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16. ABSTRACT

It has become increasingly obvious that important interactions exist between decisions regarding the treatment of contaminated ground and surface water for consumption and aquifer restoration and hazardous waste cleanup.

Many of the contaminants to be regulated under the Safe Drinking Water Act (SDWA) are the same as those to be regulated under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) Hazardous Substances List. The purpose of this paper is to (1) describe the state-of-the-art of drinking water treatment technology and (2) provide examples of some field applications that provide safe drinking water form contaminanted aquifers.

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DRINKING WATER TREATMENT TECHNOLOGY FOR GROUNDWATER REMEDIATION

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INTRODUCTION

It has become increasingly obvious that important interactions exist between decisions regarding the treatment of contaminated ground and surface water for consumption and aquifer restoration and hazardous waste cleanup.

One major distinction must be made regarding the treatment goals of Federal or State drinking water programs and for example, aquifer remediation programs. The objective of pumping contaminated groundwater to the surface and then treating it by drinking water programs, is to provide safe drinking water to consumers immediately by reducing their exposure to the contaminants. The objective of an aquifer remediation program is to restore the aquifer to its original condition. If the source of contamination is stopped, drinking water treatment may or may not restore the aquifer to its original condition, but it will provide a safe drinking water. Aquifer remediation may pump and treat the water then reinject it back into the aquifer, or use in-situ techniques, to eventually restore the aquifer, but may not deal specifically with human consumption at the point of withdrawal. Continuous aquifer contamination such as resulting from routine agricultural chemical application or natural causes could only be remedied for human consumption through application of a drinking water treatment technology.

Many of the contaminants to be regulated under the Safe Drinking Water Act (SDWA) are the same as those to be regulated under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) Hazardous Substances List. Table 1 shows this comparison.

TABLE 1. CERCLA HAZARDOUS SUBSTANCE LIST
(Priority Group 1)

Name	Drinking Water Regulation
Benzo(a)pyrene	yes
Dibenzo(a,h)anthracene	yes
Benzo(a)anthracene	yes
Cyanide	yes
Dieldrin/Aldrin	banned
Chloroform	yes
Benzene	yes
Vinyl chloride	yes
Methylene Chloride	yes
Heptachlor/heptachlor epoxide	yes
Trichloroethylene	yes
n-Nitrosodiphenylamine	no
1,4-Dichlorobenzene	yes
Bis(2-ethylhexyl)phthalate	yes
Tetrachloroethylene	yes
Benzo(b)fluoranthene	yes
Chrysene	yes
2,3,7,8-Tetrachlorodibenzo-p-dioxin	yes
Lead	yes
Nickel	yes
Arsenic	yes
Beryllium	yes
Cadmium	yes
Chromium	yes
PCBs-Aroclor 1260, 1254, 1248, 1242, 1232, 1261, 1016	yes

CERCLA requires that remedial actions be undertaken in compliance with applicable or relevant and appropriate requirements (ARARs), both State and Federal. EPA suggests that in most situations encountered in CERCLA actions, MCLs are the applicable and appropriate clean-up level. If no MCL exist, then health advisories can be used. MCLGs are often preferred by States, being more protective of human health, but long term O&M costs are high.

Each groundwater quality investigation is unique, but for each, the investigator must define the objectives of the study, that in turn will determine the complexity, time, and cost of the project. Groundwater monitoring well design, location, construction, and sampling programs must be merged with treatment technology into a decision-making framework. Knowledge of site geology, hydrology, site characteristics, contaminant source characteristics, and treatment cost and performance are required. Much is written regarding the proper monitoring network, but nothing has tied together location and sizing of drinking water treatment technologies. For example, there are many trade-offs possible locating one large packed tower aerator instead of several smaller towers scattered over an aquifer. Another possibility could be a temporary Granular Activated Contactor (GAC) to treat a hot spot while other technologies are utilized elsewhere over the aquifer. The following sections describe the state-of-the-art of drinking water treatment technology and some field applications, that could have an immediate and widespread impact on providing safe drinking water from contaminated aquifers.

DRINKING WATER TREATMENT TECHNOLOGY

The 1986 Amendments to the Safe Drinking Water Act have greatly accelerated regulatory activities in the drinking water area. It is anticipated that 83 contaminants in drinking water will be regulated by 1991 with an additional 25 standards to be written at intervals of 3 years thereafter. In developing MCLs, EPA is required by the SDWA to demonstrate the feasibility of a technology for removing a contaminant. The standard research protocol is to evaluate unit processes at the bench level; test the process at the pilot scale; and, if its performance is promising, build a prototype for field evaluation.

Table 2 summarizes the treatment technologies that the Drinking Water Research Division of the Risk Reduction Engineering Laboratory in Cincinnati, Ohio is evaluating for removal of volatile organic chemicals (VOCs), synthetic organic chemicals (SOCs), nitrates, and radionuclides from water supplies (both surface and ground). The table indicates carbon adsorption is effective for removing both VOCs and SOCs. Packed tower and diffused aeration are best suited for removing VOCs. Ion exchange has been field tested to show effective removal of nitrates and pilot-tested for uranium removal. Reverse osmosis (RO) has proven to be effective in the field for radium removal and pilot-tested for nitrate removals. Of the technologies that show promise and are being tested at the bench and pilot scales, conventional treatment with powdered activated carbon (PAC) is effective for removing a few of the SOCs, ozone oxidation is effective for removing certain classes of VOCs and SOCs, and certain reverse osmosis membranes and ultraviolet treatment are also potentially effective against VOCs and SOCs. Aeration and carbon adsorption are being examined for their radon removal capabilities.

TABLE 2. TREATMENT TECHNOLOGIES EVALUATED BY EPA's DRINKING WATER RESEARCH DIVISION FOR REMOVING VOLATILE ORGANIC CHEMICALS (VOCs), SYNTHETIC ORGANIC CHEMICALS (SOCs), NITRATES AND RADIONUCLIDES FROM DRINKING WATER[1]

Technology Status	Technology	Contaminant Class or Specific Contaminant Removed
Field-tested	1. Carbon adsorption	1. VOCs, SOCs
	2. Packed tower and diffused-air aeration	2. VOCs
	3. Ion exchange	3. Nitrates
	4. Reverse osmosis	4. Radium

TABLE 2. TREATMENT TECHNOLOGIES EVALUATED BY EPA's DRINKING WATER RESEARCH DIVISION FOR REMOVING VOLATILE ORGANIC CHEMICALS (VOCs), SYNTHETIC ORGANIC CHEMICALS (SOCs), NITRATES AND RADIONUCLIDES FROM DRINKING WATER(1)

Technology Status	Technology	Contaminant Class or Specific Contaminant Removed
Pilot-tested	1. Reverse osmosis	1. Nitrates, uranium
	2. Ion exchange	2. Uranium
Promising technologies	1. Conventional treatment with powdered activated carbon	1. SOCs
	2. Ozone oxidation	2. VOCs, SOCs
	3. Reverse osmosis	3. VOCs, SOCs
	4. Ultraviolet treatment	4. VOCs, SOCs
	5. Ion exchange	5. Radium
	6. Selective complexer	6. Radium
	7. Aeration	7. Radon
	8. Carbon adsorption	8. Radon

FIELD APPLICATIONS

Over two-thirds of the Superfund actions to date deal with a contaminated drinking water supply. As a result of contamination, conventional and "emerging" drinking water treatment technologies are being applied at several state/local utilities and Federal Superfund sites. In many cases, off-the-shelf equipment is utilized which may not be the most cost effective means to reduce the risk of exposure to hazardous toxic wastes. Many of the technologies applied for remediation, and the concentration levels of the contaminants removed at Superfund sites are not necessarily any different than those encountered by water utility managers elsewhere in the United States. Because of a lack of follow-up information regarding these treatment installations, it is difficult to know if actual performance is meeting or exceeding the design criteria.

An examination of the 204 Superfund Records of Decision (RODs) produced between Fiscal Years (FY) 82-86 indicated treatment technology as a solution in only 25% of its actions. Of the 75 RODs produced in FY 87, 59% suggested control technology as a solution, reflecting an increasing trend towards permanent treatment using engineering controls.

The majority of remedial actions nationally in FY 86 have involved offsite disposal or capping as shown in Table 3. Table 4 displays similar information for 75 RODs signed in FY 87 by Region. On the surface, it appears that a good effort is being put forth in using drinking water treatment as a solution to Superfund remedial actions. However, of the 44 source control RODs, 27 employed treatment technologies and thermal destruction was the technology most often selected (48 percent), while solidification was selected 26 percent of the time. Aeration was used only 11 percent of the time. Inclusion of thermal destruction and solidification as a "Treatment Technology" is misleading in that these technologies leave only a barren or nonuseable environment behind, and may not be permanent where solidification is concerned. These are not treatment technologies in the "drinking water" sense. The use of the term "Groundwater Treatment" in Table 4 is also very misleading in that in the RODs it can mean: a new well, pumping to waste or purge, or discharge directly to a wastewater treatment plant. In EPA Region V, between FY 82-86, 45 RODs were signed and only 11 utilized aeration or GAC. According to ROD summaries there are several "Pump and Treat" operations underway, but no other information is available. For water utility managers and Superfund personnel contemplating treatment, a great deal of information is needed for all treatment technologies in order to make rational decisions. This may include the optimization of treatment train combinations, including in-situ, to remove very high levels of organics subject to variable influent levels for full time and intermittent operation.

TABLE 3. FY 86 SUPERFUND REMEDIAL ACTIONS

Remedial Action Proposed	Percent of RODS*
Offsite Disposal	54
Capping	36
Treatment	17
Alternative Water Supplies	15

* Summed percentages exceed 100% due to multiple solutions at Superfund Sites[2]

TABLE 4. FY 87 RODS[3]

REGION	RODS	ALT WATER SUPPLY	GROUNDWATER TREATMENT	TREATMENT TECHNOLOGY	STORAGE OF WASTES
1	3	1	3	4	0
2	15	4	7	6	4
3	5	0	0	2	2
4	11	4	5	6	4
5	14	2	7	5	10
6	11	0	3	4	7
7	3	0	1	0	3
8	7	0	1	0	5
9	5	1	4	0	0
10	1	1	1	0	0
TOTAL	75	13	32	32	35

In general, there appears to be a heavy dependance on packed tower aeration for central treatment and granular activated carbon for point-of-entry (POE) installations. There is little information available on actual operating cost and performance nor does there seem to be much innovation in design. There are, however, some interesting POE applications using packed tower aeration in series with GAC units and diffused basin aeration installations for home use. A cooperative study between Superfund, Leaking Underground Storage Tank sites, and drinking water activities has been initiated to develop a guidance document for the use and management of whole house POE devices. The need for POE devices may skyrocket in the 1990s because of the possible widespread contamination of individual wells from routine application of pesticides, herbicides, and fertilizer already seen in many parts of the corn-belt.

Special attention needs to be paid to the handling of off-gases and contaminated media from both central and POE units. The probable long-term use of POE units is an even more demanding problem. Where a large number of POE units are installed in a well defined geographic area such as Long Island, NY or South Florida, central control or a circuit-rider concept is possible in monitoring contaminant breakthrough and collection and disposal of contaminated media. However, rural homeowners are presently on their own in determining POE performance, and given our experience, will often neglect their units and will be at higher risk after the systems have been operational for a period of time. In addition, without some sort of institutional mechanism, aquifer changes, or new contamination plumes, such as recently found in Wausau, WI will go undetected and the consumer will go unprotected.

EPA Region V Case Study

More than half of the 15,000 community water supply wells have been tested by Region V. Just over 600 wells have contained at least trace levels of VOCs. Of these, 138 wells in 60 communities have been taken out of service and 30 wells have had treatment equipment installed to protect public health.(4) Table 5 lists a portion of the communities for example, and the corrective action taken. Many remedies merely circumvent the contamination by using another water supply. Table 6 shows data from selected locations where air stripping is currently being used and is providing 95-99 percent removal. Table 7 displays data for two GAC units in operation that are providing 99+ percent removal. Table 8 shows some other examples of GAC removal beyond Region V that are providing 97-99+ percent removal.

A microcomputer "Register" is being developed consisting of cost and performance data, operation and maintenance histories, site plan and contaminant information and will be made available.

Questions are constantly being asked of EPA regional staff, state officials, and water utilities regarding the design and operation of recently installed treatment technology. On Site Coordinators (OSCs), Remedial Project Managers (RPMs), water system operators and municipal officials want to know who manufactures treatment technology that can be used quickly on-site. Engineering firms and manufacturers want to know where to get design information and where they can go to see operating units.

TABLE 5. REGION 5 COMMUNITY WATER SYSTEMS WHERE VOCs HAVE BEEN CONFIRMED AT LEVELS THAT EXCEED A ONE-IN-ONE-HUNDRED-THOUSAND RISK

COMMUNITY WATER SUPPLY LOCATION (CITY, STATE)	CORRECTIVE ACTION
1. Libertyville Public Water Supply Libertyville, Illinois	System placed on quarterly VOC monitoring schedule.
2. Elkhart Water Works (SF) Elkhart, Indiana	Continual monitoring being conducted by system. Aeration tower installed. City water mains extended to contaminated private wells.
3. Indiana-American Water Co. Terre Haute, Indiana	Continual monitoring being conducted by system. Conventional treatment includes aeration and blending.
4. Monon Water Utility (SF) Monon, Indiana	Packed tower aeration installed.
5. South Bend Water Works South Bend, Indiana	One well field affected. Well field management reduces VOCs to within acceptable levels.
6. Battle Creek Municipal Water Supply (SF) Battle Creek, Michigan	Interceptor/aeration treatment system and new well installed.
7. Berrien Springs Municipal Water Supply Berrien Springs, Michigan	Continual monitoring being conducted. Well field management practiced.
8. Buckhorn Mobile Home Park Berrien Springs, Michigan	Contaminated wells abandoned, new well installed.
9. Charlevoix Municipal Water Supply (SF) Charlevoix, Michigan	Water treatment plant under construction using Lake Michigan supply.

TABLE 5. REGION 5 COMMUNITY WATER SYSTEMS WHERE VOCs HAVE BEEN CONFIRMED AT LEVELS THAT EXCEED A ONE-IN-ONE-HUNDRED-THOUSAND RISK (CONT.)

COMMUNITY WATER SUPPLY LOCATION (CITY, STATE)	CORRECTIVE ACTION
10. Clare Municipal Water Supply Clare, Michigan	Aeration unit installed.
11. Greenfield Pointe Subdivision Livingston Co., Michigan	Contaminant source was corrosion inhibitor. Material removed.
12. Hartford Municipal Water Supply Hartford, Michigan	State financing secured for construction of a new well.
13. Hilltop Mobile Home Park Plainfield Township, Michigan	Water main extended from township system.
14. Kalamazoo Municipal Water Supply Kalamazoo, Michigan	Purging of Central Well Field underway.
15. Kent City Mobile Home Park Kent City, Michigan	Contaminated wells removed from routine use. New well installed.
16. Niles Municipal Water Supply Niles, Michigan	Contaminated well removed from service.
17. Petoskey Municipal Water Supply Petoskey, Michigan	One new well installed. A second well under construction.
18. Portage Municipal Water Supply Portage, Michigan	Contaminated well removed from service.
19. Saranac Municipal Water Supply Saranac, Michigan	Contaminated wells removed from service. One new well installed and a VOC removal project underway.
20. Spring Arbor College Water Supply Spring Arbor, Michigan	Two wells removed from service. New regional water system under design.
21. Sturgis Municipal Water Supply Sturgis, Michigan	New well installed. Capacity of existing wells to be increased. Contaminated wells used for peak demand only.

SF = Superfund Site

TABLE 6. AIR STRIPPING APPLICATIONS

Location (# of towers)	Production (MGD)	Contaminants	Concentration (ug/L)	Tower Air: Water Ratio	Height (feet)
Hartland, WI (1)	1.4	TCE[a], PCE[b], 1,2-DCE[c]	170	50:1	35
Schofield, WI (1)	1.1	TCE, PCE, 1,2-DCE, 1,1,1-TCA[d]	100	28:1	40
Rothschild, WI (2)	4	TCE, PCE, DCE, Benzene	100	40:1	55
Wausau, WI (2)	8	TCE, PCE, DCE	200	35:1	25
Elkhart, IN (3)	10	TCE, Carbon Tetrachloride	100	30:1	55

(a) - Trichloroethylene
(b) - Tetrachloroethylene
(c) - 1,2-Trans-dichloroethylene
(d) - 1,1,1-Trichloroethane

TABLE 7. GAC APPLICATIONS

Location (number of contactors)	Production	Liquid Loading gpm/sq ft	Contactor Diameter (ft)	Contact Time (min)	Contaminants
Atwater, MN (1)	0.22 MGD	1.9	10	NA	PCE[a], TCE[b]
Spring Grove, MN (1)	0.23 MGD	2.0	10	30.35	Carbon Tetrachloride

NA = Not Available

(a) - Tetrachloroethylene
(b) - Trichloroethylene

TABLE 8. Synthetic Organic Chemicals Removed from Hazardous Waste Streams by GAC

Compound	Location of Incident	Quantity Treated, (gallons)	Contact Time, (minutes)	Influent Concentration (ug/L)	Effluent Concentration (ug/L)
PCB	Seattle, WA	600,000	30-40	400	0.075
Toxaphene	The Plains, VA	250,000	26	36	1
Chlordane	Strongstown, PA	100,000	17	13	0.35
Heptachlor	Strongstown, PA	100,000	17	6.1	0.06
Pentachlorophenol	Haverford, PA	215,000	26	10,000	0.1
Toluene	Oswego, NY	250,000	8.5	120	0.3
Xylene	Oswego, NY	250,000	8.5	140	0.1

Once treatment units are installed, whether at a Superfund site or at a local utility, there is generally little follow-up to see if designs are proper or are adequate mechanically to stand up for a reasonable period of time. Of particular interest to researchers and designers of treatment equipment is the correlation of actual operating experience with pilot plant tests or theoretical design criteria.

The Register being developed lists units already designed and should therefore reduce design costs by allowing consultants to utilize previous design details. Follow-up information from previous installations should point out design deficiencies as well as over-design. Follow-up information might also point out serious problems caused by previous installations and how some changes in design may eliminate future problems. Entire treatment concepts may be shown to be impractical in certain circumstances, or that treatment is causing problems within households thus making a utility or Federal government potentially liable for damages.

Other factors such as weather, site conditions, or water chemistry not considered in the design might prove to be of great importance and should be considered more in future designs. Other problems may result from additional treatment such as corrosion or clogging of distribution system mains or household plumbing.

POE Field Applications

The predominant contaminants being treated are the chlorinated solvents including Trichloroethylene, Tetrachloroethylene, 1,1,1-Trichloroethane, 1,2-Dichloroethane, and 1,2-Trans-Dichloroethylene. Also being treated are waters contaminated by petroleum products, aldicarb, ethylene dibromide or radon. Table 9 summarizes the contaminants of concern and their influent levels. The removal efficiencies provided by the various systems ranged between 86 and 99+ percent. No Federal Superfund sites were found in Regions 6-10 utilizing POE units. Little has been found on Reverse Osmosis and Ion Exchange technologies. Figure 1 describes a home aerator in series with a carbon unit being used in some locations. This particular design was installed under the steps in the homeowner's basement. Costs for most POE units range between 2,000 and 3,000 dollars with carbon replacement averaging 500 dollars.

Information relative to system design and operation was identified; however, the level of detail of the design information (i.e., unit specifications) are somewhat lacking. System suppliers and designers have been either reluctant or unable to provide the type of information needed. Many are small operations with limited personnel and financial resources available for organizing and presenting the requested data.

In most cases, no quality control (QC) for analytical data obtained were available, including test methods, protocols, and QC samples. Some samples were analyzed by field gas chromatographs to determine the presence or absence of contaminants. Although these data are useful for the system monitors to determine contaminant exposure, they may not provide the level of confidence required for the development of a technical assistance document for example.

TABLE 9. SUMMARY OF EXISTING DATA
POE WATER TREATMENT STUDY(5)

SITE NAME & LOCATION	POE SYSTEM	CONTAMINANTS	MAX. INFLUENT (ug/L)	NO. POE SYSTEMS INSTALLED
State of Maine	Diffused air stripping	Gasoline and No. 2 Fuel Oil	240,000	100
State of Maine	Diffused air stripping, or packed tower	Radon	400,000 pC/L	NA

TABLE 5. SUMMARY OF EXISTING DATA
POE WATER TREATMENT STUDY(5) (CONT.)

SITE NAME & LOCATION	POE SYSTEM	CONTAMINANTS	MAX. INFLUENT (ug/L)	NO. POE SYSTEMS INSTALLED
Suffolk County Water Treatment, Suffolk County New York	Carbon cell	Aldicarb	500	3,000
Cattaraugus County, New York	2 Carbon Cells	TCE(a)	3,600	37
Green County New York	2 Carbon Cells	PCE(b)	79,500	6
Onendaga County, New Ycrk	Packed Tower	TCE		5
		1,2-DCE(c)	690	2
		1,1-DCA(d)		2
York County, Pennsylvania	Prefilter, Carbon cell, UV light	TCE	4,600	6
Berks County, Pennsylvania	Prefilter, Carbon cell, UV light	1,2-DCE	1,700	28
		TCE	23,000	
		PCE	1,000	
		DCA	50	
		1,1,1-TCA(e)	570	
Adamstown, Maryland	Prefilter, Carbon cell, UV light	TCE	520	18
		1,1,1-TCA	44,000	
		1,1-DCA	210	
		1,2-DCE	570	
Monroe County, Pennsylvania	Prefilter, Carbon cell, UV light	TCE	7,000	22
		1,2-DCE	290	
		PCE	30	

TABLE 9. SUMMARY OF EXISTING DATA POE WATER TREATMENT STUDY(5) (CONT.)

SITE NAME & LOCATION	POE SYSTEM	CONTAMINANTS	MAX. INFLUENT (ug/L)	NO. POE SYSTEMS INSTALLED
Florida	2 Carbon Cells	Napthalene	12	11
		Total hydrocarbons	220	
		Benzene	210	
		Ethylbenzene	38	
		1,2-DCA	89	
		Toluene	8	
		Xylene	63	
Polk and Jackson Counties, Florida	Prefilter, 2 Carbon Cells, UV light	Ethylene dibromide (EDB)	800	850
Byron, Illinois	Prefilter, 2 Carbon Cells	TCE	500	10
		PCE	130	
Elkhart, Indiana	Prefilter, 2 Carbon Cells,	TCE	5,000	60
	Packed Tower Aeration	Carbon tetrachloride	7,500	1
Uniontown, Ohio	Packed Tower Aeration	Vinyl Chloride	7	9
		Chloroethane	2	

(a) - Trichloroethylene
(b) - Tetrachloroethylene
(c) - 1,2-trans-dichloroethylene
(d) - 1,1-dichlorethane
(e) - 1,1-trichloroethane

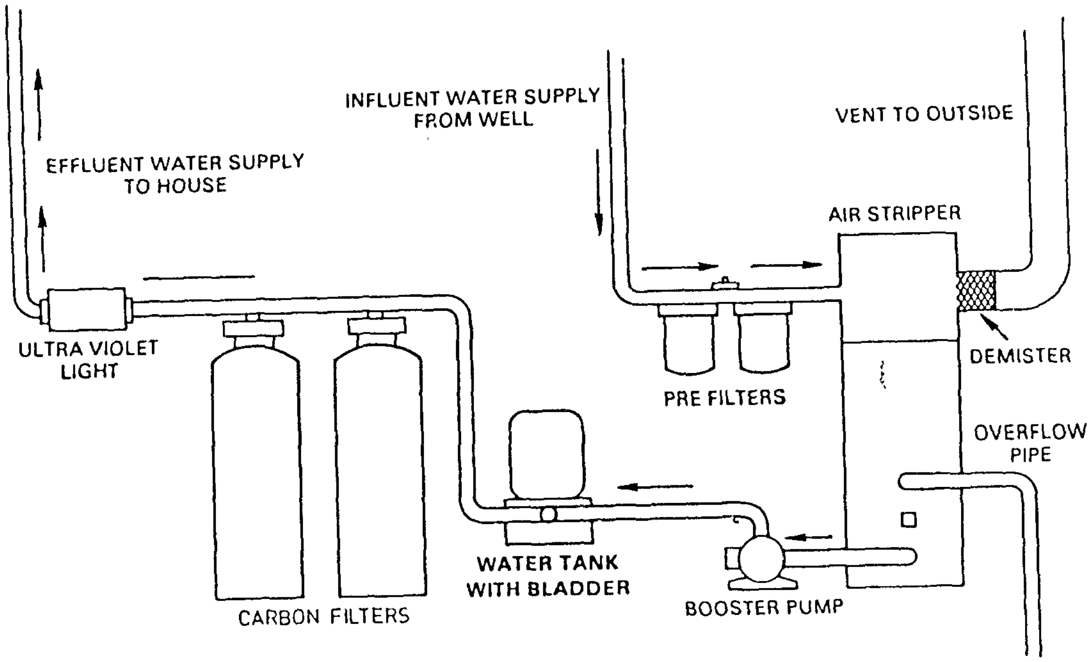

FIGURE 1. HOME AIR STRIPPER AND GAC FILTER (ELKHART, INDIANA)

CONCLUSIONS

A total of 7,900 confirmed hazardous waste sites in 46 states have been identified along with over 22,000 suspected sites.(6) Since 90% of the confirmed sites are not currently on the National Priority List and Region V alone has over 500 locations on the NPL, the need for information and technology transfer is enormous. Currently, data collection, as shown in Tables 5-9, is underway in EPA Regions V and VIII. There is a great deal of information available across the country in addition to Superfund activities that need to be synthesized and assembled into a format useable to state, local and federal authorities in order to reduce consumers' risk of exposure to toxic hazardous wastes.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the USEPA.

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