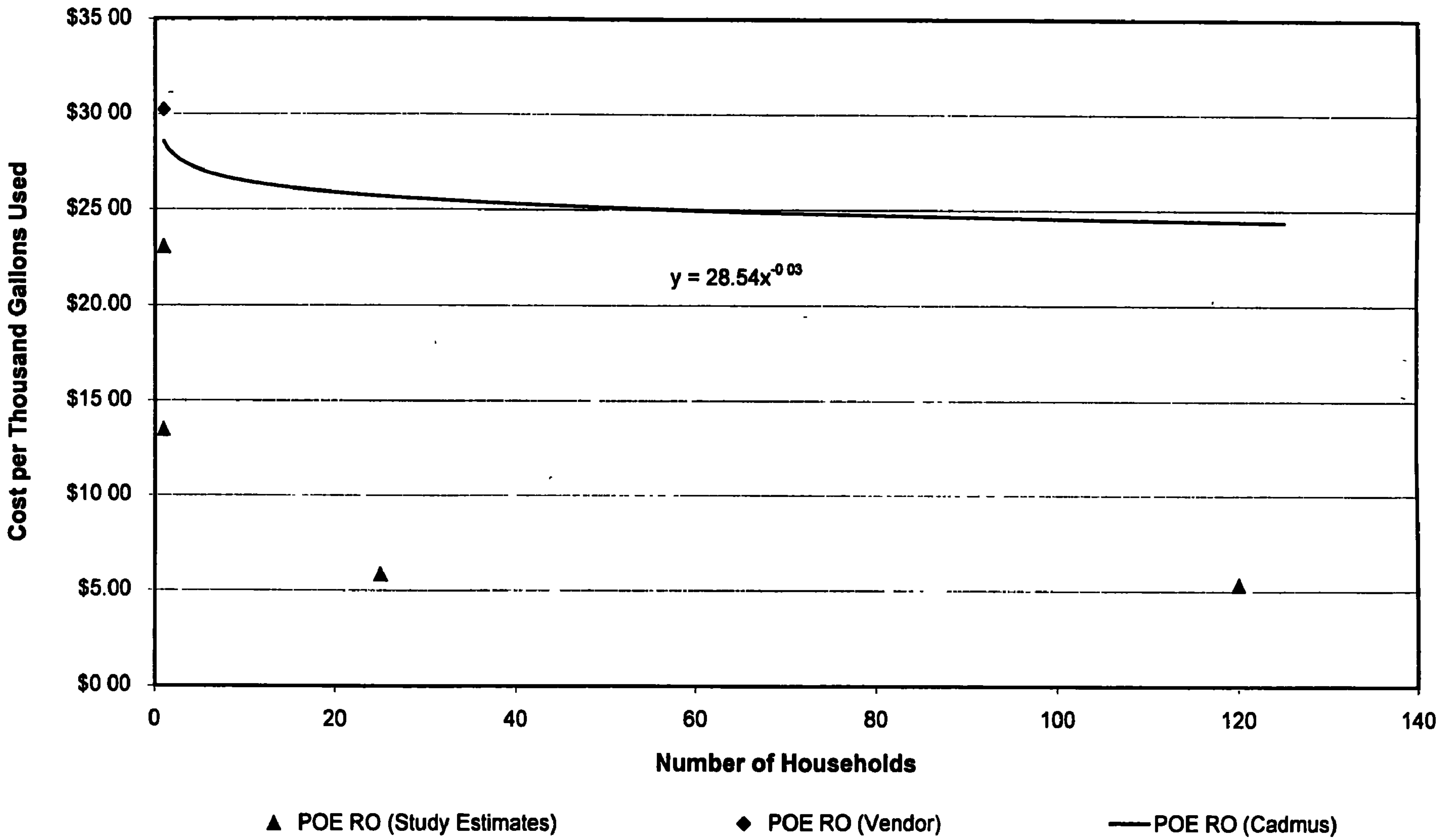


Figure 4.4.1.2.2
POE Treatment for Arsenic with Reverse Osmosis



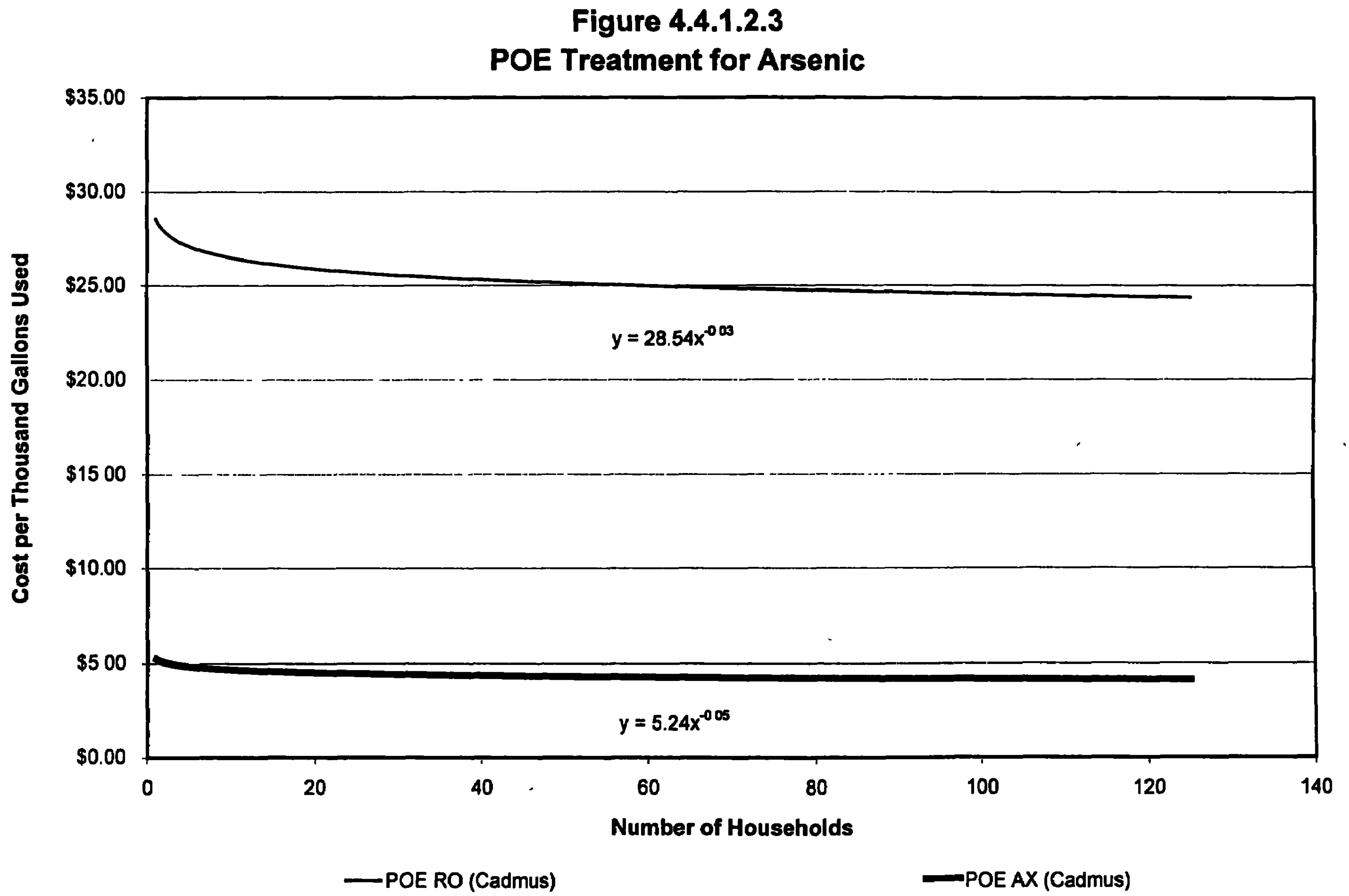


Figure 4.4.1.2.3
POE Treatment for Arsenic
Cost per Thousand Gallons Used
$35.00
$30.00
$25.00
$20.00
$15.00
$10.00
$5.00
$0.00
y = 28.54x^-0.03
y = 5.24x^-0.05
0
20
40
60
80
100
120
140
Number of Households
POE RO (Cadmus)
POE AX (Cadmus)

Figure 4.4.1.3.1
Central Treatment for Arsenic

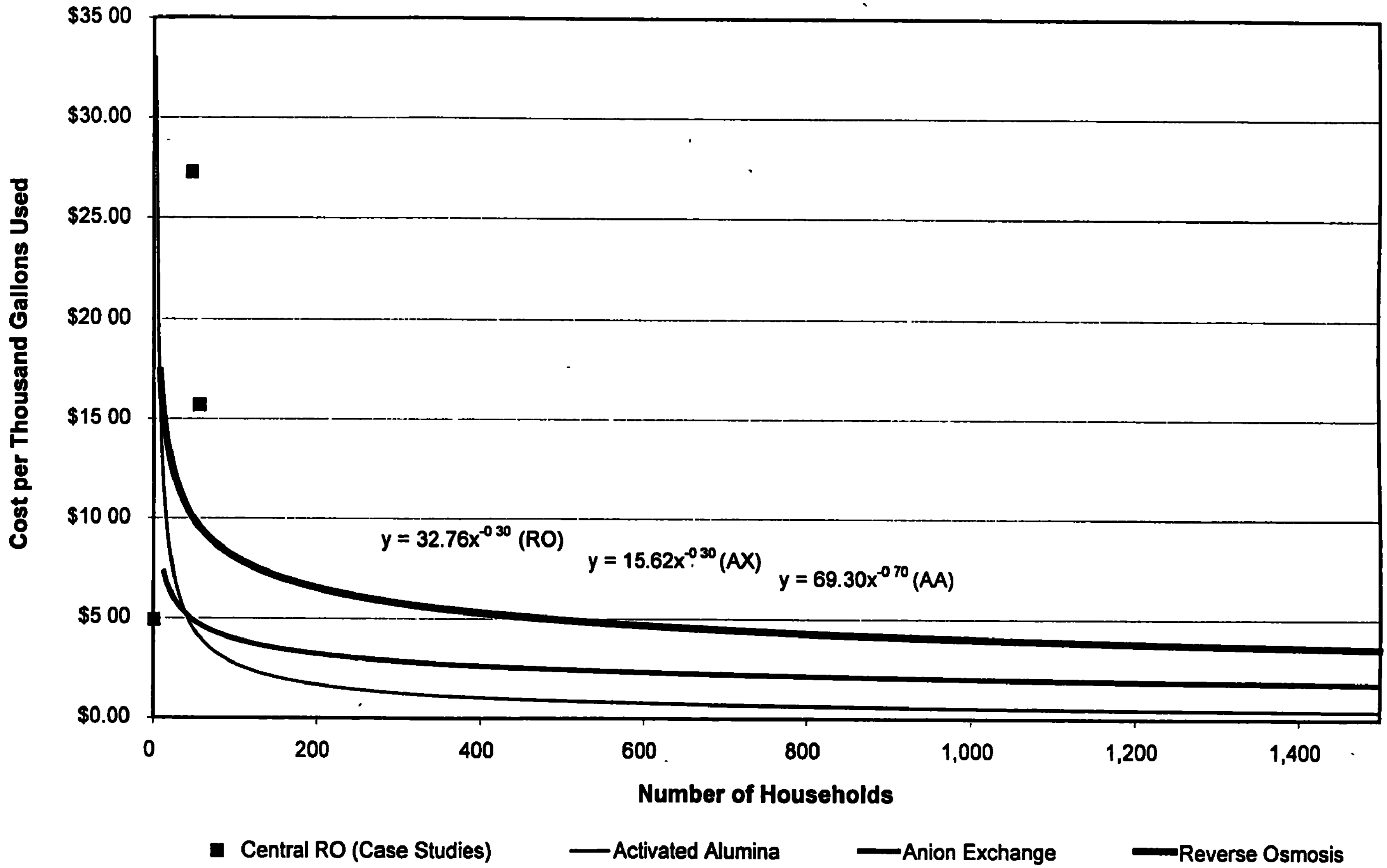
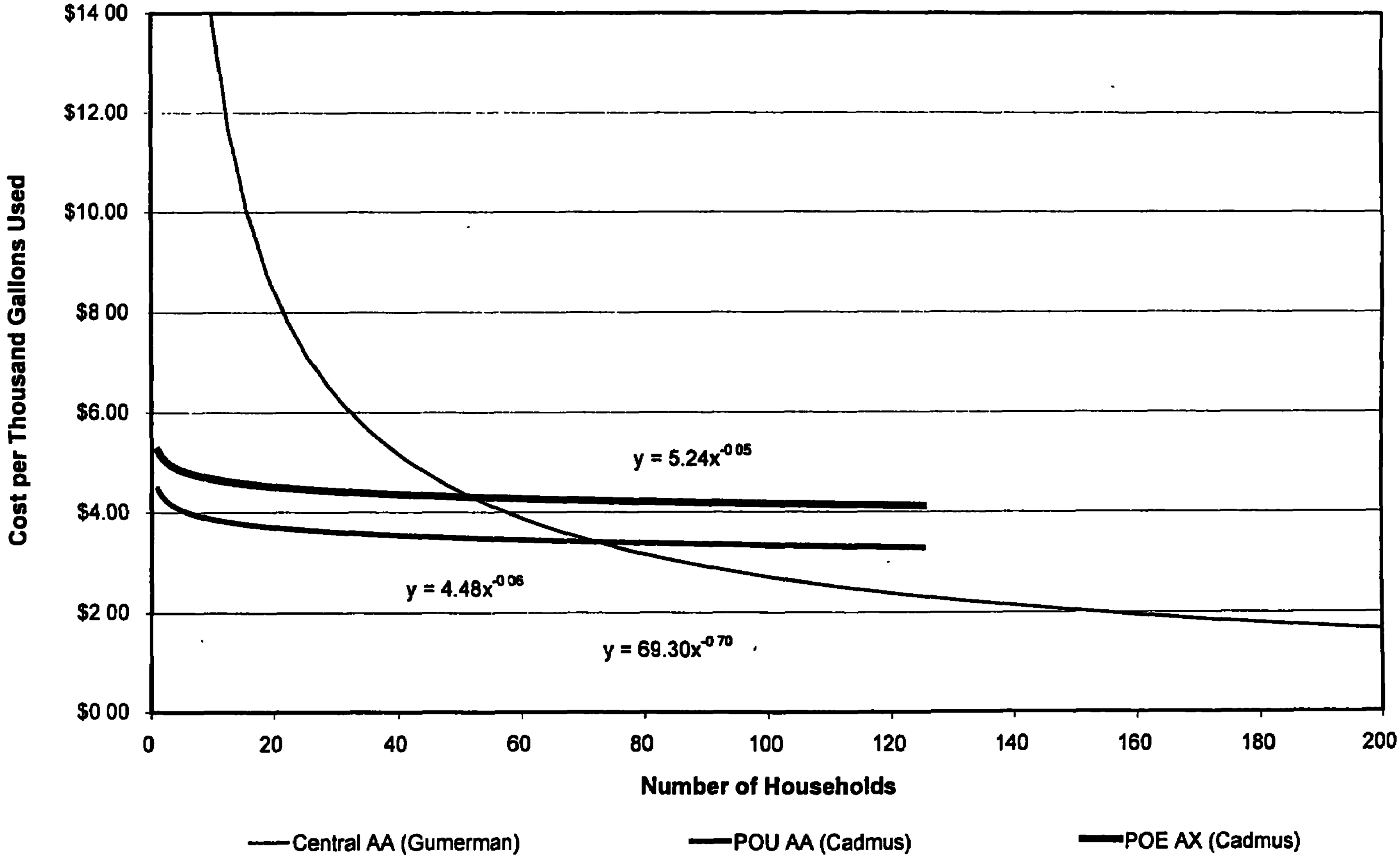


Figure 4.4.1.4.1
Treatment for Arsenic



4.4.2 Treatment for Copper

Influent water was assumed to have a neutral pH and a copper load of 2.0 mg/L. Therefore, pH adjustment technology was not included in devices designed to treat for copper. If pH is a problem, a sacrificial mineral pre-filter could be installed with the treatment unit. Although contacted vendors did not commonly install POU CX, CX treatment, commonly referred to as water softening, is often applied as a POE technology.

4.4.2.1 Point-of-Use Treatment for Copper

The cost estimate for the implementation of a POU CX strategy for the treatment of copper is presented in Figure 4.4.2.1.1. The Cadmus curve is consistent with both the case study data and the vendor-supplied data. CX is the only POU treatment technology investigated for the treatment of copper.

4.4.2.2 Point-of-Entry Treatment for Copper

The Cadmus cost curve for POE CX treatment for copper is presented in Figure 4.4.2.2.1. Higher costs were provided for the implementation of a POE CX treatment strategy in the case studies and by the vendors. The cost studies found in the literature did not include details regarding the line-items included in the O&M of POE CX devices nor the replacement schedule for device components. Cadmus' cost estimates are within 15 percent of those provided by vendors for POE CX units. As above, since CX is the only POE treatment technology investigated for the treatment of copper, it is by definition the least-cost POE treatment.

4.4.2.3 Central Treatment for Copper

Central treatment costs are provided in Figure 4.4.2.3.1.

4.4.2.4 Least-Cost Treatment for Copper

The cost curves for the POU, POE, and central treatment options for copper control are presented in Figure 4.4.2.4.1. According to the Cadmus cost equations, POU application of CX technology is the least expensive treatment alternative for communities of less than about 30 households. Larger communities would be served most cost-effectively by the application of CX technology in a central treatment plant. Central treatment with CX becomes less expensive than POE (CX) treatment for copper for communities of more than about 15 households. POE treatment for copper is more expensive than POU treatment for copper for all studied communities.

Although both the POE and POU cost curves are relatively flat at their point of intersection with the central treatment cost curve, the cost curve for central CX treatment has a steep slope at the points of intersection. Therefore, a modest change in the cost of the POU or POE application will not markedly alter the number of households at which central treatment becomes the most economical treatment option. For example, a 10 percent decrease in the cost of POU technology would result in central treatment becoming more cost-effective for communities of more than 35 households rather than communities of 30 households. In contrast, a 10 percent increase in the cost of POU technology would result in central treatment becoming more cost-effective for communities of more than 25 households rather than communities of more than 30 households.

Figure 4.4.2.1.1
POU Treatment for Copper

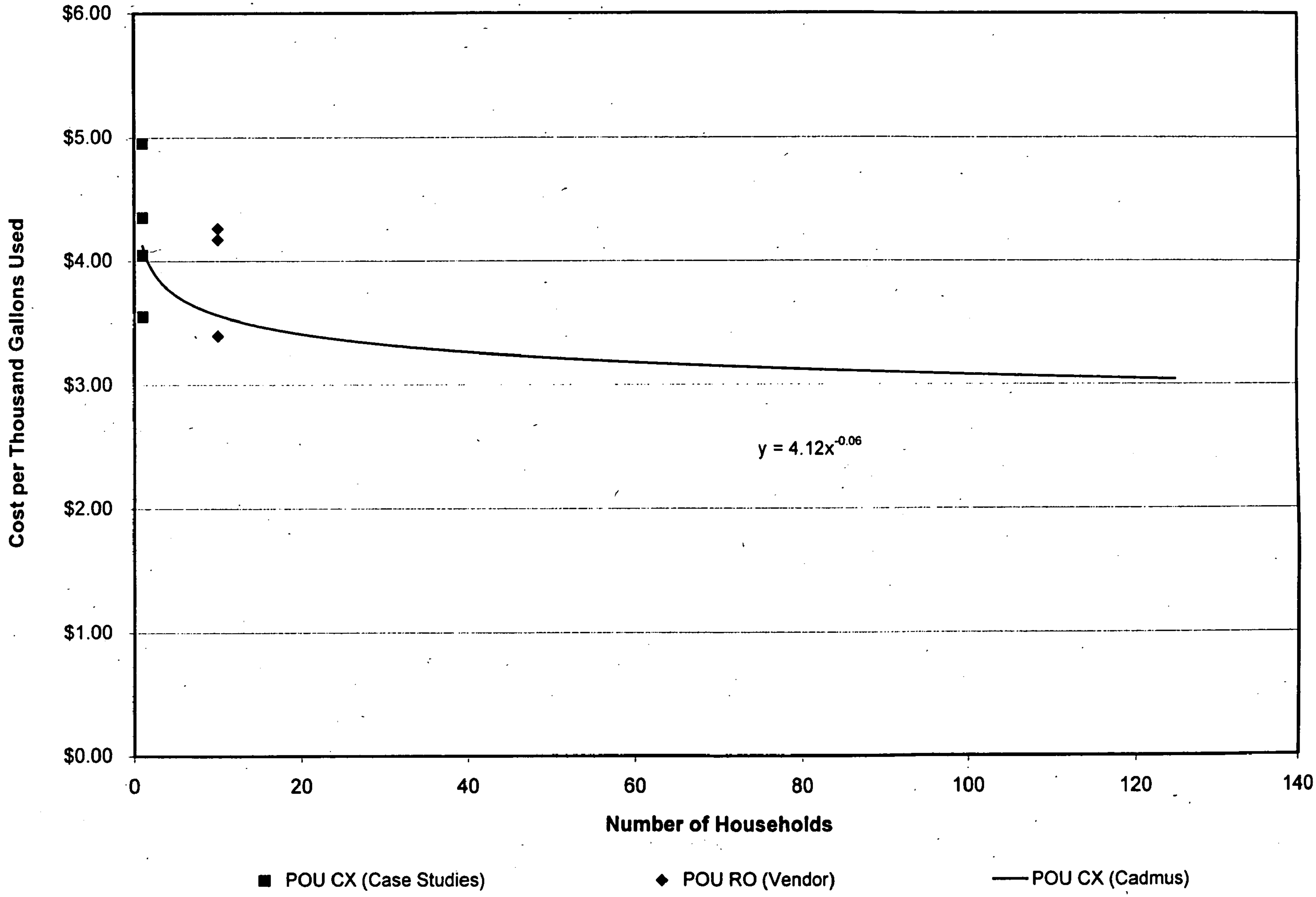


Figure 4.4.2.2.1
POE Treatment for Copper

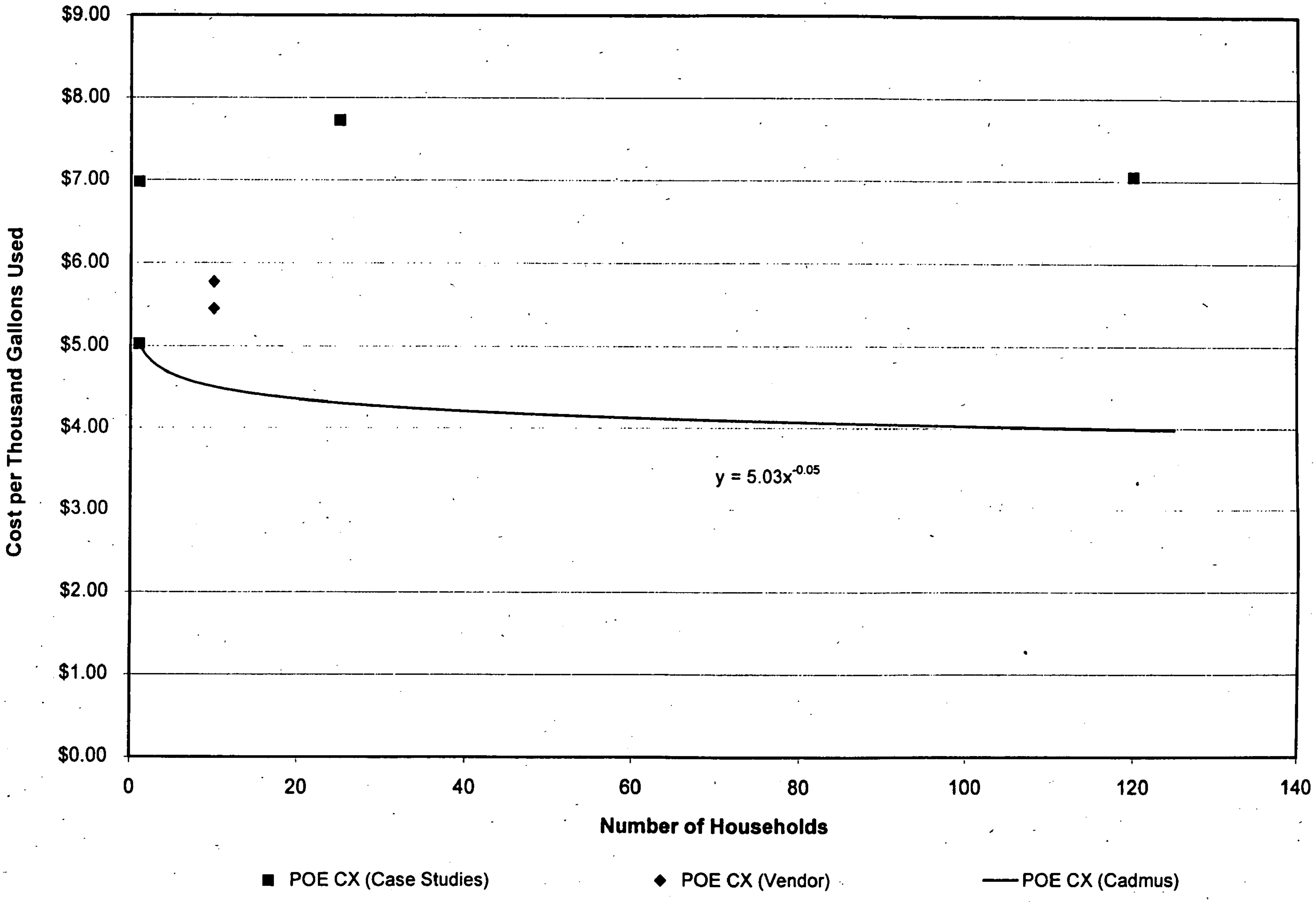


Figure 4.4.2.3.1
Central Treatment for Copper

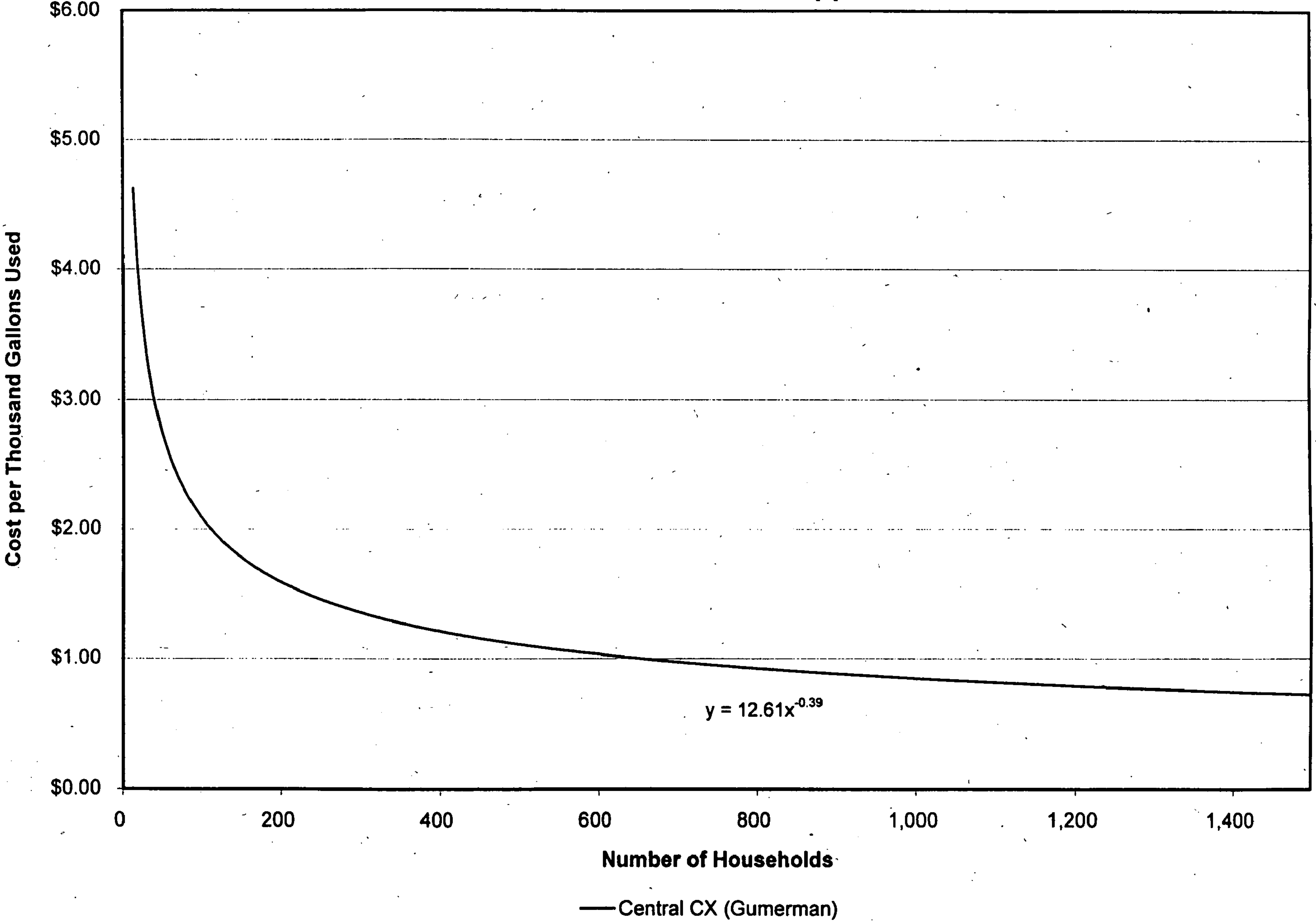
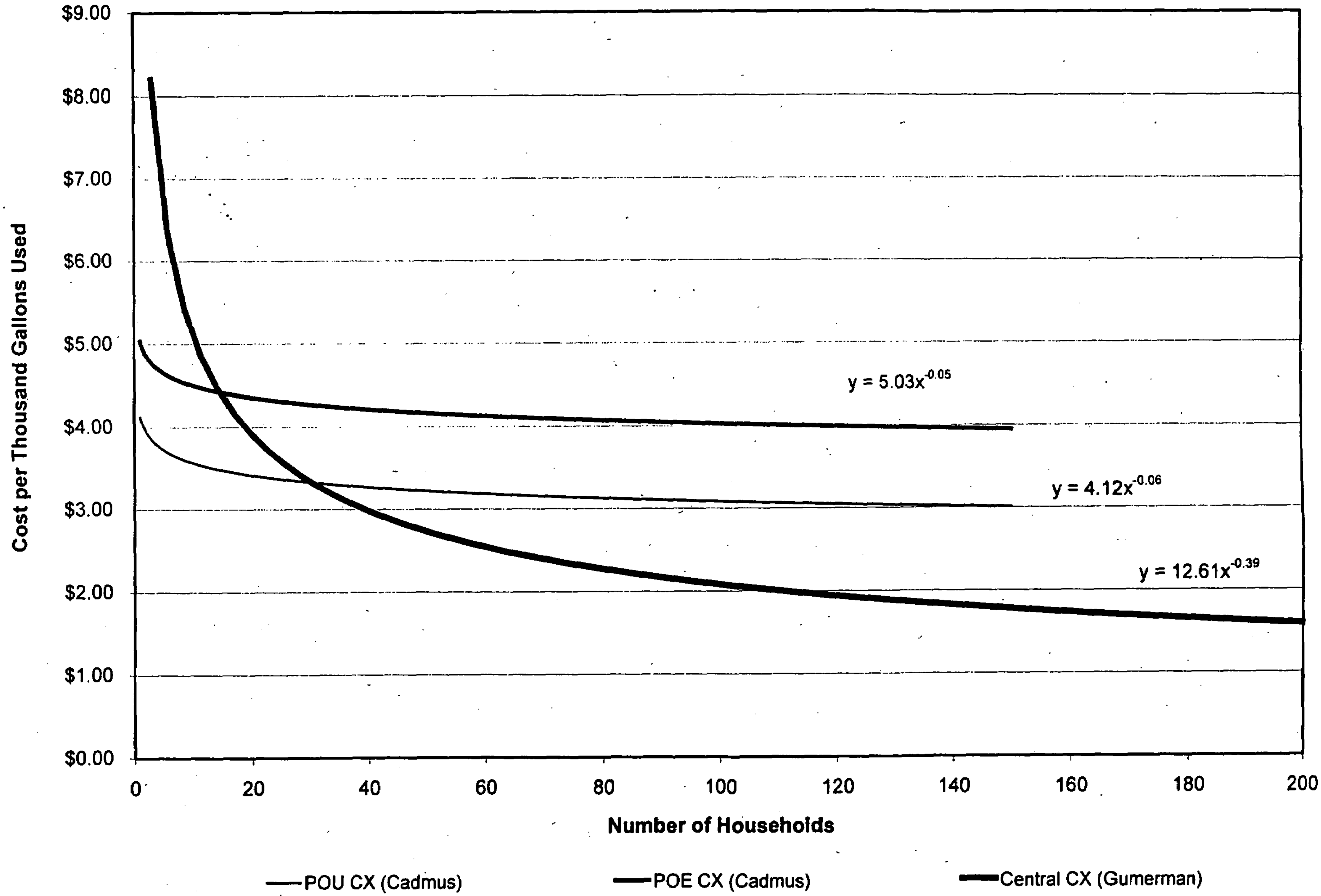


Figure 4.4.2.4.1
Treatment for Copper



4.4.3 Treatment for Alachlor

Alachlor may be successfully removed from drinking water using GAC. For the purposes of this cost analysis an influent concentration of 100 μg/L was assumed. Although the adsorption characteristics of carbon can vary greatly between different compounds, it was assumed that the adsorption requirements for alachlor were similar to those reported for VOCs. However, to ensure adequate protection of the public health, an additional margin of safety was engineered into all units used to treat for alachlor.

4.4.3.1 Point-of-Use Treatment for Alachlor

The cost estimate for the implementation of a POU GAC strategy for the treatment of alachlor is presented in Figure 4.4.3.1.1. The Cadmus cost estimates for the POU treatment of alachlor with GAC were consistent with the case study data. Although Cadmus estimates were above vendor-supplied costs, vendors specified less-frequent cartridge replacement. Less-frequent component replacement resulted in lower total costs for POU GAC treatment. GAC is the only POU treatment technology investigated for the treatment of alachlor.

4.4.3.2 Point-of-Entry Treatment for Alachlor

The Cadmus cost curve developed for POE GAC treatment for alachlor is presented in Figure 4.4.3.2.1. Although many case studies and theoretical cost estimates were provided for the treatment of VOCs such as TCE and 1,2-DCP, none of the case studies examined in the literature search provided pricing information for treatment of alachlor. Since lab analysis for alachlor is significantly less expensive than analysis for VOCs, this analysis does not compare costs associated with treatment for alachlor with costs associated with treatment for VOCs. GAC is the only POE treatment technology investigated for the treatment of alachlor.

4.4.3.3 Central Treatment for Alachlor

Central treatment costs for GAC are provided in Figure 4.4.3.3.1.

4.4.3.4 Least-Cost Treatment for Alachlor

The cost curves for the POU, POE, and central treatment options for alachlor control are presented in Figure 4.4.3.4.1. According to the Cadmus cost equations, POU application of GAC technology is the least expensive treatment alternative for communities of less than about 70 households. Larger communities would be served most cost-effectively by the application of GAC technology in a central treatment plant. Central treatment with GAC becomes less expensive than POE (GAC) treatment for alachlor for communities of more than about 10 households. POE treatment for alachlor was determined to be more expensive than POU treatment for alachlor for all studied communities.

Since both the POU and central cost curves are relatively flat at their point of intersection, a small change in the price of either treatment option would result in a sizeable change in the community population at which central treatment becomes the most cost effective method of reducing alachlor concentrations in household water. For example, a 10 percent decrease in the cost of POU technology would result in central treatment becoming more cost-effective for communities of more than 90 households rather than communities of 70 households. In contrast, a 10 percent increase in the cost of POU technology would result in central treatment becoming more cost-effective for communities of more than about 50 households rather than communities of more than 70 households.

However, the cost curve for central GAC treatment has a steep slope at its point of intersection with the POE cost curve. Therefore, a modest change in the cost of the POE application will not markedly alter the number of households at which central treatment becomes the most economical treatment option. For example, neither a 10 percent decrease nor a 10 percent increase in the cost of POU technology would not alter the 15-household "breakpoint" at which central treatment becomes more cost-effective than POE treatment for alachlor.

Figure 4.4.3.1.1
POU Treatment for Alachlor

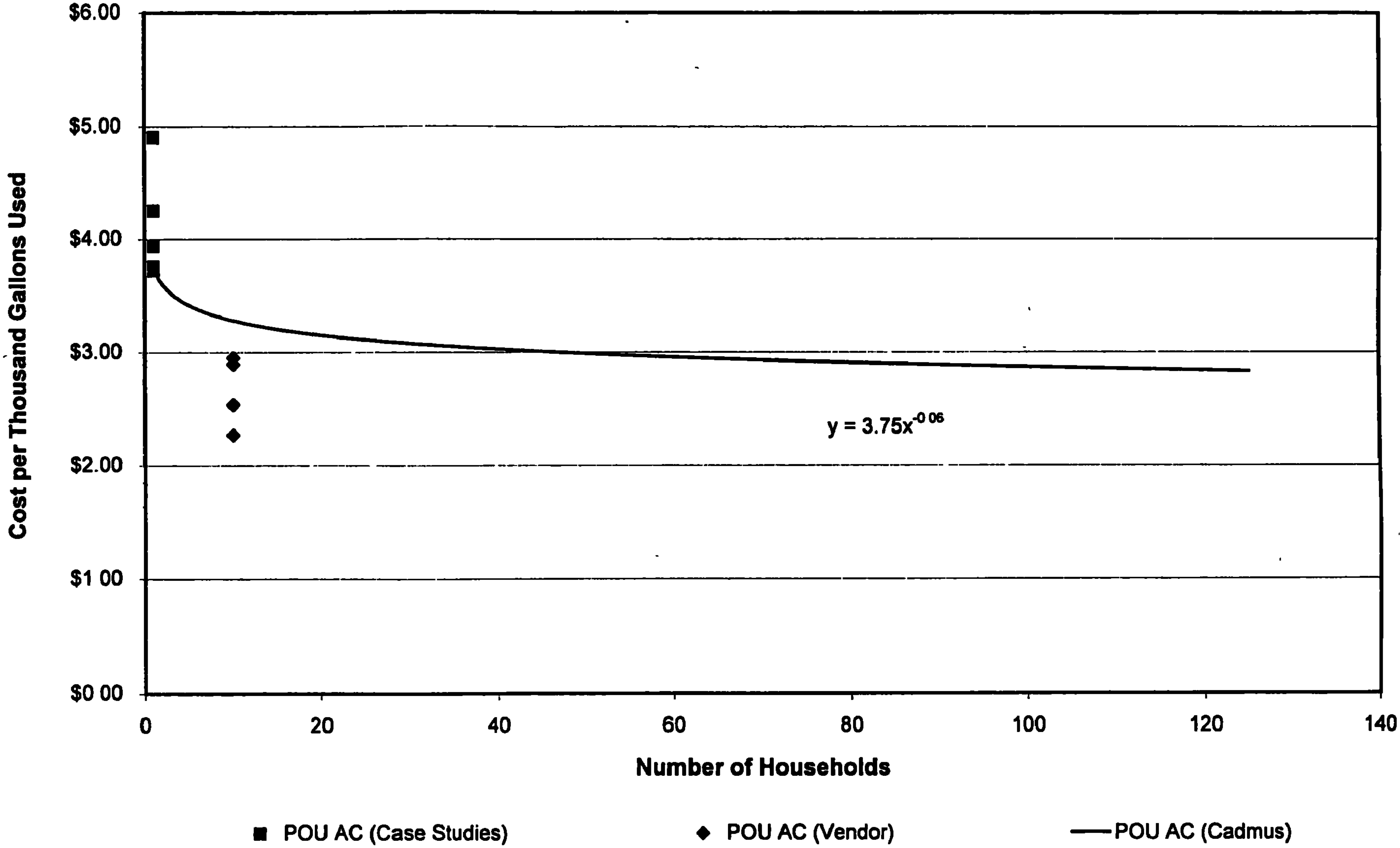


Figure 4.4.3.2.1
POE Treatment for Alachlor

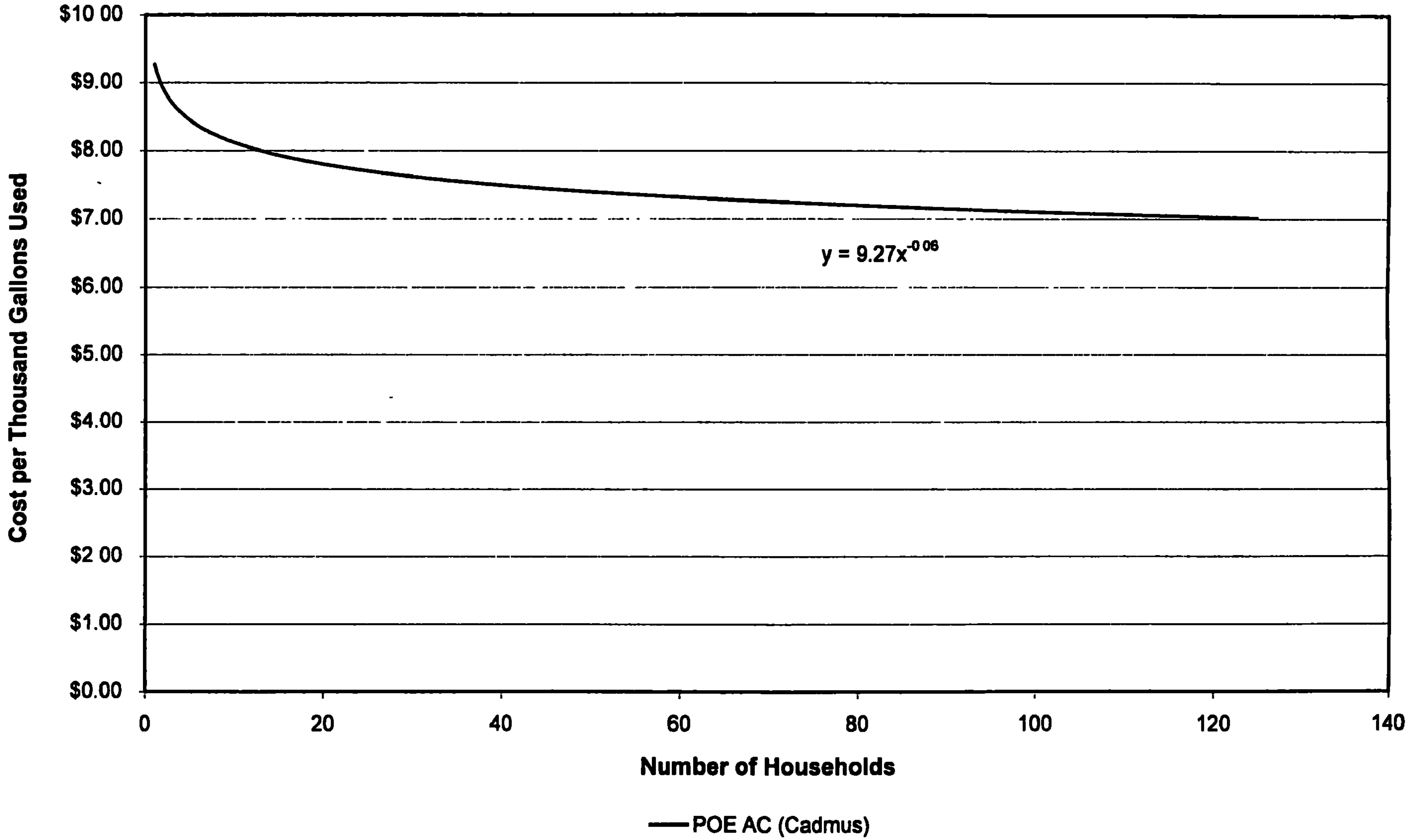


Figure 4.4.3.3.1
Central Treatment for Alachlor

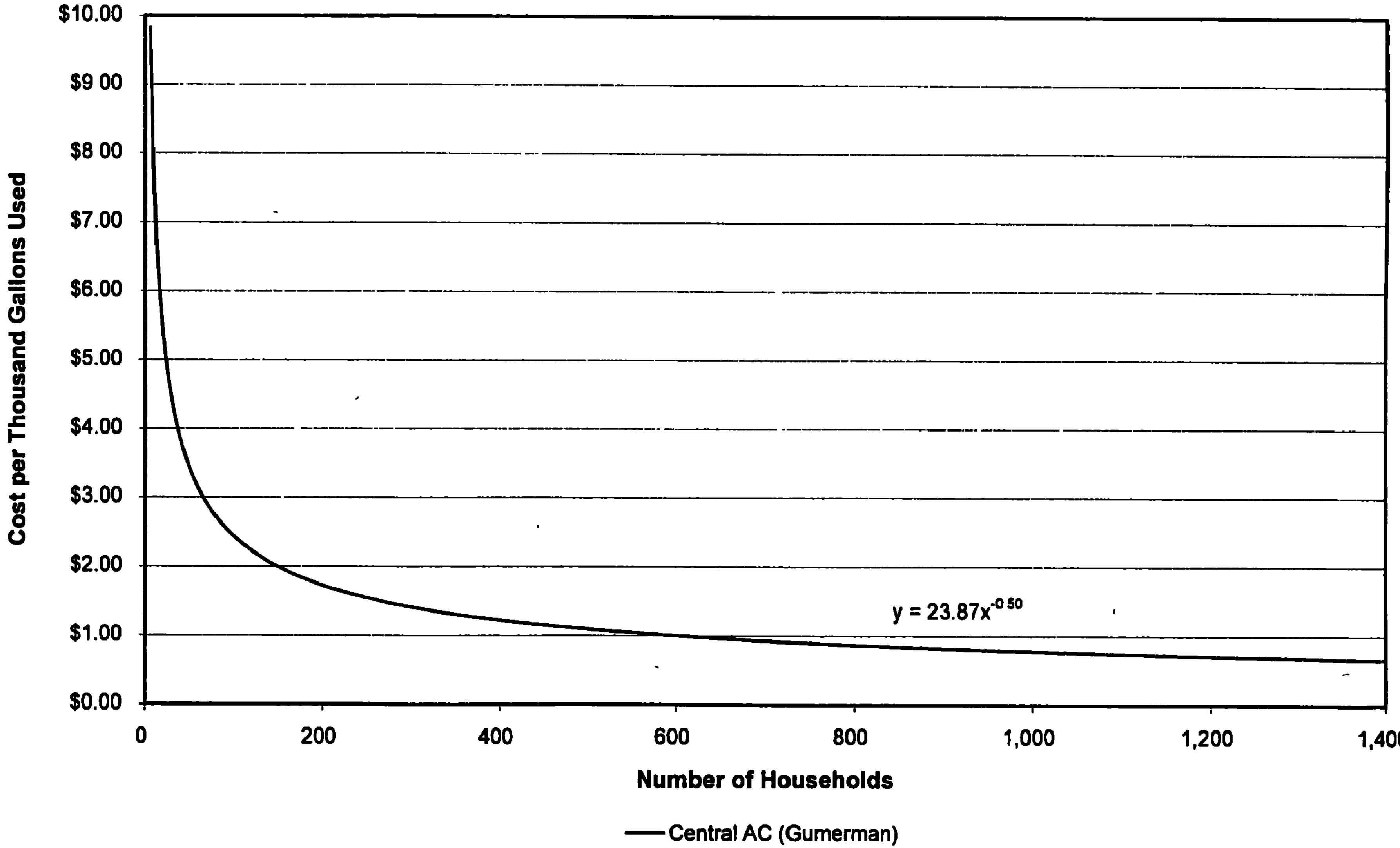
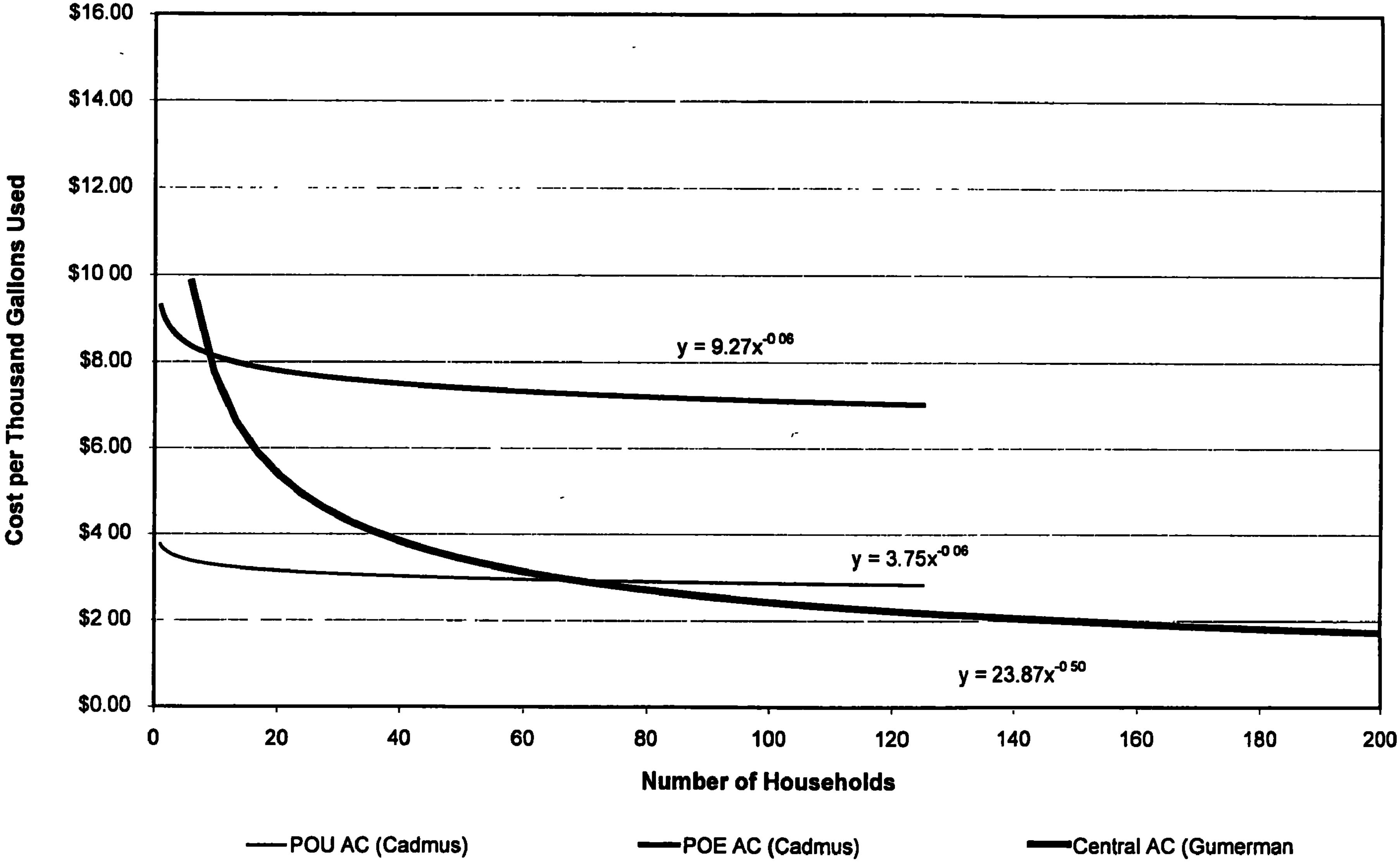


Figure 4.4.3.4.1
Treatment for Alachlor



4.4.4 Treatment for Radon to 300 pCi/L

Numerous studies have been performed to evaluate the efficacy of various potential remediation technologies for radon contamination. Both air-stripping (by PTA or DBA) and GAC have proven effective in lowering radon concentrations in drinking water by up to 99 percent (Lowry 1989). However, air-stripping routinely outperformed GAC over long periods and provided a more consistent level of radon removal.

4.4.4.1 Point-of Entry Treatment for Radon to 300 pCi/L

The cost curve developed by Cadmus for POE GAC treatment for radon (to 300 pCi/L) is presented in Figure 4.4.4.1.1. The Cadmus cost estimates were higher than the costs provided for the implementation of a POE GAC treatment for radon by the case studies and by the vendors. While some of the GAC POE units (1 to 3 cubic feet of GAC) included in the studies were effective in lowering radon levels, they may not provide sufficient contact time during peak water usage periods to provide adequate radon removal of greater than 95 percent — the rate necessary to lower influent radon concentrations of 5,000 pCi/L to the desired level of 300 pCi/L. For this reason, an 18 cubic foot POE GAC system was designed and priced for treatment of radon to 300 pCi/L for the Cadmus cost curves. Due to its larger size, greater capacity, and greater complexity, this unit was significantly more expensive than the POE units described in the available case studies.

POE aeration is relatively expensive due to the high capital costs associated with aeration equipment. Moreover, while the Cadmus cost estimates presented in Figure 4.4.4.1.2 for POE aeration exceed those provided by the cost studies found in the literature and the contacted vendors, the aeration units described in the case studies and specified by the vendors did not include the cost of a repressurization element, although aeration typically requires post-treatment repressurization.

Figure 4.4.4.1.3 compares the costs of POE GAC and POE aeration to reduce radon concentrations below 300 pCi/L. For communities of more than about 15 households, aeration is the least-cost POE treatment.

4.4.4.2 Central Treatment for Radon to 300 pCi/L

Costs for GAC central treatment are provided in Figure 4.4.4.2.1. Figure 4.4.4.2.2 compares the cost of central treatment plants that utilize DBA with those that use PTA. Central PTA is less expensive than central DBA for communities larger than about 25 households. Figure 4.4.4.2.3 compares the cost of GAC central treatment with the cost of PTA central treatment. Central PTA was found to be less expensive than central GAC treatment of radon for all communities covered by this cost analysis.

4.4.4.3 Least-Cost Treatment for Radon (300 pCi/L)

The least-cost POE and central treatment options for radon reduction are presented in Figure 4.4.4.3.1. According to the Cadmus cost equations, a community water system (i.e., a water system serving more than 15 connections) would not find POE treatment to be more cost-effective than central treatment for the reduction of radon levels below 300 pCi/L.

Figure 4.4.4.1.1
POE Treatment for Radon to 300 pCi/L with Activated Carbon

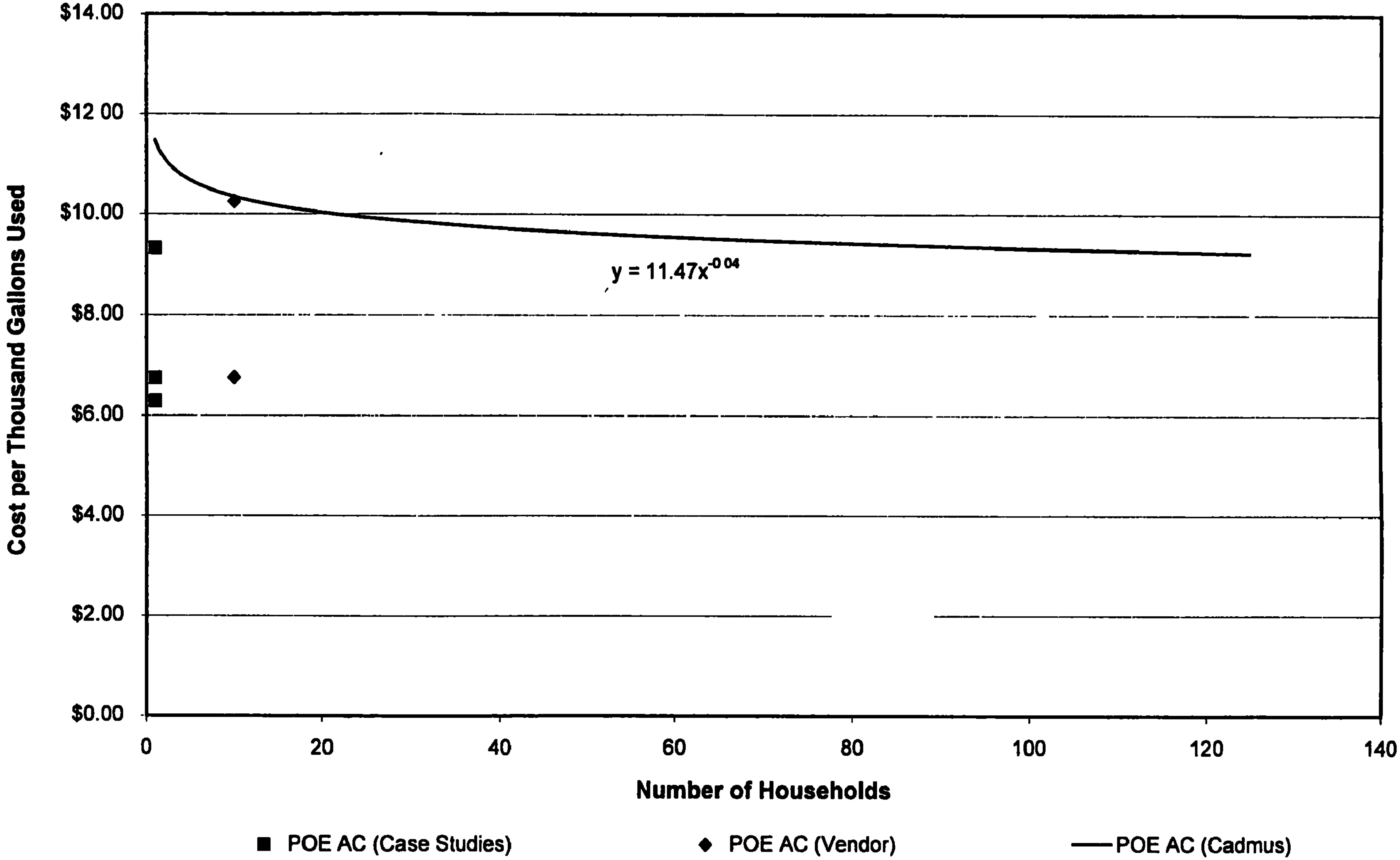


Figure 4.4.4.1.2
POE Treatment for Radon to 300 pCi/L with Aeration

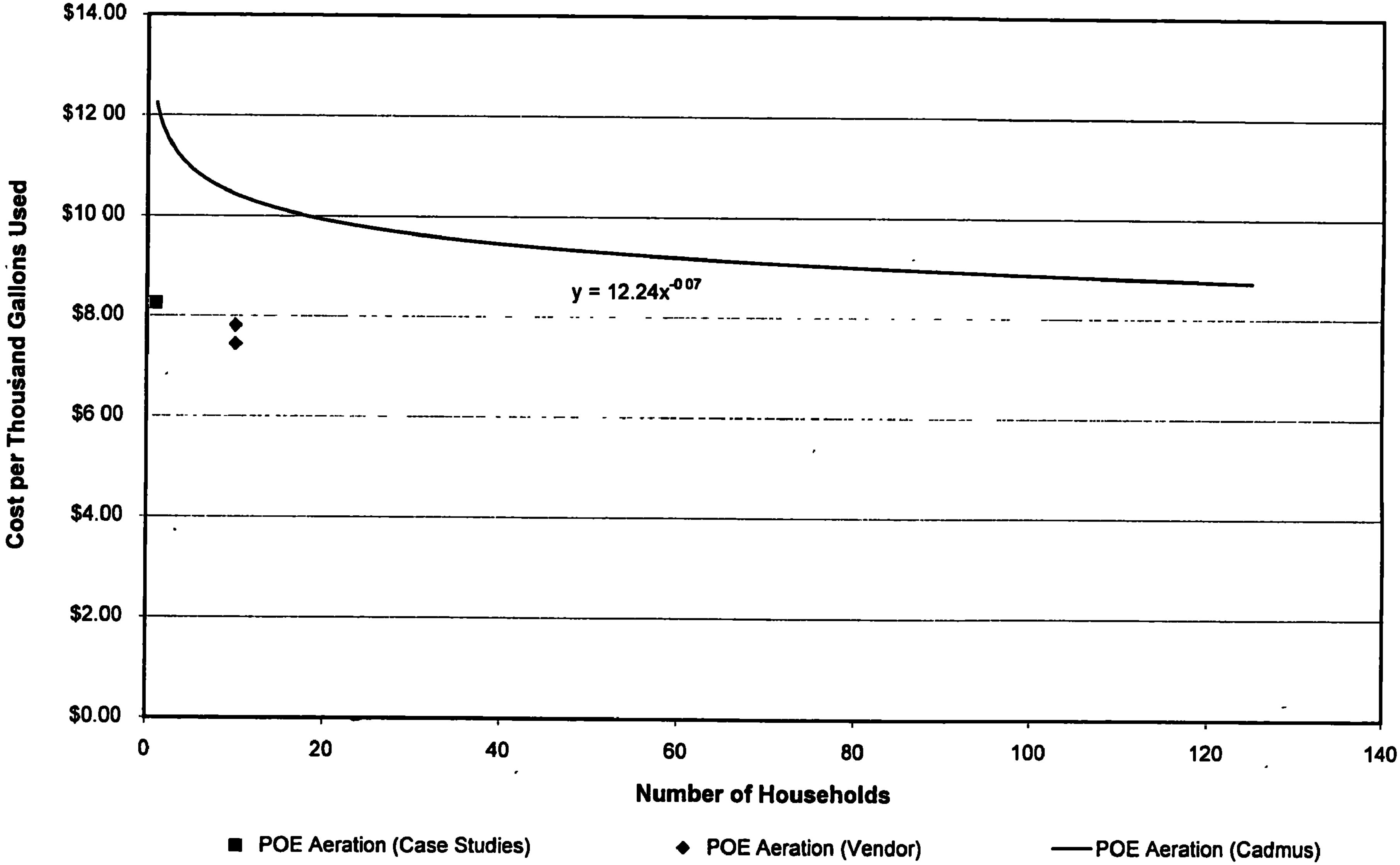


Figure 4.4.4.1.3
POE Treatment for Radon to 300 pCi/L

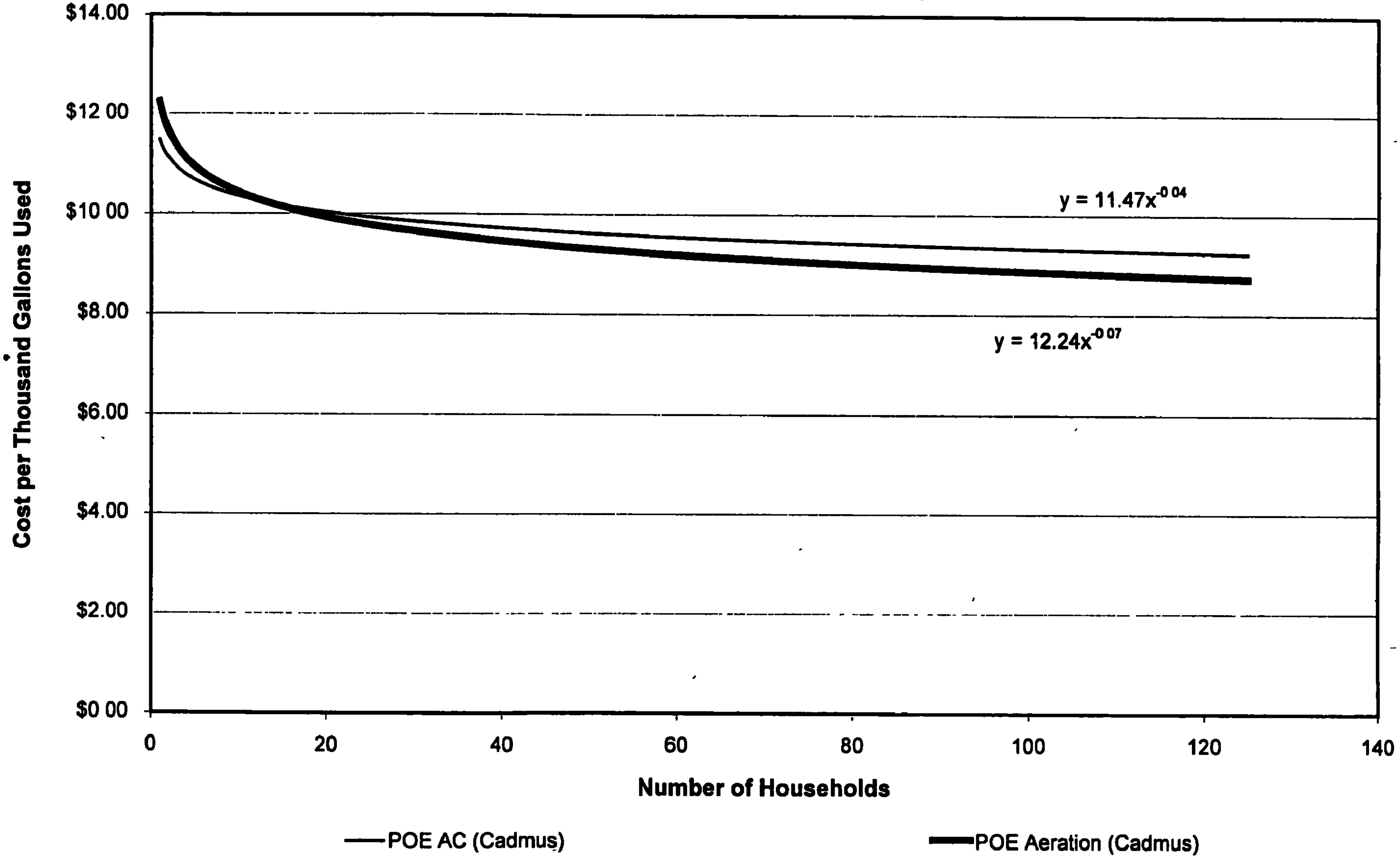


Figure 4.4.4.2.1
Central Treatment for Radon to 300 pCi/L with Activated Carbon

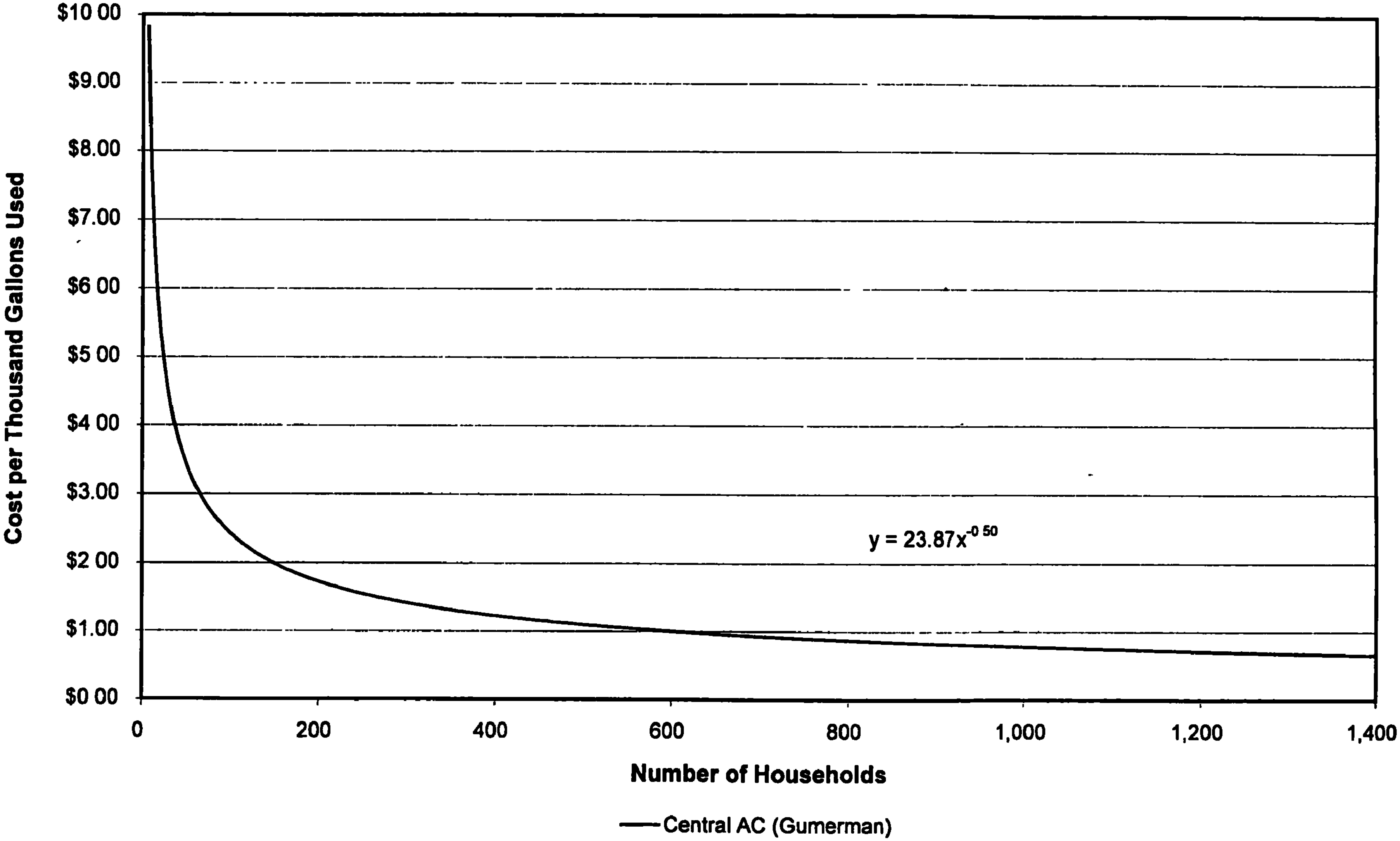


Figure 4.4.4.2.2
Central Treatment for Radon to 300 pCi/L with Aeration

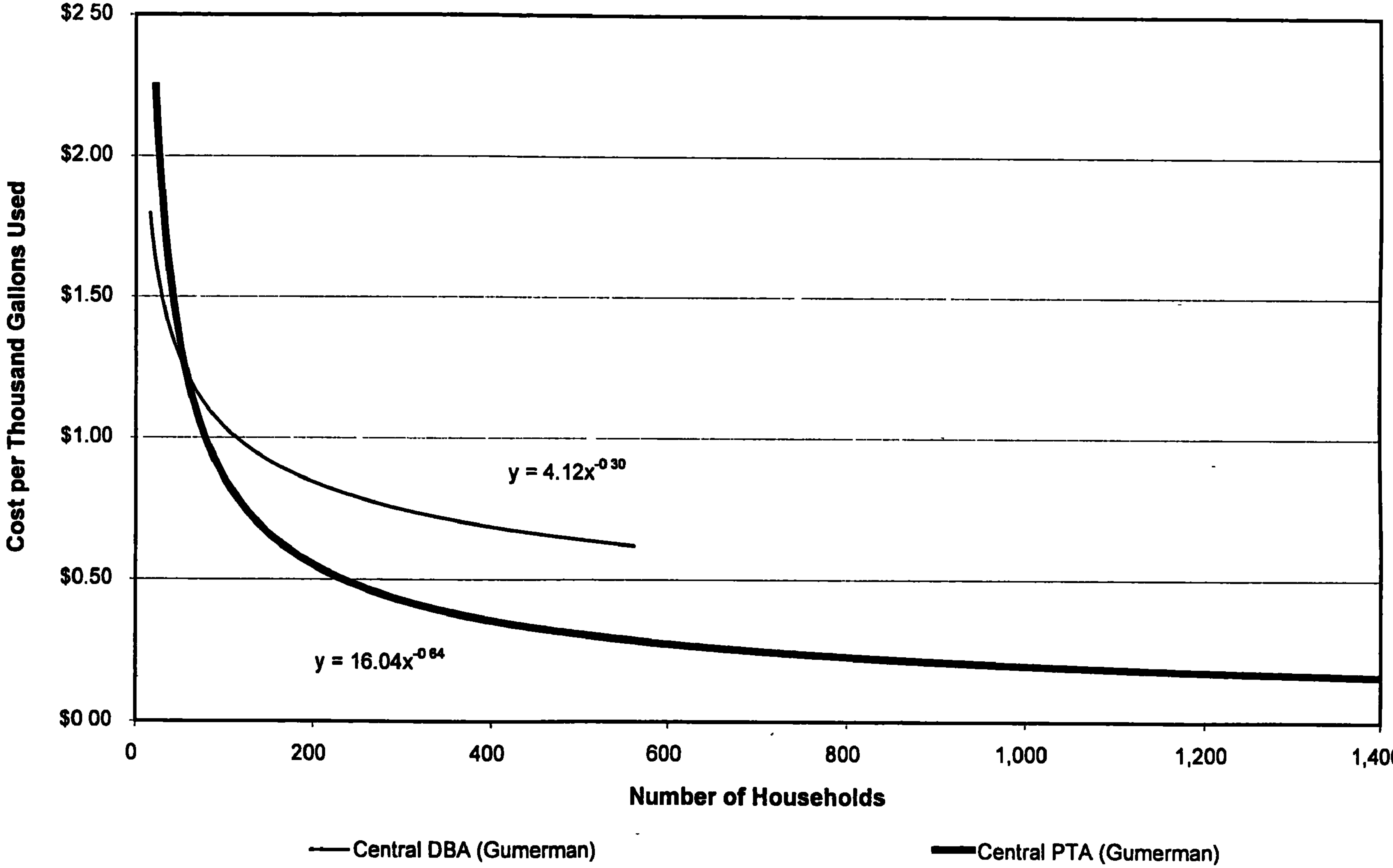


Figure 4.4.4.2.3
Central Treatment for Radon to 300 pCi/L

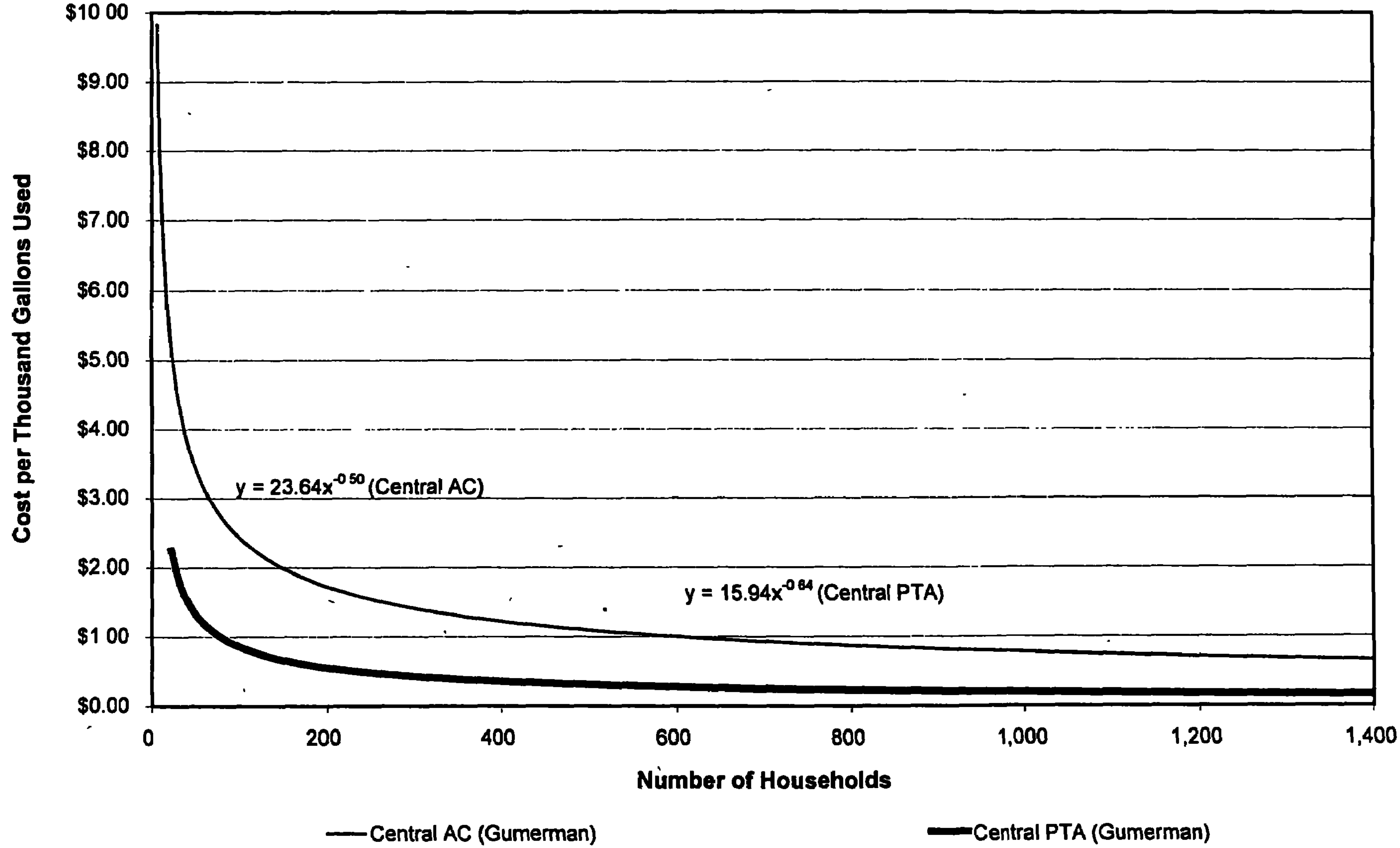
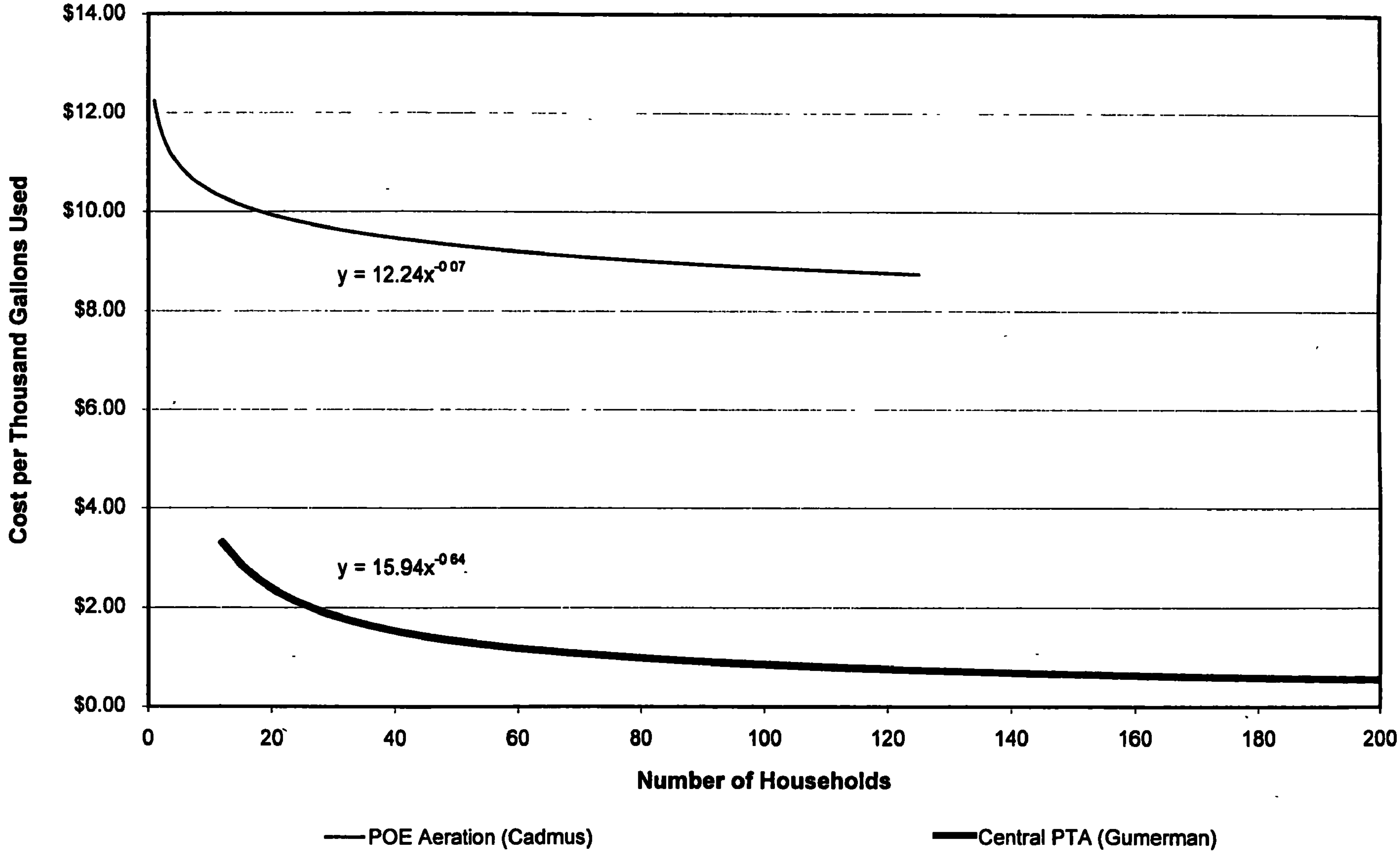


Figure 4.4.4.3.1
Treatment for Radon to 300 pCi/L



4.4.5 Radon Treatment to 1,500 pCi/L

The design parameters for a GAC system that must reduce influent radon levels by only about 70 percent (5,000 pCi/L to 1,500 pCi/L) are much less stringent than those necessary for the GAC systems designed to remove more than 95 percent of influent radon described in section 4.4.4. Smaller POE GAC units (4.5 to 6.0 cubic feet) could therefore be successfully utilized. Aeration systems identical to those described in Section 4.4.4 could be used to treat radon to effluent levels of 1,500 pCi/L.

4.4.5.1 Point-of-Entry Treatment for Radon to 1,500 pCi/L

The cost curve developed by Cadmus for POE GAC treatment for radon (to 1,500 pCi/L) is presented in Figure 4.4.5.1.1. The Cadmus cost estimates match well with the costs provided for the implementation of a POE GAC treatment for radon by the case studies. As per Lowry (1989), Cadmus assumed that radon would decay while trapped in the GAC bed, obviating the need to replace GAC in the absence of other contaminants. Since both vendors that provided pricing information for POE GAC units specified costs for carbon replacement, Cadmus' estimates were lower than those of the vendors.

POE aeration is relatively expensive due to the high capital costs associated with aeration equipment. Moreover, while the Cadmus cost estimates presented in Figure 4.4.5.1.2 for POE aeration exceed those provided by the cost studies found in the literature and the contacted vendors, the aeration units described in the case studies and specified by the vendors did not include the cost of a repressurization element, although aeration typically requires post-treatment repressurization.

Figure 4.4.5.1.3 compares the costs associated with implementing POE GAC and POE aeration to reduce radon concentrations below 1,500 pCi/L. Unlike radon treatment to 300 pCi/L (see section 4.4.4), POE GAC is less expensive than POE aeration for all small communities investigated in the cost analysis. This result is consistent with the finding that it is not necessary (and not cost-effective) to supplement GAC treatment with aeration when lower removal rates are required.

4.4.5.2 Central Treatment for Radon to 1,500 pCi/L

Costs for GAC central treatment are provided in Figure 4.4.5.2.1. Figure 4.4.5.2.2 compares the cost of central treatment plants that utilize DBA with those that use PTA. Central PTA is less expensive than central DBA for communities larger than about 25 households. Figure 4.4.5.2.3 compares the cost of GAC central treatment with the cost of PTA central treatment. Central PTA is less expensive than central GAC treatment of radon regardless of community size.

4.4.5.3 Least-Cost Treatment for Radon (1,500 pCi/L)

The least-cost POE and central treatment options for radon reduction to 1,500 pCi/L are presented in Figure 4.4.5.3.1. According to the Cadmus cost equations, a community water system (i.e., a water system serving more than 15 connections) would not find POE treatment to be more cost-effective than central treatment for the reduction of radon levels below 1,500 pCi/L.

Figure 4.4.5.1.1
POE Treatment for Radon to 1,500 pCi/L with Activated Carbon

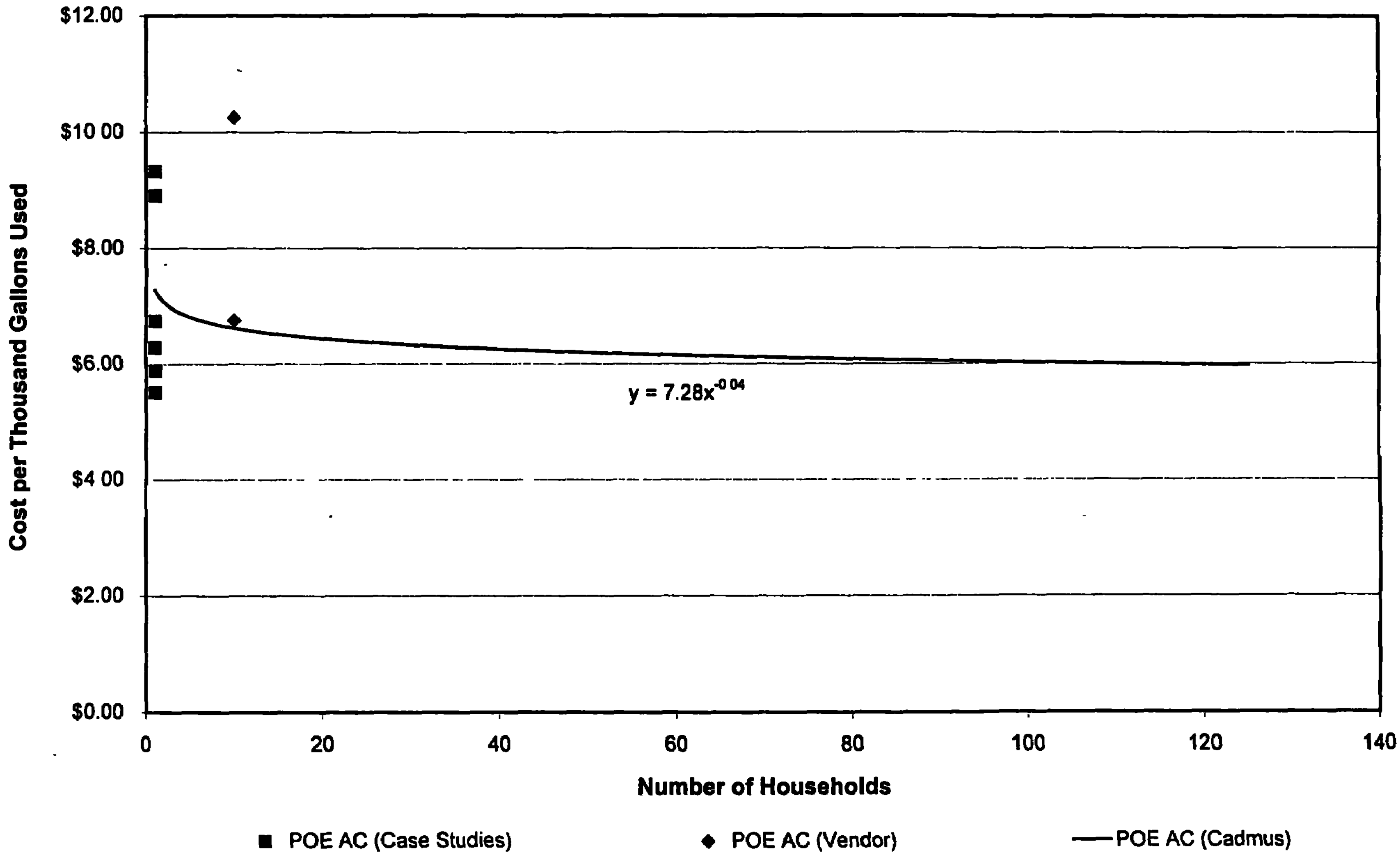


Figure 4.4.5.1.2
POE Treatment for Radon to 1,500 pCi/L with Aeration

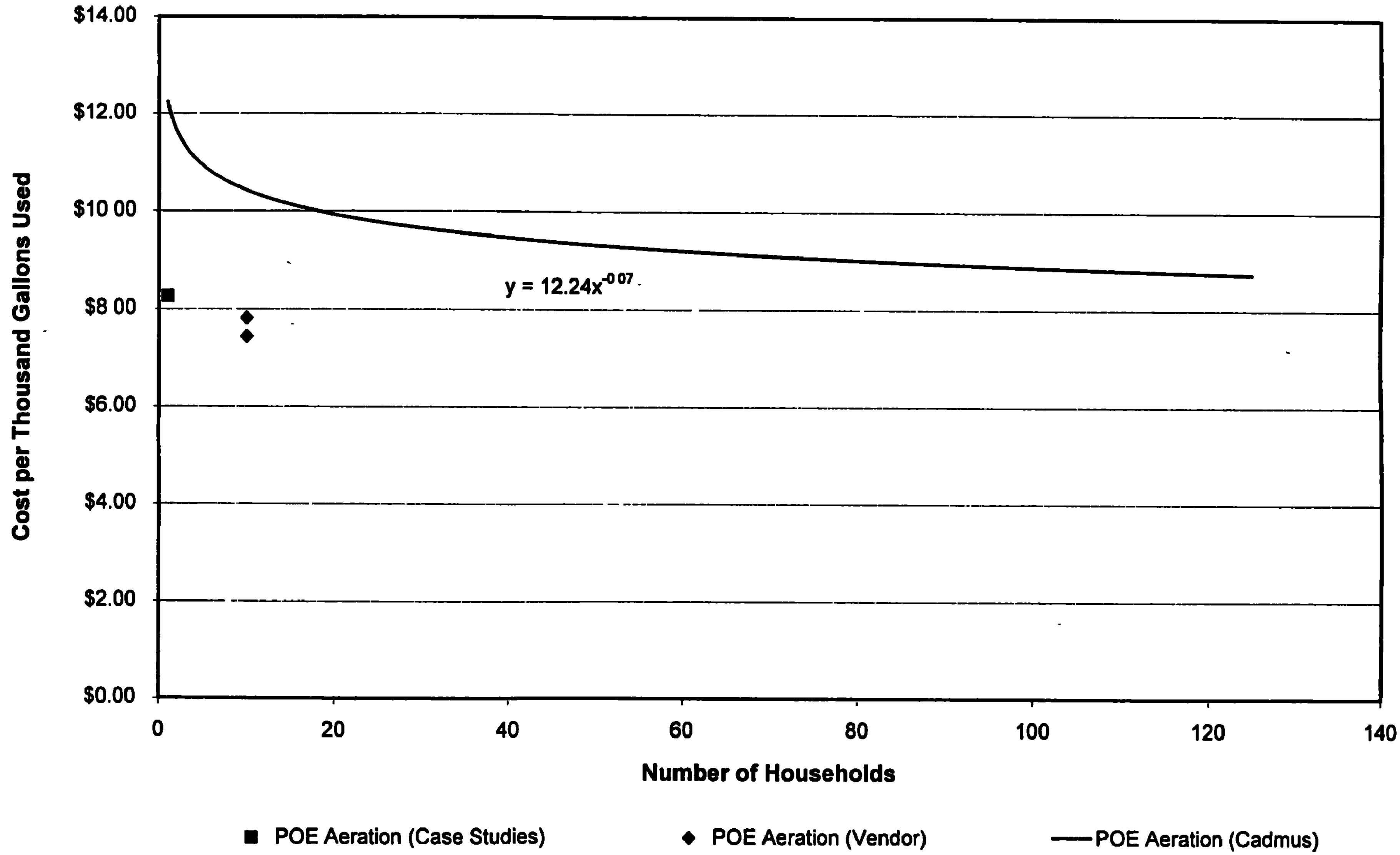


Figure 4.4.5.1.3
POE Treatment for Radon to 1,500 pCi/L

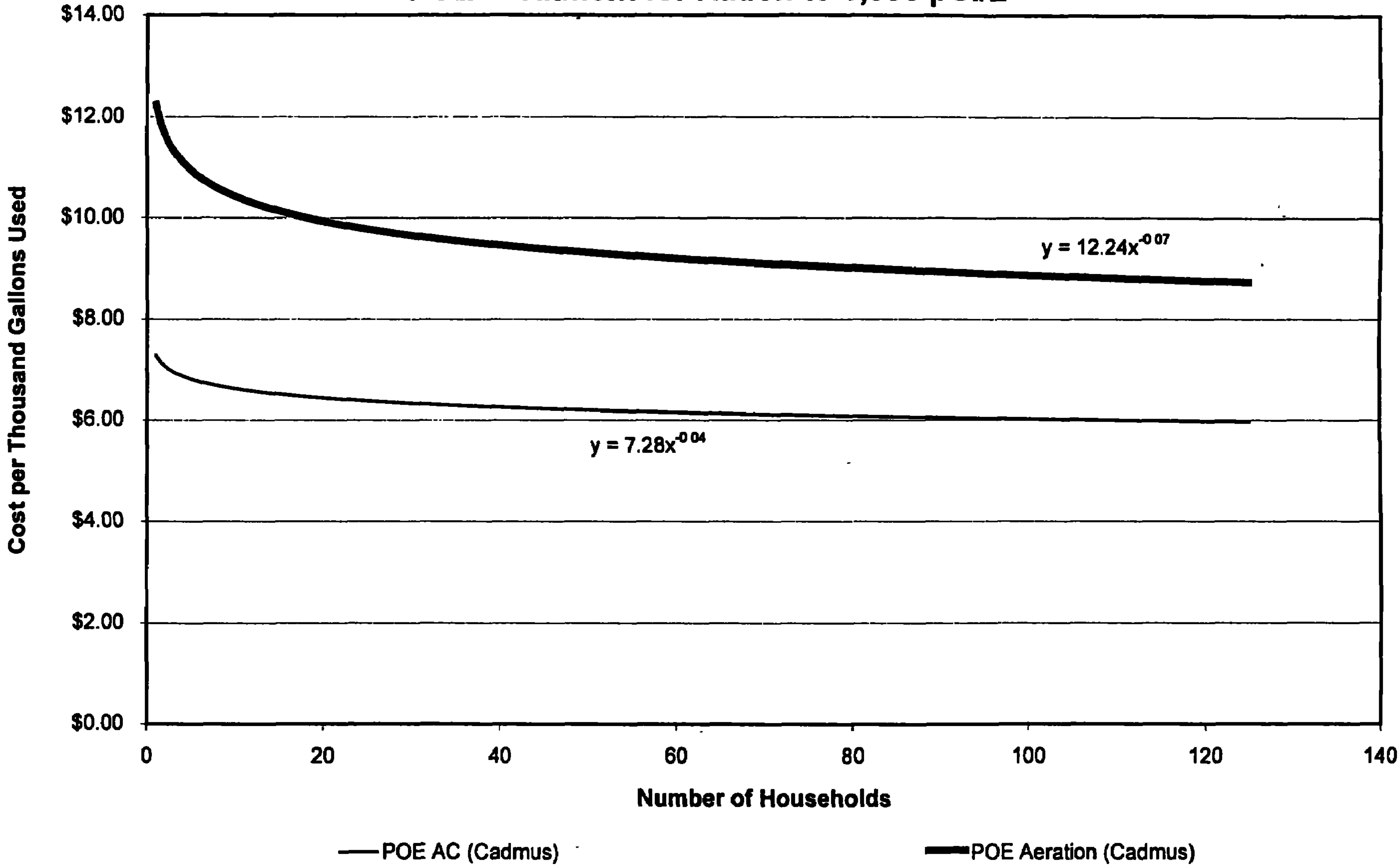


Figure 4.4.5.2.1
Central Treatment for Radon to 1,500 pCi/L with Activated Carbon

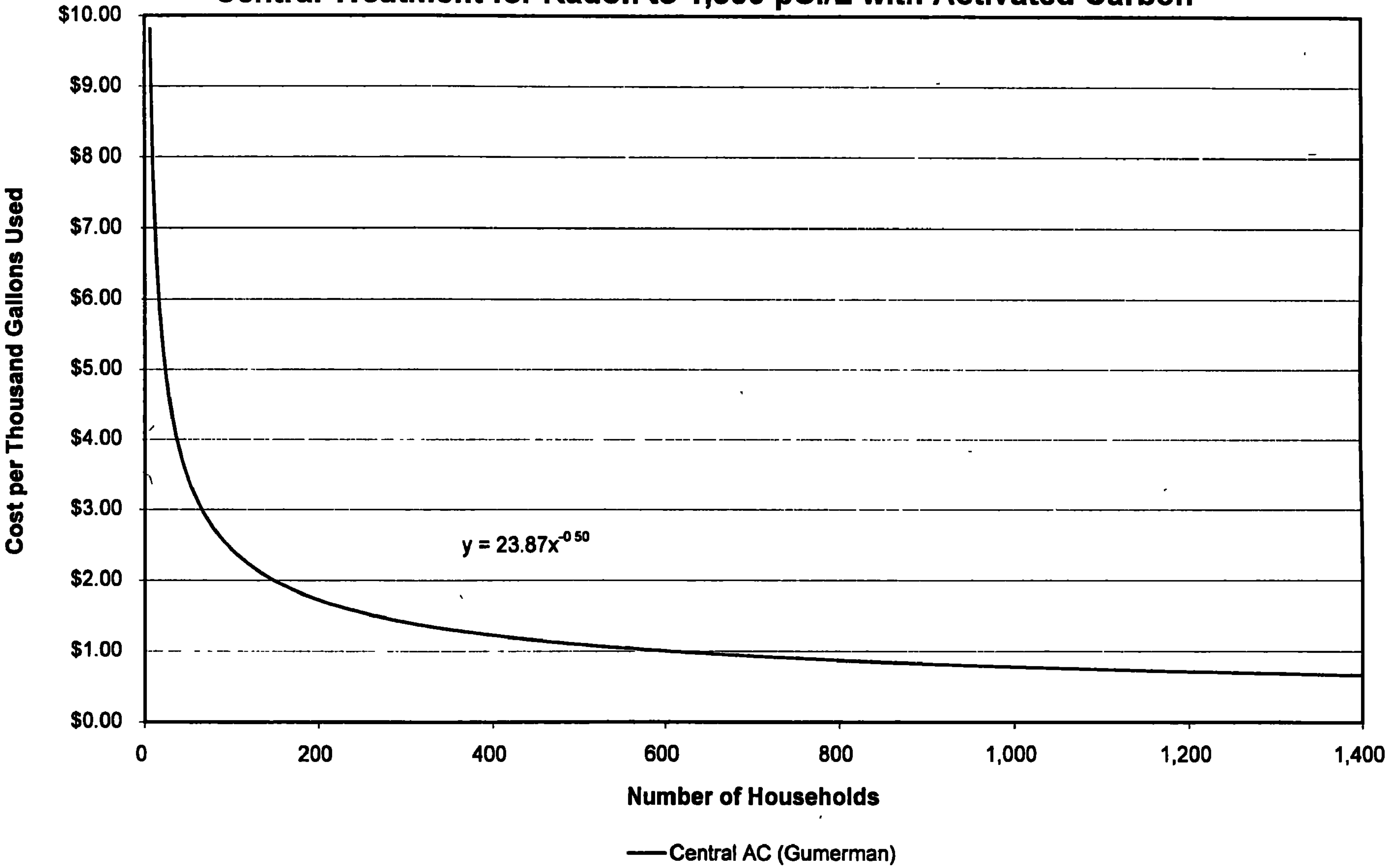


Figure 4.4.5.2.2
Central Treatment for Radon to 1,500 pCi/L with Aeration

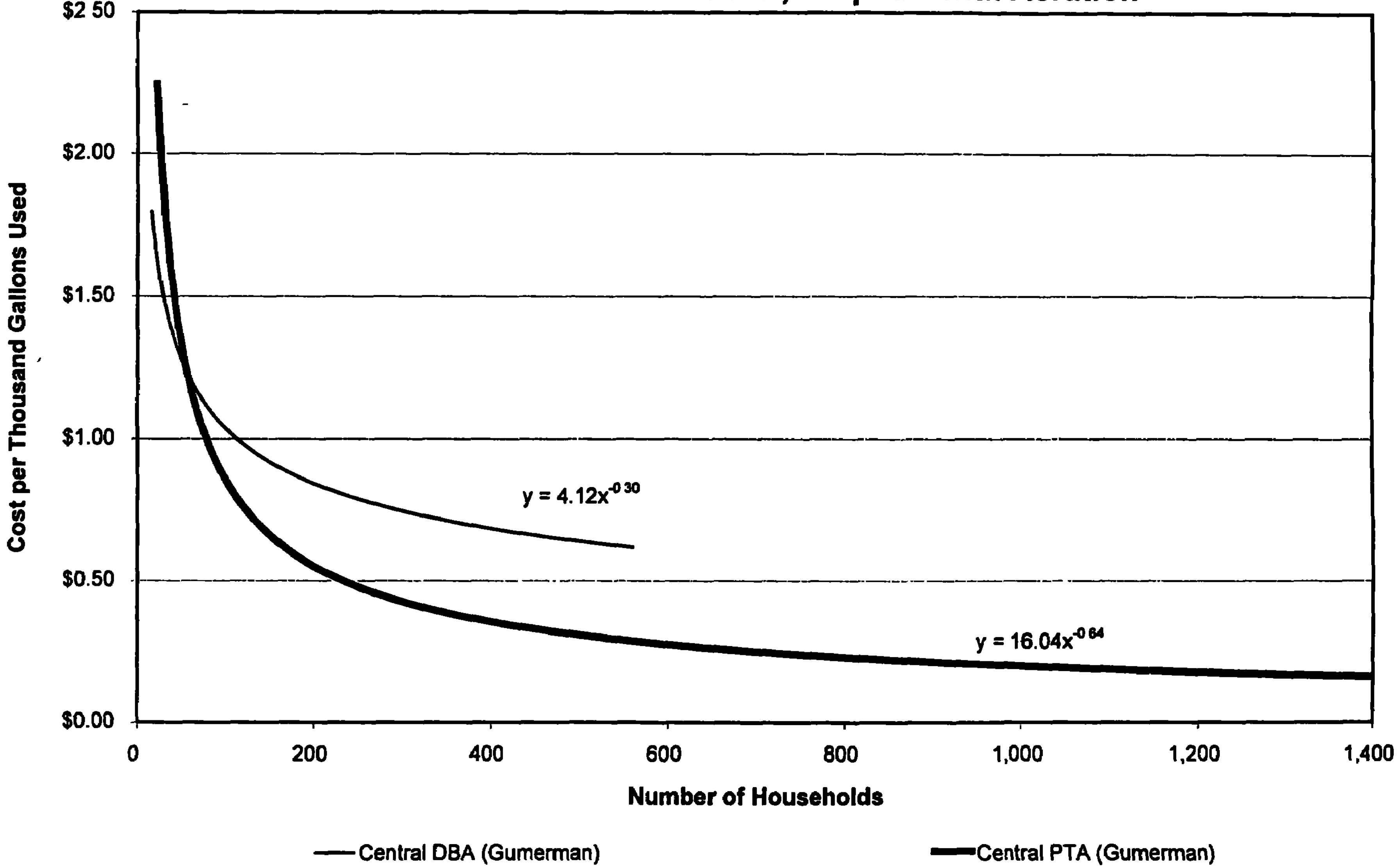


Figure 4.4.5.2.3
Central Treatment for Radon to 1,500 pCi/L with Activated Carbon

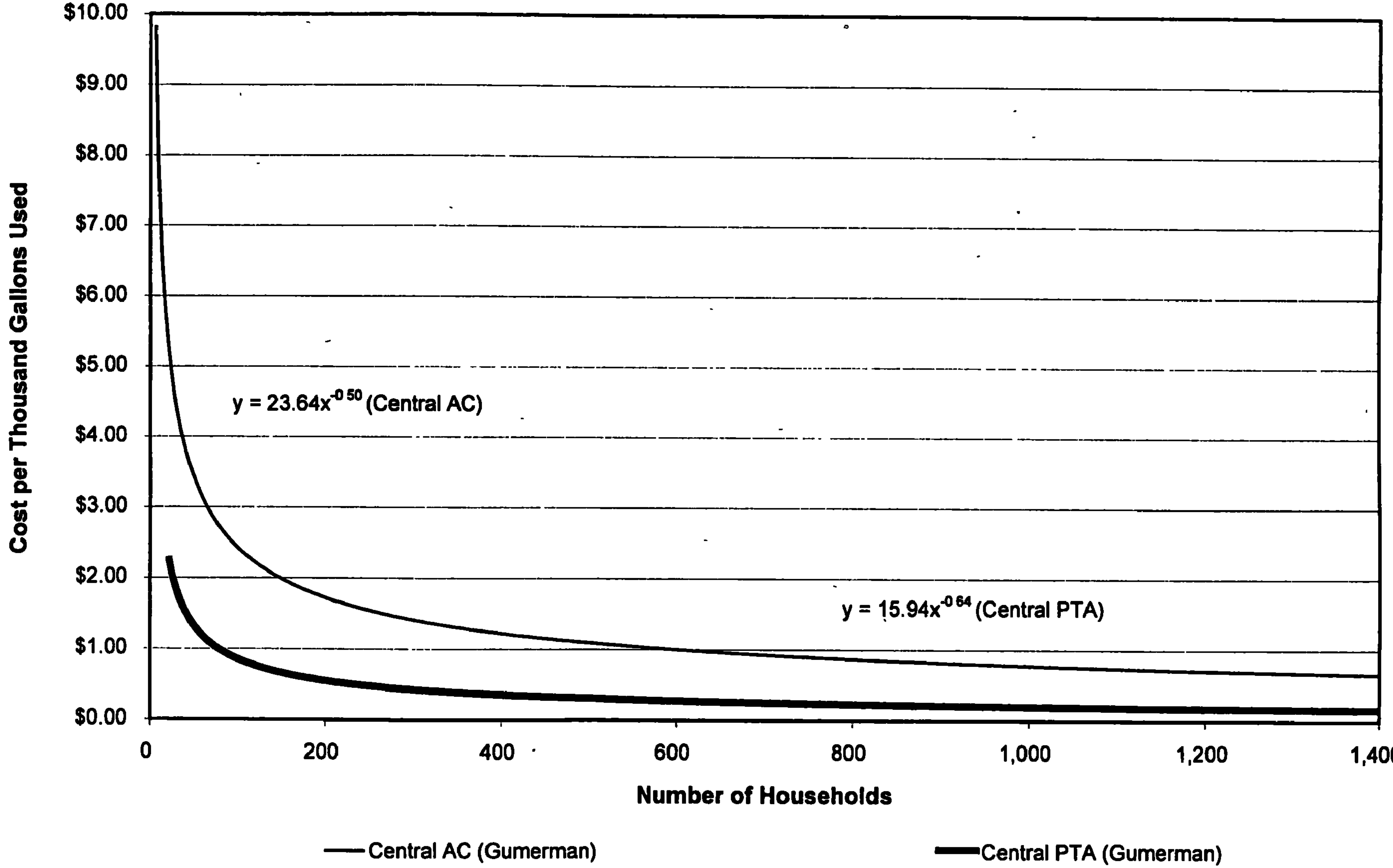
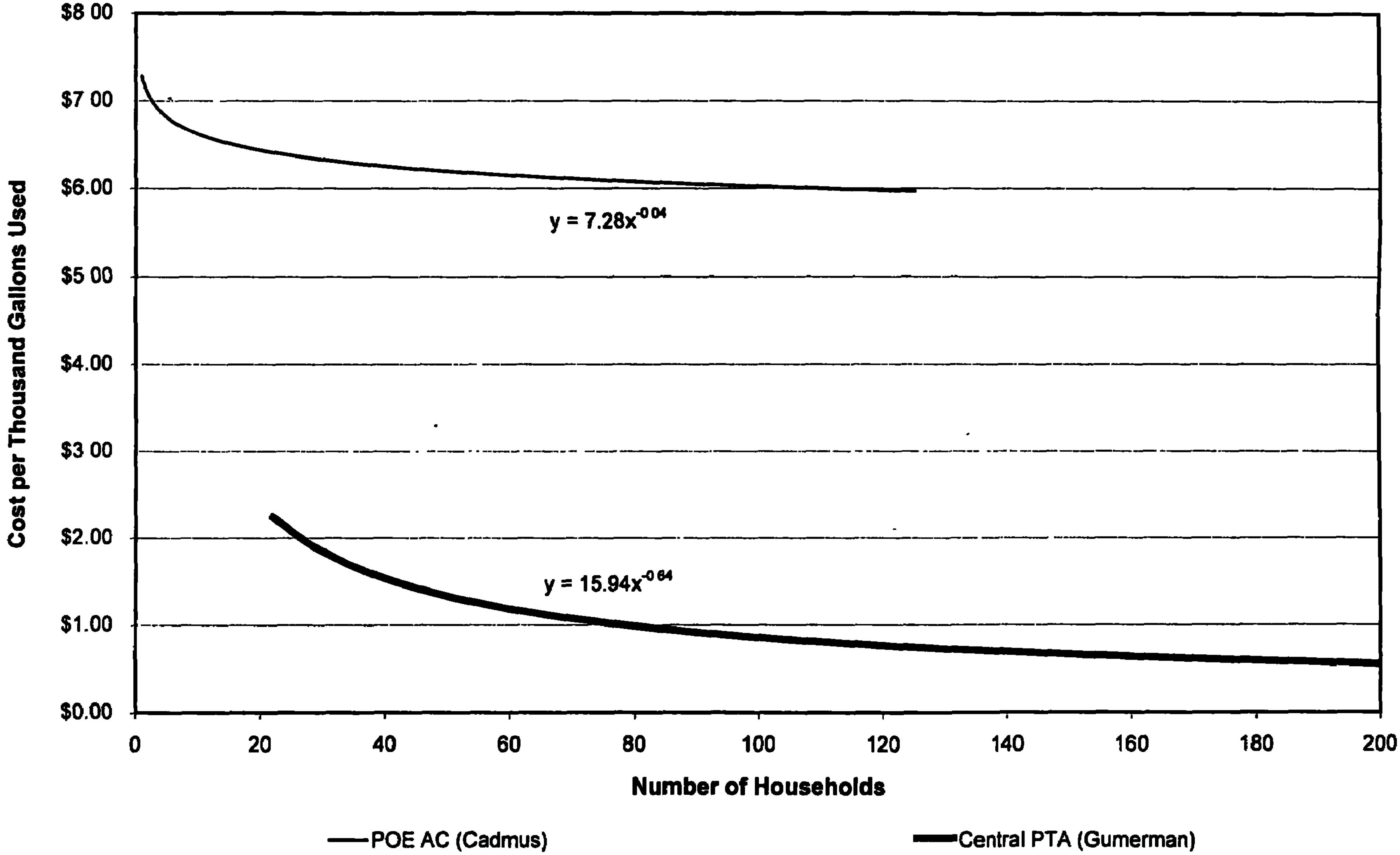


Figure 4.4.5.3.1
Treatment for Radon to 1,500 pCi/L



4.4.6 Trichloroethylene Treatment

As detailed in section 2.9, GAC treatment systems have been shown to effectively reduce concentrations of organic compounds in drinking water. However, while POU units were deemed acceptable for the treatment of alachlor (alachlor does not volatilize at low temperatures), EPA does not believed that POU devices provide sufficient protection of the public health when TCE is the contaminant of concern (see sections 1.2 and 2.9)

4.4.6.1 Point-of-Entry Treatment for Trichloroethylene

The cost curve developed by Cadmus for POE GAC treatment for TCE is presented in Figure 4.4.6.1.1. Case studies and theoretical cost estimates that investigated the use of POE devices for the treatment of VOCs (1,2-DCP) and synthetic organic compounds (SOCs such as DBCP, EDB) were included in Figure 4.4.6.1.1 since each of these contaminants require expensive lab analyses and since exposure to any of these contaminants through inhalation or dermal contact may lead to adverse health affects. The Cadmus cost curve fits well with both case study and vendor-supplied cost data. Since lab analyses of VOCs and SOCs are so expensive, the difference between Cadmus' cost estimate and those provided for some of the case studies most likely result from differences in the costs assumed for lab analysis.

POE aeration is relatively expensive due to the high capital costs associated with aeration equipment. Moreover, while the Cadmus cost estimates presented in Figure 4.4.6.1.2 for POE aeration exceed those provided by contacted vendors, they are consistent with costs provided in the case studies. The aeration units specified by the vendors did not include the cost of a repressurization element, although aeration typically requires post-treatment repressurization.

POE GAC was found to be the most cost-effective POE treatment option for TCE removal for all communities investigated in this study (see Figure 4.4.6.1.3).

4.4.6.2 Central Treatment for Trichloroethylene

Central treatment costs for GAC provided in Figure 4.4.6.2.1 seem to be consistent with the costs found in the case studies. Figure 4.4.6.2.2 compares the cost of central treatment plants that utilize DBA with those that use PTA. Central PTA is less expensive than central DBA for communities larger than about 25 households. Figure 4.4.6.2.3 compares the cost of GAC central treatment with the cost of PTA central treatment. Central PTA is less expensive than central GAC treatment for all communities covered by this analysis.

4.4.6.3 Least-Cost Treatment for Trichloroethylene

The cost curves for the least-cost POE and central treatment options for TCE control are presented in Figure 4.4.6.3.1. According to the Cadmus cost equations, central PTA is the least expensive treatment alternative for all communities investigated in this cost analysis.

Figure 4.4.6.1.1
POE Treatment for Trichloroethylene with Activated Carbon

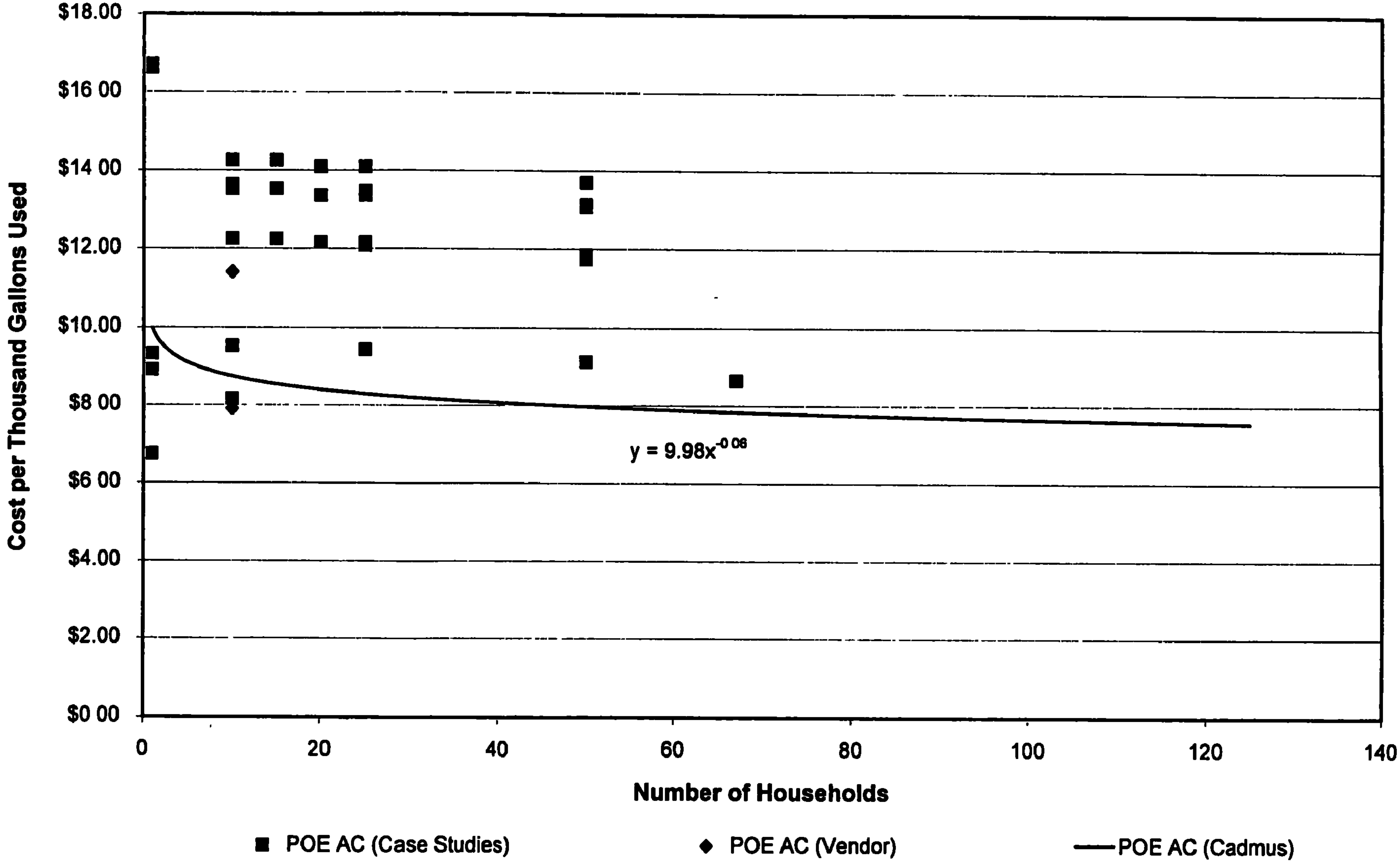


Figure 4.4.6.1.2
POE Treatment for Trichloroethylene with Aeration

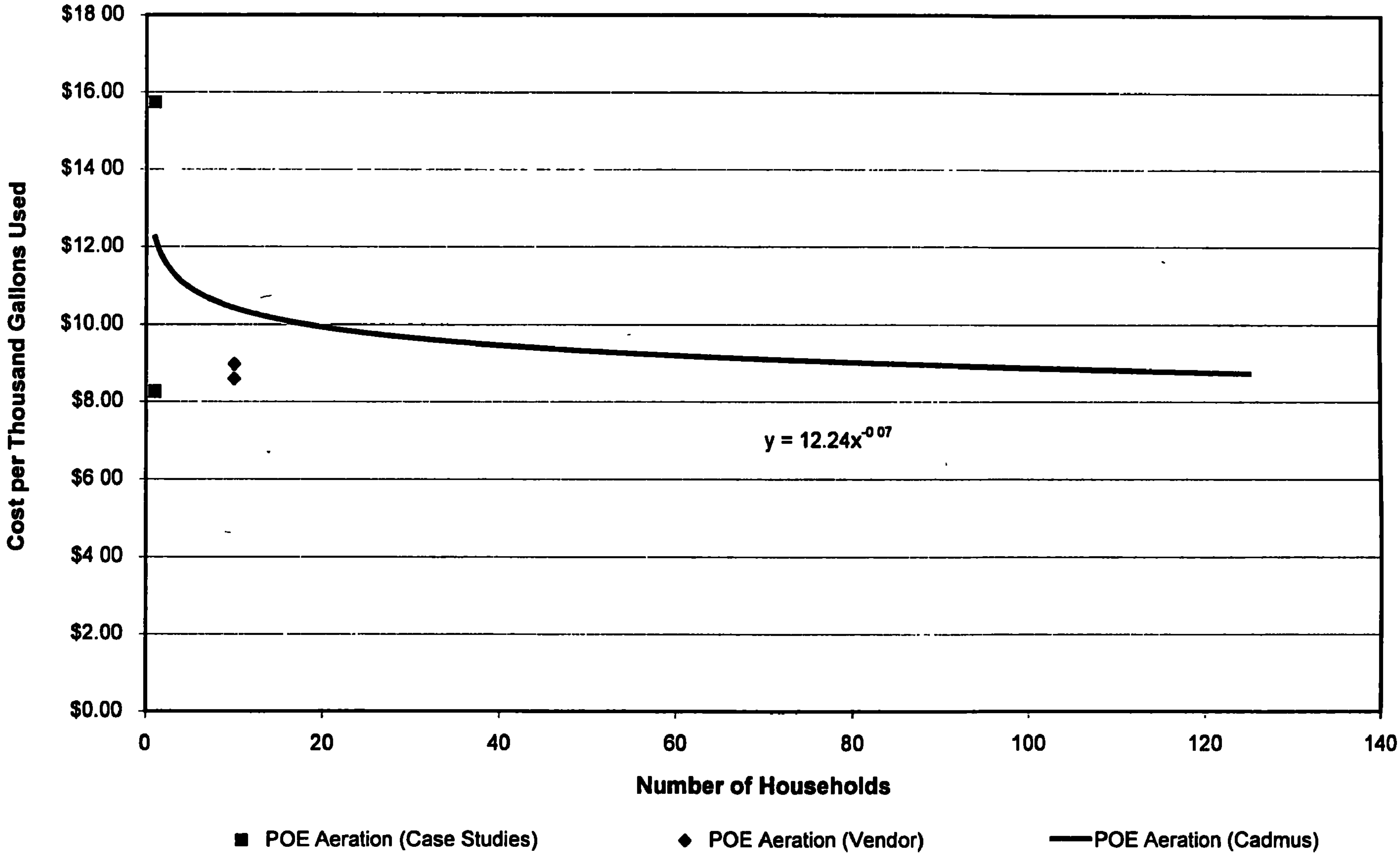


Figure 4.4.6.1.3
POE Treatment for Trichloroethylene

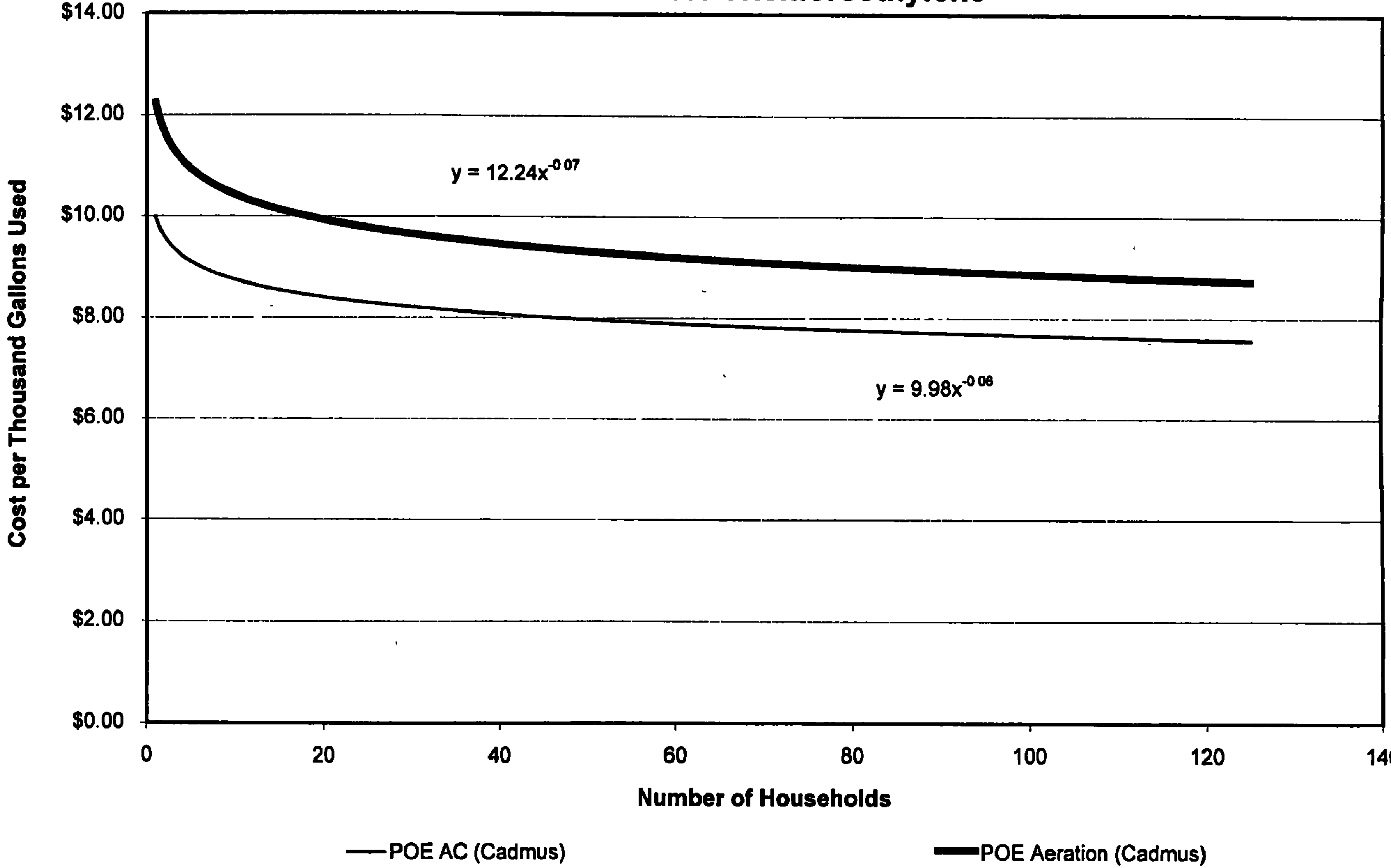


Figure 4.4.6.2.1
Central Treatment for Trichloroethylene with Activated Carbon

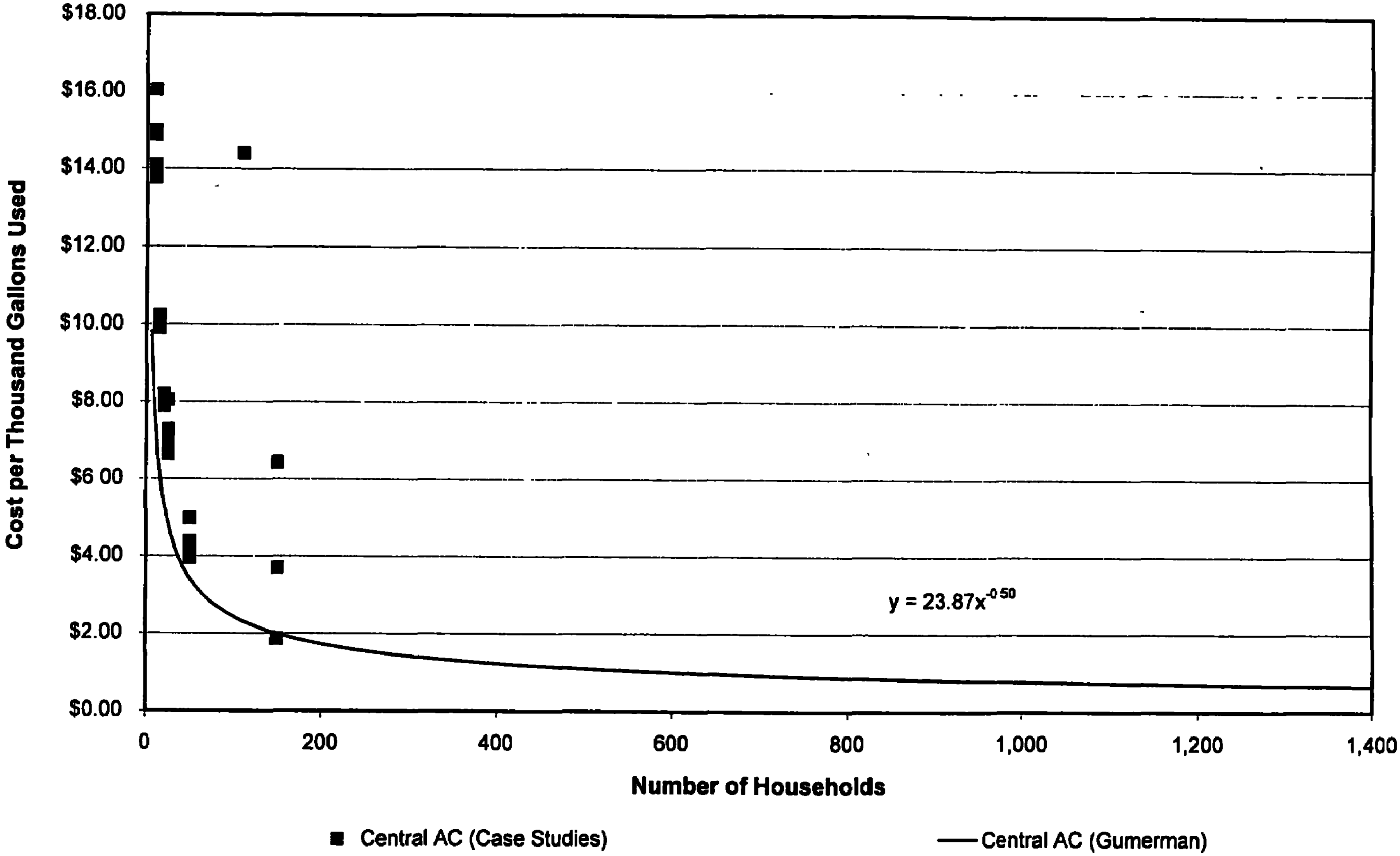


Figure 4.4.6.2.2
Central Treatment for Trichloroethylene with Aeration

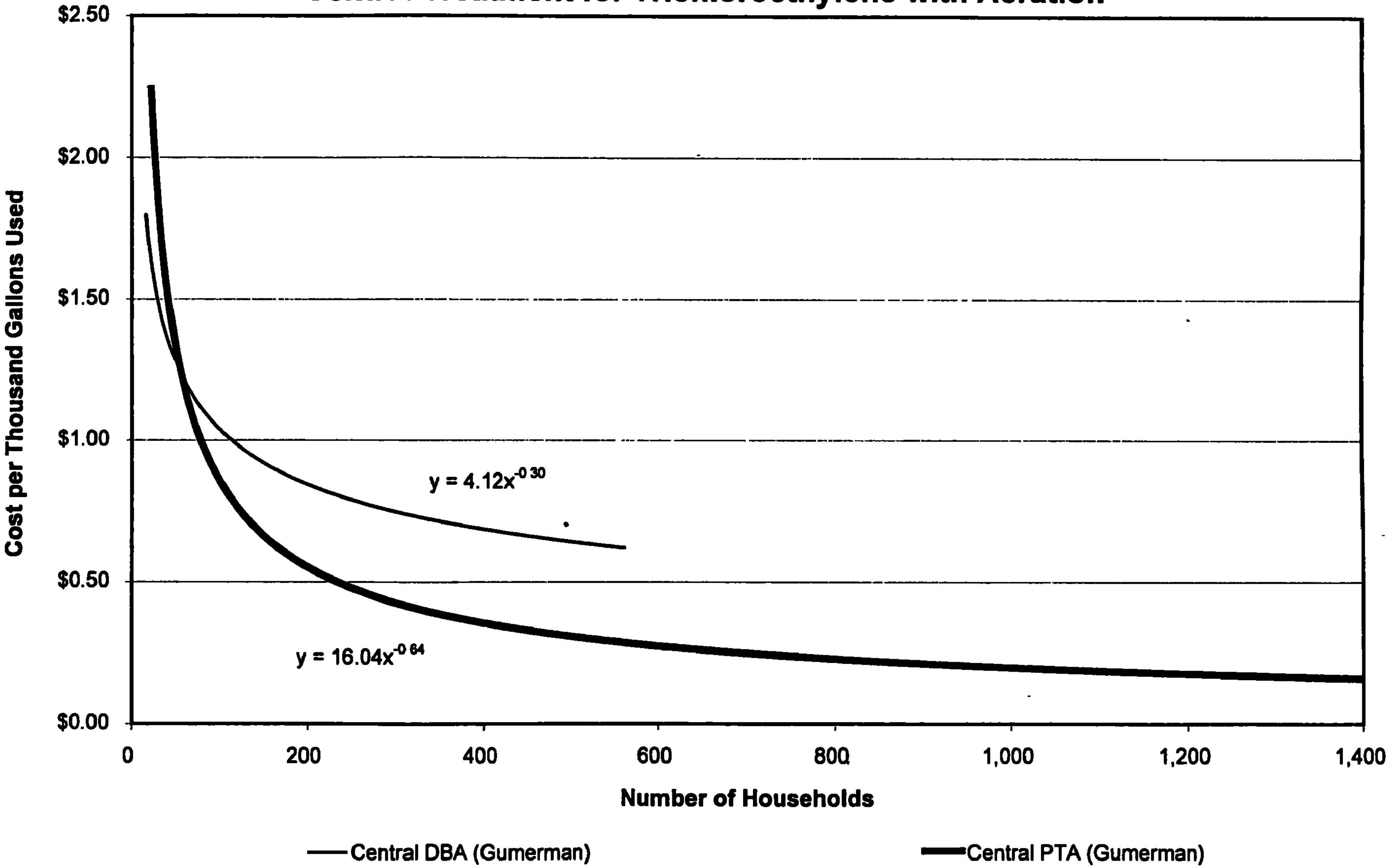


Figure 4.4.6.2.3
Central Treatment for Trichloroethylene

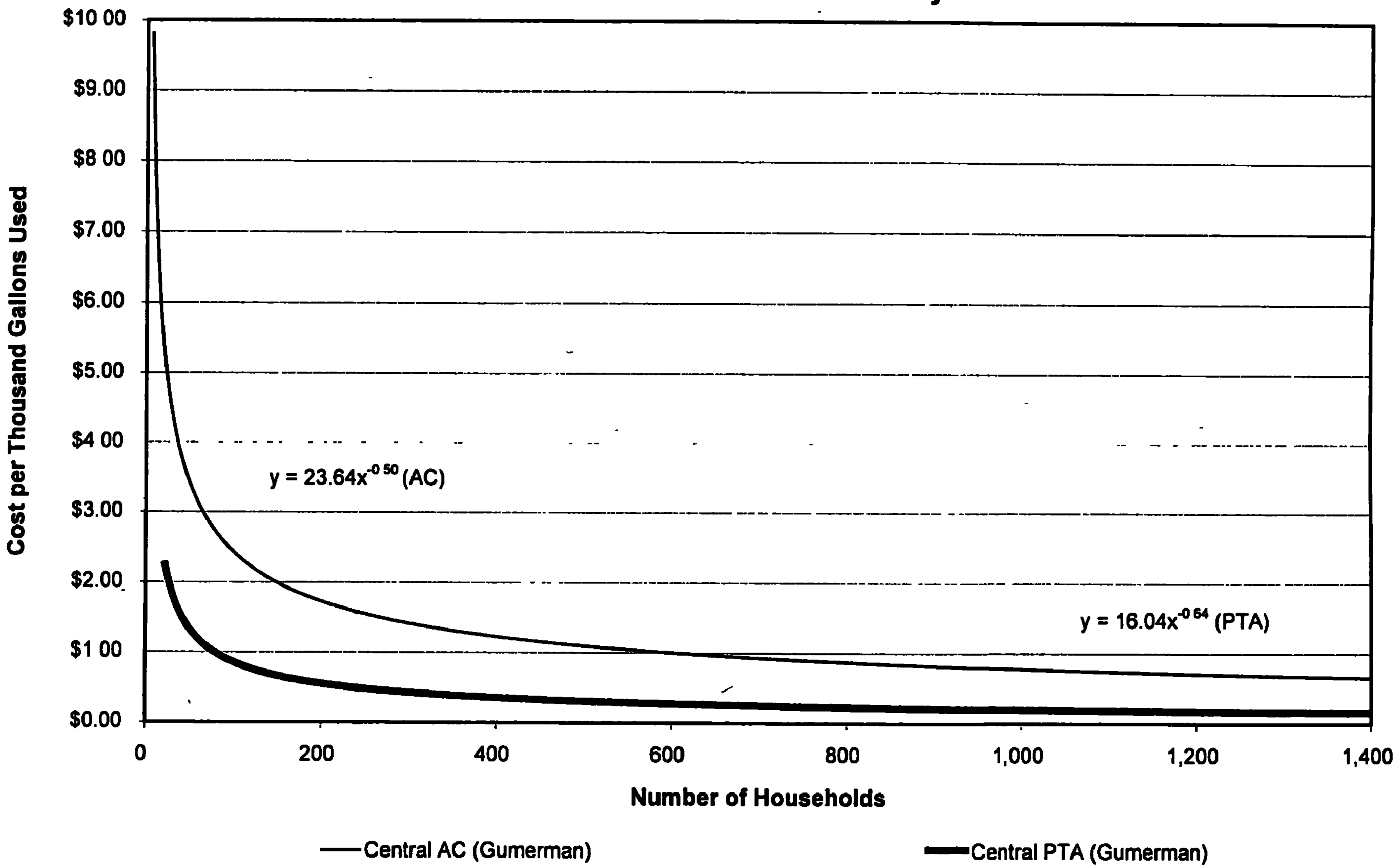
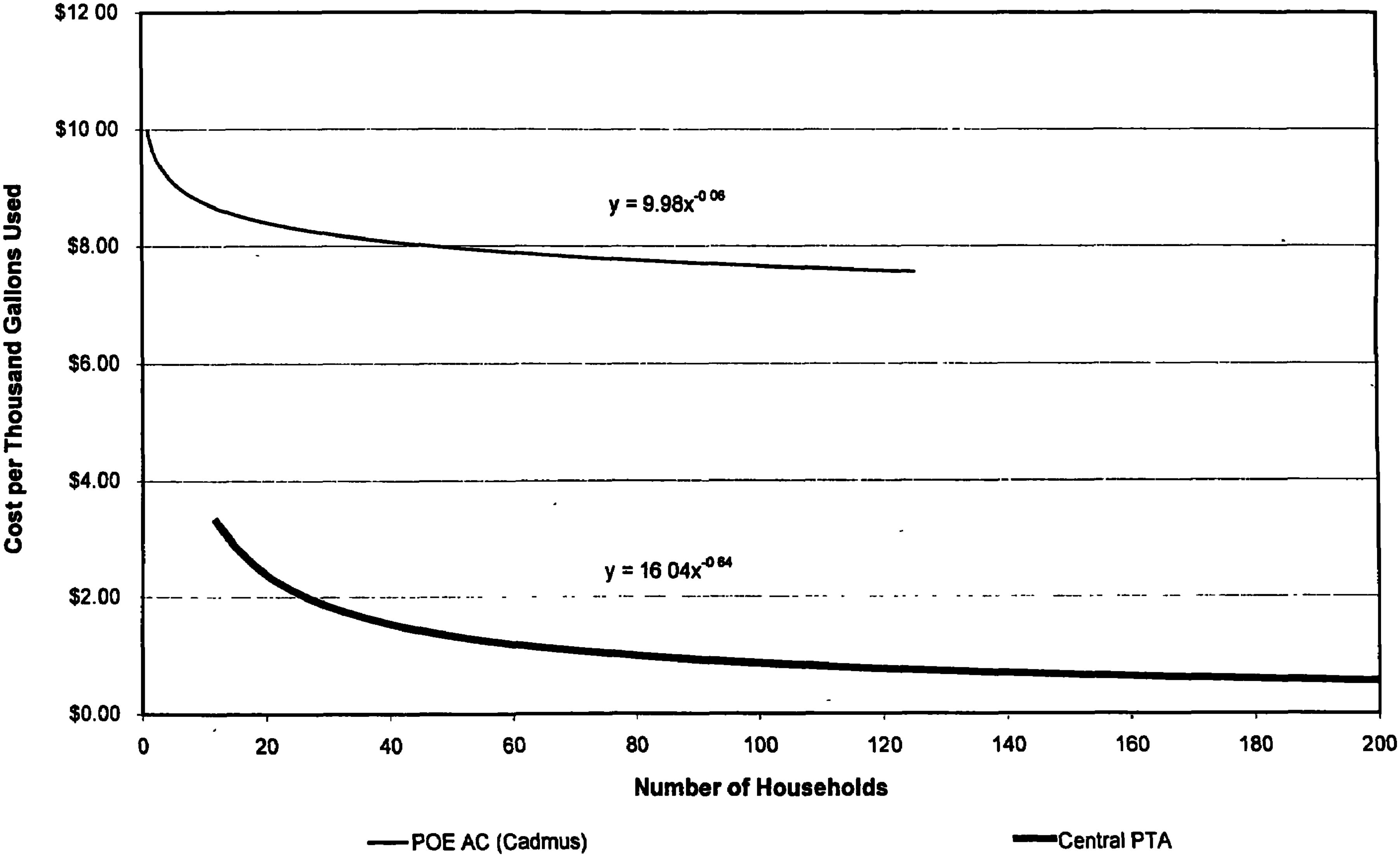


Figure 4.4.6.3.1
Treatment for Trichloroethylene



4.4.7 Nitrate Treatment

Both AX and RO technology have been proven to be effective for the treatment of nitrate contamination (see section 2.6). The influent concentration of nitrate was assumed to be 20 mg/L (double the MCL). Communities with young children should carefully consider using a POE treatment strategy rather than a POU treatment strategy due to nitrate's acute adverse impact on infant health.

4.4.7.1 Point-of-Use Treatment for Nitrate

The cost estimate for the implementation of a POU AX strategy for the treatment of nitrate is presented in Figure 4.4.7.1.1. The Cadmus curve is consistent with the case study data. No vendor provided information on the POU application of AX technology.

The Cadmus cost curve for POU RO treatment for arsenic is provided in Figure 4.4.7.1.2. The curve is straddled by the vendor-supplied data and also matches well with the costs provided by the applicable case studies.

The cost curves for the implementation of POU AX and POU RO treatment strategies are provided in Figure 4.4.7.1.3. Although AX technology is not frequently found in POU applications, POU AX is more cost effective than POU RO for the removal of nitrate.

4.4.7.2 Point-of-Entry Treatment for Nitrate

The cost curve developed by Cadmus for POE AX treatment for nitrate is presented in Figure 4.4.7.2.1. The Cadmus cost estimates are in close agreement with the costs provided by vendors and case studies.

As noted in section 4.4.1.2, POE RO treatment is extremely expensive since POE RO devices have high capital and O&M costs. The Cadmus cost curve was based on actual POE RO installation with appropriate post-treatment and a large storage tank. While the Cadmus cost estimates presented in Figure 4.4.7.2.2 for POE RO exceed those developed by theoretical cost studies found in the literature, they were in close agreement with the cost provided by the only vendor that had experience with the installation of and maintenance of a such a system. The costs for POE RO found in the literature were estimates rather than actual case studies and did not include details regarding the line-items included in the O&M of POE RO devices, the replacement schedule for device components, or the inclusion of a storage tank for treated water.

Figure 4.4.7.2.3 illustrates that POE AX treatment is significantly more cost-effective than POE RO treatment for nitrate, regardless of community size.

4.4.7.3 Central Treatment for Nitrate

Gumerman's cost estimates for central AX treatment are consistent with costs found in the case studies (see Figure 4.4.7.3.1). Central treatment for nitrate with AX is compared to central treatment for nitrate with RO in Figure 4.4.7.3.2. The least-cost technology for central treatment of nitrate is clearly AX for all communities investigated in this cost analysis.

4.4.7.4 Least-Cost Treatment for Nitrate

The least-cost POU, POE, and central treatment options for nitrate are presented in Figure 4.4.7.4.1. According to the Cadmus cost equations, POU application of AX technology is the least expensive treatment alternative for communities of less than about 180 households. Larger communities would be served more cost-effectively by the application of AX technology in a central treatment plant. Central treatment with AX becomes less expensive than POE (AX) treatment for nitrate for communities of more than about 40 households. POE treatment for nitrate was found to be more expensive than POU treatment for nitrate for all studied communities.

Since both the POE and POU cost curves are relatively flat at their point of intersection with the central treatment cost curve, a small change in the price of either treatment option would result in a sizeable change in the community population at which central treatment becomes the most cost effective method of reducing arsenic concentrations in household water. For example, a 10 percent increase in the cost of POU technology would result in central treatment becoming more cost-effective for communities of more than 120 households rather than communities of more than 180 households.

Figure 4.4.7.1.1
POU Treatment for Nitrate with Anion Exchange

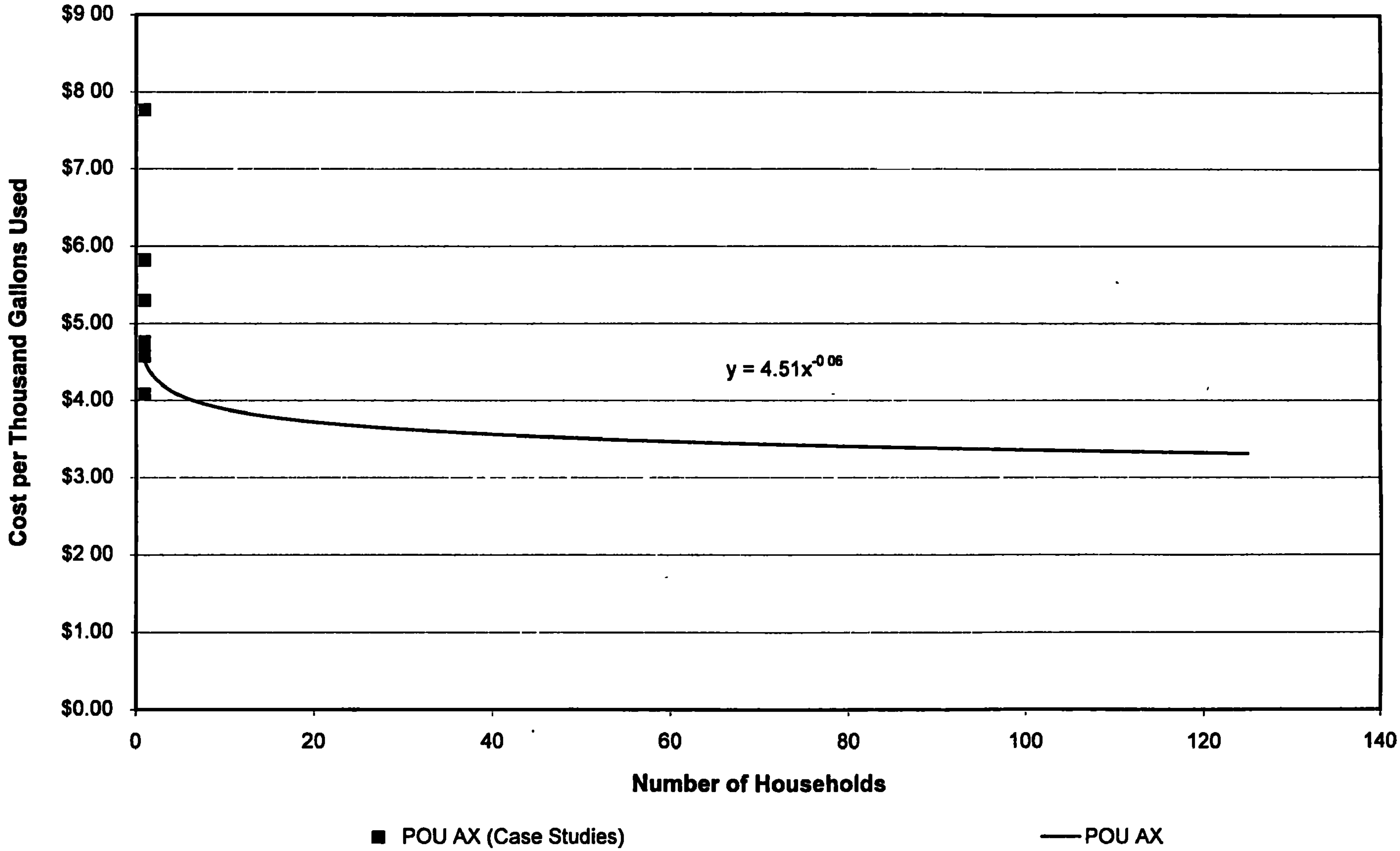


Figure 4.4.7.1.2
POU Treatment for Nitrate with Reverse Osmosis

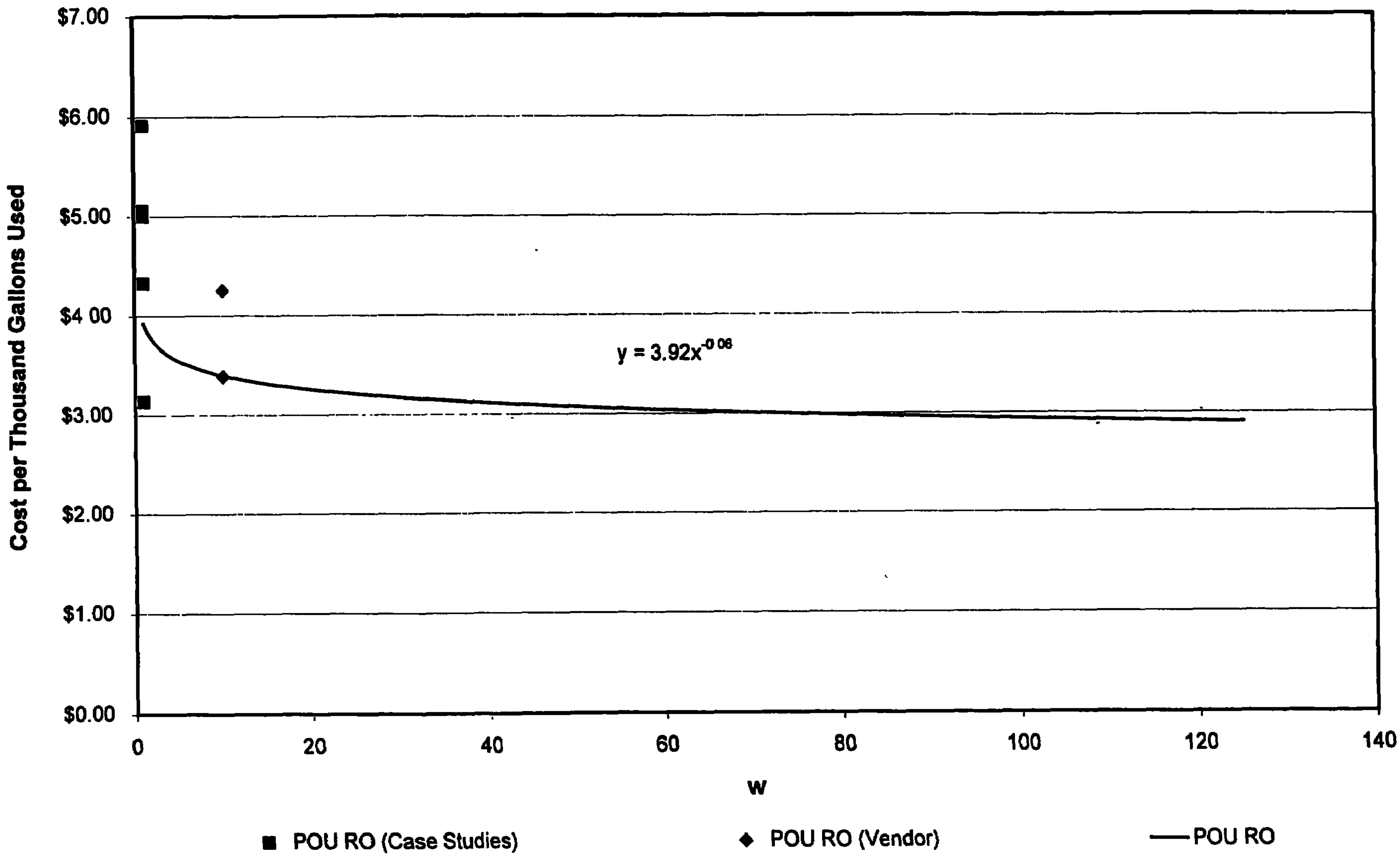


Figure 4.4.7.1.3
POU Treatment for Nitrate

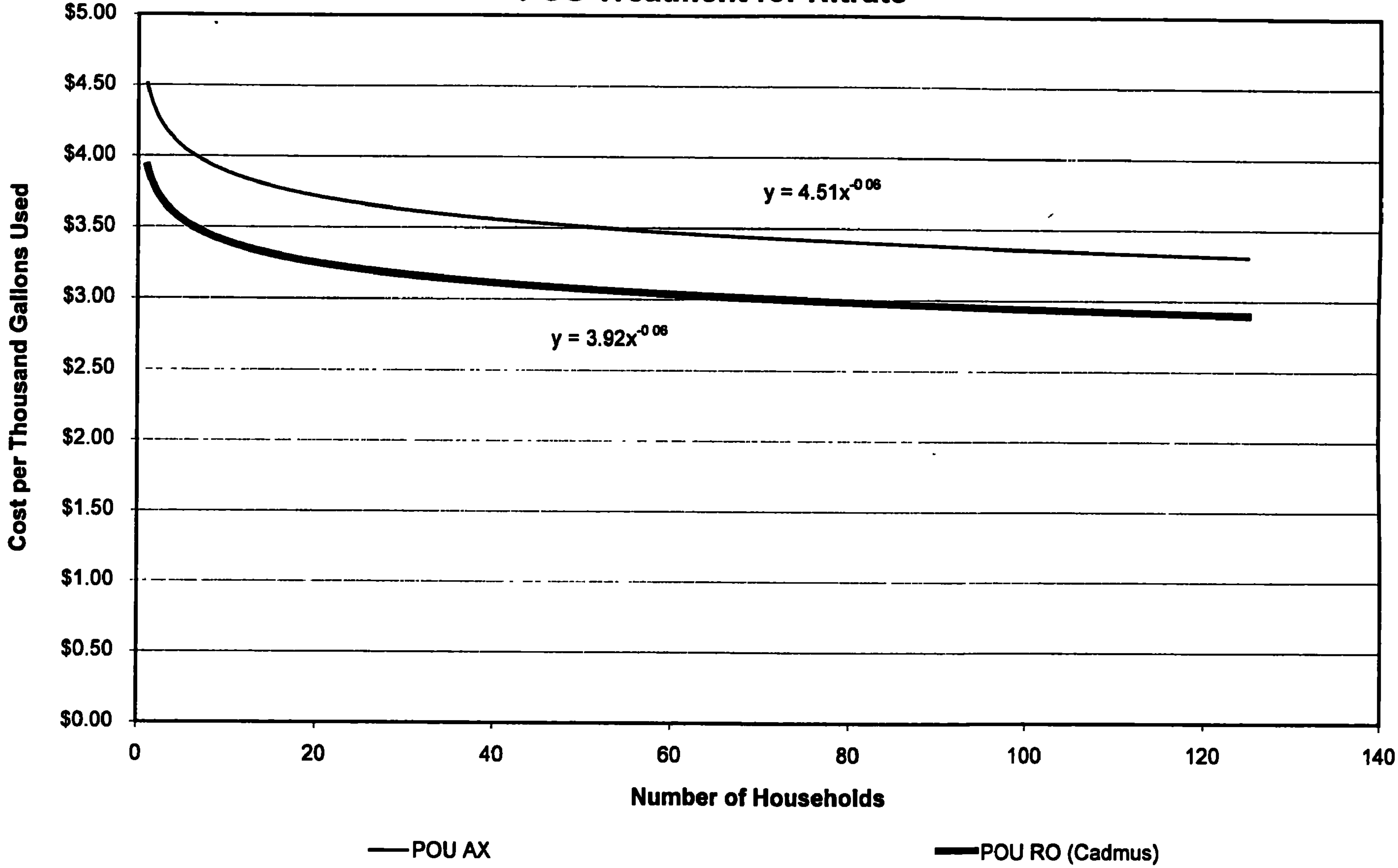


Figure 4.4.7.2.1
POE Treatment for Nitrate with Anion Exchange

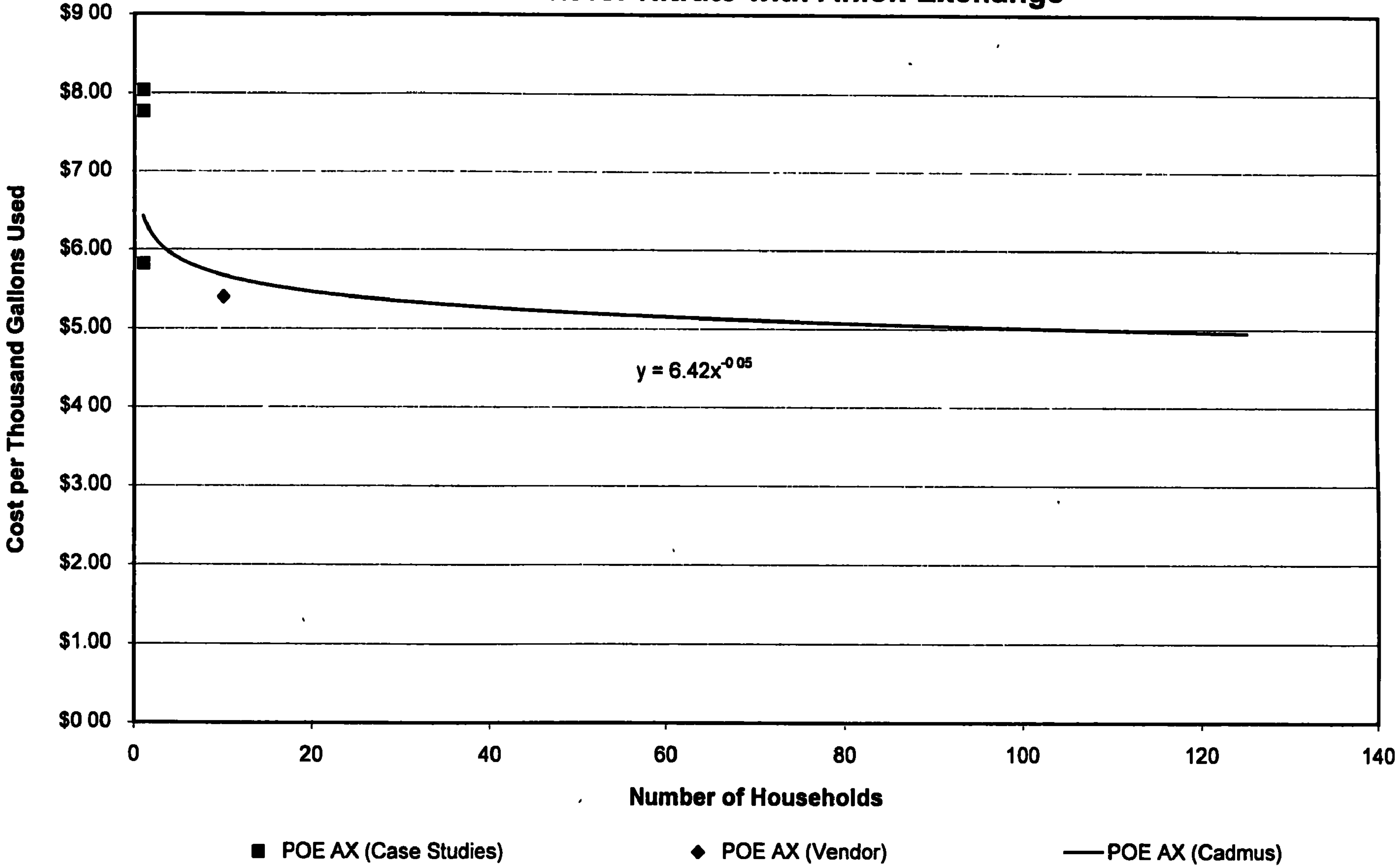


Figure 4.4.7.2.2
POE Treatment for Nitrate with RO

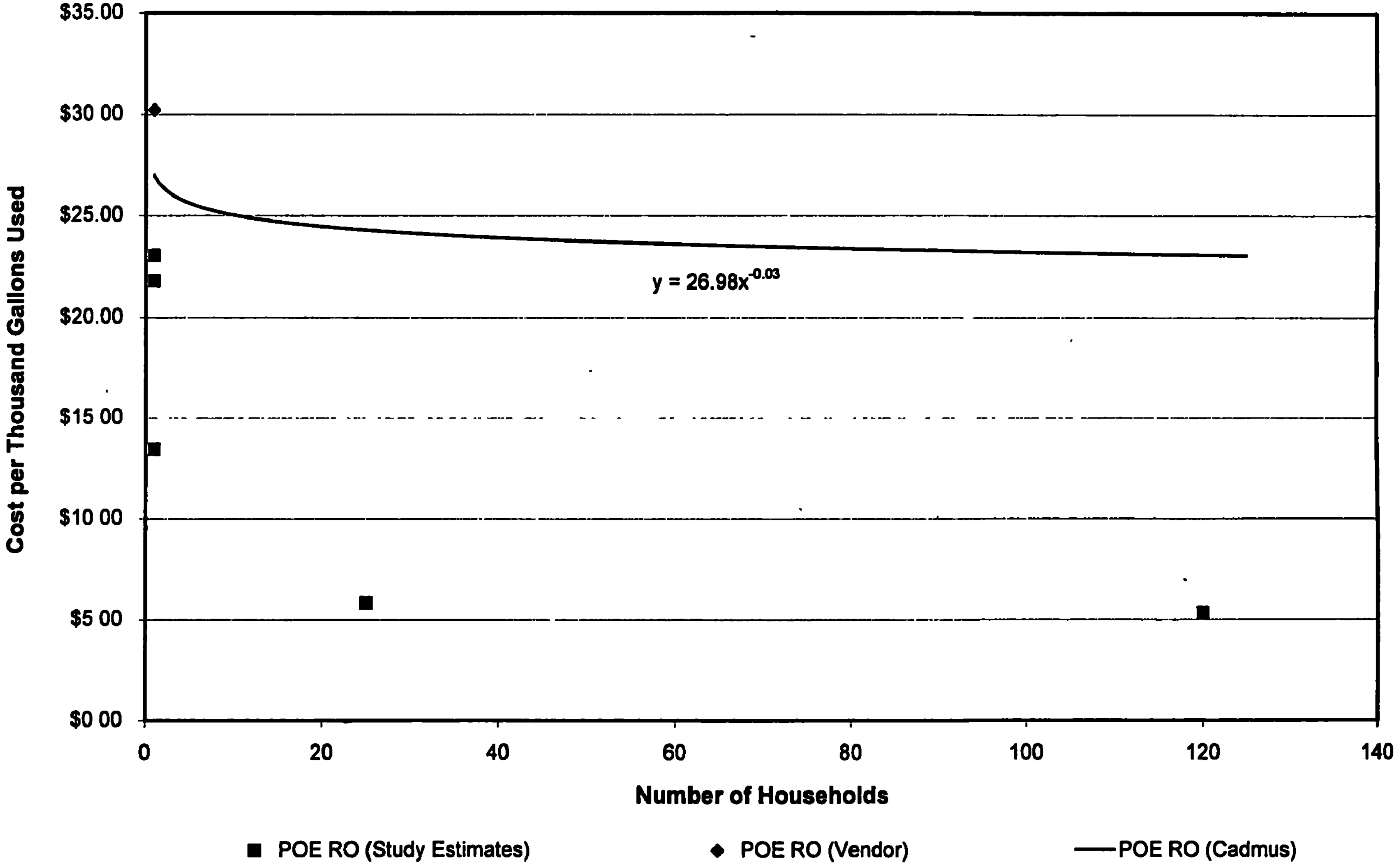


Figure 4.4.7.2.3
POE Treatment for Nitrate

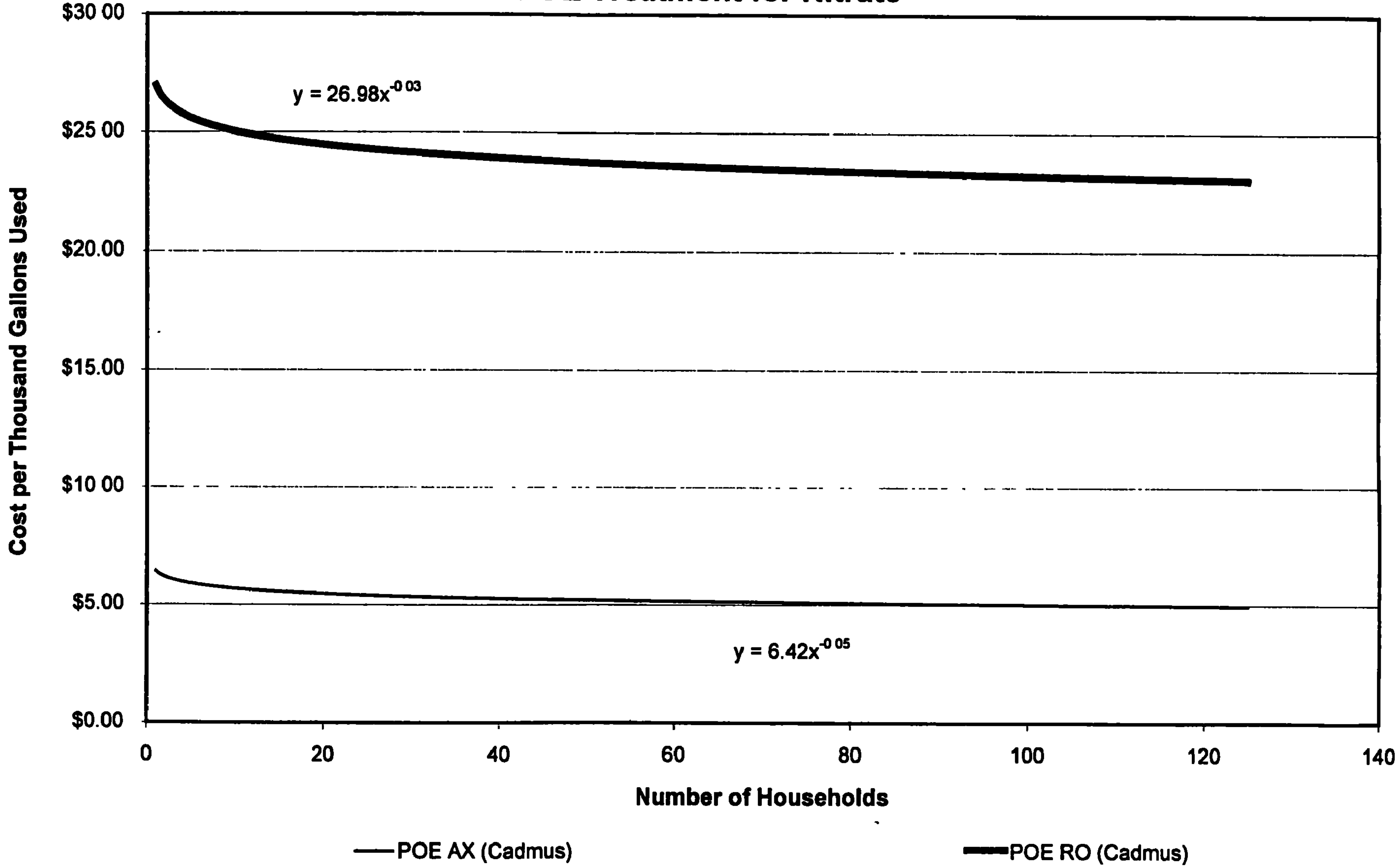


Figure 4.4.7.3.1
Central Treatment for Nitrate with Anion Exchange

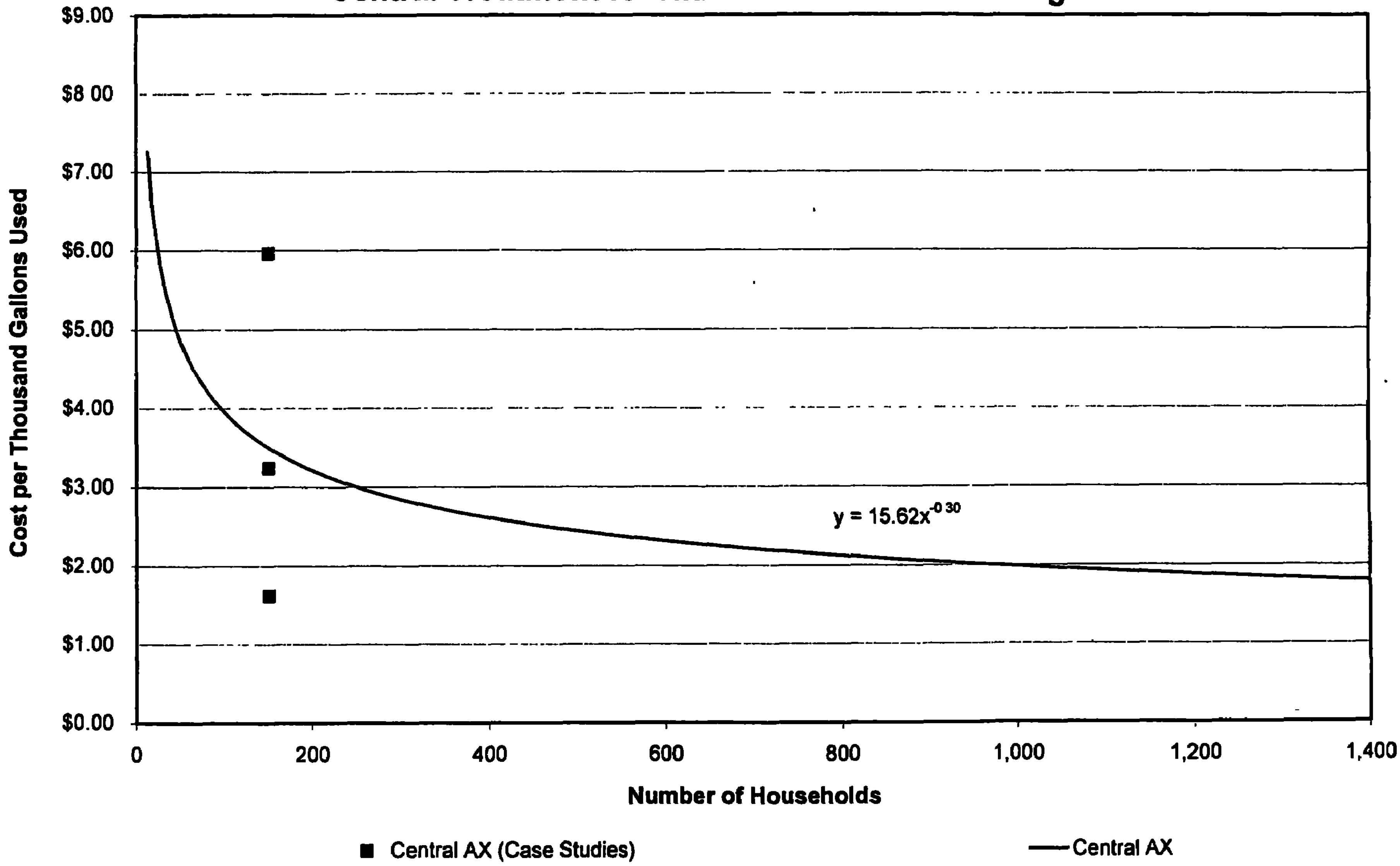


Figure 4.4.7.3.2
Central Treatment for Nitrate

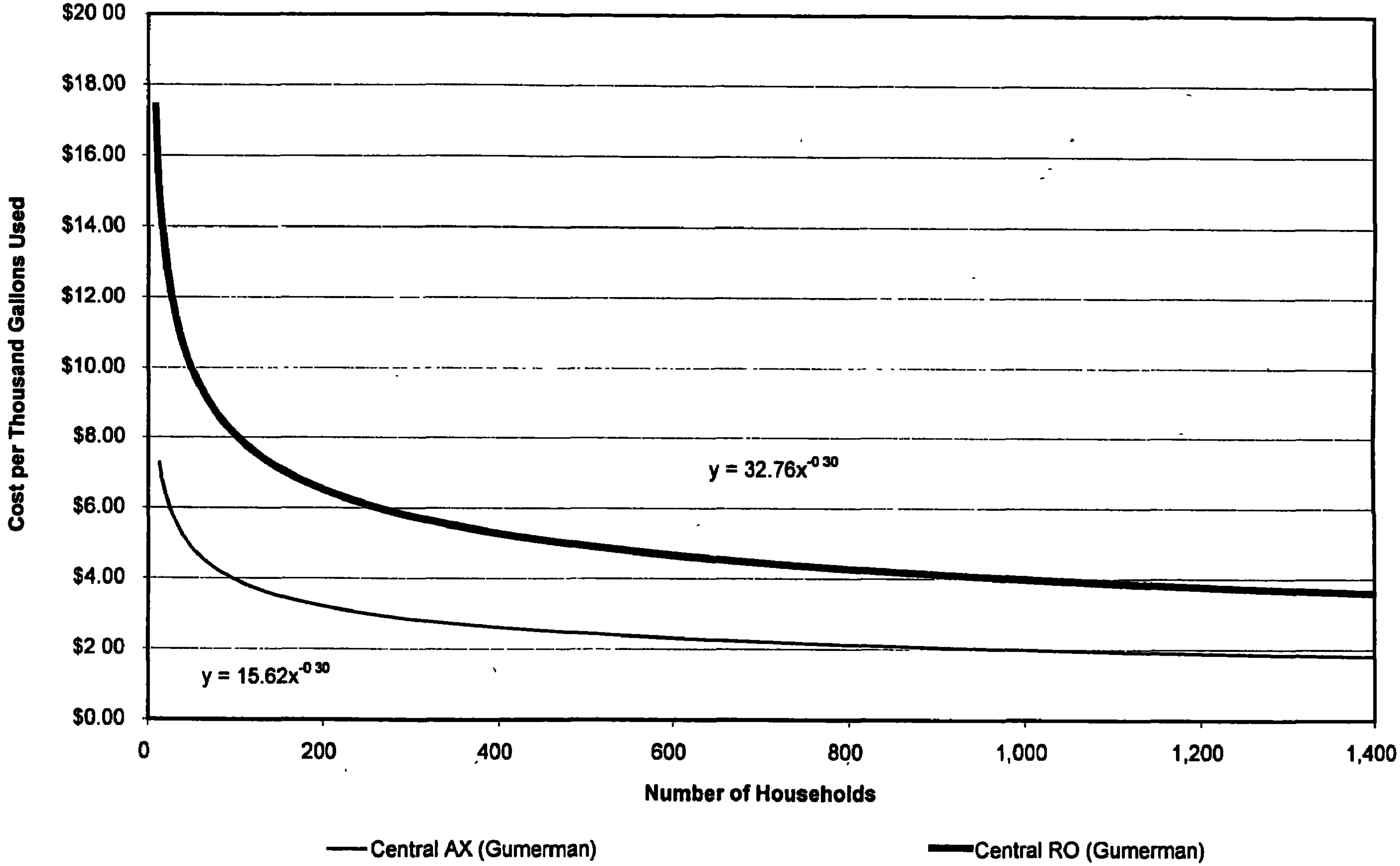
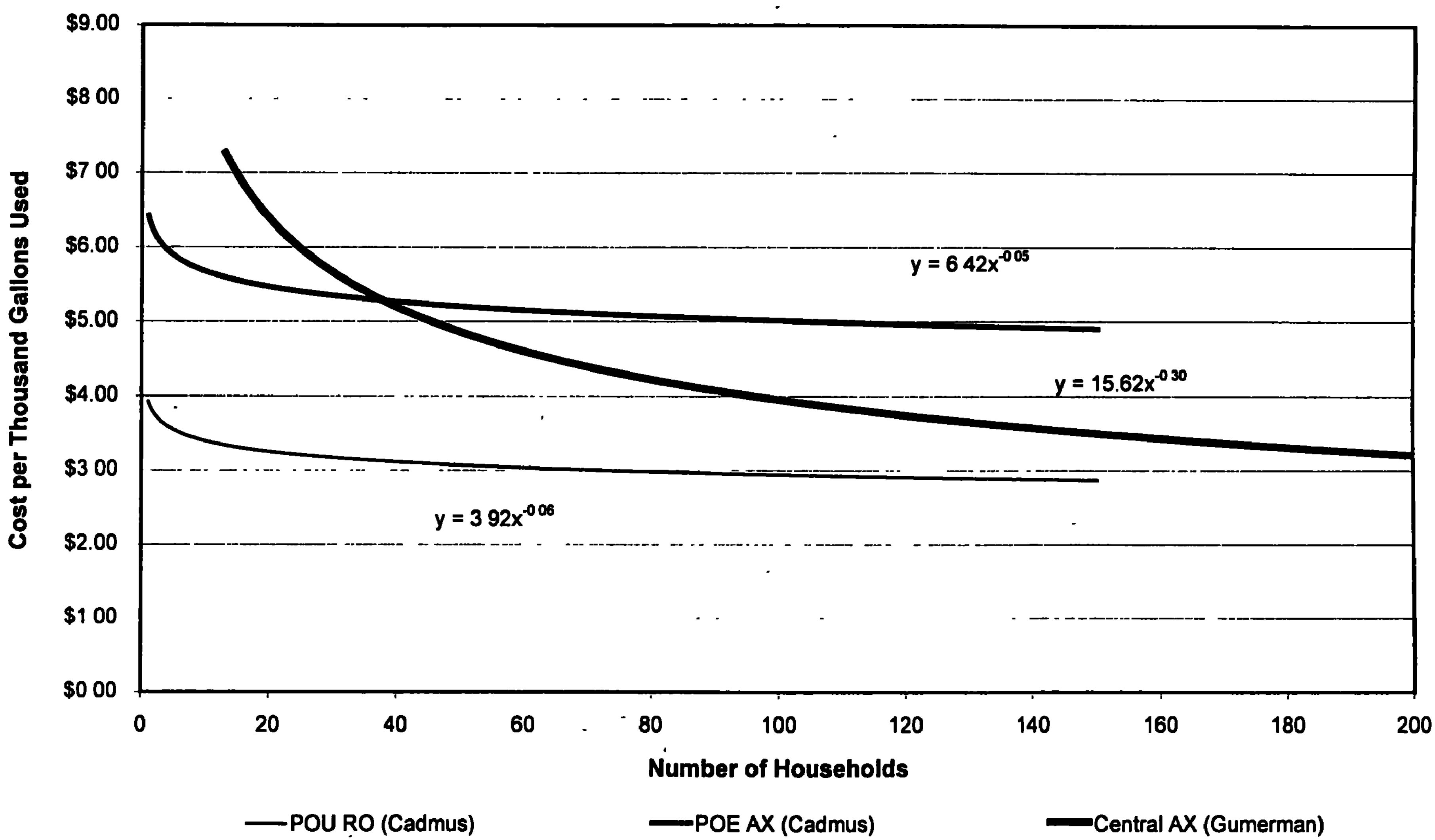


Figure 4.4.7.4.1
Treatment for Nitrate



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