Appendices

Appendix 2A-1 Cost Assumptions for Packed Tower Aeration

Vendor: Capital costs for packed tower air stripping systems were originally provided by the Layne Christensen Company (Bridgewater, NJ) in 1998.

Verified by: To verify the costs, quotes were also obtained from Carbonair Environmental Services (New Hope, MN), Branch Environmental (Somerville, NJ), and Delta Cooling Towers (Fairfield, NJ).

These cost estimates were verified again by Layne Christensen Company (Bridgewater, NJ) in 1999. In addition, Layne Christensen Company provided actual capital costs for sold equipment that supported the accuracy of these cost estimates.

Assumptions given to vendors:

Flow rate: 60, 600, 6,000 gpm
Influent concentration: 20, 200, 2,000 μg/L
Influent water temperature: 65°F
pH: 8.0
Alkalinity: 250 mg/L as $CaCO_3$
Hardness: 250 mg/L as $CaCO_3$
Iron: <1 mg/L
TDS: 750 mg/L

Assumptions made by vendors:

Liquid loading rate: 10.0 to 12.0 gpm/ft^2
AWR ratio: 200:1
Henry's constant (dimensionless) = 0.024
Aluminum tower construction
Packing Medium: 2-inch Jaeger Tri-Pack

Calculations made by vendors:

Table 2-A1
Packed Tower Aeration Assumptions

Flow (gpm)	Removal Rate (%)	Packing Height (ft)	Power Requirement (HP)
60	90	20	2
60	95	25	3
60	99	40	5
60	99.5	45	5
600	90	20	20
600	95	25	20
600	99	40	30
600	99.5	45	40
6000	90	20	30
6000	95	25	30
6000	99	40	40
6000	99.5	45	40

Appendix 2A-2 Cost Assumptions for Low Profile Aeration

Vendor: Capital costs for low profile air stripping systems were originally provided by North Eastern Environmental Products (West Lebanon, NH) in 1998.

Verified by: To verify the costs, quotes were also obtained from Carbonair Environmental Services (New Hope, MN).

These cost estimates were verified again by North Eastern Environmental Products (West Lebanon, NH) in 1999. In addition, North Eastern Environmental Products provided actual capital costs for sold equipment that supported the accuracy of these cost estimates.

Assumptions given to vendors:

Flow rate: 60, 600, 6,000 gpm
Influent concentration: 20, 200, 2,000 μg/L
Influent water temperature: 65°F
pH: 8.0
Alkalinity: 250 mg/L as $CaCO_3$
Hardness: 250 mg/L as $CaCO_3$
Iron: <1 mg/L
TDS: 750 mg/L

Assumptions made by vendors:

AWR: see the following table.
Influent air temperature: 50°F
Henry's constant = cost estimates were based on empirical data, not theoretical calculations (i.e., NEEP generated a performance curve at 1 gpm, 5 gpm, 15 gpm, and 45 gpm for various removal efficiencies and influent concentrations [maximum influent of 5 mg/L] and extrapolated for other flow rates and removal efficiencies).
Safety Factor = 1

Calculations made by vendors:

The footprint of a single unit, including the blower, ranges from 5.5 feet by 6.2 feet for low flow models of the 3600 series used at 60 gpm to 7.5 feet by 12.5 feet for the series 41200 models used for 6000 gpm flows.

Table 2A-2
Low Profile Aeration Assumptions

Flow (gpm)	Influent (µg/L)	Removal Rate (%)	Air/Water Ratio	Number of Trays	Number of Units	HP per Unit
60	200	97.5	225	3	1	10
60	2000	99.75	300	3	1	25
600	20	75	70	4	3	15
600	20	90	90	5	3	25
600	20	97.5	135	4	6	15
600	2000	99	180	4	6	15
600	200	99.75	180	5	6	25
600	2000	99.75	180	5	6	25
6000	20	75	70	4	30	15
6000	200	90	90	4	30	25
6000	20	97.5	135	4	60	15
6000	20	97.5	135	4	60	15
6000	200	97.5	135	4	60	15
6000	200	99.75	180	5	60	25

Appendix 2B 9/1/98 La Crosse, Kansas Trip Report

Introduction

The water treatment plant for La Crosse, Kansas is one of only two known large-scale facilities in the country treating public drinking water for MTBE removal and delivering the water to their customers. On September 1, 1998, four members of the MTBE Research Partnership met with representatives from the State of Kansas and their consultant to learn about the La Crosse situation and share information about MTBE occurrence and treatment. La Crosse is located along Highway 183, about 20 miles south of Hays, Kansas.

In attendance:

Todd Anderson, *Santa Clara Valley Water District*

Jim Davidson, *Alpine Environmental, Inc.*

Dave Smith, *ARCO*

Andy Stocking, *Malcolm Pirnie, Inc.*

Craig Hofmeister, *Handex*

Phil Koontz, *State of Kansas Department of Health and Environment*

Bill Reetz, *State of Kansas Department of Health and Environment*

Background

La Crosse operates a drinking water treatment plant for water softening and disinfection. Groundwater is the only water source for the plant; one source well is located 8/10 of a mile east of the town of Rush Center; the other is 1/10 of a mile further east. Rush Center is located approximately 5 miles south of the La Crosse treatment plant. Hydrated lime softening reduces the water's hardness from about 700 to 110 mg/L (as calcium carbonate). Chlorine is applied at wellheads and at the plant to maintain a free chlorine residual of between 0.5 and 1.0 mg/L in the finished water; this residual is typically 0.7 mg/L. The plant is only run during the day, and treats between approximately 300 gpm (winter) and 450 gpm (summer).

In May 1996, a nearby resident noticed chemical-like odors from his irrigation well water. A sample was sent to a laboratory for analysis; MTBE was found and was acknowledged to be the source of the odors. One of La Crosse's nearby water supply wells was sampled; this water contained about 200 µg/L of MTBE. Shutting down any wells was not an option for La Crosse because of water supply needs. A shallow tray air stripper was quickly installed at the plant as a temporary measure; a 40 percent reduction in MTBE concentration was achieved at 250 gpm. A permanent packed tower air stripping system was subsequently installed at the plant, and has been generally successful in treating the influent MTBE to

below 5 µg/L (non-detectable concentrations using a detection limit of 0.2 µg/L have been reported, but this is probably an unrealistically low detection limit). Other than the irrigation well owner, no residents have reported MTBE-related taste, odor, or other problems. The drinking water treatment plant has incorporated the air stripping towers into its treatment sequence and operations and maintenance program, and continues to deliver drinking water to its customers.

MTBE Source Investigation

Three UST sites have been identified as the sources of MTBE. These are located on three corners of the main intersection in Rush Center, Kansas, about 5 miles south of the La Crosse plant. The closest of the two affected water supply wells (Well #5) is located about 8/10 mile due east of the service station cluster. The next well is about 1/10 mile further east.

Contamination from leaking USTs at each of the three sites has resulted in a comingled total petroleum hydrocarbon (TPHg) and BTEX plume, which has been undergoing investigation for a number of years. Contamination immediately underneath the sites is fairly high and free product has been present. Until sampling was conducted for MTBE, the extent of groundwater contamination was thought to be fairly well defined with numerous monitoring wells, and the contamination appeared to reach about 800 feet downgradient (east). All three stations have had the leaking tanks removed or replaced.

MTBE was not thought to be a contaminant of concern in the investigation of the three UST sites until after it was noticed in the nearby irrigation well and the La Crosse supply well. MTBE has been added to local gasoline since 1979 as an octane booster, and since the early 1990s as an oxygenate. MTBE is reportedly the oxygenate of choice in about 80 percent of Kansas gasoline. MTBE was found in site monitoring well samples in concentrations as high as 77,000 µg/L. La Crosse's water wells are screened at about 50 to 70 feet bgs. A similarly screened monitoring well was installed about halfway between the UST sites and Well #5, and produced a 1,600 µg/L sample. This well was installed following MTBE being noticed in the irrigation and municipal wells and confirmed the concern over the MTBE presence in the plume. A shallow monitoring well installed in the same area produced water with about 5 µg/L of MTBE.

Geologic Setting and UST Site Remediation

The UST sites are located in a locally low topographic area, near an existing creek, and likely over a buried stream channel. Silts and clays are generally present to 25 feet bgs, and sands are generally present from 25 feet bgs to bedrock around 70 feet bgs. The high permeability and preferred pathway of the buried stream channel, as well as the easterly groundwater gradient, promoted the MTBE migration to the water supply wells.

Since heavy rains in 1993, groundwater levels in the area have remained about 10 feet higher than in previous years. Groundwater has risen over the zone with previously detected free product, and has submerged the screens of the soil vapor extraction wells on site. This has delayed the remediation plan for the three sites, which originally consisted of soil vapor extraction and groundwater pump-and-treat. Shallow tray air stripping, carbon adsorption, and soil vapor extraction equipment are currently sitting unused at the site. The stripping unit was temporarily relocated to the drinking water treatment plant and operated for a number of months there when MTBE was first noticed in the water. It was replaced by the two air stripping towers and was returned to the service station remediation area. The site remediation system was originally designed for just gasoline contamination, but will hopefully remove MTBE from the subsurface as well. MTBE that escapes the on-site remediation system will continue to be addressed by the point-of-use treatment at the plant's air strippers. The UST site occupying the southeast corner of the Rush Center intersection has been excavated to a depth of 20 feet to remove contaminated soil; air sparging in conjunction with soil vapor extraction is planned for this site.

Two Oxygen Releasing Compound (ORC) lines were installed in May of 1997 in an attempt to decrease the concentration of BTEX and MTBE at the site and the concentration of MTBE in downgradient wells, including the La Crosse municipal wells. The first ORC line was installed, bisecting the BTEX and MTBE plume near the downgradient third of the plume. ORC was injected from 20 to 70 feet below grade, including the entire saturated zone. The second ORC line was installed approximately 900 feet upgradient of the municipal wells. ORC was tremied in the geoprobe borings for this installation.

Quarterly monitoring following the ORC applications indicated a significant increase in dissolved oxygen concentrations downgradient of the ORC lines. BTEX and MTBE concentrations also declined in wells located downgradient of the ORC lines. However, recent monitoring results indicate that BTEX and MTBE concentrations in these wells are again beginning to increase.

MTBE Treatment

After MTBE was first identified in the drinking water, a low profile shallow tray air stripping system was used to treat the water prior to distribution. Water was pumped to a clear well, pumped through the five-tray stripping system, and then discharged back into the clear well. The residence time in the clear well was such that the water could run through the stripping system several times prior to distribution. As stated previously, this system was only capable of achieving a 40 percent reduction in influent MTBE concentrations (ranging from 200 µg/L to 500 µg/L) at the La Crosse plant.

The currently operating permanent MTBE treatment system at La Crosse's water treatment plant consists of two 35-foot tall (6-feet diameter) packed tower air strippers. Each contains about 30 feet of 2-inch Jaeger Tripacks; the towers are operated in series. Water is pumped

to the strippers following lime addition, flocculation, and settling. Effluent from the strippers is returned to the conventional treatment system and piped to the sand/anthracite filters. The consultant for the State of Kansas claims that the operating air/water ratio in each of the two stripping towers is 175. No off-gas treatment is required or performed; MTBE odors are not evident at any distance from the top of the towers, although they are strong at the immediate top of the towers. Plant operators report that the stripping system does not require significant operations and maintenance time; there have not been problems with fouling or scaling to date. The towers are operated from 8 am to 4 pm, 6 days/week. There are three 10-horsepower pumps to pump water to the top of the two towers and back to the filtration unit, and two 15-horsepower blowers used for the packed tower system.

The air stripping towers were designed by Process Equipment and Engineering (PEE) of Lakeland, Florida. PEE was selected because they provided the lowest bid of the four contractors chosen for quotations. Originally, PEE had stated that only one air stripper was needed for complete removal of MTBE to below 10 μg/L (the treatment goal); however, it has been necessary to use both towers in series to reach the goal. During summer operation, the first tower achieves approximately 90 percent removal and the second tower generally reduces the first tower's effluent concentration by an additional 90 percent. These two numbers are each about 80 percent during the winter. Water temperatures are lower during the winter due to the approximately 1 hour residence time of the influent water in the settling basin prior to treatment in the air strippers. Therefore, this may affect the removal percentages. However, the difference in removal percentages is mostly due to the large difference in air temperature between the seasons; ambient air is used in the stripping towers. Each tower was designed to handle a maximum water flow rate of 500 gpm and the blowers were designed to circulate 11,500 cubic feet/minute of air through each tower. The tower operator stated that the blowers were not turned down. This implies that the actual air/water ratio fluctuates between approximately 183 in the summer (at a flow rate of 470 gpm) and 287 in the winter (at a flow rate of 300 gpm).

Well Operation and Sampling

Well #5 (~500 gpm) is only operated 1 day per week (Saturday) to ensure that it remains operational. Well #4 (~500 gpm) is used during the rest of the week because its MTBE concentrations are generally lower. Sampling for MTBE at the plant is also performed once a week (Tuesdays). Influent concentrations generally range from 100 to 200 μg/L for well #4 and 400 to 600 μg/L for well #5; effluent concentrations are nearly always below 10 μg/L.

Public and Regulatory Relations

Working with the public and regulatory agencies has been a smooth process. A public meeting was advertised and held in La Crosse soon after the MTBE problem was discovered. Residents were informed of the situation and the system that was planned to treat the water. There has been little public or press interest in the treatment system or MTBE contamination

since the beginning, as evidenced by the lack of public comments and the low turnout at the public meeting (one press person and two residents attended). There have also been no obstacles in dealing with regulatory agencies.

Several homes are located between the supply wells and the La Crosse treatment plant, and sometimes receive direct well water. Since chlorine is applied at the wellhead, water quality (other than hardness) has historically not been a concern for these residents. Since the MTBE discovery, the State of Kansas has installed and is maintaining carbon adsorption treatment systems at each of these homes for MTBE removal. These systems consist of two carbon canisters in series; spent carbon is changed out about once every 6 to 9 months. Samples to confirm the treatment systems' effectiveness were initially collected every month and are now collected once each quarter. Effluent samples from these systems have generally not contained detectable concentrations of MTBE. Because these residents are located upstream of the treatment plant, they cannot get the benefit of the large air stripping units at the water treatment plant during daytime use (when a well is pumping and they are receiving water directly from the well). When the plant is not operating, the flow is reversed and the pipeline feeding their houses is back-pressured with treated water from the plant's clear well. The residents can then fill small individual storage tanks with the treated water. This water can be used as a daytime source of water.

Taste and Odor

Although there have been no reports from drinking water customers about adverse tastes or odors from La Crosse water, the presence of MTBE can be noticed. Prior to stripper installation, MTBE odors were occasionally evident to water treatment plant operators during filter backwashes. The taste of MTBE was also noticed in nearby restaurant drinking water by State of Kansas representatives during this time. When the shallow tray air strippers were operated at the Rush Center intersection as part of the UST plume remediation, there were odor complaints. No odor complaints have resulted from the air stripping operations at the La Crosse drinking water treatment plant.

Most individuals can detect the taste and/or odor of MTBE in untreated plant influent water. On the day of our visit, the influent MTBE concentration was 108 μg/L and the taste of MTBE was evident in influent water samples when drawing air through the mouth while tasting. Strong MTBE odors are apparent in the off-gas at the tops of the two air stripping columns. On the day of our visit, effluent water samples from the first air stripping column and the second air stripping column reportedly contained 15.2 and 3.03 μg/L of MTBE, respectively.

Follow-up

The Partnership members and the Kansas representatives agreed to continue to share information regarding their experiences with MTBE. Partnership members were particularly

interested in ongoing air stripping performance data and MTBE soil vapor sampling results (if and when the sparging/vapor extraction system is operated at the UST cluster). Kansas representatives were presented with current copies of the Partnership's source protection and treatability documents. The Kansas consultant was encouraged to publish a peer-reviewed article on the experiences at La Crosse, and the Partnership members expressed a willingness to discuss the possibility of helping to fund the preparation of such a report.

Appendix 2C Air Stripping Equipment Vendors

1. Packed Tower Air Strippers

QED Environmental Systems, Inc.
P. O. Box 3726-T
Ann Arbor, MI 48106
Toll Free: (800) 394-2674
Telephone: (313) 995-2574
Fax: (313) 995-1170

Layne Christenson Company
(Formerly HydroGroup, Inc.).
97 Chimney Rock Road
Bridgewater, NJ 08807
Toll Free: (800) 269-4590
Fax: (732) 469-7966

Delta Cooling Towers, Inc.
134-T Clinton Road
Fairfield, NJ 07004
Toll Free: (800) Buy-Delta
Telephone: (201) 277-0300
Fax: (201) 227-0458

Carbonair®
Environmental Systems, Inc.
2731 Nevada Avenue North
New Hope, MN 55427
Telephone: (612) 544-2154
Fax: (612) 544-2151

Tonka Equipment Company
P.O. Box 41126
13305 Watertower Circle
Plymouth, MN 55441
Telephone: (612) 559-2837
Fax: (612) 559-1979

EPG Companies Inc.
P.O. Box 224
Maple Grove, MN 55369
Telephone: (612) 424-2613
Fax: (612) 493-4812

Duall Industries
1550-TR Industrial Drive
Owosso, MI 48867
Telephone: (517) 725-8184
Fax: (517) 725-8188

2. Spray Tower Strippers

Branch Environmental Corporation
P.O. Bax 5265
3461 Route 22 East
Somerville, NJ 08876
Telephone: (908) 526-1114
Fax: (908) 526-2881

GDT Corporation
20805 N 19 Av
Phoenix AZ 85027-3557
Telephone: (602) 587-8858
Fax: (602) 587-1511

3. Bubble Aeration Air Strippers

The Stripper®
Lowry Engineering, Inc.
P.O. Box 189
Unity, ME 04988
Telephone: (207) 948-3790
Fax: (207) 948-2471

Remtech™ Bubble Lance Low-Profile Stripper
Remtech Engineers
Whitewater Business Center
200 North Cobb Parkway
Building 100, Suite 124
Marietta, GA 30062
Toll Free: (800) 377-3648
Telephone: (770) 427-7766
Fax: (770) 427-7001

BREEZE Compact Air Stripper
AEROMIX Systems, Inc.
2611 N. Second Street
Minneapolis, MN 55411
Toll Free: (800) 879-3677
Telephone: (612) 521-8519
Fax: (612) 521-1455

Carbonair®
Environmental Systems, Inc.
2731 Nevada Avenue North
New Hope, MN 55427
Telephone: (612) 544-2154
Fax: (612) 544-2151

4. Low Profile Strippers

Shallowtray® Low Profile Air Stripper
North East Environmental Products, Inc.
17 Technology Drive
West Lebanon, NH 03784
Telephone: (603) 298-7061
Fax: (603) 298-7063

Carbonair®
Environmental Systems, Inc.
2731 Nevada Avenue North
New Hope, MN 55427
Telephone: (612) 544-2154
Fax: (612) 544-2151

Carbtrol Corporation
51 Riverside Avenue
Westport, CT 06880
Toll Free: (800) 229-3756
Telephone: (203) 226-5642
Fax: (203) 226-5322

EZ Tray Strippers
QED Environmental Systems, Inc.
P.O. Box 3726
Ann Arbor, MI 48106
Telephone: (313) 995-2547
Fax: (313) 995-1170

Lowry Engineering, Inc.
P. O. Box 1239
Blue Hill, ME 04614
Toll Free: (800) 434-9080
Telephone: (207) 374-3502
Fax: (207) 374-3503

Northeast Environmental Services, Inc.
Maguerite Drive West
Canastota, NY 13032
Telephone: (315) 697-3979
Fax: (315) 697-3867

Geotech Environmental Equipment, Inc.
8035 East 40th Avenue
Denver, Colorado 80207
Telephone: (303) 320-4764
Fax: (303) 322-7242

5. Aspiration Strippers

Maxi-Strip® System
Hazleton Environmental
125 Butler Drive
Hazelton, PA 18201
Telephone: (717) 455-7515
Fax: (717) 454-7520

Appendix 2D Off-gas Treatment Equipment Vendors

1. Thermal and Catalytic Oxidizers

Flameless Thermal Oxidizer
Thermatrix Inc.
101 Metro Drive, Suite 248
San Jose, California 95110
Telephone. (408) 453-0490
Fax. (408) 453-0492

Regenerative Thermal/
Recuperative Cataltic Oxidizers
Advanced Environmental Systems
2440 Oldfield Point Road
Elkton, MD 21921
Toll Free: (800) 220-5330
Telephone: (410) 620-1800
Fax: (410) 620-1819

Durr Environmental, Inc.
14492 Sheldon Rd., Suite 300
Plymouth, MI 48170
Telephone: (734) 207-8500
Fax: (734) 207-8930

Megtec Systems
830 Prosper Road
P.O. Box 5030
De Pere, WI 54115
Telephone: (920) 336-5715
Fax: (920) 337-1585

HiTemp Technology Corporation
PO Box 903, Flemington NJ 08822
Toll Free: (800) 806-3408
Telephone: (908) 788-6999
Fax: (908) 806-8877

ABB Air Preheater Inc
PO Box 372 Wellsville, NY 14895
Telephone: (716) 593-2700
Fax: (716) 593-2721

Catalytic Products International
980 Ensell Road
Lake Zurich, IL 60047
Telephone: (847) 438-0334
Fax: (847) 438-0944

North American
Manufacturing Company
4455 East 71st Street
Cleveland, OH 44105
Telephone: (216) 271-6000
Fax: (216) 641-7852

CVM Corporation
402 Vandever Avenue
Wilmington, DE
Telephone: (302) 654-7070
Fax: (302) 654-2772

2. Carbon Adsorbers and GAC

Nixtox® Adsorbers
Tigg Corporation
800 Old Pond Road, Suite 706
Bridgeville, PA 15228
Toll Free: (800) 925-0011
Telephone: (412) 257-9580
Fax: (412) 257-8520

Carbonair®
Environmental Systems, Inc.
2731 Nevada Avenue North
New Hope, MN 55427
Telephone: (612) 544-2154
Fax: (612) 544-2151

Calgon Carbon Corporation
PO Box 717
Pittsburgh, PA 15230
Toll Free: (800) - 4 CARBON
Telephone: (412) - 787-6700
Fax: (412) - 787-6324

Norit Americas Inc.
1050 Crown Pointe Pkwy, Suite 1500
Atlanta, Georgia 30338
Toll Free: (800) 512-4622

Envirotrol, Inc.
P.O. Box 61-T
Sewickley, PA 15143
Telephone: (412) 741- 2030
Fax: (412) 741- 2670

Carbochem, Inc.
326 W. Lancaster Avenue
Ardmore, PA 19003-1228
Telephone: (610) 645-9200
Fax: (610) 645-5501

US Filter/Westates
5375 S. Boyle Avenue
Los Angeles, CA 90058
Toll Free: (800)659-1771
Telephone: (610) 645-9200
Fax: (610) 645-5501

Indusco Environmental Services, Inc.
P.O. Box 723365
Atlanta, GA 31139
Telephone: (770) 739-5929
Fax: (770) 739-6139

Nucon International, Inc.
P.O. Box 29151
7000 Huntley Road
Columbus, OH 43299-1022
Telephone: (614) 846-5710
Fax: (614) 431-0858

3. Biofilters

BioCube™
AMETEK® Rotron Biofiltration Products
75 North Street
Saugerties, NY 12477
Telephone: (914) 246-3711
Fax: (914) 246-3802

Bohn Biofilter Corporation
P.O. Box 44235
Tucson, AZ 85733-4235
Telephone: (520) 624-4644

Monsanto Enviro-Chem
14522 S. Outer 40 Road
St. Louis, MO 63017
Telephone: (314) 275-5937

Appendix 3A Assumptions for AOP Economic Analysis

Introduction

This appendix presents the assumptions and backup data for the range of MTBE treatment scenarios presented in Chapter 3. The summary tables presented in Chapter 3, which compile the data from the tables in this appendix, will not be repeated here. Cost estimates were requested from five AOP vendors for 24 different treatment scenarios along with additional scenarios to evaluate effects of BTEX and TOC on treatment costs. Those vendors who participated in the detailed cost evaluation are listed below. The costs were critically reviewed by performing data validation where field pilot testing data was available for comparison.

Vendors:

Applied Process Technology, Inc. (San Francisco, CA)
Calgon Carbon Corporation (Markham, Ontario, Canada)
Hydroxyl Systems, Inc. (Victoria, British Columbia, Canada)
Oxidation Systems, Inc. (Arcadia, CA)

Assumptions Given to Vendors:

Influent flow rates of 60, 600, and 6,000 gpm.
Influent MTBE concentrations of 20, 200, and 2,000 µg/L.
Effluent MTBE discharge requirements of 20, 5, and 0.5 µg/L.
Hardness: 200 mg/L as $CaCO_3$
Alkalinity: 250 mg/L as $CaCO_3$
Bromide: ND
Iron: <1 mg/L
pH : 7.0
Temperature: 65°F
TDS: 500 mg/L
Nitrate: 25 mg/L as NO_3 or 5mg/L as N

Assumptions for Capital Costs:

30-year system design life.
Seven percent rate for capital amortization.
Piping, valves, and electrical: 30 percent AOP unit costs.
Site work (e.g., clearing, excavations, foundation): 10 percent of AOP unit costs.
Contractor O&P: 15 percent of capital cost for AOP unit, site work, piping, valves, and electrical.
Engineering: 15 percent of capital costs for AOP unit, site work, piping, valves, electrical, and contractor O&P.
Contingency: 20 percent of all capital costs (engineering costs, contractor O&P AOP equipment, site work, piping, valves, and electrical).

The tables summarizing the capital costs were presented in Chapter 3. Table 3-9 presents the treatment costs for the hydrogen peroxide removal and oxidation by-product removal systems. Table 3-10 presents an example showing the breakdown of the calculations for the capital costs along with the O&M costs for one AOP system. Table 3-11, 3-12, and 3-13 present a summary of the capital, O&M, and total amortized costs for the 24 treatment scenarios. Tables showing the effects of TOC, BTEX, and design life are presented in Tables 3-15, 3-16, and 3-17, respectively.

Assumptions for O&M Costs:

Replacement parts: Costs are based on vendor's estimates (Table 3A-1). Replacement costs may include bulb replacements for MP-UV sytem, ozone generator for ozone system, catalyst replacement for TiO2 system, and other components.

Labor costs: The labor costs include water sampling, general and specific system O&M (Tables 3A-2, 3A-6, 3A-7, 3-8, and 3A-9).

Analytical costs: Costs are based on the estimated sampling frequency required as presented in Tables 3A-6 through 3A-9.

Chemical costs: Cost were provided by vendors and are summarized in Table 3A-4. This includes the consumable chemicals for the applicable technology.

Electrical costs: Electrical costs were based on power consumption estimates provided by the vendors and are presented in Table 3A-5. Power cost was based on $0.08 per kilowatt-hour.

Table 3A-1
Replacement Part Costs for AOPs

Flow (gpm)	Influent (μg/L)	Effluent (μg/L)	Removal Efficiency (%)	Calgon Carbon Corporation	Applied Process Technology, Inc.	Oxidation Systems, Inc.	Hydroxyl Systems, Inc.
60	20	5	75.00%	$ 4,800	$ 3,000	$ 1,200	$ 22,700
60	20	0.5	97.50%	$ 5,200	$ 3,000	$ 3,300	$ 25,200
60	200	20	90.00%	$ 4,800	$ 3,000	$ 1,400	$ 25,200
60	200	5	97.50%	$ 5,200	$ 3,000	$ 3,300	$ 22,700
60	200	0.5	99.75%	$ 5,200	$ 3,600	$ 3,500	$ 28,400
60	2000	20	99.00%	$ 5,200	$ 3,600	$ 3,500	$ 28,400
60	2000	5	99.75%	$ 5,200	$ 3,600	$ 3,500	$ 24,000
60	2000	0.5	99.98%	$ 10,500	$ 4,200	$ 3,500	$ 30,300
600	20	5	75.00%	$ 10,500	$ 11,300	$ 1,600	$ 63,100
600	20	0.5	97.50%	$ 25,300	$ 12,000	$ 2,100	$ 69,400
600	200	20	90.00%	$ 15,700	$ 11,300	$ 1,600	$ 69,400
600	200	5	97.50%	$ 27,900	$ 12,000	$ 2,100	$ 82,000
600	200	0.5	99.75%	$ 38,000	$ 12,000	$ 4,300	$ 91,500
600	2000	20	99.00%	$ 45,600	$ 12,000	$ 2,200	$ 91,500
600	2000	5	99.75%	$ 60,800	$ 12,800	$ 4,300	$ 113,500
600	2000	0.5	99.98%	$ 71,000	$ 12,800	$ 4,300	$ 126,100
6000	20	5	75.00%	$ 62,900	$ 54,000	$ 6,500	$ 504,600
6000	20	0.5	97.50%	$ 152,000	$ 60,000	$ 18,700	$ 567,600
6000	200	20	90.00%	$ 99,600	$ 54,000	$ 14,400	$ 567,600
6000	200	5	97.50%	$ 162,500	$ 60,000	$ 18,700	$ 725,300
6000	200	0.5	99.75%	$ 235,900	$ 60,000	$ 39,100	$ 756,900
6000	2000	20	99.00%	$ 277,900	$ 60,000	$ 19,500	$ 756,900
6000	2000	5	99.75%	$ 429,900	$ 60,000	$ 39,100	$ 1,009,200
6000	2000	0.5	99.98%	$ 592,400	$ 66,000	$ 39,100	$ 1,072,200

Replacement costs are based on vendor's estimates.

Table 3A-2
Labor Costs for AOPs

Flow (gpm)	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)	Calgon Carbon Corporation	Applied Process Technology, Inc.	Oxidation Systems, Inc.	Hydroxyl Systems, Inc.
60	20	5	75.00%	$ 21,000	$ 22,100	$ 25,900	$ 18,700
60	20	0.5	97.50%	$ 21,000	$ 22,100	$ 25,900	$ 18,700
60	200	20	90.00%	$ 21,000	$ 22,100	$ 25,900	$ 19,300
60	200	5	97.50%	$ 21,000	$ 22,100	$ 25,900	$ 19,300
60	200	0.5	99.75%	$ 21,000	$ 22,100	$ 25,900	$ 19,300
60	2000	20	99.00%	$ 29,400	$ 30,400	$ 34,200	$ 29,200
60	2000	5	99.75%	$ 29,400	$ 30,400	$ 34,200	$ 29,200
60	2000	0.5	99.98%	$ 29,400	$ 30,400	$ 34,200	$ 29,200
600	20	5	75.00%	$ 46,700	$ 57,900	$ 56,000	$ 91,200
600	20	0.5	97.50%	$ 46,700	$ 57,900	$ 56,000	$ 91,200
600	200	20	90.00%	$ 47,200	$ 57,900	$ 56,000	$ 93,400
600	200	5	97.50%	$ 47,200	$ 57,900	$ 56,000	$ 93,400
600	200	0.5	99.75%	$ 47,200	$ 57,900	$ 56,000	$ 93,400
600	2000	20	99.00%	$ 74,000	$ 82,900	$ 81,000	$ 117,300
600	2000	5	99.75%	$ 74,000	$ 82,900	$ 81,000	$ 117,300
600	2000	0.5	99.98%	$ 74,000	$ 82,900	$ 81,000	$ 117,300
6000	20	5	75.00%	$ 259,400	$ 211,500	$ 234,200	$ 868,600
6000	20	0.5	97.50%	$ 259,400	$ 211,500	$ 234,200	$ 868,600
6000	200	20	90.00%	$ 261,800	$ 211,500	$ 234,200	$ 888,600
6000	200	5	97.50%	$ 261,800	$ 211,500	$ 234,200	$ 888,600
6000	200	0.5	99.75%	$ 261,800	$ 211,500	$ 234,200	$ 888,600
6000	2000	20	99.00%	$ 424,300	$ 361,300	$ 384,000	$ 1,122,600
6000	2000	5	99.75%	$ 424,300	$ 361,300	$ 384,000	$ 1,122,600
6000	2000	0.5	99.98%	$ 424,300	$ 361,300	$ 384,000	$ 1,122,600

Breakdown of labor costs are given in Tables 3A-6 to 3A-9, based on a rate of $80/hr.

Table 3A-3
Analytical Costs for AOPs

Flow (gpm)	Influent (μg/L)	Effluent (μg/L)	Removal Efficiency (%)	Calgon Carbon Corporation	Applied Process Technology, Inc.	Oxidation Systems, Inc.	Hydroxyl Systems, Inc.
60	20	5	75.00%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
60	20	0.5	97.50%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
60	200	20	90.00%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
60	200	5	97.50%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
60	200	0.5	99.75%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
60	2000	20	99.00%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
60	2000	5	99.75%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
60	2000	0.5	99.98%	$ 20,800	$ 20,800	$ 20,800	$ 20,800
600	20	5	75.00%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
600	20	0.5	97.50%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
600	200	20	90.00%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
600	200	5	97.50%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
600	200	0.5	99.75%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
600	2000	20	99.00%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
600	2000	5	99.75%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
600	2000	0.5	99.98%	$ 31,200	$ 41,600	$ 31,200	$ 41,600
6000	20	5	75.00%	$ 135,200	$ 72,800	$ 72,800	$ 322,400
6000	20	0.5	97.50%	$ 135,200	$ 72,800	$ 72,800	$ 322,400
6000	200	20	90.00%	$ 135,200	$ 72,800	$ 72,800	$ 322,400
6000	200	5	97.50%	$ 135,200	$ 72,800	$ 72,800	$ 322,400
6000	200	0.5	99.75%	$ 135,200	$ 72,800	$ 72,800	$ 322,400
6000	2000	20	99.00%	$ 135,200	$ 72,800	$ 72,800	$ 322,400
6000	2000	5	99.75%	$ 135,200	$ 72,800	$ 72,800	$ 322,400
6000	2000	0.5	99.98%	$ 135,200	$ 72,800	$ 72,800	$ 322,400

Breakdown of labor costs are given in Tables 3A-6 to 3A-9, based on a rate of $200/sample.

Table 3A-4
Chemical Costs for AOPs

Flow (gpm)	Influent (μg/L)	Effluent (μg/L)	Removal Efficiency (%)	Calgon Carbon Corporation	Applied Process Technology, Inc.	Oxidation Systems, Inc.	Hydroxyl Systems, Inc.
60	20	5	75.00%	$ 2,800	$ 631	$ 5,000	$ 631
60	20	0.5	97.50%	$ 2,800	$ 1,600	$ 5,000	$ 631
60	200	20	90.00%	$ 5,400	$ 900	$ 5,000	$ 631
60	200	5	97.50%	$ 2,800	$ 1,600	$ 5,000	$ 631
60	200	0.5	99.75%	$ 2,800	$ 2,200	$ 7,900	$ 631
60	2000	20	99.00%	$ 5,400	$ 3,200	$ 5,000	$ 631
60	2000	5	99.75%	$ 18,000	$ 3,500	$ 7,900	$ 631
60	2000	0.5	99.98%	$ 5,400	$ 4,400	$ 8,500	$ 631
600	20	5	75.00%	$ 28,400	$ 6,300	$ 50,500	$ 6,300
600	20	0.5	97.50%	$ 41,000	$ 15,800	$ 50,500	$ 6,300
600	200	20	90.00%	$ 41,000	$ 9,500	$ 50,500	$ 6,300
600	200	5	97.50%	$ 41,000	$ 15,800	$ 50,500	$ 6,300
600	200	0.5	99.75%	$ 69,400	$ 22,100	$ 78,800	$ 6,300
600	2000	20	99.00%	$ 82,000	$ 28,400	$ 50,500	$ 6,300
600	2000	5	99.75%	$ 69,400	$ 34,700	$ 78,800	$ 6,300
600	2000	0.5	99.98%	$ 82,000	$ 44,200	$ 85,100	$ 6,300
6000	20	5	75.00%	$ 220,800	$ 63,100	$ 504,600	$ 63,100
6000	20	0.5	97.50%	$ 283,800	$ 157,700	$ 504,600	$ 63,100
6000	200	20	90.00%	$ 283,800	$ 94,600	$ 504,600	$ 63,100
6000	200	5	97.50%	$ 410,000	$ 157,700	$ 504,600	$ 63,100
6000	200	0.5	99.75%	$ 410,000	$ 220,800	$ 788,400	$ 63,100
6000	2000	20	99.00%	$ 410,000	$ 283,800	$ 504,600	$ 63,100
6000	2000	5	99.75%	$ 693,800	$ 346,900	$ 788,400	$ 63,100
6000	2000	0.5	99.98%	$ 693,800	$ 441,500	$ 851,500	$ 63,100

Chemical costs include that for H_2O_2, O_3, and TiO_2. Amounts used and their cost were supplied by vendor.

Table 3A-5
Electrical Costs for AOPs

Flow (gpm)	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)	Calgon Oxidation Technologies	Applied Process Technologies	Oxidation Systems, Inc.	Hydroxyl Systems, Inc.
60	20	5	75.00%	$ 5,000	$ 631	$ 7,300	$ 12,000
60	20	0.5	97.50%	$ 13,900	$ 1,300	$ 7,900	$ 13,200
60	200	20	90.00%	$ 6,900	$ 900	$ 7,300	$ 13,200
60	200	5	97.50%	$ 13,900	$ 1,300	$ 7,900	$ 16,700
60	200	0.5	99.75%	$ 20,800	$ 2,200	$ 8,200	$ 21,100
60	2000	20	99.00%	$ 20,800	$ 2,800	$ 8,200	$ 21,100
60	2000	5	99.75%	$ 20,800	$ 3,200	$ 8,200	$ 21,100
60	2000	0.5	99.98%	$ 41,900	$ 4,100	$ 8,200	$ 26,500
600	20	5	75.00%	$ 41,000	$ 6,300	$ 28,400	$ 63,100
600	20	0.5	97.50%	$ 104,100	$ 12,600	$ 34,700	$ 69,400
600	200	20	90.00%	$ 63,100	$ 9,500	$ 28,400	$ 69,400
600	200	5	97.50%	$ 116,700	$ 12,600	$ 34,700	$ 107,200
600	200	0.5	99.75%	$ 157,700	$ 22,100	$ 37,800	$ 116,700
600	2000	20	99.00%	$ 189,200	$ 28,400	$ 37,800	$ 116,700
600	2000	5	99.75%	$ 252,300	$ 31,500	$ 37,800	$ 173,500
600	2000	0.5	99.98%	$ 293,300	$ 41,000	$ 37,800	$ 192,400
6000	20	5	75.00%	$ 252,300	$ 63,100	$ 283,800	$ 630,700
6000	20	0.5	97.50%	$ 599,200	$ 126,100	$ 346,900	$ 693,800
6000	200	20	90.00%	$ 410,000	$ 94,600	$ 283,800	$ 693,800
6000	200	5	97.50%	$ 662,300	$ 126,100	$ 346,900	$ 1,103,800
6000	200	0.5	99.75%	$ 946,100	$ 220,800	$ 378,400	$ 1,166,800
6000	2000	20	99.00%	$ 410,000	$ 283,800	$ 378,400	$ 1,166,800
6000	2000	5	99.75%	$ 1,702,900	$ 315,400	$ 378,400	$ 1,829,100
6000	2000	0.5	99.98%	$ 2,365,200	$ 410,000	$ 378,400	$ 1,923,700

Electrical costs were based on power consumption estimate provided by the vendors, at $0.08/kWh.

Table 3A-6

Estimated Labor Costs for H_2O_2/MP-UV Systems

60 gpm Systems
1 reactor

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated UV Lamp Changeouts[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	2	104	3	52	208	367	$29,400
200	2	104	2	52	104	262	$21,000
20	2	104	2	52	104	262	$21,000

600 gpm Systems
2 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated UV Lamp Changeouts[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	3	156	41	104	624	925	$74,000
200	3	156	18	104	312	590	$47,200
20	3	156	12	104	312	584	$46,700

6,000 gpm Systems
12 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated UV Lamp Changeouts[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	13	676	260	624	3744	5304	$424,300
200	13	676	100	624	1872	3272	$261,800
20	13	676	70	624	1872	3242	$259,400

A - 1 hour/sample
B - Lamp change-outs every 3,000 hours; 1 hour labor per lamp. Number of lamps for each system assumed as follows:
for 60 gpm system: 1 at 2,000 µg/L, 200 µg/L, and 20 µg/L
for 600 gpm system: 14 at 2,000 µg/L; 6 at 200 µg/L; 4 at 20 µg/L
for 6,000 gpm system: 96 at 2,000 µg/L; 48 at 200 µg/L; 24 at 20 µg/L
C - Inspection/replacement of pump components, calibration and flow verification, change of H_2O_2 storage vessels(1hr/wk per reactor)
D - general system oversight and maintenance (e.g., pressure checks, backflushing)
for 60 gpm system: 4 hr/wk at 2,000 µg/L; 2 hr/wk at 200 µg/L and 20 µg/L
for 600 gpm system: 12 hr/wk at 2,000 µg/L; 6 hr/wk at 200 µg/L and 20 µg/L
for 6,000 gpm system: 72 hr/wk at 2,000 µg/L; 36 hr/wk at 200 µg/L and 20 µg/L
E - labor rate @ $80/hr

Table 3A-7

Estimated Labor Costs for H_2O_2/O_3 System

60 gpm Systems
1 reactor

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated O_3 System O & M[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	2	104	16	52	208	380	$30,400
200	2	104	16	52	104	276	$22,100
20	2	104	16	52	104	276	$22,100

600 gpm Systems
3 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated O_3 System O & M[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	4	208	48	156	624	1036	$82,900
200	4	208	48	156	312	724	$57,900
20	4	208	48	156	312	724	$57,900

6,000 gpm Systems
6 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated O_3 System O & M[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	7	364	96	312	3744	4516	$361,300
200	7	364	96	312	1872	2644	$211,500
20	7	364	96	312	1872	2644	$211,500

A - 1 hour/sample
B - O_3 generator replacement (one year service life, 2 days per replacement)
C - Inspection/replacement of pump components, calibration and flow verification, change of H_2O_2 storage vessels (1hr/wk per reactor)
D - general system oversight and maintenance (e.g., pressure gauges, control panel, leak checks)
for 60 gpm system: 4 hr/wk at 2,000 µg/L; 2 hr/wk at 200 µg/L and 20 µg/L
for 600 gpm system: 12 hr/wk at 2,000 µg/L; 6 hr/wk at 200 µg/L and 20 µg/L
for 6,000 gpm system: 72 hr/wk at 2,000 µg/L; 36 hr/wk at 200 µg/L and 20 µg/L
E - labor rate @ $80/hr

Table 3A-8

Estimated Labor Costs for Ultrasound/H_2O_2 Systems

60 gpm Systems
1 reactor

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated O & M[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	2	104	64	52	208	428	$34,200
200	2	104	64	52	104	324	$25,900
20	2	104	64	52	104	324	$25,900

600 gpm Systems
2 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated O & M[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	3	156	128	104	624	1012	$81,000
200	3	156	128	104	312	700	$56,000
20	3	156	128	104	312	700	$56,000

6,000 gpm Systems
6 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated O & M[B] (hours/year)	Estimated H_2O_2 System O & M[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	7	312	432	312	3744	4800	$384,000
200	7	312	432	312	1872	2928	$234,200
20	7	312	432	312	1872	2928	$234,200

A - 1 hour/sample
B - Inspection, replacement, and repair based on 1,000 hour service life
C - Inspection/replacement of pump components, calibration and flow verification, change of H_2O_2 storage vessels (1hr/wk per reactor)
D - general system oversight and maintenance (e.g., pressure gauges, control panel, leak checks)
for 60 gpm system: 4 hr/wk at 2,000 µg/L; 2 hr/wk at 200 µg/L and 20 µg/L
for 600 gpm system: 12 hr/wk at 2,000 µg/L; 6 hr/wk at 200 µg/L and 20 µg/L
for 6,000 gpm system: 72 hr/wk at 2,000 µg/L; 36 hr/wk at 200 µg/L and 20 µg/L
E - labor rate @ $80/hr

Table 3A-9
Estimated Labor Costs for TiO_2/MP-UV System

60 gpm Systems
1 reactor

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated Catalyst Maintenance [B] (hours/year)	Estimated UV Lamp Changeouts[C] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	2	104	48	5	208	365	$29,200
200	2	104	30	3	104	241	$19,300
20	2	104	24	2	104	234	$18,700

600 gpm Systems
3 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated Catalyst Maintenance [B] (hours/year)	Estimated UV Lamp Changeouts[B] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	4	208	166	53	1040	1466.8	$117,300
200	4	208	104	24	832	1167.3	$93,400
20	4	208	83	17	832	1139.6	$91,200

6,000 gpm Systems
30 reactors

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Estimated Catalyst Maintenance [B] (hours/year)	Estimated UV Lamp Changeouts[B] (hours/year)	General O & M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	31	1612	1656	364	10400	14032	$1,122,600
200	31	1612	1035	140	8320	11107	$888,600
20	31	1612	828	98	8320	10858	$868,600

A - 1 hour/sample
B - Maintenance includes spent catalyst removal, recharge, and delivery
C - 1 hour/ lamp changeout for UV/H_2O_2 (Calgon) and UV/titanium dioxide (Hydroxyl) Systems
D - general system oversight and maintenance (e.g., pressure checks, backflushing)
for 60 gpm system: 4 hr/wk at 2,000 µg/L; 2 hr/wk at 200 µg/L and 20 µg/L
for 600 gpm system: 20 hr/wk at 2,000 µg/L; 16 hr/wk at 200 µg/L and 20 µg/L
for 6,000 gpm system: 200 hr/wk at 2,000 µg/L; 160 hr/wk at 200 µg/L and 20 µg/L
E - labor rate @ $80/hr

Appendix 4A Cost Estimates for GAC

Introduction

This appendix presents cost estimates for a range of MTBE treatment scenarios using GAC technology. The cost estimates were developed based on results of carbon adsorption modeling using the AdDesignS computer model (Mertz et al., 1994), 1998 price quotes from carbon vendors, and standard cost estimating assumptions for feasibility-level evaluations. The cost estimates presented here are considered to be accurate within ±30 percent. Details regarding assumptions used in the development of the predicted carbon usage rates, which impact the estimated O&M costs, are presented in Chapter 4. Actual carbon usage rates for site-specific conditions should be obtained via testing with site water if higher accuracy cost estimates are required.

Assumptions used for development of O&M labor costs for the primary treatment scenarios and the sensitivity analyses are presented in Tables 4A-1 and 4A-2, respectively. Summaries of the cost estimates are presented in Tables 4A-3 and 4A-4. The assumptions used for development of the cost estimates are listed below.

General Assumptions

Influent MTBE concentrations: 20 μg/L, 200 μg/L, 2,000 μg/L.

Effluent water contains no detectable MTBE (<0.5 μg/L).

System flow rates: 60 gpm, 600 gpm, 6,000 gpm.

No pretreatment of influent water is required.

Assumptions for Capital Costs

Carbon adsorption unit: Standard Carbonair vessels rated for appropriate range of flow rates; costs for adsorber systems based on 1998 price quotes from Carbonair for purchase and installation of specific models. Capital cost includes initial fill with virgin, coconut shell GAC at $1.25/lb (unit cost based on 1998 vendor price quote). All systems designed as single line or parallel lines of three GAC vessels in-series.

Piping, Valves, and Electrical: 30 percent of capital cost for carbon adsorption unit.

Site Work (*e.g., clearing, grubbing, foundation placement*): 10 percent of capital cost for carbon adsorption unit.

Contractor O&P: 15 percent of capital cost for carbon adsorption unit, site work, piping and valves, and electrical.

Engineering: 15 percent of capital cost for carbon adsorption unit, site work, piping, valves, electrical, and contractor O&P.

Contingency: 20 percent of all other capital costs.

Total capital amortized over 30-year system design life using seven percent discount rate.

Assumptions for O&M Costs

Replacement GAC: Carbon changouts using virgin, coconut shell GAC at $1.25/lb (unit cost based on 1998 vendor price quotes). Estimated changeout frequency based on results of AdDesignS modeling (Tables 4-4 and 4-5), assuming increased bed life of 50 percent for in-series operation (see Chapter 4 for further details).

Changeout Labor/Transport: Estimated costs based on 1998 vendor price quotes ($0.10/lb for transport to off-site regeneration facility). Assumed $1,000 minimum cost per changeout event.

O&M Labor: Estimated costs for analytical sampling, GAC changeout oversight, and general system O&M (e.g., pressure checks, backflushing). Detailed assumptions presented in Tables 4A-1 and 4A-2.

Analytical Testing:
60 gpm systems - three samples per week per line (one influent, one midfluent, one effluent);
600 gpm systems - five samples per week per line (one influent, two midfluent, two effluent);
6,000 gpm systems - 25 samples per week per line (1 influent, 12 midfluent, 12 effluent);
Assumed testing cost - $200 per sample, Method 524.2.

Power: Assumed unit cost at $0.08 per kilowatt-hour; kilowatt-hours estimated based on flow rate and bed depth.

Table 4A-1
Estimated Labor Costs for GAC Systems

60 gpm Systems
1 line of 3 vessels in-series

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Predicted Changeouts Per Year[B]	GAC Changeout Annual Oversight[C] (hours)	General O&M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	3	156	7.9	32	208	396	$32,000
200	3	156	2.7	11	104	271	$22,000
20	3	156	1.9	8	104	268	$21,000

600 gpm Systems
2 lines of 3 vessels in-series

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Predicted Changeouts Per Year[B]	GAC Changeout Annual Oversight[C] (hours)	General O&M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	5	260	10.1	81	416	757	$61,000
200	5	260	3.4	27	208	495	$40,000
20	5	260	1.2	10	208	478	$38,000

6,000 gpm Systems
12 lines of 3 vessels in-series

Influent Concentration (µg/L)	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Predicted Changeouts Per Year[B]	GAC Changeout Annual Oversight[C] (hours)	General O&M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
2,000	25	1300	18.2	874	1664	3838	$307,000
200	25	1300	6.3	302	1040	2642	$211,000
20	25	1300	1.9	91	520	1911	$153,000

[A] 1 hour/sample.
[B] See Table 4-6.
[C] 4 hours/changeout for each line of GAC vessels.
[D] General system oversight and maintenance (e.g., pressure checks, backflushing):
For 60 gpm system: 4 hr/wk at 2,000 µg/L, 2 hr/wk at 200 µg/L, and 20 µg/L.
For 600 gpm system: 8 hr/wk at 2,000 µg/L, 4 hr/wk at 200 µg/L, and 20 µg/L.
For 6,000 gpm system: 32 hr/wk at 2,000 µg/L, 20 hr/wk at 200 µg/L, and 10 hr/wk at 20 µg/L.
[E] Labor rate @ $80/hr.

Table 4A-2
Estimated Labor Costs for Sensitivity Analysis

Water Type	Sampling Frequency (samples/wk)	Analytical Sampling Annual Labor[A] (hours)	Predicted Changeouts Per Year[B]	GAC Changeout Annual Oversight[C] (hours)	General O&M Annual Labor[D] (hours)	Total Annual Labor (hours)	Total Annual Labor Cost[E] ($)
Rhine River (high fouling)	5	260	1.6	6	208	476	$38,000
Karlsruhe gw (moderate fouling)	5	260	1.2	5	208	474	$38,000
Wausau gw (low fouling)	5	260	1.1	4	208	474	$38,000
Moderate BTEX[F] each at 200 µg/L	5	260	1.9	8	208	478	$38,000
Low BTEX[F] each at 20 µg/L	5	260	1.4	6	208	475	$38,000
No BTEX[F] each at 0 µg/L	5	260	1.2	5	208	474	$38,000

[A] 1 hour/sample.
[B] See Table 4-5.
[C] 4 hours/changeout for each line of GAC vessels.
[D] 4 hrs/wk; includes general system oversight and maintenance (e.g., pressure checks, backflushing).
[E] Labor rate @ $80/hr.
[F] BTEX and MTBE in Karlsruhe groundwater.

600 gpm Systems.
2 lines of 3 vessels in-series.
Influent MTBE = 20 µg/L; effluent contains no detectable MTBE (0.5 µg/L).

Table 4A-3
Estimated Costs for Carbon Adsorption

System Parameters: 60 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 mg/L)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$182,640**
TOTAL ANNUAL COST	**$264,731**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.84**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.6	$50,000	$80,000
Changeout Labor/Transport	event	1.6	$4,000	$6,400
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$182,640**

1 Carbon system size: three 2,500 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 2,500 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 3 samples per weekly event, 52 weeks per year.

Table 4A-3 (Continued)
Estimated Costs for Carbon Adsorption

System Parameters: 60 gpm
200 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)

Item	Cost
Carbon Adsorption Unit[1]	$105,110
SUBTOTAL	$105,110
Piping, Valves, Electrical (30%)	$31,533
Site Work (10%)	$10,511
SUBTOTAL	$147,154
Contractor O&P (15%)	$22,073
SUBTOTAL	$169,227
Engineering (15%)	$25,384
SUBTOTAL	$194,611
Contingency (20%)	$38,922
TOTAL CAPITAL	**$233,533**
AMORTIZED CAPITAL[2]	**$18,820**
ANNUAL O&M	**$73,319**
TOTAL ANNUAL COST	**$92,139**
TOTAL COST PER 1,000 GALLONS TREATED	**$2.92**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	2.7	$6,250	$16,875
Changeout Labor/Transport	event	2.7	$1,000	$2,700
O&M Labor[4]	year	1	$22,000	$22,000
Analytical Testing[5]	samples	156	$200	$31,200
Power ($0.08/kWh)	kWhr	6,800	$0.08	$544
ANNUAL O&M				**$73,319**

1 Carbon system size: three 5,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 5,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 3 samples per weekly event, 52 weeks per year.

Table 4A-3 (Continued)
Estimated Costs for Carbon Adsorption

System Parameters: 60 gpm
2,000 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)

Item	Cost
Carbon Adsorption Unit[1]	$105,110
SUBTOTAL	$105,110
Piping, Valves, Electrical (30%)	$31,533
Site Work (10%)	$10,511
SUBTOTAL	$147,154
Contractor O&P (15%)	$22,073
SUBTOTAL	$169,227
Engineering (15%)	$25,384
SUBTOTAL	$194,611
Contingency (20%)	$38,922
TOTAL CAPITAL	**$233,533**
AMORTIZED CAPITAL[2]	**$18,820**
ANNUAL O&M	**$121,019**
TOTAL ANNUAL COST	**$139,839**
TOTAL COST PER 1,000 GALLONS TREATED	**$4.43**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	7.9	$6,250	$49,375
Changeout Labor/Transport	event	7.9	$1,000	$7,900
O&M Labor[4]	year	1	$32,000	$32,000
Analytical Testing[5]	samples	156	$200	$31,200
Power ($0.08/kWh)	kWhr	6,800	$0.08	$544
ANNUAL O&M				**$121,019**

1 Carbon system size: three 5,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 5,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 3 samples per weekly event, 52 weeks per year.

Table 4A-3 (Continued)
Estimated Costs for Carbon Adsorption

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$161,040**
TOTAL ANNUAL COST	**$243,131**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.77**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.2	$50,000	$60,000
Changeout Labor/Transport	event	1.2	$4,000	$4,800
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$161,040**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-3 (Continued)
Estimated Costs for Carbon Adsorption

System Parameters: 600 gpm
200 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$281,840**
TOTAL ANNUAL COST	**$363,931**
TOTAL COST PER 1,000 GALLONS TREATED	**$1.15**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	3.4	$50,000	$170,000
Changeout Labor/Transport	event	3.4	$4,000	$13,600
O&M Labor[4]	year	1	$40,000	$40,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$281,840**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-3 (Continued)
Estimated Costs for Carbon Adsorption

System Parameters: 600 gpm
2,000 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 mg/L)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$664,640**
TOTAL ANNUAL COST	**$746,731**
TOTAL COST PER 1,000 GALLONS TREATED	**$2.37**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	10.1	$50,000	$505,000
Changeout Labor/Transport	event	10.1	$4,000	$40,400
O&M Labor[4]	year	1	$61,000	$61,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$664,640**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
4 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-3 (Continued)
Estimated Costs for Carbon Adsorption

System Parameters: 6,000 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)

Item	Cost
Carbon Adsorption Unit[1]	$2,690,940
SUBTOTAL	$2,690,940
Piping, Valves, Electrical (30%)	$807,282
Site Work (10%)	$269,094
SUBTOTAL	$3,767,316
Contractor O&P (15%)	$565,097
SUBTOTAL	$4,332,413
Engineering (15%)	$649,862
SUBTOTAL	$4,982,275
Contingency (20%)	$996,455
TOTAL CAPITAL	**$5,978,730**
AMORTIZED CAPITAL[2]	**$481,806**
ANNUAL O&M	**$1,091,000**
TOTAL ANNUAL COST	**$1,572,806**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.50**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.9	$300,000	$570,000
Changeout Labor/Transport	event	1.9	$24,000	$45,600
O&M Labor[4]	year	1	$153,000	$153,000
Analytical Testing[5]	samples	1,300	$200	$260,000
Power ($0.08/kWh)	kWhr	780,000	$0.08	$62,400
ANNUAL O&M				**$1,091,000**

1 Carbon system size: 12 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 240,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 25 samples per weekly event, 52 weeks per year.

Table 4A-3 (Continued)
Estimated Costs for Carbon Adsorption

System Parameters: 6,000 gpm
200 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)

Item	Cost
Carbon Adsorption Unit[1]	$2,690,940
SUBTOTAL	$2,690,940
Piping, Valves, Electrical (30%)	$807,282
Site Work (10%)	$269,094
SUBTOTAL	$3,767,316
Contractor O&P (15%)	$565,097
SUBTOTAL	$4,332,413
Engineering (15%)	$649,862
SUBTOTAL	$4,982,275
Contingency (20%)	$996,455
TOTAL CAPITAL	**$5,978,730**
AMORTIZED CAPITAL[2]	**$481,806**
ANNUAL O&M	**$2,574,600**
TOTAL ANNUAL COST	**$3,056,406**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.97**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	6.3	$300,000	$1,890,000
Changeout Labor/Transport	event	6.3	$24,000	$151,200
O&M Labor[4]	year	1	$211,000	$211,000
Analytical Testing[5]	samples	1,300	$200	$260,000
Power ($0.08/kWh)	kWhr	780,000	$0.08	$62,400
ANNUAL O&M				**$2,574,600**

1 Carbon system size: 12 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 240,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 25 samples per weekly event, 52 weeks per year.

Table 4A-3 (Concluded)
Estimated Costs for Carbon Adsorption

System Parameters: 6,000 gpm
2,000 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)

Item	Cost
Carbon Adsorption Unit[1]	$2,690,940
SUBTOTAL	$2,690,940
Piping, Valves, Electrical (30%)	$807,282
Site Work (10%)	$269,094
SUBTOTAL	$3,767,316
Contractor O&P (15%)	$565,097
SUBTOTAL	$4,332,413
Engineering (15%)	$649,862
SUBTOTAL	$4,982,275
Contingency (20%)	$996,455
TOTAL CAPITAL	**$5,978,730**
AMORTIZED CAPITAL[2]	**$481,806**
ANNUAL O&M	**$6,526,200**
TOTAL ANNUAL COST	**$7,008,006**
TOTAL COST PER 1,000 GALLONS TREATED	**$2.22**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	18.2	$300,000	$5,460,000
Changeout Labor/Transport	event	18.2	$24,000	$436,800
O&M Labor[4]	year	1	$307,000	$307,000
Analytical Testing[5]	samples	1,300	$200	$260,000
Power ($0.08/kWh)	kWhr	780,000	$0.08	$62,400
ANNUAL O&M				**$6,526,200**

1 Carbon system size: 12 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 240,000 lb/event; changeout frequency per Table 4-6.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 25 samples per weekly event, 52 weeks per year.

Table 4A-4
Estimated Costs for Sensitivity Analysis

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)
High fouling (Rhine Riverwater)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$182,640**
TOTAL ANNUAL COST	**$264,731**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.84**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.6	$50,000	$80,000
Changeout Labor/Transport	event	1.6	$4,000	$6,400
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$182,640**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-5.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-4 (Continued)
Estimated Costs for Sensitivity Analysis

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)
Moderate fouling (Karlsruhe groundwater)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$161,040**
TOTAL ANNUAL COST	**$243,131**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.77**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.2	$50,000	$60,000
Changeout Labor/Transport	event	1.2	$4,000	$4,800
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$161,040**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-5.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-4 (Continued)
Estimated Costs for Sensitivity Analysis

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)
Low fouling (Wausau groundwater)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$155,640**
TOTAL ANNUAL COST	**$237,731**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.75**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.1	$50,000	$55,000
Changeout Labor/Transport	event	1.1	$4,000	$4,400
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$155,640**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-5.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-4 (Continued)
Estimated Costs for Sensitivity Analysis

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)
Moderate BTEX load (200 µg/L each)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$198,840**
TOTAL ANNUAL COST	**$280,931**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.89**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.9	$50,000	$95,000
Changeout Labor/Transport	event	1.9	$4,000	$7,600
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$198,840**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-5.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-4 (Continued)
Estimated Costs for Sensitivity Analysis

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)
Low BTEX load (20 µg/L each)

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$82,091**
ANNUAL O&M	**$171,840**
TOTAL ANNUAL COST	**$253,931**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.81**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.4	$50,000	$70,000
Changeout Labor/Transport	event	1.4	$4,000	$5,600
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$171,840**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-5.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-4 (Continued)
Estimated Costs for Sensitivity Analysis

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)
10 year design life for capital amortization

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$125,592**
ANNUAL O&M	**$161,040**
TOTAL ANNUAL COST	**$286,632**
TOTAL COST PER 1,000 GALLONS TREATED	**$0.91**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.2	$50,000	$60,000
Changeout Labor/Transport	event	1.2	$4,000	$4,800
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$161,040**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 10 year period.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-5.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Table 4A-4 (Concluded)
Estimated Costs for Sensitivity Analysis

System Parameters: 600 gpm
20 µg/L influent MTBE concentration
Effluent contains no detectable MTBE (<0.5 µg/L)
2 year design life for capital amortization

Item	Cost
Carbon Adsorption Unit[1]	$458,490
SUBTOTAL	$458,490
Piping, Valves, Electrical (30%)	$137,547
Site Work (10%)	$45,849
SUBTOTAL	$641,886
Contractor O&P (15%)	$96,283
SUBTOTAL	$738,169
Engineering (15%)	$110,725
SUBTOTAL	$848,894
Contingency (20%)	$169,779
TOTAL CAPITAL	**$1,018,673**
AMORTIZED CAPITAL[2]	**$540,124**
ANNUAL O&M	**$161,040**
TOTAL ANNUAL COST	**$701,164**
TOTAL COST PER 1,000 GALLONS TREATED	**$2.22**

Summary of Annual O&M Costs

Item	Unit	Quantity	Unit Cost	Cost
Replacement Carbon[3]	event	1.2	$50,000	$60,000
Changeout Labor/Transport	event	1.2	$4,000	$4,800
O&M Labor[4]	year	1	$38,000	$38,000
Analytical Testing[5]	samples	260	$200	$52,000
Power ($0.08/kWh)	kWhr	78,000	$0.08	$6,240
ANNUAL O&M				**$161,040**

1 Carbon system size: 2 lines of three 20,000 lb vessels in series.
2 Amortization based on 30 year period at 7% discount rate.
3 Based on $1.25/lb and 40,000 lb/event; changeout frequency per Table 4-5.
4 Includes analytical sampling, oversight during changeouts, and general system O&M.
5 Based on 5 samples per weekly event, 52 weeks per year.

Isotherms provided by Calgon Carbon (Pittsburgh, PA):

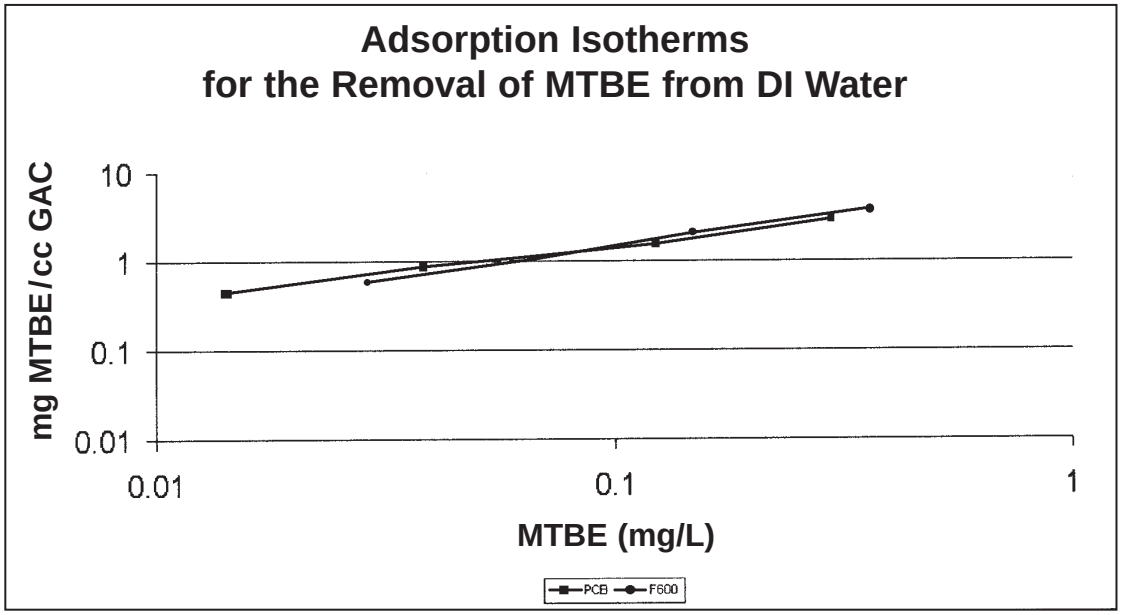

Figure 5A-1 MTBE Isotherms for Filtrasorb 600 and PCB, a coconut-based GAC.

Appendix 5B Assumptions for Synthetic Resin Sorbents Cost Estimates

A. Assumptions made by Malcolm Pirnie, Inc.:

Seven percent discount rate
30-year project life time
All costs are 1999 $

Cost: $25/lb for large quantity orders (6,000 gpm system)
$30/lb for 600 gpm system
$45/lb for 60 and 6 gpm systems

Labor: See Table 5B-4

Analytical: See Table 5B-4

Pump Requirements: 600 gpm/vessel (40 ft head loss in series; 25 ft for parallel)
74 gpm/vessel (35 ft head loss in series; 20 ft for parallel)
60 gpm/vessel (35 ft head loss in series; 20 ft for parallel)
6 gpm/vessel (20 ft head loss in series; 15 ft for parallel)

Freundlich Isotherm Parameters for Ambersorb-563 @ 15°C:
MTBE: $K_F = 17$; $n = 0.35$
TBA: $K_F = 1.797$; $n = 0.8494$

Modeling assumptions:
Breakthrough time in days and BVs treated listed in Table 5B-1;
Five percent increase in model-predicted capacity for full column exhaustion (based on laboratory and field data showing a wider breakthrough curve)

Split flow to achieve removal efficiency. Treated flow rates and corresponding carbon vessels listed in Table 5B-2.

B. Regeneration Assumptions made by Malcolm Pirnie, Inc.:

Steam Regeneration: Components: Boiler, Condensing Tank
10 BVs for regeneration (1 BV/hour)
Five percent one-time loss in sorptive capacity
$5/Mbtu natural gas
Costs estimated from Chemical Engineering Economics (Garrett, 1989)

Flow rate: 12 hours to treat regenerant for 6,000, 600, and 60 gpm
1 hour to treat regenerant for 6 gpm
For 6000 gpm: staggered regeneration

Effluent Goal: 3 mg/L for GAC, Resins, or Air Stripping to be fed back into resin influent

Freundlich Isotherm Parameters for CC602 @ 15°C: MTBE: $K_F = 11.0$; $n = 0.500$
(used by Alpine Environmental, Inc. for GAC report)

C. Regeneration Assumptions Made by Vendors (or using Vendor Models):

ShallowTray® Air Stripping with Off-gas Treatment:

Vendor: Northeast Environmental Products
6,000 gpm and 600 gpm: AWR = 121
60 gpm/2,000 µg/L influent: AWR = 156
60 gpm/200 µg/L and 20 µg/L influent: AWR = 125
6 gpm/2,000 µg/L influent: AWR = 187
6 gpm/200 µg/L and 20 µg/L influent: AWR = 137

Vendor: Advanced Environmental Systems
Catalytic Off-gas Treatment with Air Stream Preheating
Temperature = 90°F
6,000 gpm, 600 gpm: 1,500 cfm catalytic oxidizer
60 gpm, 6 gpm: 250 cfm catalytic oxidizer

Safety Kleen costs for Hazardous Waste Disposal (drum = 55 gallons)
<20 barrels: $327/drum
20-39 barrels: $298/drum
40-79 barrels: $278/drum
80-159 barrels: $261/drum
160-259 barrels: $196/drum

Activated Carbon Regeneration:
Vendor: Calgon Carbon
$1.25/lb for use and disposal

Table 5B-1.
MTBE Sorption Modeling Results

				Applicable for Option 1		Applicable for Option 2	
Flow Rate [gpm]	Influent [µg/L]	Effluent Goal [µg/L]	Removal Efficiency	Time until Column Exhaustion [days]	Bed Volumes Treated at Column Exhaustion Point	Time to Breakthrough of Effluent Goal [days]	Bed Volumes Treated at Breakthrough of Effluent Goal
6000	2000	20	99.0%	28.3	5040	26.5	4730
6000	2000	5	99.8%	27.9	5040	24.12	4360
6000	2000	0.5	99.98%	27.9	5040	17.52	3170
6000	200	20	90.0%	124	22500	117	21300
6000	200	5	97.5%	128	22500	121	21200
6000	200	0.5	99.8%	125	22500	108	19500
6000	20	5	75.0%	580	100000	553	95800
6000	20	0.5	97.5%	574	101000	540	94600
600	2000	20	99.0%	31.44	5040	29.57	4740
600	2000	5	99.8%	31.14	5040	23.01	3720
600	2000	0.5	99.98%	31.14	5040	19.59	3170
600	200	20	90.0%	155	22500	147	21300
600	200	5	97.5%	143	22500	134	21200
600	200	0.5	99.8%	139	22500	103	16600
600	20	5	75.0%	836	101000	791	96000
600	20	0.5	97.5%	638	101000	601	94700
60	2000	20	99.0%	23.89	5070	21.94	4650
60	2000	5	99.8%	23.51	5070	21.12	4550
60	2000	0.5	99.98%	23.51	5070	20.82	4490
60	200	20	90.0%	116	22600	109	21200
60	200	5	97.5%	107	22600	98.87	21000
60	200	0.5	99.8%	105	22600	94.29	20300
60	20	5	75.0%	377	102000	353	95200
60	20	0.5	97.5%	477	101000	442	93600
6	2000	20	99.0%	14.43	4620	12.57	4520
6	2000	5	99.8%	14.44	4620	11.18	4020
6	2000	0.5	99.98%	14.44	4620	9.04	3250
6	200	20	90.0%	76.66	22900	70.04	21000
6	200	5	97.5%	64.48	23200	56.85	20400
6	200	0.5	99.8%	64.45	23100	49.93	17900
6	20	5	75.0%	342	102000	317	94900
6	20	0.5	97.5%	288	103000	254	91200

Table 5B-2.
MTBE Assumptions Used in AdDesignS

Flow Rate [gpm]	Influent [µg/L]	Effluent Goal [µg/L]	Removal Efficiency	Water Requiring Treatment to Meet Effluent Goal [gpm]	Single Adsorber Flow [gpm]	Option 1: Carbonair Adsorber Name	Option 1: Number of Double (2 in series) Vessels in Parallel	Option 2: Carbonair Adsorber Name	Option 2: Number of Vessels in Pure-Parallel
6000	2000	20	99.0%	5940	660	PC78	9	PC78	14
6000	2000	5	99.8%	6000	670	PC78	9	PC78	14
6000	2000	0.5	99.98%	6000	670	PC78	9	PC78	14
6000	200	20	90.0%	5400	675	PC78	8	PC78	13
6000	200	5	97.5%	5850	650	PC78	9	PC78	14
6000	200	0.5	99.8%	6000	670	PC78	9	PC78	14
6000	20	5	75.0%	4500	642	PC78	7	PC78	11
6000	20	0.5	97.5%	5850	650	PC78	9	PC78	14
600	2000	20	99.0%	594	594	PC78	1	PC78	2
600	2000	5	99.8%	600	600	PC78	1	PC78	2
600	2000	0.5	99.98%	600	600	PC78	1	PC78	2
600	200	20	90.0%	540	540	PC78	1	PC78	2
600	200	5	97.5%	585	585	PC78	1	PC78	2
600	200	0.5	99.8%	600	600	PC78	1	PC78	2
600	20	5	75.0%	450	450	PC78	1	PC78	2
600	20	0.5	97.5%	585	585	PC78	1	PC78	2
60	2000	20	99.0%	59	59	PC13	1	PC13	2
60	2000	5	99.8%	60	60	PC13	1	PC13	2
60	2000	0.5	99.98%	60	60	PC13	1	PC13	2
60	200	20	90.0%	54	54	PC13	1	PC13	2
60	200	5	97.5%	59	59	PC13	1	PC13	2
60	200	0.5	99.8%	60	60	PC13	1	PC13	2
60	20	5	75.0%	45	45	PC7	1	PC7	2
60	20	0.5	97.5%	59	59	PC13	1	PC13	2
6	2000	20	99.0%	6	6	PC1	1	PC1	2
6	2000	5	99.8%	6	6	PC1	1	PC1	2
6	2000	0.5	99.98%	6	6	PC1	1	PC1	2
6	200	20	90.0%	5	5	PC1	1	PC1	2
6	200	5	97.5%	6	6	PC1	1	PC1	2
6	200	0.5	99.8%	6	6	PC1	1	PC1	2
6	20	5	75.0%	5	5	PC1	1	PC1	2
6	20	0.5	97.5%	6	6	PC1	1	PC1	2

Table 5B-3.
Calculation of Capital, Annual, and Unit Treatment Costs

Calculation of Capital, Annual, and Unit Treatment Costs 600 gpm system, 2000 µg/L to 20 µg/L, Option 1: Series Operations	
Line Item	**Cost**
Treatment & Regeneration Units	$603,750
Piping, Valves, Electrical (30% of resin vessel & steam regeneration equipment costs)	$165,333
Site Work (10%)	$60,375
SUBTOTAL	$829,458
Contractor O&P (15%)	$124,419
SUBTOTAL	$953,877
Engineering (15%)	$143,082
SUBTOTAL	$1,096,958
Contingency (20%)	$219,392
Resin Costs with a 10% mark-up	$1,320,000
TOTAL CAPITAL	**$2,636,350**
Amortized Annual Capital	$212,454
Annual O&M	$180,124
TOTAL ANNUAL COST	**$392,578**
Annual Flow Treated (kgal)	315,360
UNIT TREATMENT COST ($/kgal)*	**$1.24**

*To convert unit treatment cost to $/acre-ft, multiply by 326.

Amortization based on a 30-year period at a 7% discount rate.

Capital expenses include: equipment, piping, valves, and electrical components (30%), site work (10%), contractor O&P (15%), engineering (15%), and contingency (20%).

O&M Costs include:
1. Power costs at $0.80/kWhr
2. Labor costs at $80.00/hr
3. Analytical costs at $200 per sample.

See table B-4 for more details on the labor and analytical cost assumptions.

Table 5B-4.
Labor and Analytical Assumptions.

		Series Operation			Carousel Operation				
Flow Rate	Influent Concentration (µg/L)	# Weekly Samples (Series Operation)[1]	# Annual Regen. Samples[2]	Analytical Costs (Series Operation)[3]	# Weekly Samples (Carousel Operation)[1]	# Annual Regen. Samples[2]	Analytical Costs (Carousel Operation)[3]	% Time Required for Operation[4]	Labor Costs[5]
6000	2000	10	348	$173,600	10	480	$200,000	1.50 Time	$320,000
	200	10	75	$119,000	10	84	$120,800		$240,000
	20	10	15	$107,000	10	15	$107,000		$160,000
600	2000	2	36	$28,000	2	48	$30,400	0.75 Time	$120,000
	200	2	8	$22,400	2	9	$22,600		$120,000
	20	2	2	$21,200	2	2	$21,200		$80,000
60	2000	2	45	$29,800	2	54	$31,600	0.5 Time	$80,000
	200	2	9	$22,600	2	12	$23,200		$80,000
	20	2	3	$21,400	2	3	$21,400		$40,000
6	2000	2	75	$35,800	2	99	$40,600	0.25 Time	$40,000
	200	2	18	$24,400	2	18	$24,400		$40,000
	20	2	3	$21,400	2	3	$21,400		$40,000

1) Includes 1 sample at influent and 1 sample at effluent.
2) Includes approximately 3 samples each time the resin system is regenerated.
3) Samples cost $200/sample for 524.4.
4) Labor includes sampling, boiler maintenance, regeneration system upkeep; see Table 6-3a and 6-3b for annual regeneration times
5) Labor rates assume $80/hour or $160,000/year