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TECHNICAL REPORT ON THE WOBURN,  
MASSACHUSETTS WELLS G & H SITE

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## PREFACE

This document is a technical review of the Final Supplemental Remedial Investigation for the Wells G & H Site Woburn, Massachusetts, December 1988 (Supplemental RI) by EBASCO SERVICES, INC. (EBASCO), Draft Final Feasibility Study Report Wells G & H Site, Woburn, Massachusetts, January 1989 (FS) by EBASCO, and the Endangerment Assessment for the Wells G & H Site Woburn, Massachusetts, December 1988 (EA) for EBASCO by Clement Associates, Inc. and the supporting documentation and information included in the appendices to the above-referenced documents.

Specific recommendations are included for obtaining additional data, selecting appropriate treatment technologies and providing appropriate operation and maintenance services.

Conclusions are summarized, supporting technical discussions are presented and back-up information is referenced.

## I. EPA/EBASCO PROPOSAL

EPA's principal objective is to restore the aquifer that supplies Wells G & H to drinking water quality as soon as possible and to ensure protection of the public health, safety and the environment in the future. EPA also states that its preferred remedial technique will provide for drinking water if supplies are needed prior to achievement of clean-up target levels within the aquifer (EPA, 1989).

Specifically, EPA's preferred remedy includes excavation and treatment of soil because of its potential as a source of groundwater contamination, controlling the migration of contamination already within the aquifer which is now moving from the separate source areas towards the Central Area and pumping of the Central Area in order to increase the rate of remediation by means of a higher flushing rate.

The treatment technology proposed for the collected groundwater includes metals removal by coagulation and flocculation and VOC removal by air stripping (with vapor phase activated carbon treatment) at a single, centralized treatment facility.

The approach used in the EBASCO material which was reviewed emphasizes adopting an area-wide perspective and finding a single solution applicable to the entire site. This approach is evident throughout the prescribed process, from the method used to determine soil target levels to the decision to combine the waste streams from all five sources and to treat the Central Area at a single, centralized facility.

Alternatives which were considered for Management of Migration (MOM) measures in the FS were presented in Table 3-5 (pages 3-32 and 3-33). These alternatives are summarized below.

Four management alternatives were considered:

<u>Alternative Number</u>	<u>Description of Management Technique</u>
1	No Action
2	Pump and treat source areas (New England Plastics, UniFirst, W.R. Grace, Olympia Nominee Trust, and Wildwood Conservation Corporation).
3	Pump and treat central area
4	Pump and treat source areas and the central area
5	Pump and treat at the southern boundary area

For each alternative (except Alternative 1) three treatment options were analyzed:

<u>Option</u>	<u>Treatment Technology</u>
A	Air Stripping
B	Ultraviolet/Chemical Oxidation
C	Carbon Absorption

For each treatment considered for application to each of the management alternatives, two scenarios were examined:

<u>Scenario</u>	<u>Treatment Location</u>
i	Separate Treatment Plants
ii	Centralized Treatment Plant

EBASCO states that "the MOM-4 Alternatives would achieve the maximum removal of contaminants since they provide the largest capture zone" (FS, pg. 4-205) and that "Alternative MOM-4 provides the most overall protection of human health in the environment and the shortest overall time frame" for remediation (FS, p. 4-209).



## II. FUNDAMENTAL CONCEPTUAL ERRORS

EBASCO's overall viewpoint and strategy is a comprehensive one which encompasses the entire Wells G & H site. Taken at face value, this approach might seem to be the most logical and effective. However, by examining the discrete problems and issues which comprise the contamination at the Wells G & H site, it becomes evident that a more individualized approach is appropriate. The assumptions made and treatment used to arrive at soil target levels is a good illustration of this issue, as is the selection of a one single treatment train technology for all of the individual waste streams encountered at the Wells G & H site notwithstanding their marked differences from one another. Not only do the effectiveness and costs of the proposed remedial techniques for the problems currently in existence come into question; it also becomes apparent that implementation of this approach will create additional, unanticipated problems.

### A. General Summary and Conclusions

The data used to arrive at the proposals are not presented in an organized and meaningful manner. The emphasis of the sample results seems to be areal as opposed to temporal. The gathering of samples on a small number of dates over a wide area results in effectively few useful data points. In some cases, such as surface water sampling, collection was done at inappropriate times (i.e., high flow and therefore potentially high dilution rates for some contaminants). There was poor follow-up in general on detected compounds, and therefore no trends in contaminant concentrations are delineated.

The use of assumed fraction of organic carbon (foc) values resulted in grossly erroneous VOC flushing times for the Central Area. This error was compounded by lack of attention to the nearly universal experience of asymptotic contamination reduction curves in aquifer restoration projects. Due to these errors, EBASCO and EPA failed to appreciate that the pumping-induced flushing will likely have little or no effect on the time it takes for VOCs to reach drinking water levels in the aquifer.

On the other hand, due to the hydraulic connection between the Aberjona River and the aquifer serving Wells G & H, pumping of the Central Area for remedial purposes and/or drinking water supply will result in the introduction of non-VOC contaminants present in the surface water and the watershed upgradient of the Wells G & H Site into the Central Area groundwater. Contaminants such as coliform, PAHs, and heavy metals, as well as contributions from such unpredictable sources as Route 128 and other hazardous sites directly upstream, would be pulled into the aquifer and its associated soil matrix. Introduction of these contaminants will further complicate the remedial attempts and be counter-productive to the achievement of the

stated groundwater goals for the Central Area. In addition, pumping of the Central Area could induce radionuclides into the waste stream to be treated at Wells G & H.

There is evidently a general lack of understanding of the dense non-aqueous phase liquid (DNAPL) contribution to both groundwater contamination and soil contamination. The likelihood of a relatively low yield from pumping the over-burden at the UniFirst site and the presence of DNAPL in the bedrock aquifer negate the effectiveness of pumping the over-burden for groundwater remediation or effectively addressing the soil contamination problem without first addressing the DNAPL as the source of soil contamination via vapor transport through the soil matrix.

The treatability study done on contaminated groundwater served only to confirm choices of treatment technologies selected prior to the commencement of the study. Only the combined waste stream was studied and no examination of the treatability of the individual source area waste streams was performed. There also appeared to be a significant difference in the concentrations of contaminants present in the waste stream used in the treatability study versus both the concentrations of contaminants of potential concern presented in the EA and versus the total VOC concentrations presented in Table 3-4 of the FS.

The proposed combination of waste streams for treatment at a central facility violate some of the most basic principles of sanitary engineering. It would result in the dilution of highly contaminated waste streams (thereby increasing the cost per unit mass of contaminants removed), as well as the mixing and dilution of unique contaminants of particular concern such as vinyl chloride and chloroform.

Although several of the source areas contain levels of contamination which can be treated with aqueous phase activated carbon adsorption, EBASCO rejects such treatment (FS, p. 3-44) due to the "high concentration of volatile organics in the contaminated groundwater". Also cited as reasons for rejecting aqueous phase activated carbon treatment for volatile organic removal was "a high potential for carbon filter break-through resulting in inadequate treatment" (FS, p. 3-45). The problem of inadequate treatment by activated carbon adsorption due to breakthrough of a single filter is easily addressed by designing a "train" of activated carbon filters. By monitoring for breakthrough between the filters in the train and replacing filters as necessary, the opportunity for the solvent wave to break-through the last filter in the train can be eliminated.

The selected treatment train (metals removal by lime and polymer addition, followed by air stripping for VOC removal from the water stream, followed by vapor phase activated carbon adsorption) will likely be ineffective in meeting treatment

target levels at such a highly contaminated sites as Wildwood. The proposed treatment train includes unnecessary treatment steps for some waste streams, and is not the most cost-effective option for some waste streams. Also, it did not appear that the final disposition of re-claimed contaminants was adequately addressed. It is perhaps obvious, but still worth noting that, if radionuclide contamination is present in any of the waste streams, then the final disposition of all sludges, activated carbon and re-claimed contaminants will become a much more significant problem.

The combination of all of the source area waste streams and the Central Area for treatment at a central plant supposedly is shown to be more cost-effective in Table 4-4.1 of the FS (p. 4-207). The difficulties associated with piping highly contaminated waste streams across private property, wetlands and surface water, to say nothing of the matrix of problems created by the combining of the waste streams, such as dilution of concentrations and the introduction of unique contaminants, makes this cost-effectiveness conclusion improbable at best.

The cost estimation performed reflected a clear bias towards the centralized treatment facility. For example, five office trailers were specified at each of the source areas and the Central Area when separate treatment facilities were being considered (for a total of 30 trailers), while only five trailers were specified for the central treatment facility. The same comparison holds true for the number of groundwater samples specified per year of operation. Labor requirements for the operation and maintenance of all treatment facilities appeared to be excessive. Inflation of the capital costs due to inordinately high pumping rates and unnecessary redundancies coupled with high labor requirements for operation and maintenance bolstered the argument for centralized treatment.

#### B. Recommendations

The delineation of a sampling program for each specific media including surface water, groundwater, sediments and soils is appropriate. Data should be gathered over time and maintained in order to delineate contaminant trends. A centralized data base of all analytical results for the Wells G & H site should be maintained.

Treatability Studies should be done on each waste stream from each source area during a 10 to 30 day pumping test of each remediation well to be used so that appropriate treatment technologies can be determined and pilot tested. Operation and maintenance efforts could be combined for each source area's treatment facility and the centralized data acquisition and maintenance facility in order to economize and ensure the integrity of the remediation process over the entire Wells G & H site.

The bedrock aquifer should be pumped immediately at the UniFirst site in order to expedite the removal of contaminated groundwater in the bedrock aquifer. The objective of remediating the aquifer feeding Wells G & H to drinking water quality should be re-examined from a realistic perspective. The water quality within the watershed upgradient of Wells G & H has been compromised to a point at which only control of the migration of contamination from the individual source areas at the Wells G & H site would best serve public health and the environment. Pumping of the Central Area, on the otherhand, is likely to introduce novel and persistent contamination to the aquifer, thus compromising the stated goals of remediation.

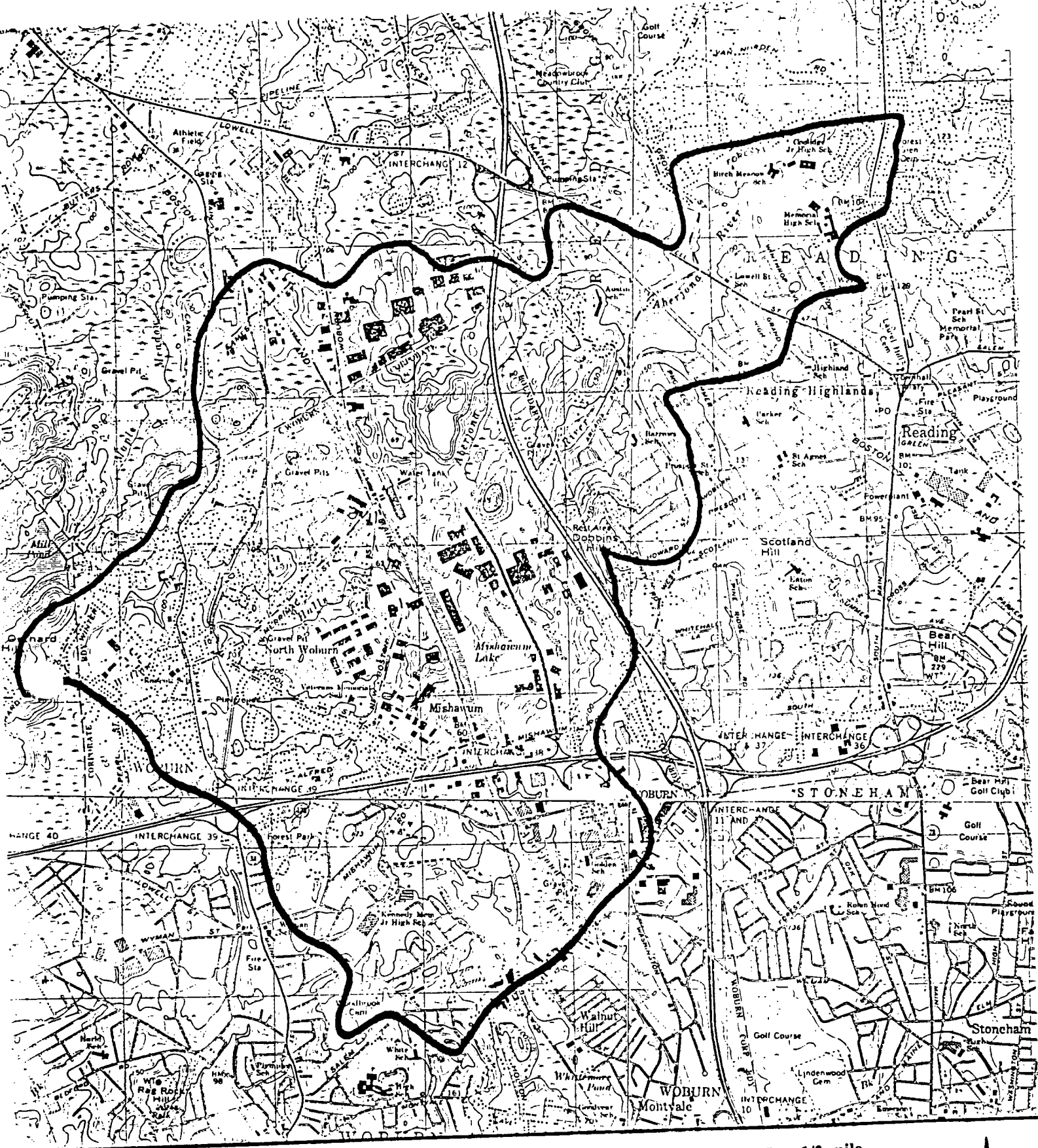
### III. WATERSHED CHARACTERISTICS

#### A. Hydrological

The watershed or drainage basin area at the Salem Street bridge (directly south of the Central Area) is 6.91 sq. mi. The watershed covers portions of Reading, Wilmington, Burlington, and Woburn (Figure A). The bedrock underlying the watershed is composed of metamorphic and igneous rock, primarily granite and gneiss. Subsequent uplifting and dissection by stream erosion carved out an extensive valley which the course of the Aberjona River now follows. Soils consist primarily of till in the more upland areas and glacial outwash which exists primarily in the Aberjona River Valley. The topography of the watershed is gently rolling with scattered hills and wetlands noted throughout the area. The groundwater flow direction is generally from the upland till covered areas toward the lower central valley area with a down valley flow component. Groundwater in the bedrock is recharged in the upland areas and discharges with a vertically upward gradient into the central valley area as is typical in buried valley sequences such as this (see Figure B).

This watershed has been significantly altered from its natural state due to heavy residential, urban, and industrial development. Effects of urbanizing a watershed include decreased infiltration, pollution of streams and wells, and increased flood flows (Chow, 1964). The hydrology of an urban water supply is frequently regional rather than local in scope (Chow, 1964), with the land use in the watershed influencing the quality of the different components of runoff. As urban runoff travels, it picks up contaminants including nutrients, sediments, metals, litter, and organic and bacterial waste. Urban runoff can contain high levels of heavy metals, especially copper, lead and zinc, with the water quality standards for these constituents being chronically exceeded (EPA, 1985). All runoff from this watershed flows through the Central Area via surface, subsurface, and groundwater runoff. Therefore, the industrial development of the watershed has a direct impact on the water quality of the watershed, including the sand and gravel aquifer located in the central portion of the Aberjona River Valley, and ultimately the water quality of Wells G & H. Aquifer characteristics are discussed in detail in Section IV-A.

The watershed upgradient of Salem Street is heavily urbanized and industrialized. It is one of the most industrialized portions at the upper Mystic Lake Watershed. It contains the Industri-plex site, which is on EPA's top ten list of hazardous waste sites in the country. It has historically contained polluting industries, including piggeries, tanneries, chemical factories and machine shops. Present day industry includes chemical, plastic, and pesticide manufacturers and other potentially polluting industries. Also, there is heavy residential development in the watershed and other potential



Aberjona River Watershed  
at the Salem Street Bridge

Scale: 1" = 1/2 mile



FIGURE A

Figure \_\_\_\_\_  
 (from Myette, *et al.*, 1987)

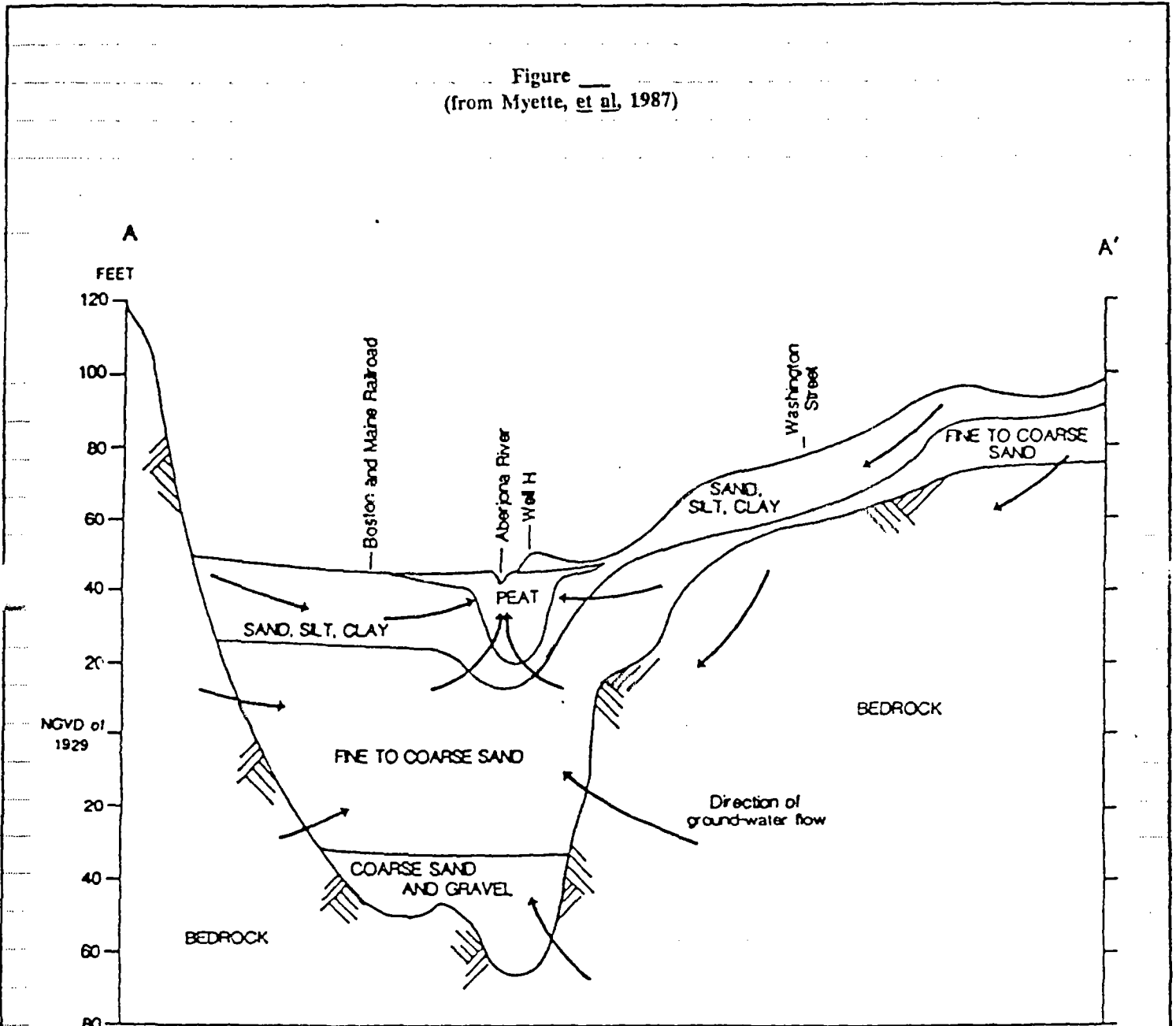


FIGURE B

pollution sources including dumps, underground fuel storage tanks, and roadways including two major interstate highways, Routes 93 and 95 (128). Essentially, a variety of point and non-point pollution sources exist in the watershed which directly affect the water quality in the central valley aquifer. Historical water quality data indicate that runoff from this watershed contains inorganic and organic compounds. The land use of the watershed is discussed in detail in the following sections.

## B. Land Use

This section presents a review of the characteristics of the Aberjona River watershed upgradient from the Salem Street Bridge, Woburn, Massachusetts. Included in this report are: (1) the hydrology of the surface water and the alluvial aquifer; (2) a history of the urbanization of the watershed; and (3) a review of the groundwater and surface water quality data. The purpose of this section is to present all data relevant to evaluating the proposed remedial plan.

### 1. Watershed

The regional geology north of Boston is characterized by metamorphic and igneous formations, primarily composed of granodiorite, and gneiss, formed during the Precambrian and Paleozoic ages. The region underwent uplift and erosion in the following three hundred million years. Finally, Pleistocene glaciation significantly modified the region up until 14,000 years ago by erosion of bedrock and deposition of till, outwash gravel, sand and silt.

The morphology of the Aberjona River basin today is the result of the redevelopment of the drainage network over the past 14,000 years. The headwaters of the Aberjona are located in Reading, Massachusetts, north of Route 129. The river meanders southward under Interstate Route 93 where it is soon channeled along the entire length of Commerce Way. Originally, at this point the Aberjona and the Hall's Brook tributary emptied into Mishawum Lake. However, considerable industrial development in the area resulted in the draining and filling in of the lake and the creation of the Hall's Brook Storage Area. At present, Hall's Brook flows through the storage area and joins the Aberjona River just north of Route 128. From the Route 128 box culvert the river meanders approximately one mile south through a large marshland to the Salem Street bridge. At the Salem Street bridge the River is approximately 15 feet wide and less than 3 feet deep (observed 2/20/89).

The area of drainage of the Aberjona watershed upgradient of the Salem Street bridge in Woburn is 6.91 square miles, and the main channel slope to this point is 13 feet per mile. The



gradient of the Aberjona River from Route 128 to Salem Street is less than 5 feet per mile. The watershed at Mishawum Road (1 mile up-river from the Salem Street bridge) is approximately 38 percent open/forested, 43 percent residential, and 19 percent industrial (Franton *et. al.*, 1982). Based on these values and a visual estimate of the remaining watershed from Mishawum Road to Salem Street, the total estimated land use is 50 percent residential, 13 percent industrial and 37 percent open land. In the following discussion, the watershed refers to the area that contributes to the Aberjona River above the Salem Street Bridge.

## 2. Urban Development History<sup>1</sup>

Industrial development within the predominantly agricultural Aberjona River valley began primarily as a result of the construction of the Middlesex Canal in 1803. From approximately 1814 to the 1850's, the region was dominated by leather processing and related industries. The industries were tanning factories, shoe and boot factories, and machine shops that manufactured equipment for these industries. By the middle 1800's, there were approximately 26 shoe and boot factories and 21 tanning factories.

Prior to the Civil War, the region experienced the introduction of chemical industry. Woburn Chemical Works started operation in 1853 producing chemicals for tanning processes and dyes. By 1899, Woburn Chemical Works had been bought out by Merrimack Chemical Corporation and had become the leading national producer of arsenic pesticides. Industrial wastes were disposed of on-site, and many by-products were stored in slag piles for possible future use. Merrimack Chemical was producing many organic chemicals, including phenol benzene, toluene, and pyric acid by 1915. During World War I Merrimack Chemical was involved in coal tar distillation, paint grinding, and the production of trinitrophenol and trinitrotoluene (TNT). After the 1929 market crash, the factory was rapidly expanded to one of the largest chemical plants in the U.S.; 415 acres covered by 90 buildings. (Krimsky *et. al.*, 1980).

Concurrent with the development and expansion of the chemical industry during the 1850's to the 1930's was a growth in the tanning and machine shop industries. The advent of chromium tanning processes at the turn of the century enabled these industries to increase production levels tremendously. Again, the industrial wastes were disposed on-site. For the Industriplex site alone, reference is made to an "approximately 80 acre burial ground". This attests to the magnitude of

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1. Unless otherwise stated all material is cited from GeoTrans (1987).

operations of the tanning industry and does not include other factories in the watershed.

Starting in approximately 1940, the Woburn area experienced a diversification of its industrial base to include light industry and manufacturing. The number of tanning operations had decreased to five. Foundries and machine shops numbered 14. In 1947, there were five chemical factories producing glue, tallow, fertilizer, and other products.

By 1989 the region contained more than 135 manufacturing firms. Of these firms, 66 to 81% are operating within the Aberjona watershed upgradient of the Salem Street bridge. Table 1 contains a partial list of products manufactured by the firms within the watershed. The processes used in production of the products involve the use of an extremely wide variety of chemicals. Although it has not been demonstrated that these sources have released their products or wastes to the environment, their existence and use of a wide array of chemicals illustrates potential sources for contaminants.

According to the Woburn Department of Public Works, there are approximately 147 miles of road in the town of Woburn; most of these roads are two lanes wide. Based on areal unitization of the amount of watershed within the town of Woburn, this translates into approximately 240 acres of roadway, which includes 5 miles of Interstate Routes 95 and 93. This is a conservative estimate, given that acreage of pavement within the watershed for Reading, Stoneham, and Burlington has not been included in this estimate. Contributions of contaminants from vehicles on these roads as well as road maintenance include salt, petroleum products, PAHs and lead, as well as direct spills from transporting vehicles.

### 3. Possible Sewer Contributions

The possibility of surface water and groundwater contamination by sewer surcharging has been documented (GeoTrans, 1987) and recognized by EBASCO (Supplemental RI, 1988). Of particular concern is the trunk sewer line that runs through the Central Area just east of the Boston and Maine railroad tracks. Portions of the sewer line in the area are located within the zone of influence of Wells G & H as defined by the U.S.G.S. 30 day pumping test.

Although it is not entirely clear, it appears that the sewer lines were constructed in the late 1920's into mid-1930's, (GeoTrans, 1987). By the late 1920's into mid-1930's, surcharging caused by the inadequate system and lack of maintenance was cause for legal action (GeoTrans, 1987). Given the age of the sewer system and depending on its maintenance history, exfiltration from the sewer induced by pumping Wells G & H should be considered as a possible means of groundwater

contamination in the Central Area. This conclusion is based on (1) sewer surcharging and historical records indicating that the sewer is, on occasion, pressurized; (2) portions of the sewer are located within the zone of influence Wells G & H; (3) the age of the sewer casts doubt on the integrity of the system; and (4) a hydraulic connection between the sewer and the river has been proposed by Warrington (1973), who suggested the possibility of infiltrative loss from the river to the sewer.

Table 1

List of Products Produced by  
Manufacturers in the  
Aberjona Watershed

Chemical factory	Generators	Motor Oil Waste Products
Electronics	Adhesives	Petroleum Waste Products
- Microwave	Textile Goods	Lead Fabrication
- Heat Exchanger	Packing Machinery	Paint
- Generators	Machine Shops	Stone Cutting
- Computers	Commercial Printing	Lighting Fixtures
Cosmetics	Wood Laminates	Manufacturing
Solvents	Formica	Wood Preservatives
Perfumes	Processed Meats	Anhydrous Ammonia
Drugs	X-ray Equipment	Glass Works
Graphic Arts	Silk Screening	Printing
Leather Manufacturing	Electro-Plating	Brass Works
Sheet Metal	Abrasives	Metals Foundry
Photographic	Greenhouse Pesticides	& Castings
Grease	Ceramic Coatings	Cryogenic Materials
Oil	Tires	Rope
Insulating Material	Metalized Film	Cleaning Materials
Plastics & Resins	Pest Control Equipment	Rubber
Hydraulic Equipment	Tallow	Vinyl
Carpet & Upholster		
Cleaners	Grinding Fluids	
Dry Cleaning	Chemical Cutting	
Metal Grinding	Industrial Laminates	
Infrared Materials	Metal Treating	

From: 1988-1989 Directory of Massachusetts Manufacturers

## C. Water Quality

### 1. Surface Water Quality

The focus of this section is on the surface water quality of the Aberjona River. The water quality of the Aberjona River tributaries, river sediment chemistry, and potential source areas for hazardous waste within the watersheds will be presented and discussed. In the following discussion, the central area refers to the region between Salem Street and Route 128 along the Aberjona River.

### 2. Historical Perspective<sup>2</sup>

Degradation of the Aberjona River basin occurred penecontemporaneously with industrial development in the region. As early as the 1870's it was noted that material spent by the tanneries rendered the stream useless for domestic purposes. Direct and indirect discharges from the tanneries appear to have been commonplace. Specific citations of pre-1900 pollution include the discharge of ammonia and tar products to Russell Brook, refuse from a glue factory causing serious pollution to the Aberjona, as well as spent bark liquor (tanning process waste) from the tanneries being discharged to gravel infiltration pits.

At the turn of the century, protest over this pollution resulted in pollution control legislation. The Massachusetts State Board of Health described the Aberjona River and its tributaries north of upper Mystic Lake in 1906 as "the most seriously polluted stream in the Mystic River watershed".

From approximately 1920 to World War II, the advent of a sewer system partially mitigated on site indirect and direct discharges. However, chromium wastes were not allowed to be disposed of in the sewers. Consequently, tannery treatment sludge as well as animal by-products were disposed of in private and public dumps. Thus, "throughout the late 1920s the Aberjona remained extremely polluted from tannery waste". In 1924, the Massachusetts State Department of Health (MSDH) prosecuted five tanneries for industrial pollution.

Throughout the 1930's, the MSDH focused on pollution from chemical factories and frequent sewage overflows from the municipal sewer system. "Partially spent chemicals" and seepage from pyrite slag deposits were identified by the MSDH as being involved in polluting the river. The partially spent chemicals came from a chemical plant that produced arseno-insecticides, acids, ammonia, sodium salts, and other chemicals. In 1937, oil

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2. Unless otherwise stated all material is cited from GeoTrans (1987).

was sprayed on the surface of the river as an insecticide "because of the pollution".

From the mid-1950's to 1980, numerous investigations and studies performed on the Aberjona watershed identified sources of pollution. Among these are investigations of wastewater overflows containing formaldehyde, acid, and oils from the National Poly Chemical plant, a salt stock pile leaching to surface waters, piggery leachate from buried and surface deposits of manure at four sites, sulfate leachate from stock piles on the Stauffer Chemical property, use of pesticides in the watershed, and Woburn Dump leachate from industrial and household waste. During the 1970's, the City of Woburn utilized various chlorinated hydrocarbon pesticides, such as malathion, methoxychlor, kelthane, and kerosene. Herbicides used along the Boston and Maine railroad include diesel fuel during the 1960's and bromacil, 2-4 D, monosodium methane arsenate, Atranol, diquat, Amdon, Banvel, and EVIK during the 1970's.

From the late 1970's to the present, the major investigations have centered around two EPA superfund sites: the Industriplex site and the Wells G & H site. Studies from both sites have generated data on groundwater and sediment chemistry. These data include an impressive array of volatile organic, semi-volatile organic, and inorganic compounds including metals (see Appendix 1 through 6). Many of these compounds are listed in the EPA priority pollutants list. Included in these appendices are site-specific data for the portion of the watershed of the Aberjona River that lies within the Town of Woburn. A partial list of contaminants identified is included in Table 2. In addition, partial lists of chemicals used in the processes at four chemical companies that are located within the watershed are shown in Appendices 7 through 11.

Although data are limited, several potential and confirmed sources of contaminants have been identified for sites other than the two EPA sites located in Woburn. Appendix 1 lists identified sites containing contaminants, as well as the major compounds identified. Among the surface water contaminants are a variety of chlorinated hydrocarbons that have been detected as high as 100 ppm, as well as nitrates and ammonia. Soils concentrations of chlorodane have been reported as high as 51,000 ppm. Appendix 12 contains a list of 21 potential sources of groundwater contamination; 19 of these sites are located within the Aberjona watershed upgradient of the Central Area. Appendix 13 contains a list of 12 sources of pollutants along the Aberjona River identified by Defo (1970). Appendix 14 contains a list of confirmed hazardous waste disposal sites and locations to be investigated identified by the DEQE for the Woburn area. Of the 41 sites listed, 25 to 29 are located in the watershed. Lastly, according to the Woburn and Reading fire departments there are approximately 50 and 44 underground

storage tanks in Woburn and Reading, respectively. The actual number of underground storage tanks are located within the watershed is not known.

### 3. Surface Water and River Sediment Chemistry

Surface water and river sediment chemistry data in the Supplemental RI are notably sparse. These data are contained in Appendices 16 and 17. This lack of data is especially disconcerting given the industrial nature and history of the watershed in conjunction with the well-documented hydrologic connection between the River and Wells G & H (see Delaney and Gay, 1980, Myette et. al. 1987, and this report).

Data for the river sediments collected by EBASCO/NUS is extremely limited (see Table 3). Sampling by EBASCO occurred on September 27, 1987 for seven stations and on December 10, 1987 for four additional stations. In general, compounds detected are similar to those found in the surface waters by EBASCO, but in higher concentrations. Of particular interest are the PAHs. The PAHs detected are very similar to, but in much higher concentrations than, those found in the surface water samples collected by the Johnson Company, Inc. on March 5, 1989.

Table 2

Partial List of Compounds Identified  
in the Aberjona Watershed: Woburn, MA

<u>Volatiles</u>	<u>Volatiles (Cont'd)</u>	<u>Pesticides/PCB'S</u>
Acetone	Benzo(Q,H,I)perylene	4,4'-DDD
2-butanone	Dibenz(A,M)anthracene	Aldrin
Benzene	Fluoranthene	
Toluene	Benzo(Q,H,I)perylene	
Fluorene	1,1-Dichloroethane	
Trichloroethene	Ideno(1,2,3-OD)pyrene	
Vinyl Chloride	Benzo(A)pyrene	
Methylene Chloride	Naphthalene	
Chloroform	Phenanthrene	
Methyl phenol	Pyrene	
Benzoic Acid	M-mitrosodiphenylane	
Piperidine	Dibenzofuran	
Benzene Propanoic Acid	Trichloropropane	
Bis(Sulfonyl)Benzene	Dichloreylhexane	
Bis(pentafluoro- phenyl)phosphine	Bromocyclohexane	
Carbon disulfide	Phthalate	
Trichloropropane	Methyl Butanoic Acid	
Bromocyclohexane	Benzaldehyde	
Octanoic Acid	Benzene	
Monanoic Acid	Acetic Acid	
Tri Decatriene Nitrile		
Carbon disulfide		
4-Methylphenol		
Bis(2-ethylhexyl)phthalate		
Dihydotetrazine		
Bis Sulfonyl Benzene		
Acenaphthene		
Acenaphthylene		
Anthracene		
Benzo(A)anthracene		
Benzo(B)fluoranthene		
Benzo(K)fluoranthene		
		<u>Inorganics</u>
		Aluminum
		Iron
		Antimony
		Lead
		Arsenic
		Magnesium
		Beryllium
		Manganese
		Barium
		Mercury
		Cadmium
		Nickel
		Calcium
		Potassium
		Chromium
		Selenium
		Cobalt
		Sodium
		Copper
		Thallium
		Vanadium
		Zinc



**Table 3**  
**Compounds Detected in Sediment at the Central Area of the Wells G & H Site**

CHEMICAL	SITE		UPSTREAM			DOWNSTREAM			
	FREQ. OF DETECTION	GEOMETRIC MEAN	MAXIMUM	FREQ. OF DETECTION	GEOMETRIC MEAN	MAXIMUM	FREQ. OF DETECTION	GEOMETRIC MEAN	MAXIMUM
COMPOUNDS DETECTED IN SEDIMENT AT THE CENTRAL AREA OF THE WELLS G & H SITE									
ORGANICS (ug/L)									
VOLATILES									
ACETONE	5/5	164	390	1/1	NA	39.9	3/4	34.5	395
2-BUTANONE	5/5	22.9	72.9	1/1	NA	12.2	1/4	NA	64.7
BENZENE	1/5	NA	4.50	ND			ND		
TOLUENE	4/5	2.22	3.30	ND			ND		
1,1-DICHLOROETHANE	1/5	NA	3.80	ND			ND		
1,1,1-TRICHLOROETHANE	1/5	NA	2.80	ND			ND		
TRICHLOROETHENE	2/5	2.03	2.50	ND			ND		
1,2-DICHLOROETHENE	2/5	2.53	4.50	ND			1/4	NA	8.50
VINYL CHLORIDE	1/5	NA	5.00	ND			ND		
METHYLENE CHLORIDE	5/5	105	153	1/1	NA	27.6	4/4	8.15	315
BASE/NEUTRAL EXTRACTABLES									
ACENAPHTHENE	2/5	160	255	ND			2/4	78.0	194
ACENAPHTHYLENE	ND			ND			2/4	72.6	511
ANTHRACENE	3/5	195	606	1/1	NA	49.0	1/4	NA	949
BENZO(A)ANTHRACENE	3/5	439	2070	1/1	NA	314	4/4	36.3	4180
BENZO(A)PYRENE	3/5	426	1650	1/1	NA	283	2/4	149	3670
BENZO(B)FLUORANTHENE	3/5	511	1950	1/1	NA	314	1/4	NA	4210
BENZO(G,H,I)PERYLENE	3/5	271	568	1/1	NA	202	2/4	155	655
BENZO(K)FLUORANTHENE	3/5	410	1340	1/1	NA	298	3/4	87.2	4860
BIS(2-ETHYLHEXYL)PHthalATE	4/5	532	1340	1/1	NA	11.6	1/4	NA	1630
BUTYL BENZYL PHthalATE	ND			ND			1/4	NA	20.0
CHRYSENE	3/5	515	2100	1/1	NA	407	3/4	59.1	4610
DIBENZOFURAN	1/5	NA	115	ND			2/4	67.2	157
DIBENZO(A,H)ANTHRACENE	3/5	174	363	1/1	NA	89.6	1/4	NA	426
DI-N-BUTYL PHthalATE	ND			ND			2/4	NR	8.00
DI-N-OCTYL PHthalATE	ND			ND			1/4	NA	6.00
FLUORANTHENE	4/5	767	3990	1/1	NA	519	2/4	199	8150
FLUORENE	1/5	NA	247	ND			1/4	NA	514
INDENO(1,2,3-C,D)PYRENE	3/5	288	649	1/1	NA	163	2/4	159	913
2-METHYL NAPHthalENE	ND			ND			1/4	NA	1.00
4-METHYLPHENOL	1/5	NA	168	ND			ND		
NAPHthalENE	1/5	NA	89.1	ND			2/4	75.1	292
N-NITROSO-DIPHENYLAMINE	ND			ND			1/4	NA	747
PHENANTHRENE	3/5	487	2400	1/1	NA	160	3/4	74.4	3380
PYRENE	4/5	687	3740	1/1	NA	465	1/4	NA	7230
CARCINOGENIC PANS, TOTAL	3/5	5440	10700	1/1	NA	1920	4/4	145	23800
NONCARCINOGENIC PANS, TOTAL	4/5	2760	11300	1/1	NA	1350	3/4	247	20900
PESTICIDES/PCB'S									
ALDRIN	4/5	16.5	84.4	1/1	NA	12.1	ND		
2,4'-DDD	ND			ND			1/4	NA	26.9
INORGANICS (mg/Kg)									
ALUMINUM	5/5	8160	48800	1/1	NA	3060	4/4	13700	18400
ARSENIC	5/5	100	3630	1/1	NA	24.0	4/4	121	325
BARIUM	5/5	37.8	63.0	1/1	NA	11.0	4/4	53.3	69.0
BERYLLIUM									
CADMIUM	4/5	2.52	15.0	ND			1/4	NA	8.30
CALCIUM	5/5	2320	7980	1/1	NA	647	4/4	4700	6840
CHROMIUM	5/5	86.6	1250	1/1	NA	12.0	4/4	701	1560
COBALT	ND			ND			3/4	8.84	17.0
COPPER	5/5	125	3010	1/1	NA	25.0	4/4	433	641
IRON	5/5	23800	89400	1/1	NA	10200	4/4	27600	41100
LEAD	ND			1/1	NA	75.0	3/3	251	319
MAGNESIUM	5/5	1810	3310	1/1	NA	1230	4/4	3610	4270
MANGANESE	5/5	260	589	1/1	NA	73.0	4/4	289	397
MERCURY	4/5	0.45	27.0	ND			3/4	1.20	17.0
NICKEL	3/5	9.61	38.0	ND			4/4	18.5	29.0
POTASSIUM	3/5	462	1030	ND			4/4	755	918
SELENIUM	1/5	NA	22.0	ND			ND		
SODIUM	5/5	277	897	1/1	NA	145	4/4	416	618
VANADIUM	3/5	29.6	2500	1/1	NA	8.80	3/4	25.0	70.0
ZINC	5/5	584	5170	1/1	NA	76.0	4/4	976	1520

NA = Not applicable; mean not calculated with only one positive detection.

ND = Not detected.

NR = Not reported; chemical was detected infrequently, and the use of one-half the detection limit in calculating a mean results in a mean concentration which exceeds the maximum detected value. Therefore a mean is not used.

NOTE# DUE TO THE OCCASIONAL REJECTION OF SAMPLES DURING THE QA/QC PROCESS THE NUMBER OF SAMPLES USED TO CALCULATE A GEOMETRIC MEAN WILL SOMETIMES BE LESS THAN THE TOTAL NUMBER OF SAMPLES AS PRESENTED IN THE DENOMINATOR OF THE FREQUENCY OF DETECTION.

For inorganics, the maximum concentrations found in the Central Area for arsenic, mercury, chromium and sodium are 3630 ppm, 27 ppm, 1250 ppm, and 897 ppm, respectively.

The surface water sampling history is sporadic. The history of sampling is presented in Appendix 16. Surface water samples from the Aberjona were screened for volatile organic compounds (VOCs) in August of 1984 at two locations. From 1985 to 1987, one station upstream (at Route 128) was sampled and analyzed on four separate dates. Within the site area five stations (from Route 128 to Salem Street Bridge) were sampled and analyzed on four separate dates. Downstream (below the Salem Street Bridge) three stations were sampled and analyzed on one date. The VOCs were the only compounds analyzed on all of the sampling dates. Semi-volatile organic compounds were analyzed on only one sampling date. Inorganics were analyzed on two of the four sampling dates. Table 4 summarizes the results from the surface water analyses.

In general, volatile and semi-volatile compounds were detected in the central area surface waters at higher concentrations (maximum = 100 ppb) than in the upstream stations (maximum = 38 ppb). Furthermore, most of these chemicals do not appear to carry through to the downstream station (maximum = 2 ppb). The emphasis of the EBASCO/NUS sampling protocol was on areal variation of surface water chemistry and not on temporal variations. This is a gross oversight given that concentrations of compounds are strongly influenced by dilutions of flows in the river and source variation. It is not surprising that the April and May 1985, and possibly the June 1985, data show few detectable compounds, as this is typically a period of high runoff relative to base flow conditions.

A more specific determination cannot be made on potential pollution because the 1985 samples are not specifically dated and the report does not identify Aberjona flow rates on the sampling dates. Unfortunately, for the 1987 sampling, flows were not presented in the report and do not appear to be available from the U.S.G.S. surface water record. However, the samples dated September 24, 1987 were taken three days after a three day rainfall totaling 3.09" of rain (Reading Meteorological Station). It is highly likely that the river, on the day of sampling, was experiencing above average flow rate and thus dilution was probably a significant factor for contaminants not emanating from roadway runoff.

COMPOUNDS DETECTED IN SURFACE WATER AT THE CENTRAL AREA OF THE WELLS G & H SITE

COMPOUND	SITE			UPSTREAM			DOWNSTREAM		
	FREQ. OF DETECTION	GEOMETRIC MEAN	MAXIMUM	FREQ. OF DETECTION	GEOMETRIC MEAN	MAXIMUM	FREQ. OF DETECTION	GEOMETRIC MEAN	MAXIMUM
ORGANICS (ug/L)									
VOLATILES									
CHLOROFORM	ND			ND			1/3	NA	2.00
1,1-DICHLOROETHANE	2/24	NR	2.00	1/4	NA	2.00	ND		
TRANS-1,2-DICHLOROETHENE	2/24	4.18	22.0	ND			ND		
1,1,1-TRICHLOROETHANE	13/22	3.48	8.00	3/4	4.30	10.0	ND		
TRICHLOROETHENE	5/24	2.71	26.0	1/3	NA	1.00	1/3	NA	0.50
TETRACHLOROETHENE	2/24	2.59	4.00	ND			ND		
TOLUENE	2/24	NR	1.00	ND			ND		
SEMI-VOLATILES									
BIS(2-ETHYLHEXYL)PHTHALATE	1/1	NA	100	1/1	NA	38.0	ND		
DI-N-OCTYL PHTHALATE	1/5	NA	5.00	ND			ND		
DI-N-BUTYL PHTHALATE	ND			ND			1/2	NA	1.00
BUTYLBENZYL PHTHALATE	2/5	5.90	29.0	1/1	NA	11.0	ND		
INORGANICS (ug/L)									
ALUMINUM	3/6	75.9	548	1/2	NA	25.0	2/3	247	396
ANTIMONY	ND			ND			1/3	NA	57.0
ARSENIC	4/6	5.45	8.80	1/2	NA	8.90	1/3	NA	6.10
BARIUM	5/6	26.0	46.0	2/2	25.5	27.0	3/3	18.1	27.0
BERYLLIUM	ND			1/1	NA	0.70	ND		
CADMIUM	ND			1/2	NA	6.00	ND		
CALCIUM	6/6	31600	43000	2/2	32900	39000	3/3	13300	28000
CHROMIUM	ND			1/2	NA	4.30	ND		
COPPER	2/5	NR	12.0	1/1	NA	10.0	3/3	12.7	17.0
IRON	6/6	1310	5200	2/2	712	1490	3/3	990	1050
LEAD	5/6	3.56	11.0	1/2	NA	2.20	3/3	7.83	20.0
MAGNESIUM	6/6	5090	8100	2/2	6140	7400	3/3	3980	4970
MANGANESE	6/6	377	460	2/2	408	480	3/3	129	230
POTASSIUM	6/6	4010	5700	2/2	4010	4700	3/3	2100	3460
SILVER	ND			1/2	NA	5.90	ND		
SODIUM	6/6	35700	70000	2/2	44000	59000	3/3	23700	33500
ZINC	6/6	141	190	2/2	183	196	3/3	99.2	192

NA = Not applicable; mean not calculated with only one positive detection.

ND = Not detected.

NR = Not reported; chemical was detected infrequently, and the use of one-half the detection limit in calculating a mean results in a mean concentration which exceeds the maximum detected value. Therefore a mean is not used.

NOTE# DUE TO THE OCCASIONAL REJECTION OF SAMPLES DURING THE QA/QC PROCESS THE NUMBER OF SAMPLES USED TO CALCULATE THE GEOMETRIC MEAN WILL SOMETIMES BE LESS THAN THE TOTAL NUMBER OF SAMPLES AS PRESENTED IN THE DENOMINATOR OF THE FREQUENCY OF DETECTION.

Table 4  
Compounds Detected in Surface Water at the Central Area of the Wells G & H Site

Sampling by The Johnson Company on February 20 and 21, 1989 (Appendix 18) served to confirm the relationship between flow and concentration for such contaminants. The February 20 sampling was done when there had been no antecedent precipitation for several days. The sampling done on February 21 was done during a heavy precipitation event. The river stage was a minimum of two feet higher on February 21 than it was on February 20 at the Route 128 culvert. In general, concentrations are noticeably lower in the February 21 sample data than in the February 20 sample data.

Sampling for river water parameters such as nitrogen species, BOD, and coliform were never performed by EBASCO. This is a glaring omission given that the river has a long history of water quality problems for these parameters (Defo, 1972 & Geotrans, 1987). Coliform found in the Aberjona at Montvale Avenue Bridge, just south of the site was reported as high as 46,000 cfu/100 ml, of which 15,000 cfu/100 ml was fecal, (Defo, 1970). Data from Defo (1970) can be found in Appendix 19 and data from the U.S.G.S. Winchester Station for water quality can be found in Appendix 20.

Samples of Aberjona River water were collected by The Johnson Company, Inc. personnel on February 20 and 21, 1989. The samples underwent analysis by EPA Methods 502 and 503, as well as for total organic halogens, chemical oxygen demand, primary and secondary drinking water standard parameters and bacteria. Field data were collected for temperature, pH, specific conductance and oxidation reduction potential. All these data are presented in Appendix 18.

The purpose of this sampling effort was to begin to determine the relationship of storm water runoff events to the contaminant hydrochemistry of the river. The weather had been dry for approximately four days up to and including February 20. At some time during the night/morning of February 20/21, rain began to fall and continued throughout February 21. Although the amount of precipitation that had fallen by the time of sampling (11:21 - 12:00 a.m.) is not known, it was observed that the river was approximately 2 feet higher than it had been during sample collection the preceding day (7:41 - 8:10 p.m.).

A sample was collected from each of two locations on both days. The first location was 10 feet downstream of the Route 128 bridge, approximately 5 feet from the east bank of the river. The second location was immediately upstream of the Salem Street bridge, approximately 3 feet from the east bank.

The river exhibited greater turbidity and total dissolved solids during the runoff event sampling than on February 20. Fluoride, chloride, nitrates, sulfates and alkalinity were all higher during the runoff event. Calcium, manganese and zinc

PAH SAMPLING RESULTS  
ABERJONA RIVER-3/05/89

PARAMETER	SAMPLE LOCATION	RESULT (FILTERED), ng/l	RESULT (UNFILTERED), ng/l
BENZ(D,A)ANTHRACENE	RT. 128 DRAINAGE SWALE	65	730
	RT. 128 BRIDGE	7.5	72
	SALEM ST. BRIDGE	6.6	28
CHRYSENE	RT. 128 DRAINAGE SWALE	190	750
	RT. 128 BRIDGE	10	78
	SALEM ST. BRIDGE	8.7	32
BENZOFLUORANTHENE(S) (BFW)	RT. 128 DRAINAGE SWALE	130	1500
	RT. 128 BRIDGE	11	160
	SALEM ST. BRIDGE	15	58
BENZ(D,A)PYRENE	RT. 128 DRAINAGE SWALE	30	600
	RT. 128 BRIDGE	12.9	59
	SALEM ST. BRIDGE	2.7	23
INDENO(1,2,3-CD)PYRENE	RT. 128 DRAINAGE SWALE	53	550
	RT. 128 BRIDGE	2.2	60
	SALEM ST. BRIDGE	3.3	24
DIBENZ(A,H)ANTHRACENE	RT. 128 DRAINAGE SWALE	19	580
	RT. 128 BRIDGE	1.4	47
	SALEM ST. BRIDGE	1.8	22
BENZ(D,G,H,I)PERYLENE	RT. 128 DRAINAGE SWALE	73	690
	RT. 128 BRIDGE	3.7	59
	SALEM ST. BRIDGE	4.1	25
NAPHTHALENE	RT. 128 DRAINAGE SWALE	9.9	160
	RT. 128 BRIDGE	5.0	15
	SALEM ST. BRIDGE	7.9	11
2-METHYLNAPHTHALENE	RT. 128 DRAINAGE SWALE	86	540
	RT. 128 BRIDGE	3.1	13
	SALEM ST. BRIDGE	2.6	14
1-METHYLNAPHTHALENE	RT. 128 DRAINAGE SWALE	32	350
	RT. 128 BRIDGE	3.0	13
	SALEM ST. BRIDGE	BOL	11
BIPHENYL	RT. 128 DRAINAGE SWALE	BOL	83
	RT. 128 BRIDGE	BOL	BOL
	SALEM ST. BRIDGE	BOL	BOL
ACENAPHTHYLENE	RT. 128 DRAINAGE SWALE	BOL	48
	RT. 128 BRIDGE	BOL	BOL
	SALEM ST. BRIDGE	BOL	BOL
ACENAPHTHENE	RT. 128 DRAINAGE SWALE	2.9	190
	RT. 128 BRIDGE	BOL	21
	SALEM ST. BRIDGE	BOL	18
DIBENZOFURAN	RT. 128 DRAINAGE SWALE	BOL	100
	RT. 128 BRIDGE	BOL	11
	SALEM ST. BRIDGE	2.2	8
FLUORENE	RT. 128 DRAINAGE SWALE	1.5	210
	RT. 128 BRIDGE	1.8	36
	SALEM ST. BRIDGE	1.5	13
TOTAL PHENANTHRENE/ANTHRACENE	RT. 128 DRAINAGE SWALE	30	1700
	RT. 128 BRIDGE	7.3	170
	SALEM ST. BRIDGE	7.1	63
FLUORANTHENE	RT. 128 DRAINAGE SWALE	120	2200
	RT. 128 BRIDGE	11	230
	SALEM ST. BRIDGE	11	110
PYRENE	RT. 128 DRAINAGE SWALE	120	1700
	RT. 128 BRIDGE	7.7	190
	SALEM ST. BRIDGE	8.1	81
BENZ(D,E)PYRENE	RT. 128 DRAINAGE SWALE	33	620
	RT. 128 BRIDGE	14.0	58
	SALEM ST. BRIDGE	14.0	22
PERYLENE	RT. 128 DRAINAGE SWALE	22	400
	RT. 128 BRIDGE	2.3	27
	SALEM ST. BRIDGE	3.4	14

BOL=BELOW DETECTABLE LIMITS

concentrations were all slightly lower during runoff. More coliform were observed in the February 20 sample than in the February 21 sample. Concentrations of volatile organic compounds as indicated by the Method 502, 503 and total organic halogen analyses were reduced during runoff.

In spite of the presence of an extensive sheen on the river and what was described by field and laboratory personnel as a "petroleum odor," very little benzene, toluene, ethylbenzene and xylene were detected. This led to the conclusion that the sheen must be associated with semi-volatile hydrocarbons, such as polynuclear aromatic hydrocarbons. To test this hypothesis, a second storm water runoff event sampling occurred on March 5, 1989.

The Route 128 bridge and Salem Street Bridge locations were sampled again. In addition, a water sample was collected from a storm water drainage swale emanating from Route 128. Duplicate samples were collected at each site. One sample of each set was filtered prior to analysis, while the duplicate was not. The purpose of this was to investigate the PAH distribution between solution and suspended particle phases. A .045 micron filter was used to remove the particulate matter.

The drainage swale consistently displayed higher concentrations of PAHs than did the river, indicating the importance of highways as a source of PAH contamination. (See Table 5) In all samples, the unfiltered portion yielded far greater concentrations than the filtered samples. Significant concentrations of dissolved phase PAHs did occur, however.

The unfiltered Route 128 samples showed higher concentrations of individual PAHs than did the unfiltered Salem Street samples for 17 parameters. Only 1 parameter out of 19 showed lower concentrations at Route 128. On the other hand, the filtered fraction from the Route 128 sample exhibited higher concentrations only 5 times and lower concentrations 10 times.

The decreased concentrations in the unfiltered samples between Route 128 and Salem Street suggests that deposition of the particulate borne PAHs is occurring. This is expected due to the low gradient of the river along this reach. Deposition rather than destruction is the most likely explanation for the decline since no declining relationship is observed for the dissolved PAH, which are more susceptible to degradation mechanisms. It is possible that some of the particle-borne PAHs entered into solution since the dissolved phase appears to increase with distance downstream. A high organic carbon content or the presence of other compounds (in which PAHs are soluble) could account for this.

Both the deposition of PAHs on particulate matter and the increase in PAHs in solution point to a risk to Wells G & H by this group of compounds. Levels were detected as high as 2,200

ug/l in the swale and 290 ug/l in the river for individual compounds. The total PAH load in the river reached 1,379 ug/l at the Route 128 location. The swale exhibited 13,681 ug/l. As explained below, these levels are, in all likelihood, not the highest levels which could be expected to occur.

First, under base flow conditions where the bulk of the river water is coming from groundwater, it would be expected that the contaminants would reflect a groundwater source for both chemical constituents and concentrations. It is possible that concentrations become greater during low base flow periods. This concept was alluded to by Defoe (1970), who concluded that water quality was a problem on the Aberjona and that flow augmentation of the river should be implemented to prevent stagnation of the river during summer months.

Second, during runoff events, flow in the river will increase thus diluting chemical constituents introduced from groundwater. However, runoff provides an additional source of chemical constituents that have accumulated on the ground surface between runoff events. Most notable in this category are PAHs derived from road sources. The sampling of the Aberjona by the Johnson Company on March 5, 1989 occurred during a small precipitation event. During this event, there was no seepage on the river or wetland or in the 128 drainage swale, as had been observed following the heavy rain on February 20/21. Thus, quite possibly the PAH concentrations in the River on February 21 were as high or higher than those found in the 128 drainage swale on March 5. (See Appendix 21) Lastly, even with the river water quality data collected by EBASCO and supplemental data collected by The Johnson Company, the variability of the compounds and their concentrations in the river has been demonstrated to be significant. It is probable that because there has been so little data collected on river chemistry that not all of the possible chemical constituents in the Aberjona have been identified.

The NUS/EBASCO surface water sampling program reflected little understanding of the role of the watershed in the chemistry of the Aberjona surface water and its relationship to Wells G & H. At the end of the U.S.G.S. Pump Test 565.5 gpm (51%) of the flow from the Wells G & H was derived from the Aberjona River (see Section IV. B, this report). It is incomprehensible the Aberjona's surface water and sediment chemistry was treated cursorily and not identified as a potential source of contaminant's to Wells G & H. From the existing surface water and sediment contaminant data, there is no reasonable way that EBASCO could have completely evaluated the realm of possible contaminants that are available to the aquifer and consequently to Well G & H. Thus, the remedial plan recommended by EBASCO under-estimates the magnitude and nature of a comprehensive pump and treat aquifer remedial program for Wells G & H.

#### 4. Groundwater Conditions in the Central Area

Appendix C of the FS states that the "Central Area would be cleaned up in 10 years" by the proposed plan. This time estimate is based on the assumption that it is appropriate to use 0.5% as an estimate for the percent solid-phase organic carbon. Appendix C states that "literature information suggests subsurface organic carbon contents (foc) are variable but may range from less than 0.1% to more than 0.5% depending on the soil. (Tedrow, 1986 and Karichkhoff 1979). The literature cited here is out-of-date and inappropriate. The essential issue pertains to foc values relevant to the aquifer rather than those to "soil" in the general sense. Specifically, the aquifer that yields water to Wells G & H in the Central Area is composed of sand and gravel. Very few values of foc for sand or gravel aquifers exist in the literature. Those that do exist are nearly without exception in the range of 0.05 - 0.005%. The upper end of this range is one tenth as large as the value used to obtain the 10 year cleanup estimate. When the foc range indicated above is used in calculating the cleanup time for the Central Area (following the calculation procedure used by EBASCO), the cleanup time is less than 2 years.

We believe that well-informed groundwater scientists would agree that the EBASCO foc values for the general aquifer in Central Area are much too large. One need not debate this issue, however, because the question can be easily settled by the drilling of one or two cored holes through the alluvial aquifer near Wells G & H. A group of sub-samples from the aquifer cores would be sent to a laboratory for foc analyses (at a cost of less than \$50 per sample). To have proposed a major pump and treat facility for cleanup of the Central Area aquifer without having done such core analyses is inexcusable.

The implications of the gross over-estimate of foc values by EBASCO go beyond their estimated pump-and-treat cleanup times, however. The reduction of the contaminant plume in fact will occur in two stages. The first stage will be characterized by a sharp, rapid reduction in concentration whether under pumping or non-pumping conditions. The concentrations obtained by the end of this stage and the actual time required to reach the end of this stage are unknown. The second stage will involve a very slow decline in the remaining concentrations over a much longer period of time than that required to reach the end of the first stage.

The long, slow decline during the second stage of aquifer flushing is due primarily to heterogenities in the aquifer. Lenses of material with greater surface area and higher carbon contents tend to serve as contaminant sinks which may contribute small concentrations to the aquifer for long periods of time. This phenomenon will occur under both pumping and non-pumping conditions.



In any event, the plume will not disappear if Wells G & H are pumped, because such pumping will draw non-VOC contaminants from the river into the aquifer. Also, it will draw deeper into the aquifer any volatile contaminants that may exist in the very shallow part of the groundwater system in the Central Area.

In this regard, the hydraulic connection between the Aberjona River and Well G & H when pumping holds still other implications for the proposed remedy. The Supplemental RI indicates that coliform bacteria have been found in Wells G & H (see Table 4E-3). A reasonable interpretation of this finding is that there exists a relatively direct or channelized hydraulic pathway between the river and the wells. Coarse-grained alluvial deposits under the influence of a large hydraulic gradient could provide this pathway. This conceptualization of hydraulic connection of Wells G & H with the river is supported by the findings of the U.S. Geological Survey based on a long-term pumping test on Wells G & H conducted in 1987 (Myette *et. al.*, 1987). According to the U.S.G.S., this test indicated that about 50% of the water from Wells G & H, when pumped for 30 days at rates of 700 and 400 gpm, respectively, was water pulled through the aquifer from the river.

We have assessed the data from the U.S.G.S. pumping test in conjunction with the available knowledge of the geology of the deposits in the vicinity of Wells G & H and the Aberjona River. We conclude that, when Wells G & H are pumped cumulatively at 54.00 gpm, it is likely that some of the water passes from the river into Wells G & H within a few days or less. The shortest travel path from the river to the well screen (Well H) is 143 feet.

Not only is it likely that coliform bacteria travel from the river to the wells, but other colloidal-sized particles may also move from the river or river-bed sediments to Wells G & H. For example, colloidal-sized mineral particles, organic particles or viruses could also reach the wells. Colloidal particles represent a threat to Wells G & H because they could carry (adsorbed on the surface of the particles) toxic metals or organic contaminants. Organic contaminants of particular concern are polynuclear aromatic hydrocarbons (PAHs), because these chemicals are derived primarily from exhaust of automobiles and trucks and from abrasion of rubber on roads and are common in urban rivers and river sediments.

Metals tend to sorb on colloidal particles composed of iron hydroxide. Colloidal particles of iron hydroxide have been found to be carried by groundwater in sand aquifers, as demonstrated by Ryan (1988) in a study of a sand aquifer in New Jersey and Delaware. This colloid movement in the aquifer occurs under hydraulic gradients much smaller than those occurring in the aquifer between the Aberjona River and Wells G & H when these wells are pumped at rates of hundreds of gallons per minute.

#### IV. PUMPING OF WELLS G & H

##### A. Aquifer Characteristics

The alluvial aquifer in the vicinity of Wells G & H (the Central Area) is composed primarily of fine to medium sand and sand and gravel. Both wells are completed in relatively coarse-grained sand and gravel. The aquifer is most transmissive in the central Aberjona River valley extending approximately 1-3/4 miles north of Wells G & H and south to the Mystic Lakes. The width of the most transmissive portion of the aquifer (>4000 ft/day) is approximately 1,700 feet in the Central Area, with Wells G & H being located in the eastern third of this zone (Delaney and Gay, 1980). A discontinuous layer of peat overlies the aquifer materials in the Aberjona River stream bed and the wetland existing on either side of the river channel. The width of this peat layer, based on seismic profiles, is approximately 675 ft. near Wells G & H, with the wells being located along the eastern extent of the peat layer. Thicknesses generally range from 2-7 feet, with a maximum thickness of approximately 26 feet near Well S-89, which is located near the river about 100 feet west of Well H (Myette, et. al. 1987). The U.S.G.S. report for Wells G & H indicates that the peat is a relatively loose, nearly saturated material which permits induced infiltration of stream water under pumping conditions (Myette, et. al., 1987).

Groundwater recharge to the sand and gravel aquifer is from upgradient portions of the watershed to the west, north and east. Groundwater in the fractured bedrock also flows vertically upward into the alluvial aquifer. The watershed upgradient of the site of Wells G & H is highly urbanized and industrialized. Urban runoff is likely a significant source of recharge water to the aquifer into which Wells G & H are installed. Historical water quality data indicate similar water quality of the Aberjona River and water from Wells G & H. Elevated levels of chloride, sulfate and nitrogen compounds in the Aberjona River are the result of runoff in its headwaters. These compounds have been consistently high in water samples from Wells G & H (GeoTrans, 1987).

##### B. Review of Existing Pumping Test Data

Pumping tests have been performed on various wells which are screened in the sand and gravel aquifer in this area. The most extensive testing was performed on Wells G & H by the U.S.G.S. from December 4, 1985 - January 3, 1986. Another test performed in this area involved the pumping of Riley Well #2, which is located approximately 1,160 ft. southwest from, and on the opposite side of the Aberjona River of, Well G.

A primary concern addressed in both of these studies is the hydraulic connection between the Aberjona River and the sand and gravel aquifer. Because of the well-documented groundwater

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 CALCULATED BY \_\_\_\_\_ DATE \_\_\_\_\_  
 CHECKED BY \_\_\_\_\_ DATE \_\_\_\_\_  
 SCALE \_\_\_\_\_

Table 6  
 (from Myette, *et al*, 1987)

Table 1.--Summary of miscellaneous discharge measurements in the vicinity of wells G and H and comparison of flow duration in nearby rivers

[All streamflow is given in cubic feet per second; a dash indicates no measurement.]

Date	Inflow				Outflow	Net gain (+) or loss (-)	Percentage of flow duration.	
	Aberjona River Olympia Avenue 01102458	Aberjona River tribu- tary 1 011024592	Aberjona River tribu- tary 2 011024594	Aberjona River tribu- tary 3 011024596	Aberjona River Salem Street 01102460		Aberjona River at Winchester 01102500	Parker River at Byfield 01101000
<b>1985</b>								
8-29	3.02	--	--	--	3.16	+0.14	64	94
9- 5	4.51	--	--	--	4.61	+ .10	56	64
9-13	6.62	--	--	0.03	6.97	+ .32	44	43
9-20	3.82	--	--	--	3.68	- .14	62	64
9-26	5.38	--	--	--	5.80	+ .42	32	70
10- 3	5.82	--	--	--	8.03	+2.21	60	67
10-10	6.22	--	--	--	6.32	+ .10	48	36
10-16	6.52	--	--	--	7.14	+ .62	50	54
10-29	2.96	--	--	--	3.06	+ .10	68	70
11-13	21.6	--	--	--	26.7	+5.1	12	18
11-25	9.68	--	--	--	11.5	+1.82	26	20
12- 4	11.6	0.004	0.34	.06	13.7	+1.70	21	19
12- 4	--	--	.33	.06	11.8	-	21	19
12- 4	--	--	.30	.07	12.2	-	21	19
12- 4	--	--	.31	.06	12.3	-	21	19
12- 4	--	--	--	--	12.2	-	21	19
12- 4	10.9	.004	.33	.06	12.5	+1.21	21	19
12- 5	10.4	.001	.29	.03	10.4	-.32	25	20
12- 6	10.1	--	.31	.05	9.69	-.77	26	21
12- 9	9.53	0	.26	.05	9.08	-.76	31	27
12-13	12.2	.004	.25	.03	12.2	-.28	23	30
12-16	10.2	.007	.28	.05	10.5	-.04	24	28
12-18	8.87	0	.25	0	8.27	-.85	32	30
12-23	6.67	0	.17	0	5.78	-1.06	42	49
12-30	5.27	0	.08	0	3.90	-1.45	50	58
<b>1986</b>								
1- 3	4.63	0	.08	.02	3.47	-1.26	26	56
1-17	3.80	0	.05	0	3.17	-.68	62	67

contamination in this area (see Appendix 22), it is important to determine the potential impact of the surface water contamination on groundwater quality. Wells representative of the water quality of Wells G & H include S68, S83, S84, S85, S86, S87, S89 (EBASCO, 1988). Both of the pumping test studies present strong evidence of a significant hydraulic connection between the Aberjona River and the sand and gravel aquifer.

The U.S.G.S. pumping test is the most extensive test performed in the alluvial aquifer in the Central Area. During this test, Wells G & H were pumped at 700 gpm and 400 gpm, respectively, for a period of 30 days. Of particular interest is the stream flow study performed from August 29, 1985 - January 17, 1986. This study monitored the flow upgradient of the test area at a gauging station just north of Olympia Avenue and downgradient of the test area at a gauging station just southeast of Salem Street to determine net gain or loss of stream flow through the study area (see Table 6). For the three months preceding the aquifer test the Aberjona River stream flow was gaining between the upgradient and downgradient gauging stations, with the exception of a gauging run on September 20, 1985. During the 30 day pumping test, the flows were measured at the two previously described stations and at three tributaries within the study area to determine the net gain or loss of flow in the Aberjona River. During the 30 day pumping test the Aberjona River had a net loss of flow through the study area. The average loss (weighted average using the data presented) was 0.87 cfs or 391 gpm. This represents 36 percent of the flow which was being pumped from Wells G & H. At the end of the 30 day test, however, the cone of depression extended under both the upgradient and downgradient gauging stations, at which time the net loss of flow from the Aberjona River was 1.26 cfs (565.5 gpm or 51 percent of the flow from Wells G & H), so the actual loss to the wells is probably greater.

Another indication of the hydraulic connection between the river and the aquifer is the reaction of the piezometer pairs installed in the stream bed. These piezometers were hand installed with the shallow (even numbered) piezometers screened in the peat layer and the deep (odd numbered) piezometers screened in the sand 1-2 feet below the peat layer (Morin, 1989). All piezometer pairs showed downward gradients during the pumping test (see data plots, Appendix A-2). However, calculations using Darcy's Law indicate the volume of water being lost from the river far exceeds the volume that would leak through the peat at the low vertical hydraulic gradients observed indicating that the peat layer is not continuous and is bypassed by river water which enters directly into the aquifer materials (see Appendix 23). Additionally, it was observed by U.S.G.S. field personnel that during the first few hours of pumping Wells G & H, at 200 gpm and 400 gpm, respectively, the water level in the wetland adjacent to the Aberjona River dropped approximately three inches and the wetland dried up.

TABLE 7

 TABLE F-25  
 CENTRAL AREA  
 SURFACE SEDIMENT SAMPLE RESULTS  
 RW 2 1

	SD-01 EDASCO 9-29-87	SD-02 EDASCO 9-29-87	SD-03 EDASCO 9-29-87	SD-04 EDASCO 9-29-87	SD-05 EDASCO 9-29-87	SD-06 EDASCO 9-29-87	SD-08 EDASCO 9-29-87	SD-09 EDASCO 12-10-87	SD-10 EDASCO 12-10-87	SD-11 EDASCO 12-11-87	G-S01 EDASCO 12-10-87
ORGANICS (ug/kg)											
VOLATILES											
ACETONE	39.9	113.5	135.7	152.7	128.8	309.6	395.1	88 B	NO	9 BJ	NO
2-BUTANONE	12.2	19.9	11.7	16.9	22.1	72.9	64.7	NO	NO	NO	NO
BENZENE	NO	4.5	NO	NO	NO	NO	NO	NO	NO	NO	NO
TOLUENE	NO	1.0	NO	3.1	2.6	2.7	NO	NO	NO	NO	NO
1,1,1-TRICHLOROETHANE	NO	NO	NO	NO	NO	2.8	NO	NO	NO	NO	NO
1,1-DICHLOROETHANE	NO	3.8	NO	NO	NO	NO	NO	NO	NO	NO	NO
TRICHLOROETHENE	NO	1.1	NO	NO	2.0	NO	NO	NO	NO	NO	NO
1,2-DICHLOROETHENE	NO	NO	NO	NO	4.5	2.6	8.5	NO	NO	NO	NO
VINYL CHLORIDE	NO	NO	NO	NO	1.9	NO	NO	NO	NO	NO	NO
METHYLENE CHLORIDE	27.6	95.7 J	85.5	112.6 J	92.4	152.6	315.0	7	2 B	1	R
1,2-DICHLOROETHANE	NO	NO	NO	NO	NO	NO	NO	NO	NO	R	NO
CHLOROFORM	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	3
SEMI-VOLATILES											
4-METHYLPHENOL	NO	NO	NO	NO	168.1 J	NO	NO	NO	NO	NO	NO
BIS(2-ETHYLHEXYL)PHTHALATE	246.0	910.3	1,337.5	NO	518.5	410.4	1,630.9	NO	NO	NO	NO
ACENAPHTHENE	NO	255.0	91.4	NO	NO	NO	194.3	NO	NO	NO	NO
ACENAPHTHYLENE	NO	NO	NO	NO	NO	NO	510.7	NO	NO	NO	NO
ANTHRACENE	49.0	606.0	189.2	NO	91.3	NO	949.1	NO	NO	NO	NO
BENZO(A)ANTHRACENE	314.4	2,871.2	721.4	NO	399.0	NO	4,182.7	4 J	4 J	4 J	NO
BENZO(B)FLUORANTHENE	314.2	1,953.4	900.7	NO	678.9	NO	4,213.0	NO	NO	NO	3 J
BENZO(K)FLUORANTHENE	297.9	1,338.2	563.2	NO	568.0	NO	4,877.6	9 J	8 J	9 J	NO
BENZO(O,H,I)PERYLENE	201.7	567.6	337.9	NO	200.9	NO	665.1	NO	NO	NO	NO
BENZO(A)PYRENE	282.9	1,649.9	673.0	NO	464.9	NO	3,665.2	5 J	NO	6 J	NO
CHRYSENE	407.2	2097.4	951.3	NO	664.1	NO	4,612.8	4 J	4 J	4 J	2
DIBENZO(A,H)ANTHRACENE	89.6	363.1	123.7	NO	131.1	NO	425.9	NO	NO	NO	NO
FLUORANTHENE	519.2	3986.3	1,640.5	NO	1,099.3	223.1	8,151.3	NO	7 J	NO	NO
FLUORENE	NO	247.2	NO	NO	NO	NO	513.9	NO	NO	NO	NO
INDEN(1,2,3-CD)PYRENE	162.6	649.1	373.1 J	NO	298.6	NO	913.4	NO	NO	NO	NO
INDEN(1,2,3-CD)PYRENE	NO	89.1	NO	NO	NO	NO	292.2	NO	NO	NO	NO
PHENANTHRENE	150.5	2,399.5	912.4	NO	458.1	NO	3,377	NO	6 J	NO	NO
PYRENE	464.6	3,737.5	1,356.9	NO	808.5 J	218.9	7228.7	NO	NO	NO	NO
N-NITROSOETHANAMINE	NO	NO	NO	NO	NO	NO	746.8	NO	NO	NO	NO
DIBENZO(P,Q)ANTHRACENE	NO	114.9 J	NO	NO	NO	NO	187.1	NO	NO	NO	NO

Historical water quality data indicate that coliform bacteria have been found in Wells G & H in December 1967, August 1976, and August 1977 while these wells were being pumped for municipal supply (GeoTrans, 1987, water quality results as presented in Appendix 22). A reasonable interpretation of this finding is that there exists a relatively direct or channelized hydraulic pathway between the river and the wells. Coarse grained alluvial deposits under the influence of a large hydraulic gradient could provide this pathway. This information further indicates the degree of connection between the surface water and the aquifer and the ability for contaminants to travel from the river into the aquifer. The U.S.G.S. report goes on to state that the water quality of Wells G & H is affected by the stream water flowing past these wells (Myette, et. al., 1987).

Calculations performed to determine aquifer parameters from the 30 day pumping test verify that the transmissivity and storativity values calculated by the U.S.G.S. from Step Test data are representative of the aquifer. For the aquifer in the vicinity of Well G the transmissivity ranges from 10,000 ft/day - 29,700 ft/day and the horizontal hydraulic conductivity ranges from 125 - 350 ft/day. The storativity was calculated to be 0.20. At Well H the transmissivity ranges from 10,700 ft/day - 17,600 ft/day and the horizontal hydraulic conductivity ranges from 130 - 215 ft/day. Storativity was calculated to be 0.16 (Myette et. al. 1987).

Using these aquifer parameters and the proposed remediation pumping rate of 540 gpm (divided evenly between the two wells), it is likely that some of the water would travel from the river through the coarse-grained aquifer materials to Well H in approximately 11 days. Travel time from the river to Well G ranges from 70 - 75 days (see Appendix 24). These values would be halved if the entire 540 gpm came from either Well G or Well H pumping alone. Also, these travel times may be over-estimations due to the presence of channelized hydraulic pathways from the river to the wells, which would result in shorter travel times from the river to the wells.

The pumping test performed at the Riley site occurred from July 26 - 27, 1984, for a total elapsed time of 1,340 minutes. During this time the production well was pumped at 800 gpm. Due to a non-symmetrical cone of depression and high calculated transmissivities at observation wells located toward the Aberjona River from the production well (notably Well W2), it was concluded that the Aberjona River and the adjacent swamp recharged the aquifer under pumping conditions (Woodward - Clyde, 1984).

#### C. Contaminant Transport Mechanisms Between the Aberjona River and Central Area Groundwater

The Aberjona River collects an extensive and diverse contaminant load from throughout the watershed and carries those

contaminants past wells G and H. When Wells G and H are pumping, induced infiltration from the River will carry those contaminants from the river into the aquifer and toward the pumping well(s).

Consequently, pumping wells in the Central Area in an effort to remove existing halogenated aliphatic contamination would only serve to exchange that contamination for the contaminant load of the Aberjona River. The concentrations of halogenated aliphatics in the aquifer when compared with the concentrations of contaminants in the river may initially make such an exchange appear desirable. This, however, is not the case for several reasons.

First, the river contains significant concentrations of compounds, such as polynuclear aromatic hydrocarbons (PAH), which are believed to be carcinogenic at much lower concentrations than the halogenated aliphatics. Indeed, a BaP concentration that could be sufficient to produce 1 excess cancer in 100,000 people would not even be detected by standard analytical techniques such as EPA Methods 625, 502, 503 or 610. These compounds exist in both the river water and sediment in unusually high concentrations (see Table 5 and 7).

Second, the contaminant load of the river is highly unpredictable. While base levels of certain compounds are expected to persist in the river, other compounds may fluctuate greatly in concentrations and in many cases may only be present periodically. The presence of Butyl Cellusolve<sup>R</sup> at 3.0 ppb in samples collected on March 5, 1989 is an example of this. Cellusolve is a mildly toxic compound used in the paint and furniture industries. This compound has not been reported at the Wells G & H Site previously and was identified by happenstance when using a method customized for ppt PAH detection. Consequently, it is expected that only a fraction of the amount naturally present was extracted, and that other, related compounds may have been present but were masked by the solvent used for the extraction. The potential for a wide variety of contaminants to occur undetected in the river at irregular intervals and at varying concentrations not only makes treatment of the pumpage problematical, it puts the aquifer at significant risk.

Whereas the aquifer in the Central Area will be naturally cleansed of the bulk of the existing contaminant load in a relatively short period of time without pumping, the act of pumping induces the flow of a continuous contaminant source into the aquifer. This would result in perpetual treatment at great expense with no guarantee that the pumpage is adequately treated due to the inconsistent nature of the contaminant load in the river and the difficulties of reliably detecting and measuring it. Use of these wells as a potable water supply is equally inadvisable. Regardless of the level of cleanup of contamination attributed to activities at the G&H Site, the

water supply would be at risk from contamination from throughout the watershed, including such permanent sources as Route 128 and other roadways.

While the contaminant load of the river is highly variable, certain compounds are expected to be of perennial concern. These include but, are not limited to, sodium, PAHs, lead, viruses and bacteria.

### 1. Pathogenic Microorganisms

Groundwater contaminated by pathogenic microorganisms (bacteria and viruses) is widespread and well documented. More than 50% of the documented waterborne illness in the United States is attributable to consumption of contaminated groundwater (Yates et. al., 1984). Principal sources of bacteria and viruses include sewage and landfills (containing disposable diapers). Fecal coliform is frequently used as an indicator of sewage contamination. Fecal coliform has been detected at high levels in the Aberjona River, strongly suggesting sewage contamination. The GeoTrans Report documents the occurrence of sewer system overflows in Woburn. Tables 8 and 9 list analytical results on total coliform in Wells G and H and in the Aberjona River respectively. Total coliform counts are often quite high in the river.

In excess of 110 different types of virus occur in raw sewage, including poliovirus, hepatitis virus, rota virus, norwalk viruses, giardia and other (Gerba, 1983).

Viruses can be highly mobile in the terrestrial environment. Viruses were detected at a distance of over 400 meters downgradient from a landfill in New York (Yates and Yates, 1988). Schmidt (1985) reports the detection of viruses over 1,600 meters from it's point of origin. Filtration of viruses in coarse sediments (sands) is believed to be negligible as a removal mechanism (Yates and Yates, 1988), whereas it may be a significant mechanism for large bacteria. Sobsey (1986) reports that Hepatitis A Virus is able to survive for long periods of time and to migrate long distances in groundwater. Viruses generally exhibit a longer survival time in groundwater than bacteria (Yates, et. al. 1985). These facts suggest that, if coliform bacteria are able to migrate to the wells, viruses will in all likelihood do so as well.

Difficulty in the detection of many viruses coupled with the fact that viruses are more resistant to disinfection than so-called indicator bacteria casts doubt on the ability to adequately treat and monitor this significant threat to water quality. The Aberjona River is a ready source of bacteria and, most likely, of viruses also. These microorganisms can and do readily migrate through the aquifer, as the presence of coliform in wells G and H attests.



Table 8  
Coliform in Wells G and H  
Results in CFU/100 ml

Date	Well G	Well H
12/06/67	6	38
08/04/76	3	NA
08/01/77	5	NA
12/07/67	NA	1,200

From "Review of EPA Report Titled 'Wells G & H Site  
Remedial Investigation Report, Part 1,  
Woburn, Massachusetts'"  
Geotrans, Inc. 1987

Table 9

Total Coliform in Aberjona River Results in Organisms/100 ml		
Date	River Station Number	Count
07/28/71	2	4,600
	4	< 36
	6	11,00
07/20/71	2	2,300
	6	900
07/15/71	2	4,300
	6	15,000
07/12/71	2	7,500
	4	300
	6	700
07/07/71	2	2,400
	4	1,500
	6	930

from Defo, 1970

In addition to the threat of disease presented by these organisms, they may serve as contaminant transport mechanisms for hydrophobic organic compounds as discussed below.

## 2. Polynuclear Aromatic Hydrocarbons

Pumping Wells G & H presents the risk of inducing the movement of PAHs into the aquifer and, ultimately, into the wells. The hydraulic contribution of the river has been documented elsewhere in this report.

Polynuclear aromatic hydrocarbons are a class of chemicals characterized by two or more joined benzene rings. This group shares common physical characteristics, such as low solubility in water and a high affinity for carbon. Table 4E-4 presents physical characteristic data for 19 PAH compounds (taken from the Endangerment Assessment). Eleven of the 40 PAHs listed by the National Academy of Sciences, were listed as strongly carcinogenic or mutagenic, and 10 were listed as weakly carcinogenic or mutagenic. Toxicological effects of PAHs are discussed in greater detail below. It is sufficient to state here that cancer risks have been estimated to occur at concentrations in the part per trillion range. The risks associated with these minute concentrations make an understanding of this group of compounds very important.

PAHs are typically produced by the incomplete combustion of organic matter such as fossil fuels. Sources include power generation, heating with coal, oil or wood, processing of coal (coal tar) and transportation. While all of these sources contribute to the PAH load in the environment, the proximity of major highways (especially Route 128) to Wells G & H demands that this source be considered a significant threat to the quality of the Aberjona River and, if pumped, to Wells G & H, as well. Gordon reported that PAH concentrations in air in Los Angeles came primarily from automobiles (Edwards, 1983). The highest total PAH concentration reported in soil was 300,000 ug/l located near a highway in Switzerland (Edwards, 1983). Blumer reported that PAH concentrations in soil near highways were greater than concentrations in soil near industry in the same area (Edwards, 1983).

Airborne PAHs are generally associated with particulate matter, the majority of which reach the earth's surface by dry deposition (ATSDR, USEPA, 1987). This material remains on the surface bound to particulate matter due to its low vapor pressure (although volatilization may be a significant mechanism for compounds such as naphthalene, acenaphthene, acenaphthylene and fluorene which exhibit relatively high vapor pressures), particularly if these compounds are not already sorbed onto particulate matter (EPA, 1979a).

TABLE 10

PHYSICAL-CHEMICAL PROPERTIES OF CHEMICALS OF CONCERN  
AT THE WELLS G & H SITE

CHEMICAL	MOLECULAR WEIGHT (g/mol)	DIFFUSIVITY (cm <sup>2</sup> /sec)	WATER SOLUBILITY (mg/l)	VAPOR PRESSURE (mm HG)	HENRY'S LAW CONSTANT (atm·m <sup>3</sup> /mol)	Koc	Log Kow
Polycyclic Aromatic Hydrocarbons							
Acenaphthene	154	0.05951	3.42E+00	1.55E-03	9.20E-05	4.60E+03	4.00
Acenaphthylene	152	0.06703	3.93E+00	2.90E-02	1.48E-03	2.50E+03	3.70
Anthracene	178	0.05904	4.50E-02	1.95E-04	1.01E-03	1.40E+04	4.45
Benzo(a)anthracene	228	0.04654	5.70E-03	2.20E-08	1.16E-06	1.38E+06	5.61
Benzo(b)fluoranthene	252	0.04392	1.40E-02	5.00E-07	1.19E-05	5.50E+05	6.06
Benzo(k)fluoranthene	252	0.04392	4.30E-03	5.10E-07	3.94E-05	5.50E+05	6.06
Benzo(g,h,i)perylene	276	0.04197	7.00E-04	1.03E-10	5.34E-08	1.60E+06	6.51
Benzo(a)pyrene	252	0.04653	3.80E-03	5.60E-09	1.55E-06	5.50E+06	6.06
Chrysene	228	0.04531	2.00E-03	6.30E-09	9.46E-07	2.00E+05	5.61
Dibenzo(a,h)anthracene	278	0.05707	1.40E-02	1.00E-10	2.61E-09	3.30E+06	5.61
Dibenzo(a,e)pyrene	302	0.05475	9.35E-03	4.86E-11	2.27E-09	1.22E+07	7.30
Dibenzo(a,h)pyrene	302	0.05475	6.96E-05	4.32E-15	2.72E-11	1.22E+07	7.30
Dibenzo(a,i)pyrene	302	0.05475	9.91E-01	4.30E-11	4.70E-12	2.57E+06	6.62
Fluoranthene	202	0.04944	2.60E-01	1.00E-05	1.02E-05	3.80E+04	5.33
Fluorene	276	0.05710	1.98E+00	7.10E-04	6.42E-05	7.30E+03	4.18
Indeno(1,2,3-cd)pyrene	276	0.05728	5.30E-04	1.00E-10	6.86E-08	1.60E+06	6.50
Naphthalene	128	0.08205	3.20E+01	8.70E-02	4.60E-04	9.40E+02	3.23
Phenanthrene	178	0.05430	1.29E+00	6.80E-04	1.59E-04	1.40E+04	4.46
Pyrene	202	0.05039	1.32E-01	2.50E-06	5.04E-06	3.80E+04	5.32

Sources: Callahan et al. 1979; Lyman et al. 1982; Mabey et al. 1982; Mackay and Shiu 1981; and Verschuren 1983.

Photolysis may result in short half lives (1.2 hrs for benzopyrene in solution). Photolysis is primarily of significance in aquatic systems where the PAH is not sorbed onto sediments. This is not a significant mechanism once the PAH enters the aquifer.

PAHs have been found in both the water (see Table 5) and the bottom sediment (Table 7) of the Aberjona. Table 4E-1 reflects analyses samples collected from the Aberjona during runoff from the precipitation event on March 5, 1989 after several days of dry weather. The high concentrations of PAHs in the bottom sediment (Table 4E-2) are indicative of the high sorption and low solubility of these compounds; they accumulated in the sediment. Surface soils in the Central Area have also displayed contamination by PAHs (Pyrene at 2,300 ppb).

It has been well documented that a strong hydraulic communication exists between the Aberjona River and Wells G & H during pumping and that the river contributes a very significant quantity of water to the yield of those wells. Despite the fact that the high affinity for carbon exhibited by PAHs and their low water solubility suggest that transfer in dissolved form is not very significant, we must consider the strong possibility that alternative transport mechanisms may operate such pumping conditions.

Solute transport modeling for any compound of concern should include the effect of dissolved organic carbon as well as the presence of other solutes, such as butyl cellulose, on the solubility, and hence the transport, of the compound to be modeled. An extensive sampling program is required to better define the hydrochemistry of the Aberjona River prior to designing a treatment system for Wells G & H. The following is a qualitative discussion of contaminant transport potential.

An excellent case can be made for the transport of PAHs sorbed onto colloidal-sized particles. The presence of coliform in Wells G & H (see Table 8) indicates that bacteria are moving through the aquifer. The high  $K_{OC}$  values for the PAHs indicate that they would readily sorb onto organic colloids. Ryan (1988) states that in groundwater containing inorganic colloids, up to half of the organic carbon present was associated with these colloids. Organic carbon coating of inorganic colloids would also serve as transport mechanisms for PAHs. Humic material originating in the wetland is a ready source of such coatings.

While the study of contaminant transport via colloids is in its infancy, research is beginning to reveal that this may be a significant transport mechanism. Neglecting this mechanism can result in inaccurate predictions of contaminant transport when

only solutes are considered. McDowell-Boyer et. al. (1986) provides an excellent review of the subject.

Von Guten et. al. (1987) tracked radionuclides, derived from the reactor accident at Chernobyl in the River Glatt (Zurich, Switzerland) and found that the radionuclides infiltrating into groundwater were associated almost exclusively with particles or colloids. Sheppard et. al. (1980) found that colloidal sized particles were important "vehicles for the transport of radionuclide elements in soils and groundwater" and that humic complexing alters the migration equation for radionuclides and complicates the modeling of their transport. Transport of hydrophobic organic compounds would occur in very much the same manner.

Bengtsson et. al. (1987) reports that partitioning of hydrophobic organic compounds (such as PAHs) to macromolecules may influence the mobility of those compounds allowing them to move at or above the mean linear flow velocity of groundwater (due to longitudinal dispersion).

Enfield and Bengtsson (1987) performed column experiments in which they determined that macromolecules (blue Dextran) eluted from the soil column prior to a solute (Tritiated water) injected at the same time. They conclude that hydrophobic compounds associated with macromolecules tend toward greater mobility than that predicted by standard solute transport models.

Similarly, Wood and Erhlic (1978) conducted studies on the use of bakers yeast (Diameter 2-3 um) as a groundwater tracer in sand and gravel aquifers. Both bromide and yeast were introduced to the aquifer and were monitored in a pumping well. Yeast was found to have moved more than 23 feet in less than 48 hours. The yeast was found to arrive at the well before the bromide due to partitioning of the bromide onto the soil matrix. This suggests that colloids may present a more rapid means of transport than that predicted by standard solute transport models. McDowell-Boyer et. al. (1986) report that work by Jury et. al. (1982) indicates that a small amount of naproamide moved through the soil "at a rate inconsistent with the adsorption equilibrium assumption."

Robertson et. al. (in McDowell-Boyer, 1986) found that macromolecules of tannin and lignin moved up to 900 meters horizontally in 11 years.

Nightingale and Bianchi (1977) documented turbidity in wells downgradient of a recharge basin indicating substantial colloidal movement through the aquifer. Ryan (1988) studied colloids in aquifers in New Jersey and Delaware. He states that colloidal organic carbon was present in all groundwater studied and that colloids enhance hazardous pollutant transport in the subsurface.

While the peat layer underlying portions of the Aberjona River may serve to attenuate both solute and colloidal movement, it has been shown above that much of the Aberjona's contribution to Wells G & H is not filtered through the peat. The aquifer is composed of sand and gravel (U.S.G.S. 1987) and has a relatively high porosity (0.3 assumed) and transmissivity which make it susceptible to the movement of colloids.

Furthermore, it is likely that organisms in the river and river banks provide macropores in the river bed and banks which would facilitate the movement of colloids into aquifer materials. EBASCO refers to the activities of a fur trapper in the Central Area (Endangerment Assessment). The presence of mammals, particularly burrowing mammals, in the riparian environment would produce conduits for colloid movement into the aquifer.

Once present in the aquifer, the most significant factor in the degradation of these compounds is biodegradation. The biodegradation half-life under aquifer conditions may be very long (ATSDR, U.S.E.P.A., 1987). Once PAHs are in the aquifer, it is very likely that they will persist for long periods of time. The toxicity, persistence and prolific sources of these compounds make the introduction of them into the aquifer by pumping a highly undesirable situation.

#### D. Alternative Central Area Pumping Locations

The probability of installing remediation wells for the purpose of restoring the Central Area aquifer while avoiding impact from the river water appears to be limited. Both Wells G & H are located near the eastern extent of the sand and gravel aquifer which is bound on the east by a buried bedrock valley wall which acts as a barrier boundary. During the 30 day U.S.G.S. pumping test, the cone of depression that developed extended much further to the west, into the main body of the aquifer, than to the east toward the bedrock barrier boundary. This same configuration would exist, though less pronounced, at lower pumping rates. As pumping time increases, the cone of depression would extend primarily westward, effectively increasing the induced infiltration from the Aberjona River.

The area of Well G and to the south-southeast of Well G would appear to be the most favorable location to locate additional remediation wells based on the stratigraphy and the relative distance to the Aberjona River. However, pumping 540 gpm from one or more wells in this area for long periods of time would result in a cone of depression which would likely induce infiltration from the Aberjona River using aquifer parameters calculated in the U.S.G.S. report. For instance, a well pumped at 50 gpm at the location of Well G would develop a cone of depression that would intercept the Aberjona River (with a drawdown of 0.1 feet) in 3.7 - 16.3 days (see Appendix 25). Multiple wells in this area with interfering cones of depression

would likely induce infiltration from the river in a few days or less.

The U.S.G.S. report indicates that the zone of contribution to Wells G & H is significantly influenced by pumping cycles of the Riley well located to the southwest. Therefore, remediation wells located in the vicinity of Well G would receive varying amounts of water from the Aberjona River depending on the pumping rate at the Riley well.

A remediation well will also be placed on the Wildwood property directly to the west and on the opposite side of the Aberjona River of Well G. The remediation pumping rate proposed for this site is 300 gpm. Interfering cones of depression would exist between remediation well(s) located in the vicinity of Well G and the Wildwood remediation well(s) with a groundwater divide existing somewhere between these two areas (depending on location and pumping rates). Therefore, at least one of the remediation wells would be drawing water from the river, thereby re-contaminating the aquifer with contaminated river water. For all these reasons, a re-configuration of remediation wells in the central area would not avoid the impact of inducing river water into the aquifer.

#### E. Potential Radionuclide Contamination of Wells G & H

Radionuclides have been found in the groundwater at S22, located along Washington Street, at levels that far exceed acceptable drinking water limits. Groundwater will transport these radionuclides toward the valley and Wells G & H. Lower levels of radionuclides have been found in the alluvial valley in the vicinity of Wells G & H, which indicates that this transport occurs now, but that dilution in the valley reduces the concentrations. Once EPA's proposed plan is implemented, the existing ground water flow conditions will be dramatically altered, and EBASCO's ground water modeling is not sufficient to forecast the configuration of the groundwater flow system when source control is undertaken.

It is known that groundwater flow from portions of the upper reaches of the valley toward the valley center will be significantly reduced when source control wells are in operation at UniFirst, Grace, and New England Plastics. Groundwater flow from the hillslope that is not under source control will likely occur under a larger hydraulic gradient than currently exists. This fact would be all the more significant in the case of colloid transport, as explained above. The significance of colloid flow for radionuclide transport in the Wells G & H aquifer is suggested by the report in an EPA internal memorandum, dated January 19, 1989, that when subsequent samples from S22 were filtered, the radionuclide concentrations dropped substantially. The area around S22 therefore could become a larger contributor to the total flow to be removed from the

alluvial aquifer by Wells G & H, and could yield larger quantities of radionuclide contamination to Wells G & H. These possibilities do not appear to have been considered by EBASCO.

F. Risks of PAH, Coliform, Pb, Cellusolve and Radionuclides to Public Health

1. Polycyclic Nuclear Aromatic Hydrocarbons (PAH)

EPA stated in its proposed plan that the criterion used to evaluate alternatives for the remediation of Wells G & H was, first and foremost, "the overall protection of human health and the environment". EPA stated that this consideration was intended to address whether or not a remedy, in this case the one to be applied to Wells G & H and the surrounding watershed, would provide adequate protection of public health and the environment and whether the potential risks identified in the EA are properly eliminated, reduced or controlled through treatment, engineering controls, or institutional controls. EPA further stated that the preferred groundwater alternative, active pumping of Wells G & H, would remove contamination more quickly than would any other groundwater alternatives, thus ensuring protection of public health and the environment should this water be needed in the future as a drinking water source. EPA supported the preferred groundwater alternative as being a means by which a central treatment plant could be built and used to provide drinking water if additional water were needed before aquifer cleanup levels were achieved. EPA also stated that preferred remedy will comply with the Applicable or Relevant and Appropriate Requirements (ARARs) it has established for the site.

The EA states that the ARARs for this site are presented in EA Table 1-4, at page 1-23. For carcinogenic PAH compounds (for which benzo(a)pyrene (BaP) is the listed surrogate), the Adjusted Water Quality Criterion (AWQC), the applicable federal standard, is cited as being 3.1 times  $10^{-6}$  milligrams per liter. This value is stated to be the level at which no more than a 1 in a million additional cancer risk is likely to be incurred and would be the value that is considered to be safe and protective of health. In other units, this value is 3.1 part per trillion, or 3.1 nanograms per liter. The recently published ATSDR draft for BaP gives 2.8 nanograms per liter as the  $10^{-6}$  value which includes a modest (6.5 gram) daily ration of fish. The value given for the Commonwealth of Massachusetts in EA Table 1-4 as being safe and protective of health is 0.3 parts per trillion, or 0.3 nanograms per liter, 10-fold less than the stated EPA guideline value.

We note that there exists controversy as to the level of risk which is acceptable to regulators and to the applicability of the data used to develop risk estimates. In the case of Wells G & H, the prime concern for public health has been



cancer, namely leukemia among children. Thus, in order for the proposed remedy to be safe and protective of health, by EPA's own standard, its chosen remedial actions should adequately address this concern.

It is well known that a cancer hazard is the main toxic action of concern that exists for the non-volatile, non-chlorine-containing water and soil contaminants which are polynuclear aromatic (benzene-like) hydrocarbons (PAHs). (Williams and Weisburger 1986, Casarett and Doull 1986). These materials exist in nature from combustion sources such as wood and oil smoke and automobile and truck exhaust (ATSDR, 1988) US EPA 1987, ATSDR 1987a, ATSDR 1987b, ATSDR 1987c, ATSDR 1987d). In the vicinity of Wells G & H, the proximity to Route 128 makes the latter origin of PAHs seem the most likely.

PAHs are dichotomously classified as those which are carcinogenic and those which are not. The EA cites BaP as the carcinogenic surrogate, while naphthalene is listed as being non-carcinogenic. The two classes differ in their biologic activity and the effect that biotransformation has upon them. However, these differences may be largely quantitative. At times, the range of activity of specific PAHs is not clearcut, and some less active forms may still be carcinogenic. Those listed below as having sufficient evidence have been identified by IARC as being among the carcinogenic species. As noted previously, one of them, benzo(a)pyrene [BaP] is a frequently cited compound that appears to be a potent carcinogenic species and is frequently cited as the surrogate for the entire carcinogenic PAH class.

CHEMICAL NAME	EVIDENCE OF CARCINOGENICITY FOR EXPERIMENTAL ANIMALS
ANTHANTHRENE	LIMITED
ANTHRACENE	NO EVIDENCE
BENZ(A)ACRIDINE	INADEQUATE
BENZ(C)ACRIDINE	LIMITED
BENZ(A)ANTHRACENE	SUFFICIENT
BENZO(B)FLUORANTHENE	SUFFICIENT
BENZO(J)FLUORANTHENE	SUFFICIENT
BENZO(K)FLUORANTHENE	SUFFICIENT
BENZO(G,H,I)FLUORANTHENE	INADEQUATE
BENZO(A)FLUORENE	INADEQUATE
BENZO(B)FLUORENE	INADEQUATE
BENZO(C)FLUORENE	INADEQUATE
BENZO(G,H,I)PERYLENE	INADEQUATE
BENZO(C)PHENANTHRENE	INADEQUATE
BENZO(A)PYRENE	SUFFICIENT
BENZO(E)PYRENE	INADEQUATE
CARBAZOLE	LIMITED
CHRYSENE	LIMITED
CORONENE	INADEQUATE
CYCLOPENTA(C,D)PYRENE	LIMITED
DIBENZ(A,H)ACRIDINE	SUFFICIENT
DIBENZ(A,J)ACRIDINE	SUFFICIENT
DIBENZ(A,C)ANTHRACENE	LIMITED
DIBENZ(A,H)ANTHRACENE	SUFFICIENT
DIBENZ(A,J)ANTHRACENE	LIMITED
7H-DIBENZO(C,G)CARBAZOLE	SUFFICIENT
DIBENZO(A,E)FLUORANTHENE	LIMITED
DIBENZO(A,E)PYRENE	SUFFICIENT
DIBENZO(A,H)PYRENE	SUFFICIENT
DIBENZO(A,I)PYRENE	SUFFICIENT
DIBENZO(A,L)PYRENE	SUFFICIENT
1,4-DIMETHYLPHENANTHRENE	INADEQUATE
FLUORANTHENE	NO EVIDENCE
FLUORENE	INADEQUATE
INDENO(1,2,3-CD)PYRENE	SUFFICIENT
5-METHYLCHRYSENE	SUFFICIENT
2-,3-,4- AND 6-METHYLCHRYSENES	LIMITED
1-METHYLCHRYSENE	INADEQUATE
2-METHYLFLUORANTHENE	LIMITED
3-METHYLFLUORANTHENE	INADEQUATE
1-METHYLPHENANTHRENE	INADEQUATE
PERYLENE	INADEQUATE
PHENANTHRENE	INADEQUATE
PYRENE	NO EVIDENCE
TRIPHENYLENE	INADEQUATE

Source: IARC 1983, IARC 1984, IARC 1987

With regard to PAHs in general, it is usually reported that PAH compounds are water insoluble (Safe Drinking Water Committee 1982) and that drinking water sources contain few, if any, PAHs. Solubility in the bulk liquid phase (not bound to particulates) is reported by Andleman and Snodgrass 1974 (as cited in National Academy of Sciences (NAS) Drinking Water and Health (DW&H) volume 4, Safe Drinking Water Committee 1982) to be 10 nanograms per liter. More recent publications such as ABDR 1988, US EPA 1987, ATSDR 1987a, ATSDR 1987b, ATSDR 1987c, ATSDR 1987d) and IARC indicate that solubilities may range from 0.5 to 6 micrograms per liter, values greatly in excess of that previously thought and amounts which exceed the applicable AWQC and the Massachusetts standard. Of particular note and according to the NAS, the relative insolubility of PAHs can be modified, that is, it can be increased by the action of water-borne detergents, by other dissolved or suspended substances such as colloids, and by the presence of organic solvents like the cellosolves in water. The latter two circumstances appear to be present within the Aberjona watershed which provides water recharge to Wells G & H.

Concentrations of PAHs are reported by the NAS to be in the ranges of 0.14 to 2.5 micrograms per liter (2,500 nanograms (ng) per liter (1)), while BaP concentrations per se are reported to range from .6 ng/l to 350 ng/l. This appears to be in the range of 10% to 15% of total PAHs. The following data were compiled by ENSR Consulting and Engineering for unfiltered water that was taken from the Route 128 drainage swale.

PARAMETER	RESULT (ng/l)	MDL <sup>3</sup> (ng/l)
BENZO(A)ANTHRACENE	730.	4.30
CHRYSENE	750.	2.60
BENZOFLUORANTHENES (B&K)	1,500.	1.40
BENZO(A)PYRENE	600.	2.90
INDENO(1,2,3-CD)PYRENE	530.	0.67
DIBENZ(A,H)ANTHRACENE	580.	0.42
BENZO(G,H,I)PERYLENE	690.	0.67
NAPHTHALENE	160.	2.00
2-METHYLNAPHTHALENE	540.	1.60
1-METHYLNAPHTHALENE	350.	1.30
BIPHENYL	83.	1.30

### 3. Maximum Detection Limit

ACENAPHTHYLENE	48.	1.00
ACENAPHTHENE	190.	1.20
DIBENZOFURAN	100.	0.69
FLUORENE	210.	0.64
TOTAL PHENANTHRENE/ANTHRACENE	1700.	3.40
FLUORANTHENE	2200.	0.97
PYRENE	1700.	0.74
BENZO(E)PYRENE	620.	4.00
PERYLENE	400.	1.20

The NAS reports that of the total PAHs found in surface waters, 1/3 is bound to large suspended particles, an additional 1/3 is bound to finally dispersed particles, and the remainder is present in a dissolved form (US EPA, 1980 as cited by NAS DW&H, volume 4). The NAS reports that

"The usual sedimentation, flocculation, and filtration process removes a good share of the PAHs present in the water. In addition, from 50 to 60 percent of PAHs, such as BaP, are removed by chlorination of the water." (EPA, 1979)

The following data are from the same Route 128 drainage swale water following filtration through a 0.045 micron filter so that only dissolved materials remain.

PARAMETER	RESULT (ng/l)	MDL (ng/l)
BENZO(A)ANTHRACENE	65.	4.30
CHRYSENE	190.	2.60
BENZOFLUORANTHENES (B&K)	130.	1.40
BENZO(A)PYRENE	30.	2.90
INDENO(1,2,3-CD)PYRENE	59.	0.67
DIBENZ(A,H)ANTHRACENE	19.	0.42
BENZO(G,H,I)PERYLENE	73.	0.67
NAPHTHALENE	9.9	2.00
2-METHYLNAPHTHALENE	86.	1.60
1-METHYLNAPHTHALENE	32.	1.30
BIPHENYL	BDL	1.30
ACENAPHTHYLENE	BDL	1.00
ACENAPHTHENE	2.9	1.20
DIBENZOFURAN	BDL	0.69
FLUORENE	1.5	0.64
TOTAL PHENANTHRENE/ANTHRACENE	30.	3.40
FLUORANTHENE	120.	0.97
PYRENE	120.	0.74
BENZO(E)PYRENE	33.	4.00
PERYLENE	22.	1.20

While the data above might appear to be comforting in that they show PAH removal, only an experiment would determine the utility and efficacy of a water treatment facility that would be sufficient to reduce the concentration of carcinogenic PAHs to the level required by the AWQC. Conducting such an experiment with Wells G & H in Woburn certainly would not be protective of health or the environment. The possibility exists that such a facility may not be able to adequately treat water which is highly contaminated with PAHs of natural origin. In this example, the standard is exceeded both for the total concentration of carcinogenic PAHs and for BaP individually.

With regard to the toxicity of benzo(a)pyrene, the recently published draft profile written by Clement Associates for the Agency for Toxic Substances and Disease Registry (ATSDR) states that

..."short term and long term exposures to BaP cause death in experimental animals fed BaP in the diet. The offspring of animals that ate levels of 10 mg of BaP per kilogram of body weight (mg/kg) during pregnancy had problems reproducing. Some of these offspring were low birth weight and had birth defects. Cancer has been found in animals breathing approximately 1.25 mg of BaP per cubic meter of air per day (mg/m<sup>3</sup>/day), eating 5 mg/kg BaP per day or having 0.05 milligrams/kg of BaP applied to their skin throughout their lives."

The ATSDR report further states that

..."These levels are at least 1,000 times higher than those to which humans are normally exposed."

In the case of the Aberjona watershed, it is not known how much of these PAHs will enter Wells G & H. The applicable standards are so low as to demand that, in the absence of better data, the water not be used for drinking and such a possibility should not even be contemplated.

The ATSDR document states,

..."Because it is believed that cancer causing agents can increase risk, even at very low exposures, dose ranges for cancer are not identified for any route of exposure, although, BaP has been shown to cause cancer in laboratory animals by many routes."

The ATSDR draft further states that

... "The Environmental Protection Agency (EPA) developed guidelines for permissible levels of carcinogenic PAHs in ambient water, based on data from a carcinogenesis study on BaP. EPA recommended that for the protection of human health, from the potential carcinogenic effects due to exposure to PAHs through the ingestion of contaminated water, fish, and shellfish, the ambient water concentrations of total carcinogenic PAHs should be 0. However, EPA realized that a zero concentration of carcinogenic PAHs may not be possible to achieve, because of naturally occurring levels in the environment and consequently estimated ambient water concentrations of total carcinogenic PAHs of 28, 2.8, and 0.28 nanograms per liter of water, corresponding to incremental lifetime cancer risk levels of one additional cancer case for every 100,000, 1,000,000, and 10,000,000 people exposed, respectively, based on consumption of contaminated water, fish, and shellfish as an aid in developing water quality regulations."

It should be noted that the EPA Water Quality Criterion reported by ATSDR assumes that each adult consumes 6.5 grams of fish and shellfish and 2 liters of water each day over his or her lifetime. It is to be expected that persons in the New England area would consume shellfish and fish, and thus, no higher allowance for contamination of water by PAHs would be regarded as appropriate or safe.

The basis for this standard is cited by the ATSDR draft to be Neal and Rigdon (1967) among other works (Rigdon and Neal 1965, Rigdon and Neal 1966, Rigdon and Neal 1969) by the same authors. It is assumed that the cited study was used to generate the risk estimates using the linear multi-stage model. The authors also reported that 0.001 and 0.01 mg of BaP per gram of food for 110 days did not result in the development of tumors. A higher daily dosing, namely 0.04 mg per gram resulted in 1 tumor in a group of 40 animals, while mice treated with 0.25 mg of BaP per day, had a tumor incidence of 66 out of 73 animals. It is intriguing to note that all mice fed 0.25 mg of BaP for 30 days and kept for 77 days, developed gastric tumors, while 50% of a group of 33 mice fed 5 total mg of BaP in one day (mg) and kept for 103 to 113 days also developed gastric tumors. Therefore, while these results suggest the existence of a threshold below which tumors will not occur in animals fed low levels of BaP repeatedly, single doses or multiple exposures to this compound over a short time appear to result in a high

frequency of gastric tumors among the animals tested. The high incidence rate and the short duration of exposure do not support the existence of a threshold in these cases.

In addition to the studies used to estimate the human health risk for PAHs, Rigdon and Neal (1969) reported that mice treated with BaP developed leukemia in addition to lung and stomach tumors. Their data showed a correlation between lung adenomas and the frequency of leukemia. While the nature of the leukemia in mice and its use in the prediction of human risk is uncertain, the findings that PAHs produce leukemia in experimental animals, and that Wells G & H will have levels of PAHs from their drawdown of river water require that the relationship of these facts to human health must be carefully considered. Whether the pharmacokinetics of mice and humans are sufficiently similar to confirm a relationship should be the subject of intense investigation, especially in Woburn, before these waters are used for public consumption.

Moreover, a report by Vogt et al. (1986) describes their determination of PAHs in various soils and in air. In these analytical studies, a local peat bog near an aluminum smelter which was a site of increased localized organic matter concentration, namely humic and fulvic acids and five particles with substantial filtration capacity, was found to have an elevated level of BaP. Such a bog might act as both a collector and a source of PAHs. PAHs, in this published case, released by a nearby aluminum reduction facility, may have preferentially accumulated in the soil as a result of collection or entrapment from either rain or as a result of groundwater transport to this location. The water discharged from such a bog or wet-lands, not unlike those wetlands and bogs near Wells G & H, may contain higher than expected levels of PAHs and, along with fine particles which become available to enter a local well system when heavy water demands are made upon the surrounding watershed.

There is little data available to rank the carcinogenic potency among PAHs. The carcinogenic forms of which benzo(a)pyrene is but 1 among 30 or more have been ranked according to their mutagenic activity (Mohammad et al. 1983, Environmental Criteria and Assessment Office 1984). The mutagenicity-based potency estimates for fluoranthene, dibenz(ac)anthracene, 7,12-dimethylbenzanthracene and 7-methylbenzanthracene suggest a potency in a somewhat lower range compared to BaP, i.e. less active but still within an order of magnitude of BaP potency. A large number of mutagenic PAHs have been identified with physical-chemical characteristics that are intermediate between BaP and the relatively non-mutagenic (and likely non-carcinogenic) substances such as pyridine, isoquinidine and the previously used moth preparation, naphthalene. These polycyclic compounds cover a wide range of genotoxic potencies (with some lacking activity, presumably these are not carcinogenic). The complex mixture that results

delivers an uncertain potential for carcinogenicity when presented in combination.

In the absence of careful speciation (knowledge of which compounds are present), it cannot be known which components of ground water or surface water are likely to be present in the greatest quantities nor which will produce the largest risks. Furthermore the NAS has reported that PAHs in combination with asbestos and in combination with radionuclides have the potential for additive as well as synergistic interaction. The route of exposure in these cases appears to be inhalation as opposed to ingestion, so while not strictly relevant, the comparison among risks and routes for PAHs which are carcinogenic and present within the watershed and the other contributing factors cannot be ignored.

## 2. Coliform bacteria

A prime objective of the physical and chemical treatment of water that is intended for public consumption is to reduce the levels of total coliform bacteria to less than 1 coliform/100 ml. This value represents the applicable Massachusetts and World Health Organization standard.

Water treatment by chlorination as described elsewhere in this document has proved to be an effective barrier against transmission of infectious disease by water (Safe Drinking Water Committee 1982). According to the water quality sampling data which was presented earlier in this report, in the period from 1963-1980 for Well G and from 1964-1980 for Well H, the levels of coliform ranged from 3-1,200 coliform/100 ml. Bacterial concentrations of this range are likely to result in an increased risk of transmission of infectious disease by water and will necessitate a precautionary degree of disinfection.

## 3. Compounds formed by chlorination of water containing dissolved or suspended organic compounds

Chlorination has been the predominant method of disinfection of water distribution systems. However, the process of chlorination of the water system has, within the past ten years, been found to be a source of a wide variety of chlorinated species. These exist and can result from the reaction of chlorine with a variety of non-chlorinated organics that are usually of natural origin. Reaction of chlorine and hypochlorite ion with these contaminants may produce more toxicologically active forms.

Alternatively, the reaction of chlorine with organics acids such as humic, fulvic acids has led to the appearance of dichloro- and trichloroacetic acids. This finding is especially significant here because highly chlorinated metabolites of



trichloroethylene and tetrachloroethylene generated in situ in mice, in particular trichloroacetic acid, are thought by many toxicologists to be responsible for the carcinogenicity observed when these compounds are experimentally administered to mice. Pharmacokinetic analysis reveals, however, that trichloroacetic acid production may be comparatively unique to the mouse hepatic drug metabolizing enzyme system, and not be present in humans, rendering trichloroethylene and tetrachloroethylene carcinogenic in mice, but not in humans. Thus, chlorination of Wells G & H water may present a human cancer hazard via these metabolites, whereas trichloroethylene and tetrachloroethylene by themselves would not.

Furthermore, chlorination studies of groundwater which contains significant concentrations of organic substances such as humic and fulvic acids in addition to bacterial contamination have disclosed a variety of halogenated compounds, some of which contain surprising mutagenic activity. In addition to the two organochlorine acids cited above, other major compounds which are mutagenic and have been detected in heavily chlorinated water include a material identified as compound MX (a chlorinated hydroxyfuranone). The material is identified as being present in small quantities, but is reported to be responsible for 50% of the mutagenic activity found in chlorinated drinking water. This work suggests that the existence of such active compounds, even in minute quantities, should warrant a careful evaluation of any water source which must be heavily chlorinated to make it safe for public consumption.

#### 4. Lead

Lead is a heavy metal of significant public health interest. A number of scientists and regulatory agencies, among them EPA (EPA, 1988) and ATSDR (ATSDR 1988), have expressed the opinion that some of the toxic effects of lead, like those effects due to carcinogen exposure, may occur without a threshold for the dose-response relationship. Thus, all sources of lead should represent a basis for concern.

The presence of lead and that of related compounds in water from Wells G & H has been poorly studied. Few analyses have been done which were intended specifically to look for elevated concentrations of lead, lead compounds and other metals. However, on the only reported occasions when Wells G & H were tested for lead, it was detected in Well G at 270 micrograms per liter, well above the current drinking water standard of 50 ug/l, and was reported as being "less than" 270 micrograms per liter in Well H.

Subsequent tests of groundwater monitoring wells in 1987 and 1988 reported in the Supplemental RI repeatedly detected lead in groundwater within about a 1000 foot radius of Wells G &

H. Concentrations in the four wells tested ranged from 19.6 to 58 ug/l, with the highest concentration, 58 ug/l, found in a monitoring well directly between Wells G & H.

a. Developmental Effects

With regard to lead toxicity and as far back as 1977, the Safe Drinking Water Committee of the NAS (as cited in Safe Drinking Water Committee 1982) reported that

... "The present limit of 50 micrograms per liter of lead may not, in view of other sources of environmental exposure, provide a sufficient margin of safety, particularly for fetuses and young children."

In the 1988 draft ATSDR document on lead, the authors reported that developmental effects were of concern. Preterm birth, impaired learning, reduced birth weight and decreased IQ were associated with exposure of the mother to lead during pregnancy. These observations have created a climate of concern for any source of lead that might contribute to developmental defects as well as lags in development. The possibility of lead being in the water taken from Wells G & H must be carefully considered in evaluating it as a drinking water source. In order for the remedy chosen by the Agency to make the water safe and protective of health, the possibility of increased lead concentrations in the water must be considered.

b. Carcinogenity

In addition to this concern for the well-being and mental health of children, although the Safe Drinking Water Committee of the National Academy of Sciences (Safe Drinking Water Committee 1982), stated that

... "There is no evidence that lead is carcinogenic or teratogenic in humans and evidence of mutagenicity is scant"

newer data have superceded this pronouncement. Some of this evidence, referenced in Appendix D of the Endangerment Assessment, has caused EPA to conclude that compounds of lead may be probable human carcinogens (classification B2) and may pose a cancer risk in man. (EPA, 1988).

c. Effects on Blood Pressure

Exposure in the environment is less a result of pure substances and more the consequence of multiple interactions which produce a complex result. To better understand this phenomenon, the Committee on Toxicology of the NAS has used lead as a component of complex environmental mixtures as the basis

for a case study on complex mixtures (Board On Environmental Studies and Toxicology, 1988). The possibility is examined by them that lead may be a factor in hypertension and the underlying data supporting this hypothesis are described. Hypertension is stated to be a risk factor in cardiovascular disease, with this condition being a main source of mortality and morbidity in the USA. While dietary factors are known to be contributors to both hypertension and cardiovascular disease, complex interactions between lead and other dietary metals, e.g. calcium and sodium, are well known. The possibility exists, moreover, that numerous other interacting factors may contribute to the toxic effects due to lead. Among these may be stress, diet, and "life style" factors.

With regard to the interaction of lead with hypertension, the observation is made that, among Boston police officers, Weiss et al. (1986) reported that elevated blood lead concentrations were predictive of a later elevation in systolic blood pressure. Other studies, while of quantitatively different magnitude, appear to support this hypothesis that elevated blood lead level is related to blood pressure elevations in a manner which suggests causation. Large scale dietary studies have shown this. Pirkle et al. showed that, based on NHANES II data (Pirkle et al. 1985), elevated blood lead level is a significant factor in blood pressure elevation even after correction for other factors.

In the vicinity of Wells G & H and in the wells themselves, numerous detections of sodium at levels in excess of that considered subject to notification have been reported. While these levels, in the 20 to 100 mg per liter range, may be considered low although elevated when taken alone, the concern exists that elevated sodium intake through a drinking water source, plus elevated levels of lead from the same drinking water and other sources may contribute to a synergistic, or at least, additive interaction.

d. Allowable lead levels in Woburn drinking water

The FS calculates a soil action level for lead at the Wells G & H site based on a total allowable daily intake of lead, but has not done so for drinking water. Yet, the data summarized above suggest that drinking water would be a much more likely, regular and widespread source of lead in Woburn should Wells G & H ever again be used for drinking water than would be the episodic ingestion by children of soil from the site area. The importance of this inconsistency can be seen by reviewing the FS soil calculation in the context of the ATSDR document's estimates of dietary sources of lead.

In making its soil action level calculation, the FS first states that, based on some of the recently reported, low-level

toxic effects of lead, the total daily intake of lead from all sources should be limited to 25 ug per day. The FS then estimates that 11.8 ug of the 25 ug daily allowance will be supplied by inhalation of the ambient air in Woburn. The FS concludes that this leaves 13.2 ug/day for lead from all other sources and calculates a concentration of lead in soil which could be consumed without exceeding 13.2 ug/day.

The ATSDR draft, however, points out that the "baseline" daily intake of lead from food, beverages and water may range from 25.1 to 45.2 ug/day, depending on age and sex. Of these amounts, at least one half, and probably more, would be expected to come from food and beverages, independently of the effects of lead solder used in cans and domestic drinking water pipes. Using the FS's assumptions of drinking water consumption of 2 liters/day and a gastrointestinal lead absorption rate of 30%, it can be seen that effectively no allowance can be made for lead in Woburn drinking water without exceeding the 25 ug limit, quite apart from any ingestion of contaminated soil. The ability of existing treatment technologies reliably and consistently to remove the lead likely to be found water from Well G & H to this extent may well be doubted.

## 5. Radionuclides

The radionuclides have been separated into the following four categories: Radium 226 and Radium 228, gross alpha particles, gross beta particles, and uranium. Carcinogenicity such as osteogenic sarcoma, lung cancer and leukemia are the major endpoints of concern for exposure to radiation and radionuclides (IARC 1983, Regnier et al. 1985, Reid et al. 1985). Gross alpha particles from radon are associated with an increased risk of lung cancer. Exposure to Radium is associated with an increased risk of skeletal cancers (bone sarcomas and carcinomas of the head and sinuses). For alpha emitters which are deposited in mineral bone, the risks from radiation-induced leukemia in humans have been insignificant relative to the risk due to bone sarcomas (Mays et al. 1985, Mays et al. 1985). Nonetheless, leukemia is an issue in Woburn.

Gross alpha particles were estimated in the FS to be in the range of 5 - 250 picocuries/liter (pCi/l) at the Wells G & H site. The maximum contaminant level (MCL) for gross alpha particle activity from radium, but excluding radon and uranium, is 15 pCi/l with a detection limit of 3 pCi/l. Furthermore, the Guidelines for Drinking Water Quality (World Health Organization Volume 1, 1984, World Health Organization 1984), state that 0.1 Becquerel (Bq, IARC 1988)/l or 2.7 pCi/l for gross alpha activity represents a value below which water can be considered potable without any further radiological examination. These levels could be exceeded at Wells G & H, depending on the hydrogeological factors described above, and on the uncertainties in the analyses reported in the FS, where the

stated margins of error often exceeded the reported value and could mean that all but two of the samples exceeded 15 pCi/l. This suggests that the levels of gross alpha particles at the wellheads may not be protective of human health.

Radium 226 and Radium 228 were estimated to be in the range of 0.7 to 14 pCi/l at the Wells G & H site. The MCL for Radium is 5 pCi/l with a detection limit of 1 pCi/l. A study by Mays et al. (1985) found that the cumulative lifetime risk to 1 million people, each ingesting 5 pCi of a Ra isotope per day, was calculated to be nine bone sarcomas plus 12 head carcinomas for Radium 226, 22 bone sarcomas for Radium 228 and 1.6 bone sarcomas for Radium 224. For ingestion of 5 pCi/day Radium 226 and 228, the excess skeletal cancers would be expected to be 43 per million people. A dose of 5 pCi/day would result from a water concentration of 2.5 pCi/l (assuming human consumption of 2 liters of water per day). This suggests that the concentrations of Radium in Wells G & H may exceed levels which are safe and protective of human health.

Gross beta activity was estimated to be in the range of 2-180 pCi/l at the Wells G & H site. The MCL for gross beta particles is 4 Mrems/year to total body or critical organ with a variety of detection limits. The overall method of compliance for the MCL is divided. The first step is to perform gross beta analysis. If the gross beta particle activity is less than 50 pCi/l, then check for tritium to be less than 20 pCi/l and strontium 90 less than 8 pCi/l. If both tritium and strontium are present, sum the annual dose equivalent to bone marrow, and if less than 4 mrems/yr, then the water source is in compliance. If the gross beta particle activity is greater than 50 pCi/l, then radiochemical analysis is required and the critical organ dose must be precisely calculated. For compliance, the dose must not exceed 4 Mrem/yr.

According to the Guidelines for Drinking Water Quality (World Health Organization Volume 1, 1984), 1 Becquerel (Bq)/l or 27 pCi/l for gross beta activity represents a value below which water can be considered potable without any further radiological examination. This level, too, could be exceeded for Wells G & H.

## V. PROPOSED MANAGEMENT OF CONTAMINANT MIGRATION

### A. General Approach

As described previously in this report, EBASCO's proposed treatment system for removal of contaminants from the groundwater was identical for each source location as well as the central area and combined treatment plant. Reviewing the available groundwater quality data, however, indicates that there is a wide range of contaminants of varying concentrations at the different sources at the Wells G & H site.

Due to the unique characteristics of groundwater at the various sites, it is essential to design the treatment specifically for each site when individual treatment plants are utilized. To use the same treatment scheme at each site is not cost-effective. This makes the cost biased towards a central treatment facility that is designed specifically for the combined waste stream.

Additionally, in order to properly select appropriate technologies for treatment, it is necessary to know what the design concentrations of individual contaminants are at each site. EBASCO has presented total VOC's as the design criteria, with no breakdown of individual contaminants. EBASCO has also recommended that combining the individual waste streams is the most cost-effective solution. Despite the fact that our review of EBASCO's costs indicates that there probably is little if any cost advantage to a central combined plant (as discussed in Section VI of this report), there are some fundamental problems with this approach that EBASCO did not address.

Firstly, there is one major source that has an order of magnitude higher concentrations than the other sources (Wildwood). To combine this source with more dilute waste streams will lower the treatment efficiencies for most technologies selected. Secondly, if there are specific contaminants at only one or two sources that require specialized treatment (e.g. vinyl chloride at W.R. Grace, iron and manganese at N.E. Plastics, or heavy metals at Wildwood), then combining the flows will create a need for all of the needed treatment steps for the total flow. This increases the required capital cost and decreases the removal efficiencies of treatment.

Following such a careful review of the specific contaminants at the individual sources, treatability studies should be conducted to properly evaluate the appropriate technologies and develop design criteria. EBASCO had a treatability study performed for the Wells G & H site. However, the EBASCO treatability study was based on faulty premises.

A problem with the EBASCO Treatability Study is that it was not used to help select the most cost-effective and appropriate

technologies, but only to develop design criteria for already selected technologies, namely:

Pretreatment: . Chemical  
precipitation/flocculation/clarification/filtration  
VOC removal : . Air stripping

We believe that alternative technologies should have been tested which have potential to be less costly and require less operational attention. At the very least the following should also have been evaluated:

Pretreatment: . Plain filtration  
. Aeration and plain filtration  
. Potassium permanganate oxidation and green sand filtration  
. Chlorine oxidation, plain filtration and dechlorination  
VOC removals: . Aqueous phase carbon (without air stripping)

The general approach that we have taken to develop a recommended scheme for the management of contaminant migration at the Wells G & H site is to review the likely treatment technologies for the contaminants present, then to review carefully the available data and determine the most appropriate design concentrations of all contaminants at every site. These design criteria will then be used as the basis for selection of the recommended treatment system for each site and the development of cost estimates for construction and operation and maintenance. In this way, the most cost-effective approach can be developed for the site. Prior to final process selection and design, a much more rigorous evaluation of the water quality data and proposed pumping rates at each of the sites should be accomplished. More comprehensive treatability studies should also be performed prior to final design.

## B. Review of Appropriate Treatment Technologies

### 1. Volatile Organics Removal.

Both aqueous phase granular activated carbon (GAC) and air-stripping are proven methods of removing volatile organic compounds (VOCs) from water. However, air-stripping transfers the VOCs to air which must then be treated by vapor phase granular activated carbon or some other means to avoid contaminant emissions to the atmosphere. Vapor phase GAC typically has a removal efficiency advantage over aqueous phase GAC, and it is possible to regenerate vapor phase GAC on-site with steam. Spent aqueous phase GAC must be shipped to commercial facilities for regeneration. Air stripping with vapor phase carbon treatment with on-site regeneration ability

has a much higher initial capital expense than aqueous phase carbon.

At lower contaminant concentrations and smaller flows, aqueous phase GAC can be the most cost-efficient option. As concentrations increase and flow volumes increase, the reduced operational costs make air-stripping and vapor phase GAC the most viable option.

We recommend that air stripping be followed with aqueous phase GAC as a polishing step. This increases the capital costs associated with air-stripping but still keeps the operating costs lower than aqueous phase GAC alone. However, it does raise the threshold contamination levels and flow rates at which air-stripping becomes more cost-effective than aqueous phase GAC. Only a detailed analysis and thorough treatability studies can determine conclusively which is the best option according to costs.

## 2. Carbon Adsorption (Aqueous Phase)

EBASCO considered carbon adsorption as a primary treatment alternative for volatile organics removal under MOM alternative 2c in the FS. This alternative was eliminated from further detailed study by EBASCO. The reasons are not clear, although they apparently were not based on cost since preliminary cost estimates developed show the UV/Chemical oxidation alternative to be significantly more expensive than the other alternatives, yet UV/Chemical oxidation was retained for further detailed study. The present worth costs from the preliminary evaluation as developed by EBASCO are presented below.

	<u>Present Worth by EBASCO</u>		
	<u>Air Stripping</u>	<u>Carbon Adsorption</u>	<u>UV/Chemical Oxidation</u>
Separate treatment Plants	\$ 65.7M	\$76.7M	\$90.2M
Central Treatment Plant	\$ 26.4M	\$34 M	\$42.2M

The decision to eliminate carbon adsorption is apparently based on the following statements by EBASCO in the Feasibility Study Report:

"The carbon adsorption process is not well-suited for high concentrations of volatile organics as a primary treatment process, particularly at the Wildwood Property due to the following operation and maintenance difficulties:

- o Activated carbon has a relatively low capacity to adsorb volatile organics;



- o The process operation requires frequent replacement of spent activated carbon; and
- o There is a high potential for carbon filter breakthrough resulting in inadequate treatment."

We believe that these statements are not substantiated on fact, and although these points are applicable for some of the sites (particularly Wildwood), carbon adsorption should not have been eliminated from consideration for the other, lower concentration sites. The first statement above regarding low capacity is not entirely understood. Carbon adsorption is an established and recommended technology for removal of volatile organics (e.g. EPA Handbook of Remedial Action at Waste Disposal Sites). The other established technology is air stripping, which still will require contaminant removal in the off-gas with vapor phase carbon adsorption. Although vapor phase carbon generally has a higher capacity than aqueous phase, it is highly contaminant dependent, and further, on-site vapor phase regeneration involves significant capital requirements and on-going handling of the collected contaminants as a hazardous waste.

The second statement needs to be evaluated on a source-specific basis. For example, some of the sites at the Wells G & H site would only require carbon replacement about every six months. Further, the contaminant levels in the groundwater will decrease with time, with the majority of the contaminant removal occurring during the first several years of pumping, so that over the course of a 30 year pumping program the carbon replacement costs for some of the sites will be relatively small on a present worth basis.

The third statement is not true because reliability can be designed into the system, i.e., by employing multiple carbon trains in series with intermediate monitoring points for break-through. Additionally, there is an equivalent potential for break-through of vapor phase carbon which would result in unacceptable air emissions.

In summary, aqueous phase carbon should not have been eliminated from consideration for individual source treatment schemes without looking at the individual contaminants, and the concentrations in each of the ground water streams, their respective adsorbabilities, and the resulting expected carbon requirements.

a. Air stripping and off-gas treatment with vapor phase carbon

EBASCO has selected air stripping as the primary treatment technology for volatile organic removal. This is a well established and demonstrated technology for this application. The expected removal efficiency with this technology has been stated by EBASCO as 99.9%, which was based on the treatability

study results. The extrapolation of the results of the treatability study to full scale plant performance and use of that conclusion for selection of a treatment alternative that meets discharge quality goals is very dubious. Also, the water quality of the UniFirst and Wildwood groundwater used in the treatability study by EBASCO as analyzed by ESE is significantly different than the EBASCO summary of total VOC's used as design criteria. This is shown in the following Table:

	<u>Wildwood</u>		<u>UniFirst</u>	
	<u>Treatability Study</u>	<u>EBASCO Feasibility Study</u>	<u>Treatability Study</u>	<u>EBASCO Feasibility Study</u>
Total VOC's (ug/l)	28,461	52,255	826	3,925

There are also significant differences between the Treatability Study data by ESE and the data presented in the Endangerment Assessment for these sites, as well as the samples taken by EBASCO three months earlier from the same wells as the treatability samples. This brings into question the representativeness of the samples and necessitates the exercise of caution in applying the results to full scale treatment with expectations of meeting target goals. Further, as discussed previously, treatability of the various and unique waste streams was not evaluated, yet the results were applied uniformly to all sites.

We do agree that air stripping will likely be very effective treatment for the volatile contaminants of concern, however, pilot scale and full scale air stripping operations rarely achieve 99.9% removal for many volatile contaminants (Crittenden, et. al., Hand, et. al., Nirmakkhandan, et. al.). Further, even if this level of removal efficiency were possible, it would not meet the proposed ARAR's for some compounds. This is demonstrated by applying 99.9% removal to the total average VOC concentration for Wildwood of 52,255 ug/l (as presented in the FS). The resulting effluent concentration would then be 52 ug/l. Since the major VOC at Wildwood is TCE with a target level of 5 ug/l, this level of treatment may not be acceptable. Similarly, 99.9% removal of the combined flow total VOC concentration of 30,860 ug/l (FS) would yield 31 ug/l, most of which will probably be TCE and PCE, both with target levels of 5 ug/l.

The risk of not meeting treatment goals is further demonstrated by the treatability study, which did not meet effluent goals with air stripping for trichloroethene. Although theoretically the air-to-water ratio can be increased to overcome this failure to meet the ARAR's, there is a practical limit to how much this ratio can be increased before tower volumes and power requirements become excessive, along with developing potential tower flooding conditions.

Air stripping alone will therefore not reliably meet the ARARs for the highly contaminated sources, particularly Wildwood and a combined flow central treatment plant. A final polishing step will be required for these situations to ensure the reliability of treatment that is likely to be necessary at these sites.

The treatability study did include a polishing step of aqueous phase carbon after air stripping which was needed to bring the effluent below the ARARs. The intent of including this treatment step is described by the following statement from the Treatability Study:

"The objective of using carbon in the treatment train is to remove organic compounds not removed by prior treatment processes".

Despite the necessary inclusion of a final aqueous phase carbon polishing step in the treatability study, EBASCO did not include this step in the recommended treatment systems for the highly contaminated groundwater, namely, Wildwood and the combined flow treatment plant.

Another apparent discrepancy between the FS and the treatability study is the ultimate fate of the contaminants collected on the vapor phase carbon. The treatability study states that "the vapor recovery equipment will generate additional waste contaminated with organics, which will require proper off-site disposal." The FS states that "permanent destruction of contaminants would be achieved during carbon regeneration in the vapor phase adsorption system". We are not aware of any cost-effective, on-site carbon regeneration systems that also provide for permanent destruction of the adsorbed organics. Such systems would also require public acceptance which might be difficult. The capital costs indicated by EBASCO for the regeneration system appear to be for conventional regeneration equipment. There are no cost provisions indicated, however, for the handling, storage and disposal of the collected product (hazardous waste) from the regeneration process.

### 3. Iron and Manganese Removal

The basic premise, stated in the treatability study, that secondary drinking water standards are the treatment goal for iron and manganese (0.3 mg/l & 0.05 mg/l, respectively), should be re-assessed. Ambient levels of iron and manganese in the Aberjona River have been reported to average 1.7 mg/l and 4.5 mg/l, respectively (data from Appendix E of The Endangerment Assessment). Since the effluent from the proposed treatment plants will be discharged to the River, there is little reason to require treatment to secondary drinking water levels. We are aware of a Massachusetts community's (Merrimack) Fe/Mn removal scheme for drinking water which includes permission by the state

to discharge decanted filter backwash water (with Fe and Mn concentrations greater than drinking water standards) to the river, thus supporting the argument that such discharge standards will not be mandated.

We believe that the goal should be instead to reduce, if necessary, the detrimental impact that iron and manganese may have on subsequent treatment processes, particularly air stripping and carbon adsorption. The threshold levels of iron, with respect to fouling of carbon beds or air strippers, are not very well defined, and will certainly depend on chemical conditions in the water such as pH, redox potential, iron speciation, organic levels, etc.

Chemical precipitation is a commonly used iron and manganese removal method, depending on the character of the particular water, so it was reasonable for EBASCO/ESE to give it consideration in the treatability study. However, thoroughness was lacking in respect to other options. Other processes are much more common, especially oxidation followed by direct filtration or green sand filtration. This scheme was not considered in the study. There also may be the potential for significant iron removal with plain sand filtration. This is indicated by the fact that samples analyzed for filtered and unfiltered iron (9 samples from Olympia, Wildwood and New England Plastics) indicated that about 97% of the total iron in these samples was filterable. (However, a statement in the treatability study was made that "The raw groundwater results show that 80 percent of the iron is dissolved", so this would need to be confirmed.)

Only one, composited sample from two wells on only one site (Wildwood) was used in the iron and manganese pretreatment portion of the treatability study. The raw water analysis of this composite sample indicated an iron concentration of about 1.2 mg/l. It is not clear whether this is total or dissolved but analyses of samples from the same wells 3 months earlier indicated an iron concentration about ten times larger. The concentrations of dissolved iron in each of the jar tests without any chemical addition ranged from .058 to .875 mg/l. These levels are very likely already low enough to avoid operational problems in air strippers or carbon adsorption units, and chemical addition to remove these levels is unnecessary. Iron and manganese pretreatment was not evaluated on the UniFirst sample since levels were already below secondary drinking water standards (.3 mg/l). However, analysis of a sample taken by EBASCO from the same well three months earlier indicated an iron concentration of 25.4 mg/l. A sample taken by us from Well UC-7 on the UniFirst site showed an iron concentration of 25 mg/l. The average iron concentration in UniFirst wells as shown in Appendix E of the Supplemental RI Report by EBASCO was 4.4 mg/l. We agree that if one is assured

that the iron content is only 0.06 mg/l, then there is no need for removal testing. But the fact that the same well within only months demonstrated such pronounced variation in water quality should have led to further sampling to confirm the presence (and concentration) or absence of iron at the UniFirst site.

There was a significant range of iron/manganese concentrations reported by EBASCO at the Wells G & H site (4 mg/l / 0.2 mg/l average concentrations at UniFirst to 350 mg/l / 8 mg/l at Olympia). Since we believe it is practical and economical to treat the source areas separately, the treatability study would ideally address the full matrix of contaminant characteristics and treatment options. For example, simple filtration may be more than adequate to meet the treatment goals at UniFirst and W.R. Grace, while Olympia may need precipitation/clarification for economical removal of the high concentrations of iron, manganese, and other metals found. This statement is based on a purported iron concentration in Olympia's groundwater of over 450 mg/l. Analyses of the iron forms should be done to confirm or modify that level of iron.

Further reason for sampling and testing each site in regard to iron and manganese removal lies in the fact that these metals can react with organics to form relatively soluble organic complexes and chelates. These resist desolubilization by oxidants or coagulants unless the complex can be broken by chemical treatment. One or more of the source sites may contain organics which react with iron or manganese as described above. It would have been little trouble and expense to sample all the sites to determine if any site's unique chemical makeup had any adverse affect on pretreatment.

In regard to the oxidation portion of the treatability study, it was reported that neither aeration nor potassium permanganate ( $\text{KMnO}_4$ ) oxidation produced a precipitate. This is especially curious in the case of  $\text{KMnO}_4$ , which is a commonly used and generally very successful oxidant for this purpose. The "persistence throughout the test" of the violet color and relative success of lime both suggest that aeration or  $\text{KMnO}_4$  oxidation were not successful because of organically bound iron and manganese, perhaps including the presence of organic acids. EBASCO's report provided no discussion or possible explanation for this of phenomenon. To achieve optimum Fe or Mn removal, if needed at all, a speciation analysis should be done.

A concentration of iron as high as 4 mg/l may be successfully removed directly by filtration, or with the assistance of a powerful oxidant like  $\text{KMnO}_4$ , but with an elevated pH, about 7.5 - 8.5. The pH of the oxidants tested in the treatability study was not noted, only that they increased due to  $\text{CO}_2$  stripping.

Before giving up on oxidation/filtration in favor of coagulation-precipitation we suggest further analysis of the form of iron in the raw waters, and testing of plain filtration. Also, oxidation methods should be further investigated, if needed, such as aeration for at least 15 minutes at a pH of 8. If the treatability study  $\text{KMnO}_4$  test was as brief as the aeration, it should be repeated for longer duration - but only after identifying the iron species. If significant iron is present in organic form, aeration will not be successful and a more powerful oxidant will be necessary, such as chlorine or  $\text{KMnO}_4$ . Manganic hydroxide removal rates are even slower and need higher pH than self-precipitation of ferric hydroxides. Chlorination (gas, hypochlorite, or dioxide) may have been successful where the permanganate was not.

We recommend consideration of green sand (or manganese-impregnated zeolite) filtration with permanganate addition for regeneration of the bed. Though its effectiveness is reported to be greater in high-carbonate waters lacking other reducing substances (e.g. nitrogenous matter, hydrogen sulfide) and in waters with lower iron and manganese concentrations than reported for this site, the research literature is not unanimous on this point. Therefore, green sand filtration is worth investigating.  $\text{KMnO}_4$  will work on just about any concentration of Fe and Mn, if enough dose is applied: approximately 1 gram is needed per gram of iron; a bit more is need for manganese.

Summarizing our discussion of the pretreatment portion of the treatability study, we make the following conclusions and recommendations. Unless it is absolutely necessary, the use of processes like coagulation/sedimentation, which produce sludge requiring handling, dewatering, and ultimate disposal, should be avoided.

EBASCO did note, but with very little emphasis, that pretreatment may not be necessary at all source sites, and that this needs to be evaluated during remedial design. We concur.

- Chemical coagulation and flocculation may not be necessary at all of the sites. In fact very little pre-treatment may be required at some sites. The basic treatability goal premise of drinking water standards is unreasonably conservative.
- Sampling analyses data on iron and manganese concentrations were confusing or conflicting: level of concentration and soluble vs. insoluble form.
- Insufficient sampling was conducted, involving only three wells at two sites, and ultimately, using only two wells at one site for the test samples.

- The study was not thorough. It ignored commonly used Fe/Mn removal processes and too quickly discounted aeration or oxidation.
- All sites should be re-sampled sufficiently to obtain Fe and Mn data that are consistent and unequivocal in regard to concentration and form. Included would be speciation analyses.
- Treatability studies on filtration should be performed, and aeration/oxidation tests should be re-run for at least 1 to 2 hours, and at various pH levels.
- Treatment goals for Fe and Mn concentrations should be raised to levels that the State would allow to be discharged to the river, as long as those concentrations did not hinder the VOC treatment processes.
- Accordingly, treatability studies on air stripping and GAC removal of the VOCs should be performed using samples of varying Fe/Mn concentrations and different types of air stripping and GAC media.

### C. UniFirst Site Conditions

#### 1. Introduction

##### a. Purpose of Section

This section presents the results of investigations at the UniFirst site that have been undertaken during the past six years. These intensive investigations have defined the geologic, hydrologic, and groundwater quality conditions at the site at a level of detail that far exceeds that provided by EBASCO in any of their reports. This report summarizes the major results of those investigations.

##### b. Site Conditions

The three acre UniFirst property, located at 15 Olympia Avenue contains one 50,000 square foot building. The only unpaved areas of the site are narrow strips of grass near Olympia Avenue and a small area in the northeast corner of the property. The existing building is currently empty and unused, but in the past was used primarily for storage and offices. Limited dry cleaning operations were conducted in the building during the period 1966 through 1968. From the mid-1970's until it was removed in 1982, a 5,000 gallon tank storing tetrachloroethylene for transshipment offsite was located above ground inside the building.

## 2. Geology

### a. General Description

The UniFirst property is located on the perimeter of the north-south trending valley which contains the Aberjona River and associated wetlands. Soil materials on the east side (UniFirst side) of the valley are glacial tills underlain by a bedrock ridge. Unconsolidated materials in the valley are glacial outwash deposits and recent alluvial sediments consisting of interbedded sands, silts, clays, and gravels. Peat deposits of varying thickness underlie the wetland areas near the Aberjona River.

### b. Overburden

The nature of the overburden material at the UniFirst property has been investigated with twenty boreholes drilled for the purpose of installing ground water monitoring wells and several test pits. The overburden ranges in thickness from less than ten feet at the eastern end of the UniFirst property and to approximately 70 feet toward the western side.

The overburden material encountered on the UniFirst site generally is glacial till which has been described as brown to yellow brown, very dense fine sand with silt containing some fine to medium gravel. As a result of the poorly sorted nature of glacial till, it has a low void ratio. Numerous large boulders are found throughout the site within the till.

### c. Bedrock

The bedrock beneath the UniFirst property and the site area is a gray to pink granodiorite. Numerous fractures of various sizes are found throughout the bedrock. Many of these fractures are filled or partially filled (coated) with calcium carbonate or iron oxide deposits. The regional fracture system is known to have a northeast to southwest trend with orthogonal joints.

Bedrock on the UniFirst property is found at depths ranging from less than ten feet to over seventy feet. Contour plots indicate that the bedrock surface dips steeply toward the west at a rate of approximately 16 feet per 100 feet across the UniFirst site. This steeply dipping rock surface forms the edge of a valley in the bedrock that trends north to south. It is this valley that is filled with the glacial outwash deposits and recent alluvial sediments described above.

## 3. Groundwater Hydrology

### a. General Description

Groundwater flow in the area of the UniFirst site occurs in a southwesterly direction, generally consistent with the slope



of the bedrock surface. The higher hydraulic heads which are found to the northeast of the site area decrease at a relatively constant rate toward the Aberjona River valley. In general, the shallow bedrock aquifer is recharged by downward vertical movement of groundwater from the overburden. Area-wide water level measurements also indicate that the intermediate and deep zones within the bedrock discharge horizontally and/or vertically upward through the sides and bottom of the alluvial valley.

b. Overburden

According to contoured water levels measured in the overburden, ground water flow occurs toward the southwest under a gradient with a horizontal component of 0.020 feet per foot. When these water levels are compared to water levels from the shallow bedrock aquifer, it is found that the downward vertical component of the hydraulic gradient is a factor of two larger than the horizontal component of the gradient. Thus, the primary direction of groundwater flow in the overburden at the UniFirst site is downward into the shallow bedrock.

Hydraulic conductivity values have not been determined for the overburden material at the UniFirst site, but it is clear from the geologic logs that the soil materials at the UniFirst site are not nearly as permeable as those in the valley that are capable of yielding significant quantities of water.

c. Bedrock

Groundwater in the shallow bedrock flows horizontally toward the southwest under a similar gradient to that found in the overburden. The largest component of the hydraulic gradient causes the majority of the water in the overburden to flow vertically downward into the shallow bedrock. Limited water level elevations are available for the deep aquifer, but all of the measurements available indicate that there is a strong component of upward vertical flow from the deep bedrock zone to the intermediate bedrock zone.

A three-day aquifer test was conducted in February 1988 to determine the hydraulic properties of the bedrock in the vicinity of the UniFirst site. The hydraulic conductivity of the bedrock was determined from this test to be approximately  $6.0 \times 10^{-4}$  ft/min. This value is well within the range considered reasonable for fractured rock.

The nature and extent of the fracture network within the bedrock cannot be determined from small diameter cores. However, the pattern of water level declines associated with the three-day aquifer test suggests that a large, linear fracture crosses the site from the northeast to the southwest. It cannot be determined from the data available whether this fracture dips

to the southeast or the northwest. The aquifer test results also suggest that the shallow bedrock fracture system has many interconnections, but no clear pattern is presented -- a result not unexpected in such a system.

#### 4. Groundwater Quality

##### a. DNAPL Behavior

Dense non-aqueous phase liquids (DNAPL) are those products, such as tetrachloroethylene, which have a density greater than that of water. When DNAPL enters soil material at the ground surface it tends to migrate downward, usually very quickly. As the DNAPL moves downward, some of the material adheres to soil or rock particles causing a reduction in the volume of DNAPL as it moves. DNAPL spills can move downward, losing mass along the way, and cause a pool of the material to form when the downward migration is halted by an impermeable layer such as a clay or, in some cases, bedrock. If the bedrock is fractured, as is the case here, the DNAPL will follow a path through the fracture network and settle out in tiny, dead-end fractures in a matter of days. The DNAPL will then yield dissolved constituents to flowing groundwater. If the DNAPL remains stationary, dissolved constituents will leach from it until the mass is depleted.

##### b. Overburden

Water quality analytical results for wells screened in the vicinity of the UniFirst site indicate tetrachloroethylene contamination of the groundwater downgradient (to the southwest) of the site. Contamination has been found just above the bedrock surface on the UniFirst site at levels between 0.05 and 1.9 milligrams per liter. Similar levels are found off-site within 600 feet of the site to the south and southeast.

##### c. Bedrock

The shallow bedrock at the UniFirst site has been found to have tetrachloroethylene concentrations ranging from 0.03 to 9.4 milligrams per liter. To the southeast of the UniFirst site in the direction of groundwater flow, tetrachloroethylene has been found in monitoring wells at concentrations ranging up to 0.9 milligrams per liter. Concentrations of tetrachloroethylene in the deep bedrock beneath and downgradient of the UniFirst site have been found at levels up to 17 milligrams per liter. The highest concentrations have been found along a southwest-trending line that appears to originate in the area of the UniFirst loading dock, where a small quantity of DNAPL was discovered and removed. The dissolved concentrations are believed to be located in the southwest trending fracture discussed above. No DNAPL has been found anywhere else on or off the UniFirst site.

#### d. Volume Estimates

Contoured water level data have been used to generate groundwater flow lines in the vicinity of the UniFirst site. These groundwater flow lines can be used to define "streamtubes" -- sections of the aquifer having definable properties such as hydraulic conductivity and depth. Using this streamtube approach, the total volume of groundwater flowing beneath and in the vicinity of the UniFirst site in the bedrock has been estimated to be approximately 6 million gallons per year.

The volume of the streamtubes also can be used to obtain an estimate of the volume of tetrachloroethylene in groundwater in the UniFirst plume. Using a streamtube length of approximately 1300 feet (the distance from the UniFirst site to the edge of the alluvial valley), less than four gallons of tetrachloroethylene are estimated to be present in a dissolved form in approximately 2 millions gallons of groundwater in the bedrock aquifer.

#### 5. Groundwater Remediation

The distribution of tetrachloroethylene in the vicinity of the UniFirst site has been well-defined and is primarily confined to the granodiorite bedrock. Low levels of tetrachloroethylene which have been found in the overburden are migrating under natural hydraulic gradients to the shallow bedrock and have not migrated any significant distance from the UniFirst site.

The EPA preferred remedy for groundwater recovery at the UniFirst site is pumping of the overburden at a rate of 60 gallons per minute (gpm) and pumping of the bedrock at a rate of 20 gpm. Previous discussions in this document have indicated that a pumping rate of 60 gpm from the overburden is not achievable. In fact, the overburden material is probably not capable of yielding 5 gpm on a sustained basis. Pumping of the bedrock at a rate of 20 gpm was demonstrated during a three-day aquifer test during early 1988. Further long-term testing of this pumping rate was proposed during 1988, but permission to conduct this pilot test could not be obtained from the EPA. UniFirst is in agreement with the proposed pumping rate for the bedrock aquifer and is convinced that the existing recovery well (UC22) can be used effectively to remediate both the overburden and the bedrock aquifer.

#### a. Pumping System

During early 1988, UniFirst demonstrated that well UC22, located in the northeast portion of the site, could be pumped for a period of three days at a rate of 20 gallons per minute and effectively alter the hydraulics of the bedrock zone contaminated with tetrachloroethylene. This test also indicated

that pumping at UC22 had sufficient influence upon water levels in the shallow bedrock to cause an increase in the vertical downward component of the hydraulic gradient from the overburden to the bedrock. The depression of water levels caused by pumping UC22 reached out within a matter of hours to areas well beyond the site perimeter, especially along the fracture discussed above. By the end of the test, responses were measureable in both overburden and bedrock wells. Extrapolation of these results to a long-term pumping program using UC22 indicates that contaminated groundwater in the vicinity of the UniFirst property can be effectively contained and retrieved. No technology currently exists for extracting the DNAPL itself; however, pumping the groundwater will hasten DNAPL depletion as well as control off-site migration of the dissolved fraction.

#### b. Control of Mass Flux

Pumping a well at a rate of 20 gallons per minute produces 5.25 million gallons of water per year. Previous calculations showed that the volume of contaminated ground water in the vicinity of the UniFirst property was approximately 2 million gallons. Thus, a pumping rate of 20 gpm will remove approximately 2.5 plume volumes per year. Virtually all ground water within the UniFirst streamtubes will be influenced by the hydraulic control effected by pumping UC22. The migration of contaminated ground water away from the UniFirst site will cease within a short period of time (days to weeks) of initiation of pumping at UC22.

#### D. Recommended Source Treatment for UniFirst

The major contaminant found at the UniFirst site is PCE. Other solvents such as TCE, DCE's, 1,1-DCA and 1,1,1-TCA are found at much lower levels but still above the MCL's. None of the metals are detected above MCL's except chromium which ranged from none detected to 1,230 ug/l in data presented in the RI/FS Appendix E.

Since the VOC levels are not exceptionally high at UniFirst, aqueous phase GAC adsorption is a viable alternative to air stripping with vapor phase GAC. Though the operational costs for aqueous phase GAC are higher than air stripping with vapor phase GAC, the savings in capital cost makes the two options comparable economically. For ease of operation, and to eliminate the inherent risks of air emissions with an air stripping tower, aqueous phase carbon treatment is the recommended treatment for VOC removal at UniFirst. At start-up, with the VOC levels assumed and using EPA carbon adsorption isotherms it is predicted the aqueous phase GAC will use approximately 160,000 pounds of carbon per year. This is based on removing the components such as 1,1-DCA, 1,1,1-TCA and the DCE's, which have poorer removal characteristics than PCE.

These compounds will break-through much sooner than PCE making them the controlling factor in carbon usage. As the aquifer is cleaned, the VOC levels should decrease. If the same relative proportions of VOCs are maintained through the life of the project, at some point PCE will be the only contaminant above MCL's, making break-through of the others unimportant at that time. At year 30, it is predicted that only 1,200 pounds of carbon per year will be required. This reduction in carbon use rates has been roughly approximated in the present worth analysis for ease of calculations by assuming a linear decrease in influent VOC concentrations. This will very likely still be an over-estimate of carbon use.

Iron and manganese do not appear to be present in the UniFirst wells in high enough concentrations that will require lime precipitation for removal. Plain filtration is recommended ahead of the GAC beds to remove as much iron and manganese precipitates as possible prior to VOC removal. The percentage of iron that is filterable shown in Appendix E of the RI/FS indicates that a significant portion of the iron will be removed with filtration.

Chromium is present in some of the UniFirst wells above the MCL of 50 ug/l. However, it is anticipated that adequate removal will be accomplished with filtration and GAC treatment. This is based on the fact that the significant levels of chromium found in wells at Olympia, Wildwood and New England Plastics were all 100% filterable in the lab. If chromium does remain soluble through the filter, and is in the hexavalent form, a significant percentage of it will be removed on the carbon.

It has already been determined that an 80 gpm design flow for UniFirst is overly optimistic, and that 10 to 20 gpm is more likely going to be the upper limit. This has a very dramatic effect on carbon usage rates. The proposed treatment system for UniFirst has been costed at 20 gpm.

A three day pumping test was run at 20 gpm on well UC-22 at the UniFirst site on February 29 to March 3, 1988, and samples taken periodically during the test and analyzed for VOC's. The results indicated similar concentrations to the data presented in the EBASCO report; however, there was a uniform and continuous increasing trend in concentrations over time. For example, results for tetrachloroethylene over time are summarized as follows:

<u>Pumping Time</u> <u>(hrs.)</u>	<u>Tetrachloroethylene</u> <u>(ug/l)</u>
0	N.D.
8	83
16	240
24	520
32	770
40	900
48	1,400
56	1,700
64	2,000
72	2,200

This indicates that the levels of VOC's to be removed may increase above the concentrations presented by EBASCO, resulting in increased carbon consumption.

#### E. Recommended Treatment for Other Sources

The unique characteristics of the waste streams at the other source areas makes tailored treatment schemes for each advisable. Below are rough, proposed treatment schemes for each of the other source areas. These treatment schemes are based on the VOC contents as described previously. It is imperative that more conclusive information be obtained for all the waste streams before the optimum design can be determined.

W.R. Grace - The presence of vinyl chloride along with other VOC's limits the treatment options. Vinyl chloride has extremely poor carbon adsorption characteristics, so aqueous phase carbon is not feasible. It does however, have a high Henry's Constant so it is readily strippable. This makes air stripping and vapor phase GAC a viable option; however, UV/oxidation treatment may be a preferable treatment option. It may cost slightly more than air stripping, but it eliminates any concerns about air pollution associated with air stripping.

With an air stripper, fouling of the packing by build up of iron and manganese precipitants is a concern. This means pre-treatment of the waste stream is necessary to remove iron and manganese. The lime precipitation, flocculation, filtration and re-carbonation proposed by EBASCO is adequate. However, it may be possible to remove iron and manganese more cost effectively using green sand filtration. This would eliminate more steps, especially the recarbonation which is quite expensive.

W.R. Grace has hired a consultant (Canonie Environmental) to evaluate its treatment needs. They essentially concur with our evaluation, and in order to avoid potential air emission

problems, they have recommended UV/Chemical oxidation for VOC removal. The proposed treatment system and associated capital and operation and maintenance costs as prepared by Canonie have therefore been presented in the summary tables in this report.

New England Plastics - The low levels of VOC's and the low flow rate make aqueous phase carbon the obvious choice for treatment at this site. No metals are of concern except iron and manganese. Filtration is proposed for iron and manganese removal similarly to UniFirst. If filtration is not sufficient, it could be replaced by a green sand filter.

Olympia - The VOC's at Olympia are not very high, and with a moderate flow rate aqueous phase GAC is an obvious choice. However, at this site several metals are at very high levels and considerably above MCL's. In particular, the presence of lead makes a precipitation process necessary. The system proposed by EBASCO of lime precipitation, flocculation, clarification, filtration and re-carbonation is appropriate.

Wildwood - This site has high levels of many VOCs, especially TCE. Included in the VOC's are vinyl chloride and chloroform. In addition, iron and manganese levels appear to be fairly high, and an occasional sample shows lead exceeding the MCL.

The high flow rates, high level of VOC contamination and the presence of vinyl chloride makes air stripping and vapor phase GAC the most practical option. Aqueous phase GAC is necessary as a polishing step. Even if the air stripper removed 99.9% of VOC's, some would still be above the MCL's, so a second step is required.

Pre-treatment to remove iron and manganese is needed to protect the air stripper. To just remove iron and manganese a green sand filter would most likely be a cost effective option. However, with lead a potential problem it may be prudent to use the pretreatment scheme proposed by EBASCO which includes chemical precipitation.

#### F. Central Area

It is not recommended to pump and treat the Central Area. If pumping were undertaken, treatment of the resulting waste stream would be very complex.

The VOC contamination levels are fairly low in the Central Area but the flow rates are high making a decision between air stripping and aqueous phase GAC more difficult.

The levels of iron and manganese may be of little concern. If the treatability study results are accurate for removal by

filtration, this may be all the pre-treatment that is needed for these metals. However, if this is inadequate it could be replaced with a green sand filter.

What contaminant levels will be drawn in from other sources such as the Aberjona is uncertain. However, it appears that these contaminants would include PAHs, lead, radionuclides and microorganisms. These would all influence the treatment scheme as follows:

PAHs - PAHs adsorbed to colloids will be caught at the filtration step. Other PAH's will be adsorbed by the GAC. The GAC usage rates may increase depending on what level of removal is required for PAHs, but should not be significant compared to the use rates required for VOCs. Verification of removal of PAHs to drinking water standards will be difficult, however. The testing required is difficult, expensive and time consuming.

Lead - Data from the Central Area wells and the Aberjona River indicate that lead removal will be required if Wells G & H are to be put into potable service, particularly if the proposed MCL of 5 ug/l or the target goal of <1 ug/l are required. Lead removal will require the addition of a chemical (lime) precipitation step followed by filtration. This would also remove iron and manganese, making the green sand filter unnecessary. Removal rates for lead using chemical precipitation and filtration can be 99+%. The sufficiency of the actual removal rate reliably achievable at Wells G & H is unknown at this time.

Radionuclides - If radon is present in Wells G & H it will be adsorbed by the GAC which would be consumed more quickly. Radium would pass through the GAC making other treatment necessary. The chemical (lime) precipitation process would remove radium along with lead, iron and manganese. Uranium will most likely be below MCL's, however, if present at higher levels, it should successfully be removed by lime precipitation and GAC.

Microorganisms - Chlorination as a final step for disinfection if the water is for potable consumption. If the water is discharged directly to the Aberjona this will not be necessary. The GAC step will remove most of the organic carbon prior to chlorination so it is not anticipated that formation of trihalomethanes will be significant. As a result, meeting drinking water standards of 100 ug/l for trihalomethanes should not require additional treatment.

#### G. Comparative Cost Estimates

This section presents a comparison of the estimated costs of the three treatment scenarios described above. The first is



the treatment scenario proposed by EPA/EBASCO, i.e. a single, centralized treatment plant. The costs of this scenario as estimated by EBASCO are presented in Table V-1, along with EBASCO's estimates of the costs of separate treatment plants.

The second scenario is the treatment scenario we propose, i.e. customized treatment at each of the five VOC source areas. The costs of this scenario as estimated by The Johnson Company and W.R. Grace are presented in Table V-2. Table V-2 presents a comparison with the major cost components for each source as estimated by EBASCO.

Table V-3 presents the cost of the small, separate Central Area treatment plant discussed above. This Table contrasts the major costs and components of this plant with that proposed by EBASCO. The cost of this plant can be added to the costs of the other separate plants to arrive at a hypothetical, comparative cost for separate source and Central Area plants, as shown on Table V-4.

Finally, Table V-5 presents a summary comparison of the total present worth costs of the EPA/EBASCO plan, the plan we recommend (Alternative 1) and the hypothetical plan utilizing separate source and Central Area treatment plants.

From these tables, it can be seen that the EPA/EBASCO plan is the most costly alternative, \$37.1 million. Even the hypothetical plan utilizing six separate, but properly designed plants is less costly, at \$36.3 million. Alternative 1, which we recommend as the best approach to controlling and removing VOCs from the five source areas and from the aquifer is easily the most cost-effective, at \$27.1 million.

Table V-1

Summary of EBASCO Cost Estimates  
Woburn Wells G & H Site

Source	EBASCO-MOM Alternative	EBASCO Design Flow	EBASCO Cost Estimates		
			Capital	O & M	PW
1. Unifirst	2A (i)	80 gpm	\$1,518,000	\$776,500	
2. W.R. Grace	2A (i)	65 gpm	1,402,000	752,900	
3. N.E. Plastics	2A (i)	21 gpm	1,338,000	521,800	
4. Olympia	2A (i)	50 gpm	1,249,900	543,400	
5. Wildwood	2A (i)	<u>300 gpm</u>	<u>2,616,600</u>	<u>1,119,100</u>	
	2A (i)	Subtotal:	\$8,124,500	\$3,713,700	\$ 65.2M
6. Central Area	3A	<u>540 gpm</u>	<u>3,079,000</u>	<u>1,373,600</u>	<u>\$ 24.2M</u>
	4A(i)	Total:	\$11,203,500	\$5,087,300	\$ 89.4M
Treatment of combined flow from 1) through 5)	2A (ii)	516 gpm	\$ 4,588,600	\$1,485,400	\$ 27.4M
Treatment of combined flow from 1) through 6)	4A (ii)	1056 gpm	\$ 7,000,000	\$2,271,700 (1-10 yrs) \$1,485,400 (11-30 yrs)	\$ 37.1M

XP-9121/z

Unifirst Corporation  
 Alternative MOM-2A(l) Pump & Treat Source Areas  
 Separate Treatment Plant  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost(20gpm)
Recarbonation System	An 800 gallon reinforced concrete tank with CO <sub>2</sub> diffuser, bulk CO <sub>2</sub> Storage tank and refrigeration unit	38,000	not necessary, no lime used	
Filtration	A 5-ft diameter by 8-ft deep dual media pressure filter, with backwash pump and automatic controls. 2400 gallon backwash tank	45,000	May be necessary to replace with a green sand filter	38,000*
Air Stripper	One 2 ft. diameter by 20-ft high packed tower filled with 50 ft <sup>3</sup> of one inch raschig ring, 700 scfm blower and 80 gpm pump.	51,000	Use aqueous phase, GAC	10,000
Vapor Phase Activated Carbon Adsorber	One 6-ft diameter by 4 ft high carbon adsorption unit with regeneration unit (113 ft <sup>3</sup> carbon)	150,000	Not needed, with aqueous phase GAC	
Treated groundwater Discharge system	1300 L.F. 2 inch diameter carbon steel pipe	130,000	Use PVC**	26,000
Control Building		196,000	Use existing building Cost is high enough to include utilities	100,000

\* based on EBASCO cost for N.E. Plastics Filtration System (20 gpm design flow)

\*\* may be able to use existing storm sewer

TABLE V-2

Unifirst Corporation  
 Alternate MOM-2A(i) Pump and Treat Source Areas,  
 Separate Treatment Facilities  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Adjusted Cost
Construction Indirects		100,000	Covered under the contingency item	0
	Total Direct Construction Costs	1,116,000		414,000
	Contingency (21%)	234,000		86,940
	Engineering (10%)	111,600		41,400
	Legal and Administrative (5%)	<u>56,000</u>		<u>20,700</u>
	Total Cost	1,518,000		563,040

TABLE V-2 continued

Unifirst Corporation  
 Alternate MOM-2A(i) Pump and Treat Source Areas,  
 Separate Treatment Facilities  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost(20 gpm)
Construction Indirects		100,000	Covered under the contingency item	0
	Total Direct Construction Costs	1,116,000		286,000
	Contingency (21%)	234,000		60,060
	Engineering (10%)	111,600		28,600
	Legal and Administrative (5%)	<u>56,000</u>		<u>14,300</u>
	Total Cost	1,518,000		388,960

TABLE V-2 continued

UNIFIRST - O & M

NOTE: All cost estimates rounded up to nearest hundred.

Alternative MOM 2A(i) Annual Operation and Maintenance Cost Estimates  
(1988 Dollars)

Cost Component	EBASCO Annual O&M Cost Estimate	EBASCO Adjusted Annual O&M Cost Estimate	Johnson Proposed 80 GPM Annual O&M Cost Estimate	Johnson Proposed 20 GPM Annual O&M Cost Estimate
1. Monitoring				
GroundWater Sampling	\$2,400			
Laboratory Analysis	\$16,000			
Report	\$3,000			
	-----			
	\$21,400	21,400	21,400	21,400
2. Pumping (Extraction)				
Power	\$1,600	1,600	1,600	600
3. Equalization Tank				
Power for 1 Pump	\$500	500	500	500
4. Chemical Feed/Storage System				
Lime Usage	\$2,100			
Polymer Usage	\$2,800			
	-----			
	\$4,900	4,900		
5. Recarbonation System				
Power for 1 Pump	\$700			
Carbon Dioxide Usage	\$17,000			
	-----			
	\$17,700	17,700		
6. Filtration System				
Power for 1 Pump	\$700	700	600	600
7. Air Stripper				
Power for 1 Pump	\$500			
Blower	\$200			
	-----			
	\$700	700		
8. Vapor Phase Activated Carbon Absorbers				
Fuel Cost	\$4,000			
Carbon Make Up	\$700			
	-----			
	\$4,700	3,300		
8a. Aqueous Phase Activated Carbon Absorbers			160,000	40,000
9. Sludge Off-Site Disposal	\$46,300	46,300	2,000	500
10. Labor	\$525,600	(1 MAN @ \$30/HR, 2080 HRS/YR) 62,400	62,400	62,400
11. Maintenance Cost (Building & Equipment)	8% of Capital Cost \$121,400	73,800	50,200	45,400
12. Contingency	5% of annual O&M \$31,200	11,700	14,900	8,600
	-----	-----	-----	-----
TOTAL ANNUAL O&M COST	\$776,500	245,000	313,600	180,000

TABLE V-2 continued

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TABLE V-2

W.R. GRACE SATELLITE TREATMENT UNIT  
 CANONIE CONCEPTUAL UV/CHEMICAL OXIDATION  
 CAPITAL COSTS

Component	Description	Feasibility Study Costs	General Comments	Canonie Cost Estimate
Site Preparation	Site clearing of trees, bushes, and debris, and a 1,000 sy area of crushed stone for parking of equipment.	\$ 14,000	No site preparation necessary. Area adjacent to Cryovac Facility is paved.	\$ -0-
Support Facilities	Consist of four office trailers for the EPA/DE, Engineers, Health and Safety, Contractor, and one contractor equipment trailer.	156,000	Construction of on-site treatment unit could be completed in less than three months. Trailer rental (2).	3,000
Pumping (Extraction)	Installation of two, 6-inch-diameter wells, 20 ft. deep, and one 6-inch-diameter well, 100 ft. deep with pumps, pipeline, and building for pumping station.	11,000	No building necessary for pumping station. Two recovery wells are present on-site.	70,000
Equalization Tank	One 16,000-gallon in-ground carbon steel tank with a discharge pump.	37,000	Tank sized to handle four hours of flow is excessive; 2,000-gallon above-ground tank acceptable.	7,500
Chemical Feed/Storage System	Includes a hydrated lime storage bin with a lime solution feed tank and pump. A polymer storage and feed tanks with a feed pump.	15,000	Pretreatment for removal of inorganics is not required to achieve required VOC removal efficiencies.	-0-
Chemical Coagulation/Flocculation/Clarification and Sludge Handling System	A 15-ft. upflow solids-contact type clarifier complete with drive mechanism, mixers, flocculation and settling zone, and a sludge transfer pump.	76,000	Pretreatment for removal of inorganics is not required to achieve required VOC removal efficiencies.	-0-

TABLE V-2  
(Continued)

W.R. GRACE SATELLITE TREATMENT UNIT  
CANONIE CONCEPTUAL UV/CHEMICAL OXIDATION  
CAPITAL COSTS

<u>Component</u>	<u>Description</u>	<u>Feasibility Study Costs</u>	<u>General Comments</u>	<u>Canonie Cost Estimate</u>
Recarbonation System	A 700-gallon reinforced concrete with CO <sub>2</sub> diffuser. A bulk CO <sub>2</sub> storage tank and refrigeration unit.	34,000	Pretreatment for removal of inorganics is not required to achieve required VOG removal efficiencies.	\$ -0-
Filtration	A 5-ft. diameter by 8-ft. deep dual media pressure filter with a backwash pump and automatic controls A 2,000-gallon filtered water collection tank.	43,000	Fabric filter after oxidation unit.	15,000
UV/Chemical Oxidation Unit	Oxidation chamber (stainless steel) with feed pump and piping. A chemical feed system with storage tank (100-gallon stainless steel) and metering pump.	118,000		110,000
Vapor Phase Activated Carbon Adsorber	One, 3-ft. diameter by 4-ft. high carbon adsorption regeneration with automatic controls and in-situ regeneration option.	150,000	Vent-Sorb units to be used for equalization tank, oxidation unit is pressurized.	-0-
Treated Ground Water Discharge System	800 lf of 3-inch-diameter carbon steel.	80,000	PVC pipe substituted for carbon steel pipe.	70,000
Control Building		186,000	25 ft. x 40 ft. building (Butler building). Possibility of using existing building.	100,000*

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TABLE V-2  
(Continued)

W.R. GRACE SATELLITE TREATMENT UNIT  
CANONIE CONCEPTUAL UV/CHEMICAL OXIDATION  
CAPITAL COSTS

<u>Component</u>	<u>Description</u>	<u>Feasibility Study Costs</u>	<u>General Comments</u>	<u>Canonie Cost Estimate</u>
Construction Indirects		80,000	Controls and instrumentation,	50,000
Utilities		155,000	Using Grace's existing power service	25,000
Treatability Study		50,000		15,000
Total Direct Construction Costs		\$1,031,000	Subtotal	\$465,500
Contingency (21 Percent)		274,000	Contingency (10 Percent)	46,600
Engineering (10 Percent)		124,500	Engineering (10 Percent)	46,600
Legal & Administrative (5 Percent)		66,300		
<b>TOTAL</b>		<b>\$1,774,800</b>	<b>TOTAL</b>	<b>\$558,700</b>

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TABLE V-2  
 (Continued)

CANONIE CONCEPTUAL W.R. GRACE SATELLITE TREATMENT UNIT  
 UV/CHEMICAL OXIDATION  
 ANNUAL O&M COSTS

<u>Cost Component</u>	<u>Basis of Estimate</u>	<u>Annual O&amp;M Cost Estimate</u>	<u>Year</u>	<u>General Comments</u>	<u>Canonie Cost Estimate</u>
<u>Chemical Feed/Storage System</u>					
Line Usage	23 T/yr @ \$75/T	1,700	1-30	Not necessary.	-0-
Polymer Usage	1,138 lbs/yr @ \$2/lb	2,300	1-30	Not necessary.	
<u>Recarbonation System</u>					
Power for 1 Pump	At \$0.10/kW-hr Total 0.8 HP 14 kW-hr/day	500	1-30	Not necessary.	-0-
Carbon Dioxide Usage	28 T/yr @ \$500/T	14,000	1-30	Not necessary.	
<u>Filtration System</u>					
Power for 1 Pump	At \$0.10/kW-hr Total 0.8 HP 14 kW-hr/day	500	1-30	Filter fabric, 24 rolls @ \$300/roll Disposal of 24 drums @ \$750/drum.	25,700

TABLE V-2  
(Continued)

CANONIE CONCEPTUAL W.R. GRACE SATELLITE TREATMENT UNIT  
UV/CHEMICAL OXIDATION  
ANNUAL O&M COSTS

<u>Cost Component</u>	<u>Basis of Estimate</u>	<u>Annual O&amp;M Cost Estimate</u>	<u>Year</u>	<u>General Comments</u>	<u>Canonie Cost Estimate</u>
<u>Chemical Feed System (Hydrogen Peroxide)</u>					
Hydrogen Peroxide	9.5 lbs/day @ \$0.75/lb	2,600	1-30		2,600
Hydrogen Peroxide Pump	@ \$0.10 kW-hr Total 0.1 HP 2 kW-hr/day	100	1-30		100
Pump to Feed Oxidation Chamber	@ \$0.10/kW-hr Total 0.8 HP 15 kW-hr/day	500	1-30		500
Oxidation Chamber	@ \$0.10/kW-hr 1,620 Kw-hr/day	59,100	1-30	\$0.10/kW-hr 1,440 Kw-Hr/day	52,600
<u>Vapor Phase Activated Carbon Adsorbers</u>					
Fuel Cost		4,000	1-30		-0-
Carbon Makeup	800 lbs/yr @ \$0.75/lb	600	1-30	Vent-Sorb units to treat air stream from equalization tank.	10,000

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TABLE V-2  
(Continued)

CANONIE CONCEPTUAL W.R. GRACE SATELLITE TREATMENT UNIT  
UV/CHEMICAL OXIDATION  
ANNUAL O&M COSTS

<u>Cost Component</u>	<u>Basis of Estimate</u>	<u>Annual O&amp;M Cost Estimate</u>	<u>Year</u>	<u>General Comments</u>	<u>Canonie Cost Estimate</u>
<u>Sludge Off-Site Disposal</u>	300 tons/yr @ \$125/ton	37,500	1-30	Not necessary.	-0-
<u>Labor</u>	6 men @ \$30/hr 8 hrs/day	525,600	1-30	One plant person @ 45 hrs/wk.	70,200
<u>Maintenance Cost (Building and Equipment)</u>	8 Percent of Capital Cost	142,200	1-30		44,700
<u>Contingency</u>	5 Percent of Annual O&M	30,500	1-30		12,100
<b>TOTAL ANNUAL O&amp;M COST</b>		<b>847,500</b>	<b>1-30</b>		<b>252,700</b>

Note: All cost estimates rounded up to nearest hundred.

New England Plastics  
 Alternative MOM-1A(II) Pump & Treat Source Area  
 Separate Treatment Plant  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Site Preparation	Site Cleaning, 1000 s.y. gravel parking area	14,000		14,000
Support Facilities	2 contractor, 1-EPA/DEQE 1 Engineers, 1 safety trailer	156,000	2 Trailers total or rent trailers for shorter duration	62,000
Pumping (Extraction)	Installation of one 6" well 20 feet deep, one 6" well 100' deep with pumps piping and well houses	67,000		67,000
Equalization Tank	One 5,100 gallon inground tank with discharge pump	20,000		20,000
Chemical Feed/ Storage System	Hydrated lime storage bin with lime solution feed tank and pump Polymer storage tank with feed tanks and pump	15,000	not required for iron and manganese removal	
Chemical Coagulation/ Flocculation/Clarification	A 10 foot upflow solids contact type clarifier with drive mechanisms mixers, flocculation and settling zones.	64,000	not required for iron and manganese removal	

TABLE V-2 continued

New England Plastics  
 Alternative MOM-2A(l) Pump & Treat Source Areas  
 Separate Treatment Plant  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Recarbonation System	A 200 gallon reinforced concrete tank with CO <sub>2</sub> diffuser, bulk CO <sub>2</sub> Storage tank and refrigeration unit	21,000	not needed, no line used	
Filtration	A 3-ft diameter by 8-ft deep dual media pressure filter, with backwash pump and automatic controls. 700 gallon backwash tank	38,000	green sand filter may be required	38,000
Air Stripper	One 1 ft. diameter by 20-ft high packed tower filled with 50 ft <sup>3</sup> of one inch raschig ring, 200 scfm blower and 21 gpm pump.	44,000	use aqueous phase GAC	44,000
Vapor Phase Activated Carbon Adsorber	One 3-ft diameter by 4 ft high carbon adsorption unit with regeneration unit (28 ft <sup>3</sup> carbon)	150,000	no air stripper	
Treated groundwater Discharge system	1100 L.F. 2 inch diameter carbon steel pipe	160,000	Use PVC	44,000*
Control Building		160,000	Cost is high enough to include utilities	160,000

\* *Additional cost over other alternatives due to wetlands*

*TABLE V-2 continued*

Alternative NOM 2A(i) Annual Operation and Maintenance Cost Estimates  
(1988 Dollars)

Cost Component	EBASCO Annual O&M Cost Estimate	EBASCO Adjusted Annual O&M Cost Estimate	Johnson Proposed Annual O&M Cost Estimate
1. Monitoring			
Groundwater Sampling	\$2,400		
Laboratory Analysis	\$16,000		
Report	\$3,000		
	-----		
	\$21,400	21,400	21,400
2. Pumping (Extraction)			
Power	\$300	300	300
3. Equalization Tank			
Power for 1 Pump	\$100	100	100
4. Chemical Feed/Storage System			
Lime Usage	\$500		
Polymer Usage	\$700		
	-----		
	\$1,200	1,200	
5. Recarbonation System			
Power for 1 Pump	\$100		
Carbon Dioxide Usage	\$4,500		
	-----		
	\$4,600	4,600	
6. Filtration System			
Power for 1 Pump	\$100	100	100
7. Air Stripper			
Power for 1 Pump	\$100		
Blower	\$100		
	-----		
	\$200	200	
8. Vapor Phase Activated Carbon Absorbers			
Fuel Cost	\$4,000		
Carbon Make Up	\$600		
	-----		
	\$4,600	1,400	
8a. Aqueous Phase Activated Carbon Absorbers			1,700
9. Sludge Off-Site Disposal	\$12,000	12,000	500
10. Labor	\$350,400	(1 MAN @ \$30/HR, 2080 HRS/YR) 62,400	62,400
11. Maintenance Cost (Building & Equipment)	8% of Capital Cost \$107,000	65,200	42,600
12. Contingency	5% of annual O&M \$19,700	8,400	6,500
	-----	-----	-----
TOTAL ANNUAL O&M COST	\$521,800	177,300	135,600

TABLE V-2 continued



Olympia Nuisance Trust  
 Alternative MOM-2A(ii) Pump & Treat Source Areas  
 Separate Treatment Plant  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Site Preparation	Site Cleaning, 1000 s.y. gravel parking area	14,000		14,000
Support Facilities	2 contractor, 1-EPA/DEQE 1 Engineers, 1 safety trailer	156,000	2 Trailers total or rent trailers for shorter duration	62,000
Pumping (Extraction)	Installation of two 6" wells 40 feet deep with pumps, piping and well houses	96,000		96,000
Equalization Tank	One 12,000 gallon inground tank with discharge pump	31,000		31,000
Chemical Feed/ Storage System	Hydrated lime storage bin with lime solution feed tank and pump Polymer storage tank with feed tanks and pump	15,000		15,000
Chemical Coagulation/ Flocculation/Clarification	A 10 foot upflow solids contact type clarifier with drive mechanisms mixers, flocculation and settling zones.	70,000		70,000

*TABLE V-2 continued*

Olympia Nominee Trust  
 Alternative MOM-2A(i) Pump & Treat Source Areas  
 Separate Treatment Plant  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Recarbonation System	A 500 gallon reinforced concrete tank with CO <sub>2</sub> diffuser, bulk CO <sub>2</sub> Storage tank and refrigeration unit	27,000		27,000
Filtration	A 4-ft diameter by 8-ft deep dual media pressure filter, with backwash pump and automatic controls. 1500 gallon backwash tank	42,000		42,000
Air Stripper	One 2 ft. diameter by 20-ft high packed tower filled with 50 ft <sup>3</sup> of one inch raschig ring, 450 scfm blower and 50 gpm pump.	48,000	use aqueous phase GAC	25,000
Vapor Phase Activated Carbon Adsorber	One 3-ft diameter by 4 ft high carbon adsorption unit with regeneration unit (28 ft <sup>3</sup> carbon)	150,000	Only needed for Pretreatment off-Gas no regeneration system	5,000
Treated groundwater Discharge system	200 L.F. 3 inch diameter carbon steel pipe	20,000		4,000
Control Building		175,000	Cost is high enough to include utilities	175,000

*TABLE V-2 continued*

Olympia Nominee Trust  
 Alternate MOM-2A(i) Pump and Treat Source Areas,  
 Separate Treatment Facilities  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Construction Indirects		75,000	Covered under the contingency item	0
	Total Direct Construction Costs	919,000		566,000
	Contingency (21%)	193,000		118,860
	Engineering (10%)	91,000		56,600
	Legal and Administrative (5%)	<u>46,000</u>		<u>28,300</u>
	Total Cost	1,249,000		769,760

*TABLE V-2 continued.*

Alternative MOM 2A(i) Annual Operation and Maintenance Cost Estimates  
(1988 Dollars)

Cost Component	EBASCO Annual O&M Cost Estimate	EBASCO Adjusted Annual O&M Cost Estimate	Johnson Proposed Annual O&M Cost Estimate
1. Monitoring			
GroundWater Sampling	\$2,400		
Laboratory Analysis	\$16,000		
Report	\$3,000		
	-----		
	\$21,400	21,400	21,400
2. Pumping (Extraction)			
Power	\$1,400	1,400	1,400
3. Equalization Tank			
Power for 1 Pump	\$300	300	300
4. Chemical Feed/Storage System			
Lime Usage	\$1,400		
Polymer Usage	\$1,800		
	-----		
	\$3,200	3,200	3,200
5. Recarbonation System			
Power for 1 Pump	\$400		
Carbon Dioxide Usage	\$11,000		
	-----		
	\$11,400	11,400	11,400
6. Filtration System			
Power for 1 Pump	\$400	400	400
7. Air Stripper			
Power for 1 Pump	\$300		
Blower	\$100		
	-----		
	\$400	400	
8. Vapor Phase Activated Carbon Absorbers			
Fuel Cost	\$4,000		
Carbon Make Up	\$600		
	-----		
	\$4,600	2,200	
8a. Aqueous Phase Activated Carbon Absorbers			45,000
9. Sludge Off-Site Disposal	\$28,800	28,800	28,800
10. Labor	\$350,400	(1 MAN @ \$30/HR, 2080 HRS/YR) 62,400	62,400
11. Maintenance Cost (Building & Equipment)	8% of Capital Cost \$100,000	60,000	46,600
12. Contingency	5% of annual O&M \$21,100	9,600	11,000
	-----	-----	-----
TOTAL ANNUAL O&M COST	\$543,400	201,500	231,900

TABLE V-2 continued.

Wildwood Conservation Corporation  
 Alternative MOM-2A(ii) Pump & Treat Source Areas  
 Separate Treatment Plant  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Site Preparation	Site Cleaning, 1000 s.y. gravel parking area	17,000		17,000
Support Facilities	2 contractor, 1-EPA/DEQE 1 Engineers, 1 safety trailer	156,000	2 Trailers total or rent trailers for shorter duration	62,000
Pumping (Extraction)	Installation of four 6" wells 75 feet deep, three 6" well 100' deep with pumps piping and well houses	316,000		316,000
Equalization Tank	One 720,000 gallon inground tank with discharge pump	89,000		89,000
Chemical Feed/ Storage System	Hydrated lime storage bin with lime solution feed tank and pump Polymer storage tank with feed tanks and pump	28,000		28,000
Chemical Coagulation/ Flocculation/Clarification	A 25 foot upflow solids contact type clarifier with drive mechanisms mixers, flocculation and settling zones.	186,000		186,000

*TABLE V-2 continued.*

Wildwood Conservation Corporation  
 Alternative MOM-2A(i) Pump & Treat Source Areas  
 Separate Treatment Plant  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Recarbonation System	An 3000 gallon reinforced concrete tank with CO <sub>2</sub> diffuser, bulk CO <sub>2</sub> Storage tank and refrigeration unit	94,000		94,000
Filtration	A 9-ft diameter by 8-ft deep dual media pressure filter, with backwash pump and automatic controls. 9000 gallon backwash tank	86,000		86,000
Air Stripper	One 4 ft. diameter by 35-ft high packed tower filled with 380 ft <sup>3</sup> of one inch raschig ring, 2500 scfm blower and 300 gpm pump.	70,000	add aqueous phase GAC as polishing step	220,000
Vapor Phase Activated Carbon Adsorber	One 10-ft diameter by 4 ft high carbon adsorption unit with regeneration unit (314 ft <sup>3</sup> carbon)	410,000		410,000
Treated groundwater Discharge system	600 L.F. 5 inch diameter concrete pipe	80,000	Use PVC or CMP	18,000
Control Building		292,000	Cost is high enough to include utilities	292,000

*TABLE V-2 continued*

Wildwood Conservation Corporation  
 Alternate MOM-2A(i) Pump and Treat Source Areas,  
 Separate Treatment Facilities  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Construction Indirects		100,000	Covered under the contingency item	0
	Total Direct Construction Costs	1,924,000		1,818,000
	Contingency (21%)	404,000		381,780
	Engineering (10%)	192,000		181,800
	Legal and Administrative (5%)	<u>96,200</u>		<u>90,900</u>
	Total Cost	2,616,600		2,472,480

*TABLE V-2 continued*

WILDWOOD - O & M

NOTE: All cost estimates rounded up to nearest hundred.

Alternative MOM 2A(i) Annual Operation and Maintenance Cost Estimates  
(1988 Dollars)

Cost Component	EBASCO Annual O&M Cost Estimate	EBASCO Adjusted Annual O&M Cost Estimate	Johnson Proposed Annual O&M Cost Estimate
1. Monitoring			
GroundWater Sampling	\$2,400		
Laboratory Analysis	\$16,000		
Report	\$3,000		
	-----		
	\$21,400	21,400	21,400
2. Pumping (Extraction)			
Power	\$12,600	12,600	12,600
3. Equalization Tank			
Power for 1 Pump	\$2,000	2,000	2,000
4. Chemical Feed/Storage System			
Lime Usage	\$8,100		
Polymer Usage	\$10,500		
	-----		
	\$18,600	18,600	18,600
5. Recarbonation System			
Power for 1 Pump	\$2,500		
Carbon Dioxide Usage	\$64,500		
	-----		
	67,000	69,000	69,000
6. Filtration System			
Power for 1 Pump	\$2,500	2,500	2,500
7. Air Stripper			
Power for 1 Pump	\$2,000		
Blower	\$1,300		
	-----		
	3,300	3,300	3,300
8. Vapor Phase Activated Carbon Absorbers			
Fuel Cost	\$4,000		
Carbon Make Up	\$34,400		
	-----		
	38,400	43,800	43,800
8a. Aqueous Phase Activated Carbon Absorbers			38,000
9. Sludge Off-Site Disposal	\$175,000	175,000	175,000
10. Labor	\$525,600	(2 MEN @ \$30/hr, 2080 HRS/YR) 124,800	124,800
11. Maintenance Cost (Building & Equipment)	8% of Capital Cost \$209,400	138,400	150,400
12. Contingency	5% of annual O&M \$43,300	30,600	33,000
	-----	-----	-----
TOTAL ANNUAL O&M COST	\$1,119,100	642,000	694,400

TABLE V-2 continued



Central Area  
Alternative MOM-3A Pump & Treat Central Area  
Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Site Preparation	Site Cleaning, 1000 s.y. gravel parking area	18,000		18,000
Support Facilities	2 contractor, 1-EPA/DEQE 1 Engineers, 1 safety trailer	156,000	2 Trailers total or rent trailers for shorter duration	62,000
Pumping (Extraction)	Rehabilitation existing wells	123,000		123,000
Equalization Tank	One 130,000 gallon inground tank with discharge pump	116,000		116,000
Chemical Feed/ Storage System	Hydrated lime storage bin with lime solution feed tank and pump Polymer storage tank with feed tanks and pump	28,000	not necessary for iron and manganese removal	28,000
Chemical Coagulation/ Flocculation/Clarification	A 35 foot upflow solids contact type clarifier with drive mechanisms mixers, flocculation and settling zones.	442,000	not necessary for iron and manganese removal	442,000

TABLE V-3

Central Area  
Alternative MOM-3A Pump & Treat Central Area  
Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Recarbonation System	A 5500 gallon reinforced concrete tank with CO <sub>2</sub> diffuser, bulk CO <sub>2</sub> Storage tank and refrigeration unit	128,000	not needed, no line used	128,000
Filtration	A 12-ft diameter by 8-ft deep dual media pressure filter, with backwash pump and automatic controls. 16200 gallon backwash tank	204,000	green sand filter may be required	204,000
Air Stripper	One 6 ft. diameter by 35-ft high packed tower filled with 850 ft <sup>3</sup> of one inch raschig ring, 4500 scfm blower and 540 gpm pump.	87,000	use aqueous phase GAC	270,000
Vapor Phase Activated Carbon Adsorber	One 10-ft diameter by 4 ft high carbon adsorption unit with regeneration unit (314 ft <sup>3</sup> carbon)	410,000	not needed with aqueous phase GAC	
Chlorination/Disinfection			Disinfection was not included	2,000
Treated groundwater Discharge system	700 L.F. 5 inch diameter concrete pipe	110,000		28,000*
Control Building		342,000	Cost is high enough to include utilities	342,000

\* Additional cost over other alternatives due to wetlands

TABLE 4-3 continued

Central Area  
 Alternate MOM-3A Pump and Treat Central Area,  
 Capital Costs

Component	Description	Feasibility Study Costs	General	Johnson Proposed Cost
Construction Indirects		100,000	Covered under the contingency item	0
	Total Direct Construction Costs	2,264,000		1,763,000
	Contingency (21%)	475,400		370,230
	Engineering (10%)	226,400		176,300
	Legal and Administrative (5%)	<u>113,200</u>		<u>88,150</u>
	Total Cost	3,079,000		2,397,680

TABLE V-3 continued

TREATMENT PLANT - 3A(i) - O & M

Alternative NOM 2A(i) Annual Operation and Maintenance Cost Estimates  
(1988 Dollars)

Cost Component	EBASCO Annual O&M Cost Estimate	EBASCO Adjusted Annual O&M Cost Estimate	Johnson Proposed Annual O&M Cost Estimate
1. Monitoring			
GroundWater Sampling	\$2,400		
Laboratory Analysis	\$16,000		
Report	\$3,000		
	-----		
	\$21,400	21,400	21,400
2. Pumping (Extraction)			
Power	\$15,200	15,200	15,200
3. Equalization Tank			
Power for 1 Pump	\$3,600	3,600	3,600
4. Chemical Feed/Storage System			
Lime Usage	\$14,600		
Polymer Usage	\$18,900		
	-----		
	\$33,500	33,500	33,500
5. Recarbonation System			
Power for 1 Pump	\$4,500		
Carbon Dioxide Usage	\$116,000		
	-----		
	\$120,500	120,500	120,500
6. Filtration System			
Power for 1 Pump	\$4,500	4,500	4,500
7. Air Stripper			
Power for 1 Pump	\$3,600		
Blower	\$4,300		
	-----		
	\$7,900	7,000	
8. Vapor Phase Activated Carbon Absorbers			
Fuel Cost	\$4,000		
Carbon Make Up	\$7,100		
	-----		
	\$11,100	24,100	
8a. Aqueous Phase Activated Carbon Absorbers			38,000
8b. Chlorine			5,300
9. Sludge Off-Site Disposal	\$312,500	312,500	312,500
10. Labor	\$525,600	(2 MAN @ \$30/HR, 2080 HRS/YR) 124,800	124,800
11. Maintenance Cost (Building & Equipment)	8% of Capital Cost \$266,000	165,600	147,400
12. Contingency	5% of annual O&M \$52,700	41,600	41,300
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TOTAL ANNUAL O&M COST	\$1,373,600	874,300	868,000

TABLE V-3 continued

Table V-4

Cost Summary - Recommended Treatment  
Woburn G & H Site

Source	Proposed Treatment	Proposed Flow (gpm)	PROPOSED COSTS		
			Capital	O & M*	PW
Unifirst	Equalization, Filtration, Aqueous phase Carbon	20	\$ 388,960	\$ 180,000	
W.R. Grace	Equalization, Oxidation and Filtration, UV/Chemical Oxidation**	20**	\$ 558,700**	\$ 252,700**	
N.E. Plastics	Equalization, Filtration, Aqueous phase carbon	21	\$ 610,640	\$ 135,600	
Olympia	EBASCO Pretreatment Aqueous phase carbon	50	\$ 769,760	\$ 231,900	
Wildwood	EBASCO pretreatment, Air stripping with off-gas treatment, Aqueous phase carbon polishing	300	\$2,472,480	\$ 694,400	
		Total:	\$4,800,540	\$1,494,600*	\$27.1M
Central Area	EBASCO Pretreatment Aqueous phase GAC, Chlorination	540	\$2,508,000	\$ 868,000	\$9,174,680

\* These costs represent year 1 costs: carbon use decreases over the life of the project (see details) and present worth reflects this.

\*\* As proposed by Canonic Environmental (draft)

Note: PW - 5% interest rate  
Source Areas 30 year operation  
Central Area 10 year operation

Table V-5

Treatment Plant Cost Summary

Present Worth Costs

	Unifirst	Grace	Olympia	Wildwood	N.E.Plastics	Sub- Total	540 GPM Central Area Plant	Total	1056 GPM Central Area Plant
EBASCO/Proposed plan *	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	\$37.1M
Alternative - 1	\$ 2.9M	\$ 4.4M	\$4.1M	\$13.0M	\$ 2.7M	\$27.1M	N/A	N/A	N/A
o Unifirst @ 20gpm/GAC									
o Grace @ 20 gpm/UV									
o No Central Area Plant									
Alternative - 2	\$ 2.9M	\$ 4.4M	\$4.1M	\$13.0M	\$ 2.7M	\$27.1M	\$9.2M	\$36.3M	N/A
o Alternative 1+									
o 540 gpm Central Area Plant upgraded for PAH, Lead, Radionuclides and Coliform									

\* Note that no land aquisition costs are included

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## VI. SOIL CONDITIONS AT UNIFIST

### A. Introduction

Soil Samples were collected by EPA during the drilling of UC4 through UC7 and UC15 through UC20 on the UniFirst site. Of these samples, EBASCO reported detections of tetrachloroethylene above the EBASCO target soil concentrations at UC5, UC7, and UC17. Investigations at the UniFirst property during the past six years have given no indication that shallow soil contamination exists or is likely to exist outside of the area around the former loading dock (the area of UC5). Thus, the reports of detections of tetrachloroethylene in shallow soils were somewhat surprising. Accordingly, we undertook limited field investigations and modelling based on our experience at this site and at the Tyson's Superfund site in Upper Merion Township, Pennsylvania. This program provided strong indications that the shallow soil contamination found is not due to a source of tetrachloroethylene within the soil, but rather, vice versa, that the shallow soils have been contaminated by movement of volatile tetrachloroethylene vapors emanating from the groundwater.

### B. Field Investigations and Modelling

During February 1989 two shallow borings were made in the area of the test pit which was excavated near the loading dock during 1986 to investigate shallow soil conditions around the fill line to the former tetrachloroethylene storage tank. During the original excavation of this pit, tetrachloroethylene odors were easily detected by field personnel and HNu equipment, but these odors rapidly dissipated. After the odors had dissipated, the test pit was backfilled, and the area was repaved. The soil samples obtained during February 1989 were collected into methanol-prepared sampling bottles and analyzed for halogenated volatile organic compounds. The results are as follows:

<u>Boring</u>	<u>Depth</u>	<u>PCE (ug/kg)</u>
VB4	6" - 2'	6,500
VB4	2' - 3'8"	<700
VB5	6" - 2'	23,000
VB5	2" - 3"	1,200

These results suggest that the soil in the test pit apparently has been recontaminated with tetrachloroethylene. Since tetrachloroethylene has not been handled on the UniFirst property since 1982, the source of tetrachloroethylene contamination in the soil cannot be spilled product. The source of the tetrachloroethylene contamination is likely to be migrating vapors trapped by the pavement.

The inferences derived from the test pit are supported by other data collected during 1986 and 1987 and confirmed during February 1989. During the drilling of borings UC4, UC5, and UC7 (during 1986 and 1987), rapidly dissipating HNu responses were observed immediately below the pavement. This response was not observed when drilling boring UC6, located in an unpaved area of the site.

During February 1989, new borings were completed adjacent to each of the borings that were determined by EBASCO to be located in areas of shallow tetrachloroethylene-contaminated soil. Boring VB1 was located immediately adjacent to UC5, VB2 was next to UC17, and VB3 was next to UC7. Soil samples were collected at approximately two-foot intervals to refusal and immediately upon retrieval placed in methanol-prepared bottles. Laboratory analyses were made for halogenated volatile organic compounds. The results for tetrachloroethylene are as follows:

<u>Boring</u>	<u>Depth</u>	<u>PCE (ug/kg)</u>
VB1	3" - 2'3"	580
VB1	2'3" - 3'3"	2,500
VB2	3" - 2'3"	1,200
VB2	2'3" - 4'3"	82
VB2	4'3" - 5'3"	57
VB3	3" - 2'3"	<22
VB3	2'3" - 4'3"	<16
VB3	4'3" - 6'	79
VB3	8' - 10'	<11
VB3	10' - 12'	54
VB3	12' - 13'	110

These results (especially those at VB1 and VB2) suggest that tetrachloroethylene contamination of the shallow soil persists in these areas. Since some of these values are larger than those determined by EBASCO, it is possible that the tetrachloroethylene concentrations are increasing -- a highly unlikely situation if the source of the contamination is the soil and not migrating vapors. It is also possible that the high concentrations found at some locations during 1989 are the result of an improved field collection technique (immediate field methanol extraction) compared to that likely used by EBASCO for the earlier samples.

The relatively lower levels of tetrachloroethylene found at VB3 are consistent with EPA's findings during previous sampling. The mathematical modeling demonstrated that soil vapor concentrations in areas not covered with asphalt would be significantly lower than in covered areas. It is thought that the lower concentrations at VB3 are due to the soil venting



mechanism provided by the manholes used to house the well heads of UC7, UC7A, and S71.

Upon completion of the soil sampling in each 1989 boring, four-inch diameter PVC casings were installed in the boring. These casings were only open at the bottom and were sealed along their exterior length with cement. Seals also were installed at the top of each casing to make them air-tight. One week after installation, a vapor sample was collected from each device by inserting a small diameter teflon tube through an access port drilled through the top seal. The vapor samples, which were analyzed for tetrachloroethylene, had the following results:

<u>Boring</u>	<u>Depth</u>	<u>PCE (ppb)</u>
VB1	3 ft.	34,000
VB2	4.75 ft.	22,000
VB3	10 ft.	6,020

Each of these sample tubes terminates near refusal and is only open at the bottom. As a result, the vapor concentrations detected are those that have risen vertically upward into the device. The vapor concentrations, therefore, cannot be attributed to horizontal migration of shallow vapors immediately below the pavement. These results indicate that significant tetrachloroethylene concentrations are found in soil vapors at some depth below the ground surface and suggest that the vapors are a result of volatilization of tetrachloroethylene from groundwater.

Prediction of vertical diffusion of vapors from contaminated groundwater upward to the vadose zone soils and gases requires knowledge of a number of variables including soil moisture content, soil organic carbon fraction, ground water chemical concentrations, and tortuosity of the air-filled pore space. For the case of the UniFirst site, some of these variables are known and others must be estimated. Using reasonable estimates for the unknown variables, mathematical modeling of vapor diffusion under the paved areas of the site was undertaken. Since the modeling of vapor migration was only one-dimensional, the variables could not be adjusted to account for heterogeneous subsurface conditions. The results of these simulations indicate that the tetrachloroethylene concentrations found in groundwater underlying the site can potentially contaminate soils in the vadose zone at levels up to several hundred parts per billion (ug/kg). If the heterogeneity of the subsurface could have been included in these simulations, it is possible that this estimate of soil tetrachloroethylene concentration could increase by an order of magnitude or more. In this context, it is reasonable to state that the tetrachloroethylene concentrations found on shallow soils during the recent sampling are achievable with the conditions present at the UniFirst site.

### C. Remedial Implications

The observations made in the field, the results of soil and vapor sampling and analysis, and the conclusions of vapor diffusion modeling at the UniFirst site, all suggest very strongly that the concentrations of tetrachloroethylene found in shallow soils do not represent soil contaminated by past practices, but rather that the contamination is the result of upward vapor migration. Excavating and incinerating shallow site soils at UniFirst will not provide a long-term remedy. The field investigations and vapor modeling described above suggest that similar levels of tetrachloroethylene will be found in the replacement backfill in a period of two to five years. The only remedy for soil contamination caused by upward vapor migration from contaminated groundwater is to treat the source of the contamination -- the groundwater.

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