

PROBLEMS OF MUNICIPAL DRINKING WATER SUPPLY
AND EVALUATION OF
A CHLORINATED BY-PRODUCTS POLICY

by

Takao Ikegami

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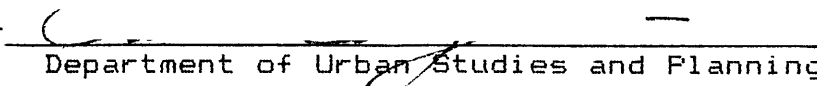
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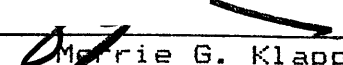
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by

TAKAO IKEGAMI

Submitted to the Department of Urban Studies and Planning
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ABSTRACT

The by-products of a chlorination of drinking water such as trihalomethanes (THMs) which possess a potential chronic health risk, caused a major reassessment of water treatment practices in the USA. In 1975, the Environmental Protection Agency (EPA) conducted a 80-city survey in which the drinking waters were examined for six organic compounds and the Agency concluded the presence of THMs in finished water was due to chlorination practice. In 1983, the EPA set the final THM rule for the best technology, treatment techniques or other means that the EPA found to be generally available, taking cost into consideration.

This paper focuses on this period and reviews the literature of drinking water disinfection, the substance of concerns in drinking water, the history of chlorination and the technologies of THMs control.

In addition, it describes the EPA's regulatory and rule making policy change concerning THMs and reevaluates Granular Activated Carbon as the ultimate method for removing the THMs from drinking water, from the standpoint of benefit-cost analysis.

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Chapter 1

INTRODUCTION

1.1 INTRODUCTION

The relatively recent discovery that chlorination of most natural waters for bacterial and viral disinfection produces chlorinated by-products with potential chronic health risks, has caused a major reassessment of water treatment practices in the USA. [These by-products include the trihalomethane (THM) group. It is probable that no other public health issue affects a larger proportion of the population than drinking water disinfection.] With cancer as a major cause of death in the United States, it is not easy to disregard chlorinated by-products as a possible cancer cause.

In 1975 Environmental Protection Agency (EPA) produced a report, "Preliminary Assessment of Suspected Carcinogens in Drinking Water," to Congress. In this report the EPA conducted a 80-city survey in which the raw and treated drinking waters were examined for six organic compounds. Results of the survey showed that chloroform was detected in the finished water of 100% of the cities surveyed, and that bromodichloroethane was found in 97.5% of the finished waters. Results of the survey indicated that the formation of these compounds is caused by the chlorination practices normally followed during water treatment operations.

In 1976 the National Cancer Institute released the results of a study which showed chloroform to be the cause of cancer in rats and mice under laboratory conditions. Although the actual effect on humans from drinking water containing chloroform at low levels over a long period of time is unknown, sufficient information has been accumulated to establish that a risk does exist.

In 1977 a National Academy of Sciences discussed the health effects of organic and other contaminants in drinking water. After assessing the available toxicological information, the report emphasized that:

1. When properly qualified, effects in test animals are applicable to man.
2. Methods do not presently exist to establish a threshold for long-term effects of toxic agents.
3. The exposure of experimental animals to toxic agents in high doses is a necessary and valid method of discovering possible carcinogenic hazards in man.
4. Material should be assessed in terms of human risk rather than "safe" or "unsafe".

The EPA set the trihalomethane (THM) rule on February 28, 1983 about the best technology, treatment techniques, taking costs into consideration. This rule applies to all public water systems that serve more than 10,000 persons and specifies what treatment methods a system may be required to install and/or use to come into compliance with the

trihalomethane's maximum contaminant level. In this rule, the EPA identified only chlorine dioxide and chloramine as acceptable alternative disinfectants.

When we look upon the history of chlorination which has been believed to be a safest disinfectant for a long time, the following questions come to mind.

1. Are chlorine dioxide and chloramine really acceptable alternatives of chlorine ?
2. Are these alternatives really as easy to handle for operators as well as chlorine ?
3. Isn't it necessary to remove the THM group from the drinking water for providing risk-free drinking water ?

This paper reviews these concerns on municipal drinking water supply and evaluates the EPA's chlorinated by-products policy as follows:

Chapter 1: Literature review of drinking water disinfection.

Chapter 2: Reviews the substances of concerns in drinking water .

Chapter 3: Reviews the history of chlorination and the characteristics of ideal chemical disinfectant.

Chapter 4: The case study at Huron by EPA.

Chapter 5, 6, 7: How they can be controlled.

Chapter 8: Describe EPA's regulatory and rule making policy change concerning THM.

Chapter 9: Assessment of the Granular Activated Carbon as

the ultimate method for removing the THMs from drinking water from the stand point of benefit-cost analysis.

1.2. REVIEW OF THE LITERATURE OF DRINKING WATER DISINFECTION

Since Kleeper and Fairless' first discovery of chlororganics in municipal drinking water in 1972, a number of studies have been done on drinking water disinfection problems. The following studies are the cornerstones of our understanding of this problem.

In 1975, the EPA concluded that trihalomethanes in drinking water were due to chlorination practice. In 1977, Hoehen, et. al. provided the first indication that algae may be important as trihalomethane precursors. In 1977, Tardiff discovered several significant facts about quantitative carcinogen risks to man and mouse.

In the following year, the EPA set the maximum contaminant level of 0.1 mg/l THM for systems serving more than 10,000 persons. In 1983, the EPA set the final rule for the best technology, treatment techniques but Granular Activated Carbon (GAC) was not included in this category.

Table 1: Literature Review (96)

Year	Name	Major Findings
1972	Kleeper & Fairless	First discovery of chlororganics in municipal drinking water from the Ohio river
1974	Beller, <u>et al.</u>	The presence of organochlorine compounds and some brominated hydrocarbons in tap water and detected trihalomethane level as low as 0.5-1 ppb
1975	Symons, <u>et al.</u>	The correlation of organic content of water to final trihalomethane concentrations
	EPA	National Organic Reconnaissance Survey (NORS) concluded that the presence of trihalomethanes in finished water was due to chlorination practice
1975	Glaze	Although trihalomethane does not result from chlorination of sewage, he has shown evidence for three chlorinated acetone derivatives that are possible precursors of chloroform
1976	Stevens, <u>et al.</u>	Significant quantities of halogenated methanes do not result from the chlorination of ammonia-containing sewage
1976	Page/Harris	Supported the hypothesis that there is a link between carcinogens in drinking water and cancer mortality
1976 1977	Rock	Clearly established a relationship between organic content of natural colored waters (fulvic and humic acids) and THM production

Year	Name	Major Findings
1977	Coleman, <u>et al.</u>	Found 72 volatile organic compounds in the finished waters, including chloroform, bromodichloromethane, dibromochloromethane, and bromoform
1977	Hoehn, <u>et al.</u>	On the Occoquan Reservoir chloroform was found to be the volatile organic appearing in highest concentrations
1977	Hoehn, <u>et al.</u>	Discussed the (paradox) of trying to protect public health by chlorination
1977	Hoehn, <u>et al.</u>	Provided the first indication that algae may be important as trihalomethane precursors
1977	Hoehn, <u>et al.</u>	Concurred that humate sources of trihalomethane precursors may have algal precursors superimposed upon them in spring and summer
1977	Tardiff	Chloroform has produced tumors in more than one species (mouse and rat)
	Tardiff	Quantitatively man and mouse appear to metabolize chloroform by similar pathways
	Tardiff	Concluded that hepatotoxicity in humans may require oral doses of greater than 1 mg/kg/day but less than 25 mg/kg/day
	Tardiff	Recommended the maximum chloroform concentration in tap water should be less than 70 ppb to ensure a dose of less than 0.01 mg/kg/day ✓
1977	Stevens/Symons	The reaction producing chloroform from chlorination disinfection is not an instantaneous reaction but it occurs until either chlorine or precursor is exhausted

Year	Name	Major Findings
1977	Morris/Baum	Postulated that the major mechanism for production of trihalomethanes by chlorination of organic matter in water is the classical haloform reaction
1978	Trussel/Umphres	The presence of bromide increases the yield of trihalomethanes for a given chlorine dose
1979	Hoehn <u>et al.</u>	Algae in exponential phase of growth yielded higher amounts of trihalomethane precursors than during other phase of their life cycle
1979	Babcock/Singer	There was a liner relationship between amount of total organic carbon (TOC) present and chloroform produced
1979	Moore, <u>et al.</u>	Chlorine dose was a major factor influencing variations in the chloroform levels of 19 chlorinated water supplies
1978	EPA	Set the maximum contaminant level of 0.10 mg/l total trihalomethanes (MCL) for systems serving more than 10,000 persons
1983	EPA	Set the final rule about the best technology, treatment techniques

CHAPTER 2

TRIHALOMETHANES IN DRINKING WATER

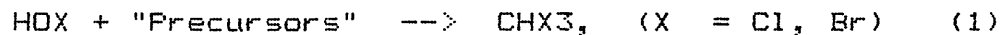
2.1 FORMATION OF TRIHALOMETHANES

The EPA set the THMs regulation of maximum contamination level (MCL) as 0.1 mg/l for the sum of four trihalomethanes. Chloroform and THMs are only some of the major products of chlorination but they happen to be relatively easy to analyze. THMs are ubiquitous and we can thus use them as indicators of the general contamination that result from chlorination.

As reviewed in the previous chapter, there are rapid developments in THMs' studies. The following list summarizes our present knowledge concerning the formation of occurrence of trihalomethanes (THMs) in drinking water: (98)

1. The trihalomethanes are generally not found in raw water sources but are found almost ubiquitously in finished water supplies where chlorination is used.

2. The trihalomethanes are formed in the process of treatment by a reaction often symbolized as follows:



where CHX₃ is the general formula for THM's.

This is an incomplete description of prevailing chemistry.

3. Bromine enters into the reaction by oxidation of naturally occurring bromide by hypochlorous acid (HOCl), the active chlorinating agent in water



Hypobromous acid, HOBr, is formed in this process and competes for precursor molecules with HOCl.

4. "Precursor" is a general term expressing all possible types of chemical species which may react with hypohalous acids to yield trihalomethanes (THMs). While the chemical identity of these precursors is unknown, and may never be known, they appear to be naturally occurring organic compounds rather than man-made (synthetic) compounds. Natural compounds or compound classes which have been shown to act as precursors include humic and fulvic acids from soils and aquatic sources, plant pigments, and algal extracellular products.

2.2. NATIONAL ORGANIC MONITORING SURVEY (NOMS) (29)

The EPA conducted the National Organic Monitoring Survey (NOMS) in 1977 to determine the frequency of occurrence of specific contaminants in drinking water supplies in 113 cities. (29) In addition NOMS was to provide data for the possible establishment of additional maximum contaminant levels for organic compounds or for a treatment requirement for the control of organic compounds in drinking water. The NOMS data (Table 2) shows that THM (chloroform, bromodichloromethane, dibromochloromethane, bromoform and dichloroiodomethane) are the most ubiquitous synthetic organic contaminants in drinking water and that they also occur at the highest concentrations (up

to 784 ppb THM potential were detected). They are produced by chlorination during treatment of their naturally occurring precursor—probably humus, but possibly algae and other chemicals as well considerable amounts of THM can form in the water after entering the distribution system and on its route to the consumer. In many instances, 2,4-dichlorophenol has also been found after chlorination.

It showed further that THM's far exceed the concentrations of other detectable synthetic organic contaminants in finished drinking water and that brominated THM's could also exceed the chloroform concentrations. As shown in Table 2, which summarizes the results of the NOMS study, chloroform has been found in water supplies at levels as high as 0.54 mg/l with TTHM levels reaching 0.695 mg/l.

Table 2: Trihalomethane Results from National Organics Monitoring Survey (NOMS) (29)

Trihalomethane	Concentration (mg/l)			
	Phase1	Phase2	Phase 3	
			Dechlorinated	Terminal
Chloroform				
Median	0.027	0.059	0.022	0.044
Mean	0.043	0.083	0.035	0.069
Range	*NF-0.271	NF-0.47	NF-0.20	NF-0.540
Bromoform				
Median	**LD	LD	LD	LD
Mean	0.003	0.004	0.002	0.004
Range	NF-0.039	NF-0.280	NF-0.137	NF-0.190
Dibromochloromethane				
Median	LD	0.004	0.002	0.003
Mean	0.008	0.012	0.006	0.011
Range	NF-0.190	NF-0.290	NF-0.114	NF-0.250
Bromodichloromethane				
Median	0.010	0.014	0.006	0.011
Mean	0.018	0.018	0.009	0.017
Range	NF-0.183	NF-0.180	NF-0.072	NF-0.125
Total trihalomethane				
Median	0.045	0.087	0.037	0.074
Mean	0.068	0.117	0.053	0.100
Range	NF-0.457	NF-0.784	NF-0.295	NF-0.695

*NF = not found
 **LD = less than detection limit.
 phase1 = stored at 2-8 centigrade for 1-2 weeks before analysis
 phase2 = stored at 20-25 centigrade for 3-6 weeks before analysis
 phase3 (dechlorinated)
 = immediately dechlorinated with sodium thiosulfate
 phase3 (terminal)
 = stored at 20-25 centigrade for 3-6 weeks before analysis

CHAPTER 3

CHLORINATION

As discussed in Chapter 2, the current concerns in municipal drinking water supply focus on the formation of trihalomethanes (THMs) and their adverse health effects. These concerns have been proved to be real and important. Equally important, but often disregarded are the positive aspects of water chlorination. (43) This chapter reviews the history of chlorination and its benefit to public health.

3.1 HISTORY OF CHLORINATION

Chlorine was first used as a disinfectant in France and England around 1800. (9) Sodium hypochlorite had become well-recognized as a disinfectant and deodorizer early in the 1800s, and was in fact used for deodorizing sewage in London in 1854. At that time, however, the nature of disinfection was not associated with microorganisms, but was considered a process that merely arrested putrefactive changes. It was not until the end of the century that disinfection of drinking water via chlorination came into its own. In 1897, during a typhoid fever epidemic, chlorination was employed as a temporary emergency measure in England. The first liquified chlorine gas was introduced in the US in 1910, in the same year it was applied to the Fort Meyer, Va., supply, in 1912 to the Niagara Falls, N.Y., supply.

As shown in Figure 1, the crude death rate for typhoid fever in the United States in 1900 was 31.3/100,000

population while by 1940 the rate was 1.0/100,000. These rates correspond to 23,817 and 1317 deaths respectively. By 1961, the total number of reported deaths from typhoid fever was 17. If the death rate of 1900 had continued to the present time, we might expect close to 70,000 annual deaths. (43)

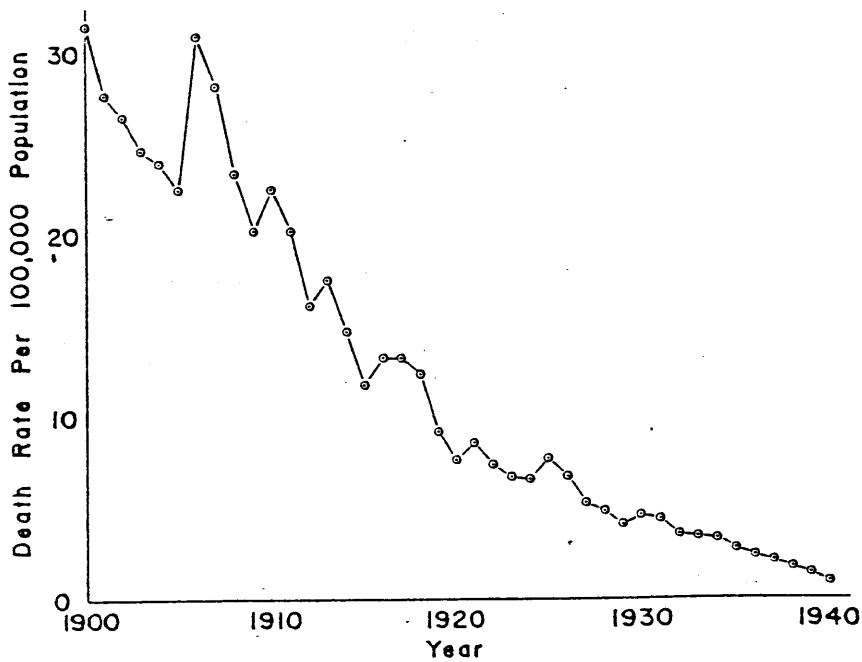


Figure 1: Crude death rates for typhoid fever in the USA from 1900 to 1940 (43)

3.2. THE TECHNOLOGY OF DISINFECTION

The purpose of the disinfection of water is to destruct disease-causing organisms. Typical waterborne bacterial diseases are typhoid, cholera, paratyphoid, and bacillary dysentery. The most common disinfectants are oxidizing chemicals of which chlorine is the most universally used. Chlorine dioxide (ClO_2), is also applied to water treatment plants and has an oxidizing power about 2.5 times as great as that of chlorine alone. Because chlorine dioxide is quickly taken up by organic matter in the water, its use is restricted to nonpolluted waters in which its bactericidal values can be utilized more fully. Because of the explosiveness of chlorine dioxide, it must be produced at the site of application.

The requirements for an ideal chemical disinfectant are reported in Table 3. (27) As shown, an ideal disinfectant would have to possess a wide range of characteristics. Although such a compound may not exist, the requirements set forth in Table 3 should be considered in evaluating proposed or recommended disinfectants. To water engineers, it is also important that the disinfectant be safe to handle and apply, and that its strength or concentration in treated water be measurable so that the presence of a residual can be determined.

Table 3. CHARACTERISTICS OF AN IDEAL CHEMICAL DISINFECTANT (27)

Characteristic	Remarks
1. Toxicity to microorganism	Should have a broad spectrum of activity of high dilutions
2. Solubility	Must be soluble in water or cell tissue
3. Stability	Loss of germicidal action on standing should be low
4. Nontoxic to higher forms of life	Should be toxic to organisms and nontoxic to man and other animals
5. Homogeneity	Solution must be uniform in composition
6. Interaction with extraneous material	Should not be absorbed by organic matter
7. Toxicity at room temperature	Should be effective in environmental temperature range
8. Penetration	Should have the capacity to penetrate through surfaces
9. Noncorrosive and nonstaining	Should not disfigure metals or stain clothing
10. Deodorizing ability	Should deodorize while disinfecting
11. Detergent capacity	Should have cleansing action to improve effectiveness of disinfectant
12. Availability	Should be available in large quantities and reasonably priced

3.3. REACTION OF CHLORINATION (96)

Chlorine is used as an oxidizing agent in water treatment plants for the removal of odors, reduction of biochemical oxygen demand (BOD), and as a disinfectant. Each mg/l of chlorine reduces BOD by around 2 mg/l (Dugan, 1978). Dugan noted that the effectiveness of chlorine depends on many factors, such as the amount and type of dissolved organic matter, temperature, pH, and the types of microorganisms to be destroyed. Also, the functional properties of chlorine as a disinfectant depend upon the amount of available chlorine in solution, called the residual chlorine.

Dugan has described the reaction involved in the chlorination process. Gaseous chlorine dissolves and reacts with water to form hypochlorous acid:



The hypochlorous acid (HOCl) is a weak acid which can (depending upon the pH) dissociate when dissolved in water to form the hypochlorite ion:



The HOCl and OCl⁻ have germicidal properties and together with Cl₂ are termed "free chlorine". The OCl⁻ has very weak germicidal properties compared to HOCl.

Chlorine reacts readily with many impurities in water and some of these reactions decrease the amount of chlorine available to inhibit microorganisms. Ammonium (NH₄⁺) or

ammonia (NH₃) react with chlorine to form chloramines. Chloramines have germicidal properties but they are much less effective than free chlorine (Hoehn et al., 1977). The term "combined chlorine residual" refers to the chlorine that is in the form of chloramine form. The term "available chlorine" includes both the combined and free chlorine. Chlorine-consuming chemicals in water exert a "chlorine demand" that must be met before a free chlorine residual can be maintained in the water.

CHAPTER 4

THE CASE STUDY AT HURON, SOUTH DAKOTA (2)

4.1. OBJECTIVES OF THE CASE STUDY

The EPA studied the Huron case in 1977, and their main purpose of this study was to find the answer to the question: What are the substances of concern ?

Among those 80 cities, Huron, South Dakota had the dubious distinction of having the highest concentration of bromodichloromethane (116mg/l) as well as the second highest concentration of chloroform (309mg/l). Consequently, the EPA selected this case and set the objectives of the studies as follows:

- (a) To qualitatively and quantitatively analyze the Huron water supply to more precisely define the problem of contaminations by chloroform and other related halogenated hydrocarbons.
- (b) To establish the source of these compounds
- (c) To find a means of water treatment which would effectively reduce the concentrations of these compounds.

4.2. TREATMENT METHOD

Water treatment at Huron consists of chemical addition, sedimentation, flocculation, clarification, recarbonation, filtration and chlorination. A process schematic is shown in Figure 2. A more detailed process description is described at Table 4.

Table 4: Process description at Huron water treatment plant

#	Process step	Description
	River to plant	Raw water is pumped from an intake located about 100' upstream from a small dam.
(1)	Initial chemical addition	Rapid dispersion of potassium permanganate, activated carbon alum, and a polyelectrolyte (Nalco 607).
(2)	Presedimentation	Settling of about 1 hour duration at a flow of 6 MGD.
(2)	Prechlorination	Initial chlorine dose, approximately 6 to 7 mg/l. Point of application revised during study period.
(3)	Rapid Mix No. 1	Chemical dispersion of lime, soda ash (occasionally), and sodium aluminate (Nalco 617)
(4)	Flocculation	Gentle stirring of the waterchemical mixture. Detention time at 6 MGD is about 1.5 hours.
(5)	Clarification	Settling of slightly more than 2 hours at a flow of 6 MGD.
(5)	Recarbonation	Adjustment of pH with CO ₂ to obtain a stable water. Fluoride for the control of dental carries and polyphosphate (Nalco 918) are added at this basin. The prechlorination dose was moved to this location in late April 1976.
(6)	Gravity filters	Filtration process using anthracite media.
(7)	Postchlorination	A final chlorine dose for disinfection.
(8)	Clearwell storage	Short term water storage at the treatment plants.

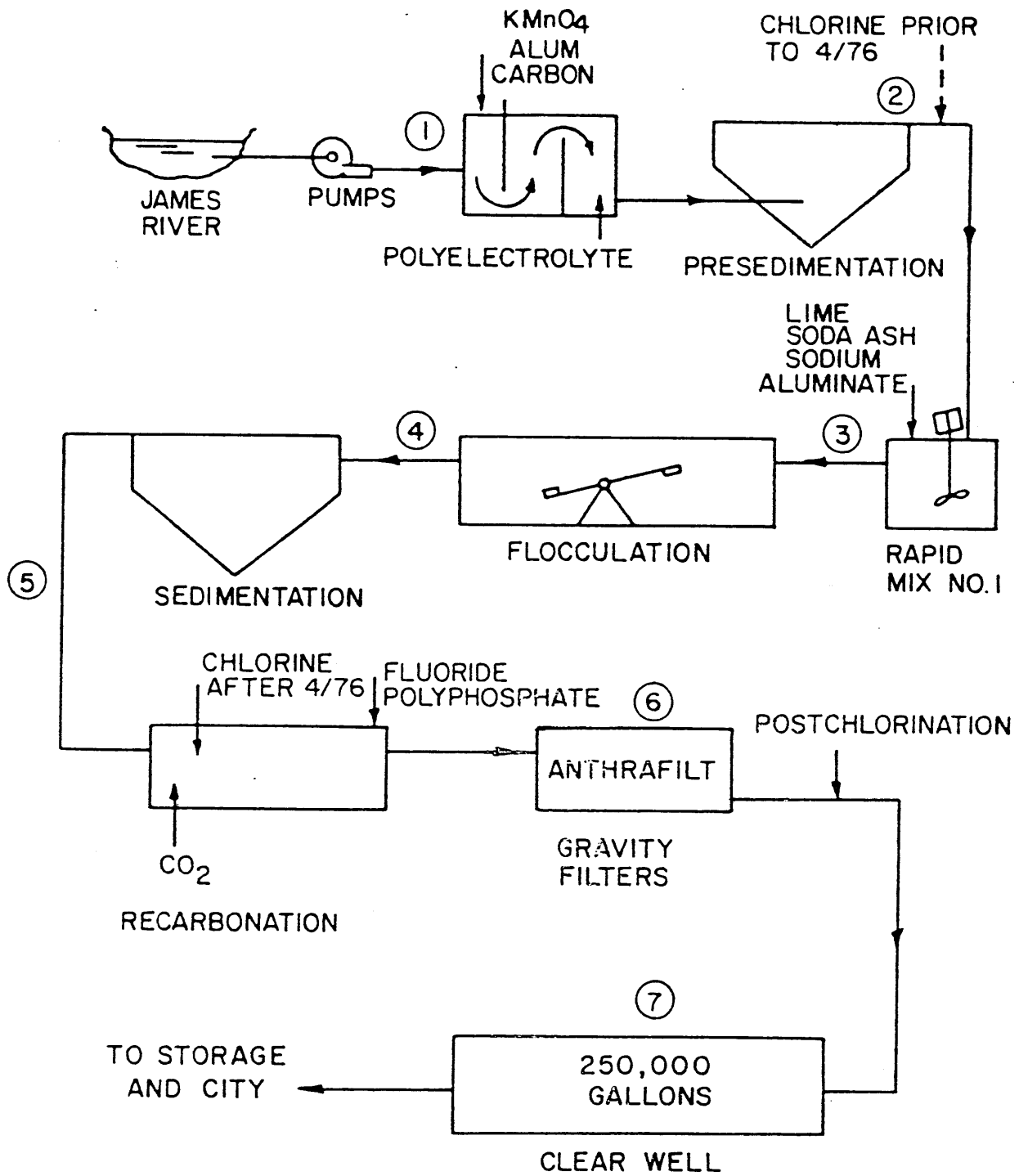


Figure 2 Process flow diagram for water treatment.

4.3. CONCLUSIONS OF THIS CASE STUDY

The investigation at Huron has provided valuable insight into the formation of haloforms under actual water treatment practices. The following conclusions were drawn from the study:

1. The haloforms form during and after water treatment. They were found to form in high concentrations at the point of chlorination and lime addition.
2. The potential chloroform concentration at Huron remains high, in the range of 200 to 325 ppb. However, the relocation of the prechlorination dose to a point following recarbonation resulted in a significant reduction in the chloroform concentration.
3. The mechanism of chloroform formation is strongly pH dependent, and the chloroform concentration in the clear well closely follows the effluent pH.
4. Lowering of the effluent pH below 9 is limited by problems of water stability.
5. Haloform concentrations continue to rise after entering the distribution system.
6. The ultimate solution to the problem of haloform formation is precursor removal, but a more practical solution is to prevent their formation during the treatment process.
7. The mechanism of bromodichloromethane formation does not appear to be strongly pH dependent.

4.4. RECOMMENDATIONS OF EPA STUDY.

Recommendations which evolved from the study are:

1. The disinfection should continue at the revised location.
2. Additional data on bromodichloromethane formation should be gathered. This constituent was not significantly reduced in this study.
3. Additional work should be done on the aftergrowth of haloforms within the distribution system.
4. Identification of the precursor source(s) should be considered in an attempt to reduce the potential for chlorinated hydrocarbon formation. Possibilities to be evaluated should include:
 - a. point sources upstream
 - b. the local practice of disposing of dead animals in the stream
 - c. precursor increase from biological growth in stagnant water
 - d. agricultural runoff as a precursor source
5. Alternate methods of disinfection should be considered such as the use of ozone, chloramines and chlorine dioxide.

4.5. SUMMARIES

This case study proposed several important facts.

Those are:

- (1) Point of chlorination moving is the good alternative.

- (2) It is difficult to control chloroform and bromodichloromethane by only pH adjustment.
- (3) Alternate method of disinfection should be considered.

According to the recommendations of this study, the EPA investigated the ozonation process in the next year's case study (1978). This process will be examined in the next chapter.

CHAPTER 5

OZONATION PROCESS

5.1. AN ASSESSMENT OF OZONE TECHNOLOGIES FOR TREATMENT OF MUNICIPAL WATER SUPPLIES. (1)

In the growing attention to the ozonation process as an alternate method of disinfection, the EPA investigated the ozonation plant in Europe. Many of the European countries have long been faced with the necessity of producing safe drinking water from chemically polluted raw water sources. As a result, there has been extensive development of drinking water technology in Europe.(1) Ozonation is the typical treatment method of drinking water.

The cornerstone of European water treatment philosophy is the desire to produce drinking waters that are free from chlorinous or other undesirable tastes and are chemically and bacteriologically safe. Actually, West European countries are searching continuously for groundwater supplies or water from mountainous areas which are relatively pure and require little or no treatment prior to distribution. Table 5 shows the operational plants using ozone and Table 6 shows the application of ozone in water treatment in Europe and Table 7 shows costs of ozonation at European drinking water plants and Figure 3 shows the typical points of application of ozone in drinking water processes.

Table 5: OPERATIONAL PLANTS USING OZONE -- 1977

Country	Number of Plants
France	539
Switzerland	150
Germany	136
Austria	42
Canada	23
England	18
The Netherlands	12
Belgium	9
Poland	6
Spain	6
USA	5
Italy	5
Japan	4
Denmark	4
Russia	4
Norway	3
Sweden	3
Algeria	2
Syria	2
Bulgaria	2
Mexico	2
Finland	1
Hungary	1
Corsica	1
Ireland	1
Czechoslovakia	1
Singapore	1
Portugal	1
Morocco	1

Total 1,039

*Includes expansions. Actual number of operating plants in Canada equals 20, with 3 more under construction

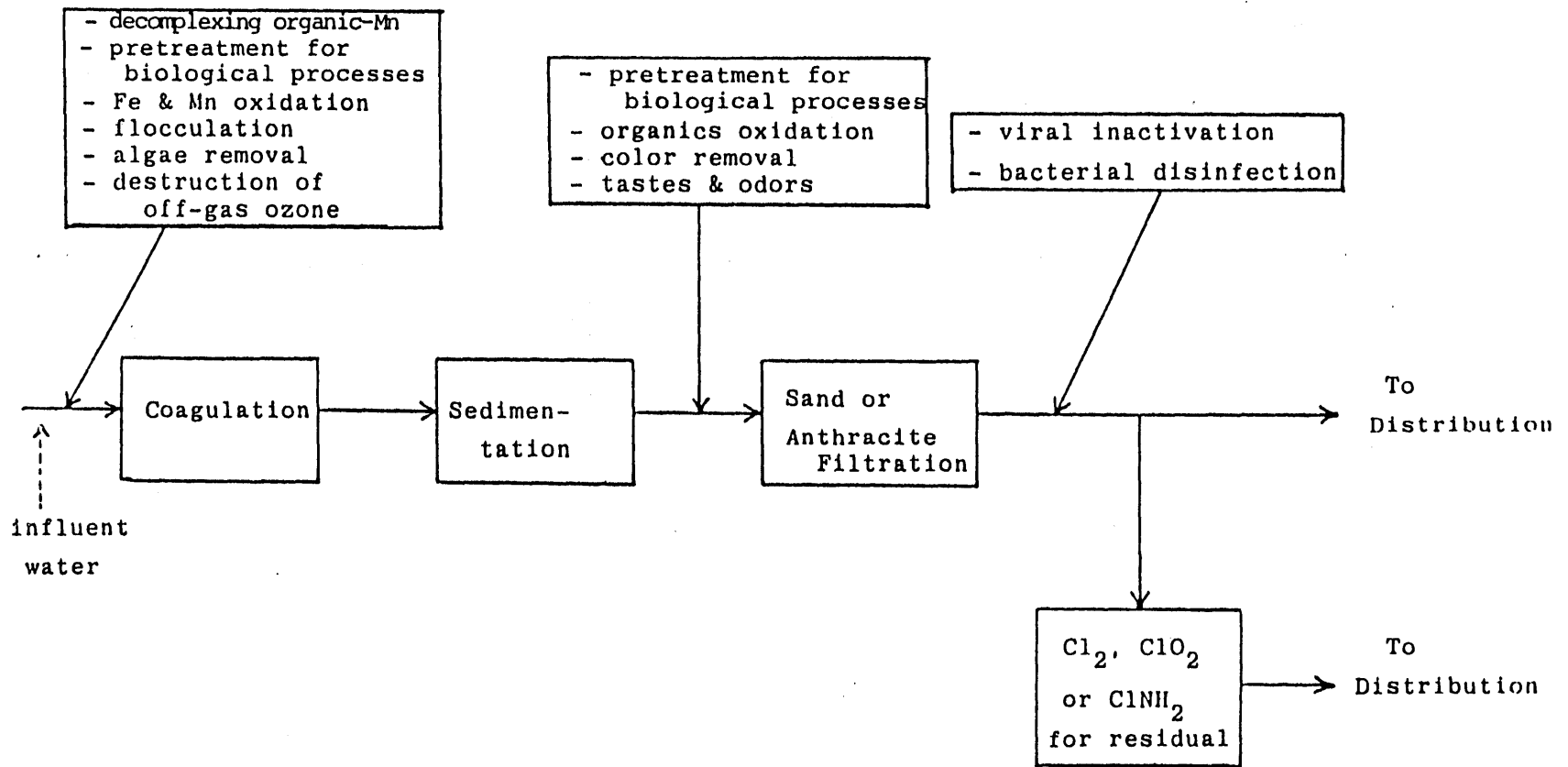


Figure 3 Typical Points of Application of Ozone in Drinking Water Processes

TABLE 7 COSTS OF OZONATION AT EUROPEAN DRINKING WATER PLANTS

Plant	water treatment capacity (mgd)	ozone generation capacity (lbs/day)	capital cost of ozonation*	capital cost/lb of ozone generation capacity	amortization period (yrs.)	av. dosage of ozone (mg/l)	ozonation operating costs (c/1000 gal)**	electrical cost (¢/kwhr)
Tailfer Brussels Belgium	68.7	1267	\$4,024,000	\$2200	20	1.7	2.52	3.01
Lengg Zurich Switzerland	66	1742	\$1,120,000	\$ 643	20	1.5	1.75	2.0
Large Automated Paris Plant	-	-	-	-	20	2.5	2.76	2.1
Several French Plants	-	-	-	-	10	1.5-3.0	3.95	3.12

*includes air preparation equipment, ozone generation, ozone contacting, treatment of off-gas ozone, instrumentation, installation and housing for ozonation system (including contact system)

**includes operation, maintenance and amortization

5.2. THE EVALUATION OF THE OZONATION PROCESS

As shown in Table 5 ozone is used as a water disinfectant in more than 1,000 facilities in Europe. It is generally agreed that the ozonation of drinking water does not produce trihalomethanes. (17) However, the investigation of organic oxidation products of ozone began only recently.

Graze reviewed (32) the ozonation of pure compounds as well as the by-products of water ozonation. In one plant several aldehydes (n-hexanal, n-heptanal, n-octanal, and n-nonanal) were identified, while in another plant a number of hydrocarbons (n-hexane, n-heptane, n-octane, and n-nonane) also were found. The formation of epoxides and organic peroxides, which are known to be hazardous, is suggested strongly by the dissociation of ozone. Studies on toxicity of ozonation and products also are meager. At present it is not known what the organic end products of ozonation are nor what their health significance may be, collectively or individually. It is certain that because of the production cost of ozone, mostly depending upon electricity, ozonation cannot be a feasible alternative to disinfection.

CHAPTER 6

CHLORINE DIOXIDE DISINFECTION AND GRANULAR ACTIVATED CARBON ADSORPTION (95)

6.1. OBJECT OF THE STUDY

In late 1974, the EPA selected Evansville Water Works Filtration Plant, located on the Ohio River, about one mile upstream from the city of Evansville, as the study site. The EPA conducted the chlorine dioxide disinfection and the granular activated carbon adsorption research study to evaluate chlorine dioxide as a viable alternative to chlorine for drastically reducing or preventing the production of trihalomethanes (THMs). Also, the EPA investigated the effectiveness of virgin and reactivated granular activated carbon (GAC) for removal of organic compounds present in the source water, as well as any formed after disinfection.

6.2. Treatment Plant Design and Operation

6.2.1. Evansville Water Works Filtration Plant

The south plant of the Evansville Water Works was used as a control of this study. The south plant (Figure 4) consists of two primary settling basins, two secondary settling basins, and eight rapid sand filters. Chlorine and alum were added before primary settling with average concentrations of 6 and 28 mg/l, respectively. A free chlorine residual of 1.5-2.0 mg/l was maintained after sand filtration.

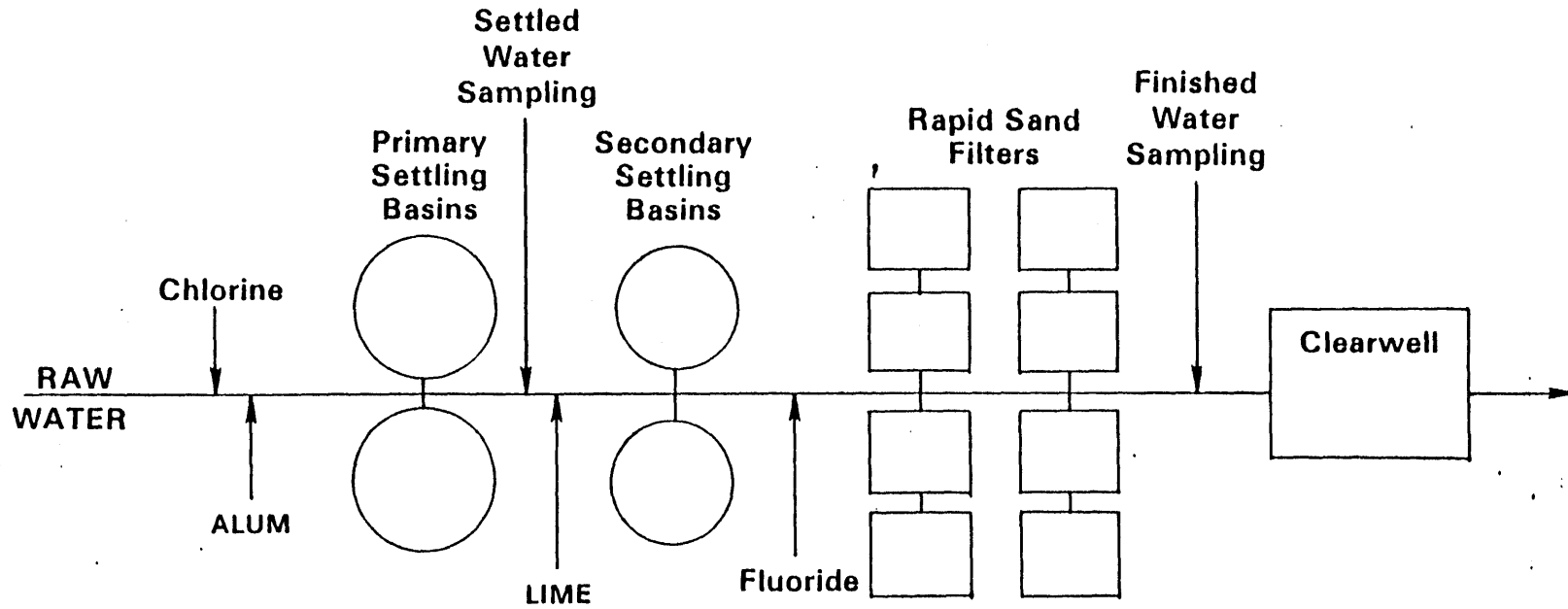


FIGURE 4. FLOW DIAGRAM OF EVANSVILLE, INDIANA FULL-SCALE SOUTH PLANT.

6.2.2. PILOT PLANT

The raw water of the Ohio River was supplied to the pilot plant and was disinfected, then treated with alum and polymer for turbidity removal (Figure 5) and treated by the following system such as flocculation, settling tube and GAC contactor. The design parameters for the pilot plant that were used in the study consist of :

Flow rate	0.38 m ³ /min.
Rapid mix chamber	1.1 m ³ volume
Flocculator	3.4 m ³ volume
Tube settler	4.2 m ³ volume
Mixed media filter	1.9 m ² surface area
GAC contactor	0.97 m diameter
Clear well	17.0 m ³ volume
Reservoir	11 m * 5.6 cm

6.3 Conclusions

A summary of conclusions from this study are:

- 1) Chlorine dioxide and chlorine provide similar disinfection qualities through conventional treatment
- 2) Chlorine dioxide requires a lower mass dose to produce effective disinfection as compared to chlorine
- 3) Average of 51 ppb THM production by chlorine dioxide and 130 ppb with chlorine.
- 4) Chlorine dioxide disinfection did not produce any organic by-products other than those noted chlorine disinfection when looking at the priority pollutants

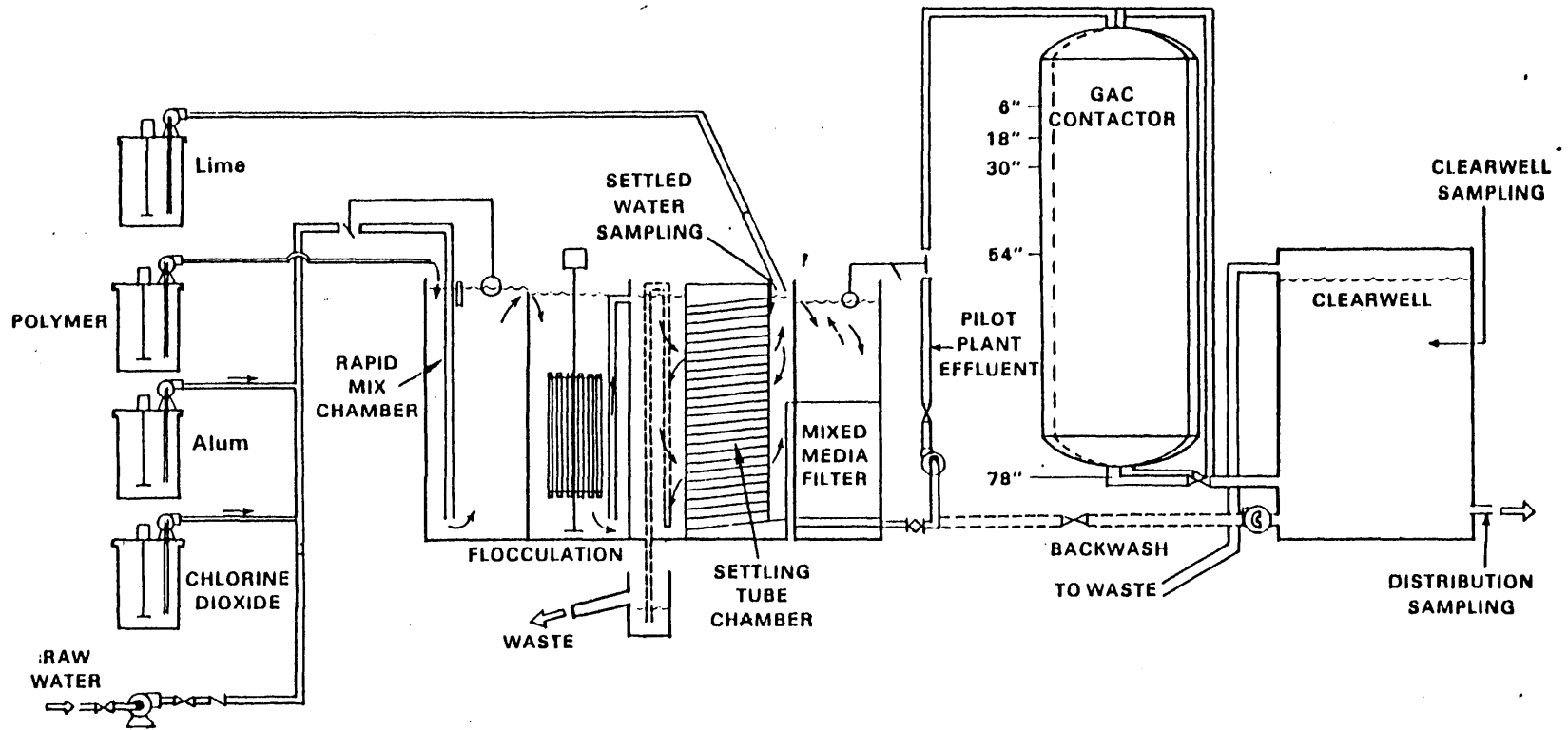


FIGURE 5 SCHEMATIC DIAGRAM OF EVANSVILLE, INDIANA PILOT PLANT.

- 5) Spent GAC was subsequently reactivated three times and restored to virgin state
- 6) Loss incurred during GAC reactivation were about 5 % with overall system losses (education, handling, transport and reactivation) averaging about 8 %
- 7) Both chlorine and chlorine dioxide were effectively removed by the GAC and the chlorite was partially removed
- 8) The use of chlorine dioxide as the primary raw water disinfectant is a viable alternative to chlorine disinfection in some situations for reducing the trihalomethane concentrations.

6.4 RECOMMENDATIONS

- 1) Comprehensive studies of health effects should be undertaken to evaluate the extended use chlorine dioxide as a alternative to chlorine for drinking water disinfection.
- 2) The production of chlorine dioxide needs improvement. Although several methods are available by various manufactures, work needs to be done on improving these procedures so that less, and preferably no, chlorite or chlorine is produced.
- 3) An analytical method for the determination of chlorate that can be used effectively by water works chemists needs to be developed.
- 4) The use of chlorine dioxide only as a raw water disinfection should be considered for reduction of

trihalomethane concentrations at Evansville, Indiana.

6.5. SUMMARIES

This case study shows that chlorine dioxide reduces the THM production about two-thirds of that of chlorine, and also GAC was subsequently reactivated three times. Reactivating the GAC is not a new technology but for the drinking water supply practice, it is relatively new because activated carbon has been used only once in the drinking water treatment in order to maintain the pure non-contaminated granular activated carbon state.

Two-thirds reduction of THM by a chlorine is a significant effect. However, when compared with the reduction rate of GAC, conservatively 90 % and usually more than this, it is not such a significant rate. Rather we should think it as 33.3 % of inefficiency, and there will be a some problem with carcinogen.

CHAPTER 7

TECHNOLOGIES AND COSTS FOR THE REMOVAL OF TRIHALOMETHANES FROM DRINKING WATER (97)

7.1. NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS: TRIHALOMETHANES

The EPA promulgated the Total Trihalomethane (TTHM) regulation in November 1979, specifying Maximum Contamination Level (MCL=0.1 mg/l) and monitoring requirements for all public water systems serving 10,000 or more persons.

This rule did not identify what were the best generally available treatment methods that a system subject to this rule be required to install and/or use to comply with the TTHM MCL. The lack of definition of available or potentially available treatment methods for reducing levels of TTHMs has raised concerns among the regulated community as to whether public water systems not in compliance with the TTHM MCL would be required to install an/or use all of the available or potentially available treatment methods in order to come into compliance with the TTHM MCL.

To dispel the ambiguity surrounding the issue, the Agency has proposed a rule for amending the Safe Drinking Water Act implementation regulations. The EPA's "Technologies and Costs for the Removal of Trihalomethanes from Drinking Water" supports the proposed rule and defines the best generally available treatment methods for reducing TTHMs, taking cost into consideration.

7.2. THE DEFINITION OF AVAILABLE OR POTENTIALLY AVAILABLE TREATMENT METHODS FOR TRIHALOMETHANE REMOVAL

In identifying the best treatment methods generally available, the EPA has considered available or potentially available technologies. These technologies are presented in the following categories.

- I Best Generally Available Treatment Methods for reducing TTHMs.
- II Additional Treatment Methods for Reducing TTHMs.
- III Granular Activated Carbon (GAC) and Biologically Activated Carbon (BAC).

Definitions for each technology described above are summarized in the following section.

7.2.1. Best Generally Available Treatment Methods for Reducing TTHMs

- (1) Use of Chloramines as an Alternate or Supplemental Disinfectant or Oxidant
- (2) Use of Chlorine Dioxide as an Alternate or Supplemental Disinfectant or Oxidant
- (3) Improved Existing Clarification For THM Precursor Removal

Conventionally, clarification is employed for turbidity rather than THM precursor removal. The pH, coagulant dosage and mixing conditions may be substantially different for removing THM precursors than for removing particulate matter, although an improvement in THM precursor removal usually improves turbidity removal. Consequently, humic and fulvic acids commonly found in surface waters, known

to include THM precursors are also removed. Laboratory studies have shown that 90% and 60%, respectively, of humic and fulvic substances can be removed by coagulation.

(4) Moving the Point of Chlorination

Shifting the chlorination point will best reduce TTHM levels if a high percentage of THM precursors are settled out during clarification.

(5) Use of Powdered Activated Carbon (PAC) at Dosages Not to Exceed 10 mg/l on Annual Average Basis.

7.2.2. Additional Treatment Methods For Reducing Trihalomethanes

(1) Off-Line Water Storage

The purpose of this method is to allow solids to settle out, thereby putting less load on the treatment process, to mitigate extreme change in water quality resulting from storm water runoff.

(2) Aeration for TTHM Reduction

Aeration may be a suitable treatment alternative in waters where it is not feasible to eliminate pre-chlorination and where the majority of TTHMs form before the aeration step.

(3) Introduction of Clarification Where Not Currently Practiced

The addition of this process may substantially remove additional THM precursors while also improving other aspects of water quality.

(4) Alternate Source of Raw Water

Technical feasibility and economic reasonableness of an alternate source of raw water are site-specific considerations.

- (5) Ozone as an Alternate or Supplemental Disinfectant or Oxidant

7.2.3. Granular Activated Carbon (GAC) and Biologically Activated Carbon (BAC)

- (1) Granular Activated Carbon (GAC)

About 41 water treatment plants in the U.S. control taste and odor problems by use of GAC in conjunction with other granular media in the filter bed. This process can be used either for the sand replacement mode or post-filter contactor mode.

- (2) Biologically Activated Carbon (BAC)

Granular activated carbon preceded by ozonation has been called biologically activated carbon (BAC) because of enhanced biological activity on the carbon bed.

7.3. NATIONAL ECONOMIC IMPACT

As shown in Figure 6, the proposed amendments are estimated to decrease capital expenditure requirements by 53 percent from \$107.5 million to \$50.9 million. This decrease in capital expenditure results primarily from the elimination of the assumption that activated carbon would be used as a technology to control TTHMs. Operation and maintenance expenses are expected to be less affected by the proposed amendments and are estimated to decrease by only 13 percent

from \$22.1 million to \$19.3 million.

National cost estimates were based on the costs of the ten group I and group II methods for reducing TTHM levels. The results of the analysis of selection of compliance strategies are shown in Figure 7.

7.4. EFFECT OF INPUT CHANGES ON THE ESTIMATE DEVELOPED IN 1979

The cost of the TTHM regulation estimated in the 1979 analysis (updated to 1982 dollars) are somewhat lower than the cost of the same regulation estimated in 1981, but the number of systems affected in the 1981 analysis is only one half the number of systems assumed to be affected in the 1979 analysis (Table 8 & Figure 8 & 9). This is because water quality data were obtained from the Community Water Supply (CWSS) in 1981, while the 1979 analysis data were based on the National Organics Monitoring Survey (NOMS).

7.5. Summary

This study analyzed the cost function of the three different categories: best generally available, additional method and GAC and BAC method. The THM final rule, on February 28, 1983 incorporated this study. We will see the cost curve of each of the alternatives and rules and regulations in the next chapter.

Figure 6

NATIONAL COSTS OF THM REGULATION
COMPARISON OF COSTS OF 1981 AMENDED IMPLEMENTATION REGULATIONS
TO COSTS OF 1979 REGULATION

MILLIONS OF 1981 DOLLARS

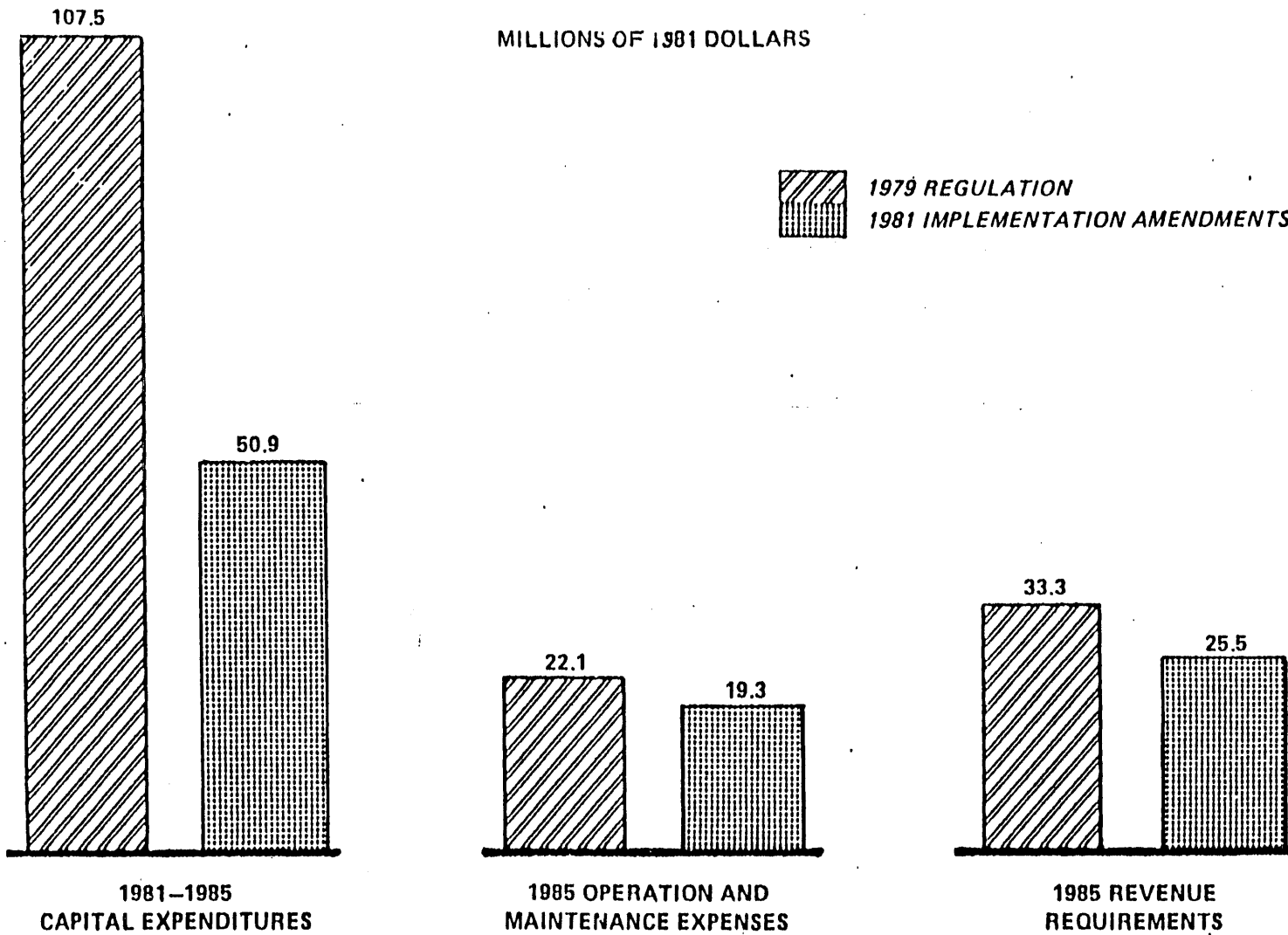
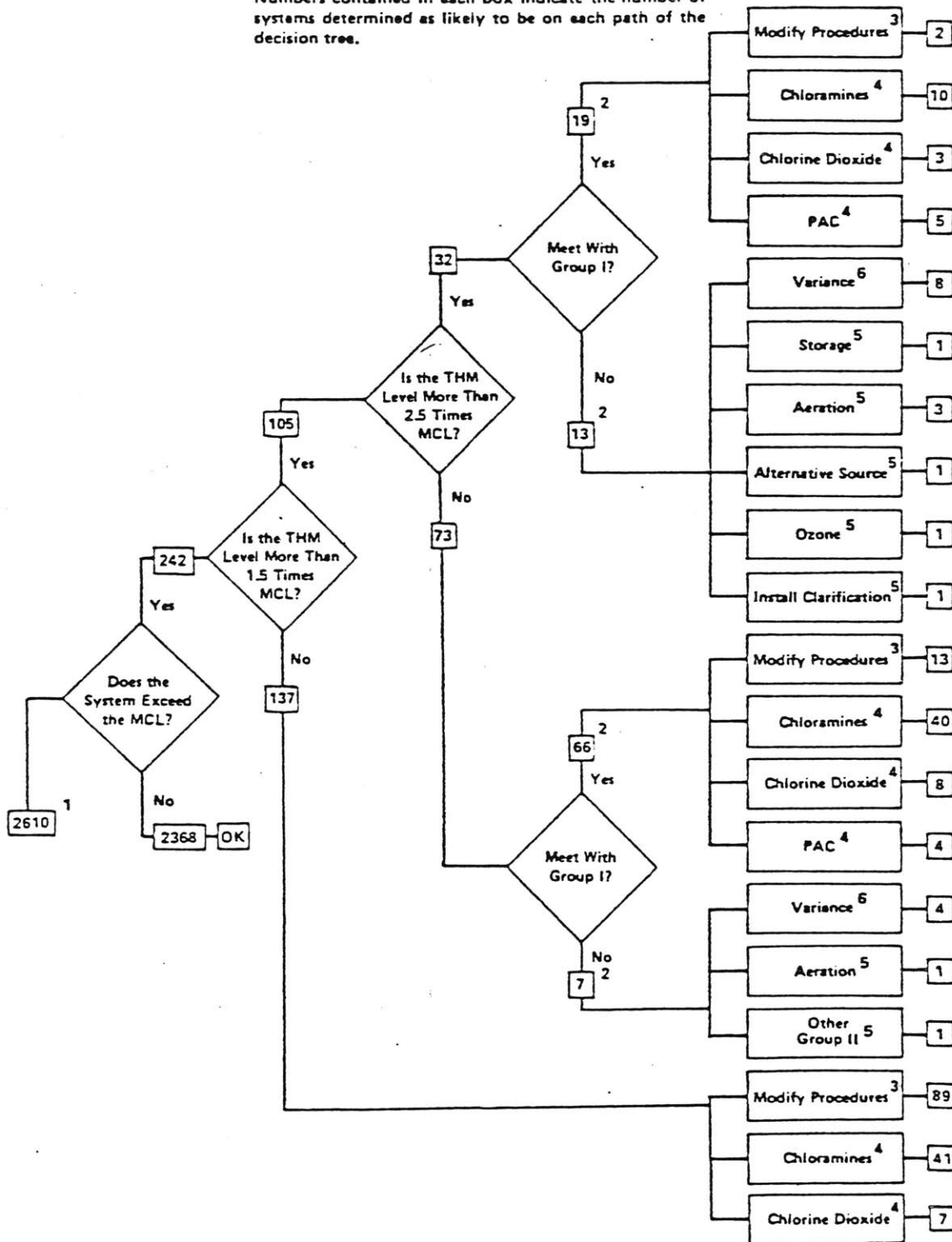


Figure 7

DECISION TREE FOR THE THM AMENDED IMPLEMENTATION REGULATIONS

Numbers contained in each box indicate the number of systems determined as likely to be on each path of the decision tree.



¹ Represents the total number of systems serving over 10,000 people (3078) minus those systems which purchase their water (468).

² Does not sum to total of treatment categories due to rounding errors in combining treatment categories.

³ Indicates changing chlorination point and/or improving clarification.

⁴ Includes systems that also modify procedures.

⁵ Includes cost of Group I technologies installed by systems that also install a Group II technology.

⁶ Systems receiving a variance first install a Group I technology but determine after a study that a Group II technology is not feasible or cost-effective.

Table 8: Comparison between the number of affected systems in the 1979 and 1981 analysis of the THM Regulations

	1979 Analysis FRDS, NOMS		1981 Analysis FRDS, CWSS	
	Number	Percent	Number	Percent
All Systems	2685	100.0%	3078	100.0%
Systems Chlorinating with THM levels				
>0.25 mg/l	36	1.3%	32	1.0%
0.15-0.25 mg/l	50	1.9%	73	2.4%
0.10-0.15 mg/l	429	16.0%	137	4.5%
Total >0.10 mg/l	515	19.2%	242	7.9%
<0.10 mg/l	1465	54.6%	2037	66.2%
Total Systems Chlorinating	1980	73.7%	2279	74.0%
No chlorination	705	26.3%	799	26.0%

SOURCE: EPA, "Technology and Costs For The Removal of Trihalomethanes From Drinking Water" February, 1982. (97)

Fig. 8 THM LEVELS AT 1979 REGULATIONS
ALL SYSTEMS = 2,085 (NOMS)

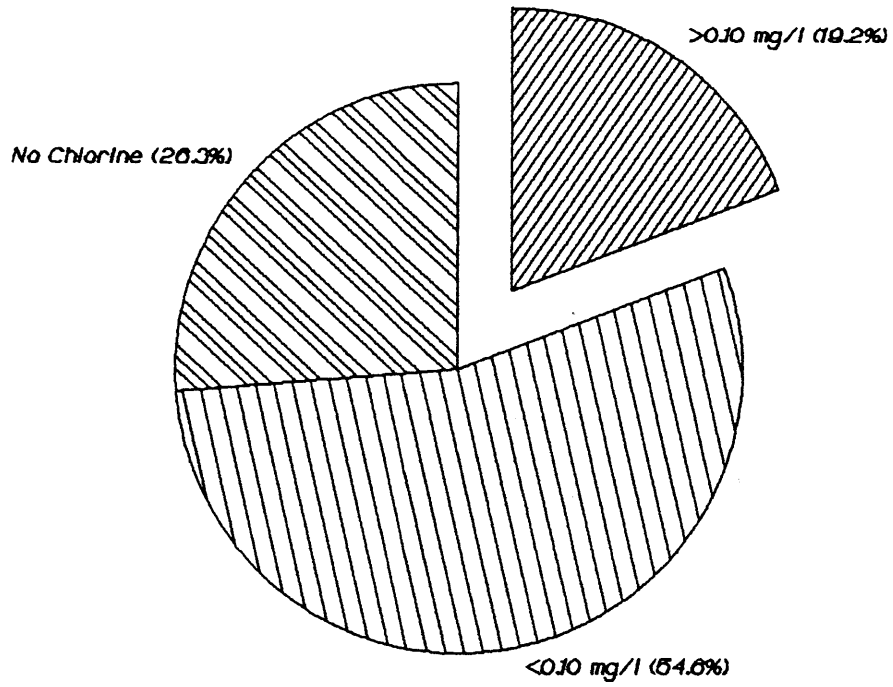
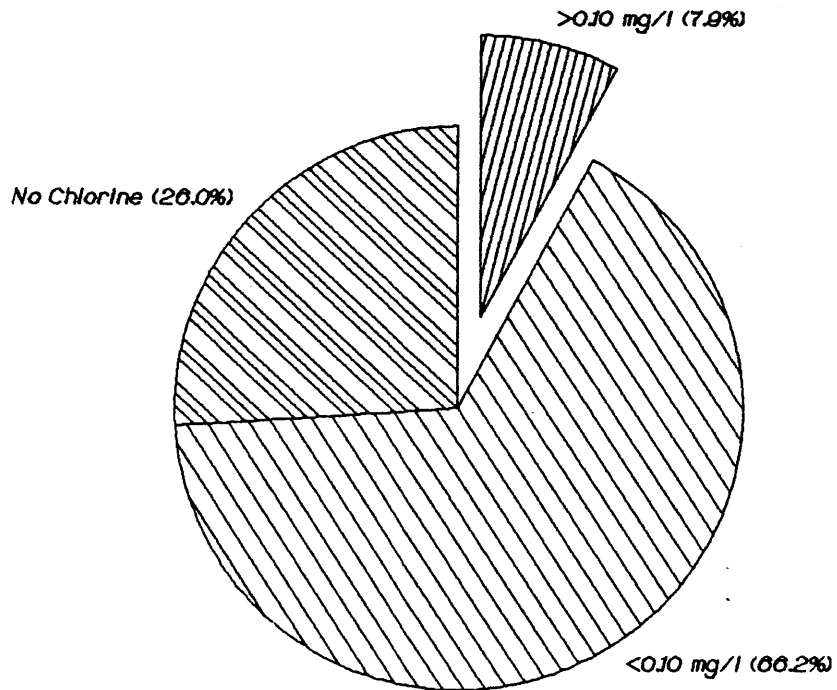


Fig. 9 THM LEVELS AT 1981 REGULATIONS
ALL SYSTEMS = 3,078 (CWSS)



CHAPTER 8

RULES AND REGULATIONS

8.1. EPA'S RECOMMENDATION FOR THE BEST TECHNOLOGY, TREATMENT, TECHNIQUES OF TRIHALOMETHANE (5).

The EPA set the final THM rule on February 28, 1983 for the best technology, treatment techniques or other means that the Administrator of the EPA found to be generally available, taking costs into consideration. This rule applies to all public water systems that serve more than 10,000 persons and specifies what treatment methods a system may be required to install and/or use to come into compliance with the trihalomethane's maximum contaminant level. These recommendations by the EPA are, (as described in the previous chapter:

I. Best Generally Available Treatment Method:

- (a) Use of chloramines as an alternate or supplemental disinfectant or oxidant.
- (b) Use of chlorine dioxide as an alternate or supplemental disinfectant or oxidant.
- (c) Improved existing clarification for trihalomethane precursor reduction.
- (d) Moving the point of chlorination to reduce the trihalomethane formation and, where necessary, substituting for the use of chlorine as a pre-oxidant chloramine, chlorine dioxide or potassium permanganate.
- (e) Use of powdered activated carbon for trihalomethane

precursor or trihalomethane reduction seasonally or intermittently at dosages not to exceed 10 mg/l on an annual average basis.

II. Additional Treatment Methods

1. Off-line water storage
2. Aeration
3. Modified chlorination
4. Alternate source
5. Ozone

III. Granular Activated Carbon (GAC) and Biological Activated Carbon (BAC)

8.2. ALTERNATIVE SELECTIONS FOR THE MUNICIPALITIES AND THEIR COST IMPACT

After promulgating the THMs final rule by the EPA, municipalities have faced the choice of technologically different and also economically different alternatives for their THM control system.

Table 9 is a summary of the treatment cost for the THM control. Figure 10-11 shows the variances for the treatment cost for different plant size. Due to the economic scale, both figures show the size of the impact for small and large plants, compared with small size plants.

Figure 12 shows the treatment cost for THM control as to Group I. From this figure it is easy to understand that C.D (Chlorine Dioxide) and M.cla (Modified Clarification) have the same tendency curve and PAC is the smallest constant cost impact from small plant to large plant.

Table 2: SUMMARY OF TREATMENT COSTS FOR THM CONTROL

TREATMENT METHOD	COSTS/1,000 GALLONS					
	PLANT CAPACITY (MGD)					
	4.23	9.30	18.26	27.00	75.60	359.73
I GENERAL METHODS						
CHLORAMINES	0.008	0.005	0.005	0.004	0.003	0.002
CHLORINE DIOXIDE	0.023	0.017	0.015	0.014	0.012	0.011
MODIFY CLARIFICATION	0.017	0.014	0.014	0.014	0.013	0.012
MODIFY CHLORINATION	0.007	0.006	0.005	0.004	0.004	0.003
PAC	0.003	0.003	0.003	0.003	0.003	0.003
II ADDITIONAL METHODS						
OFF-LINE STORAGE	0.15	0.12	0.11	0.10	0.08	0.07
AERATION	0.14	0.13	0.12	0.12	0.09	0.08
CLARIFICATION	0.21	0.20	0.16	0.14	0.10	0.06
ALTERNATE SOURCE	0.64	0.51	0.36	0.32	0.16	0.10
OZONE	0.10	0.07	0.07	0.07	0.06	0.05
III METHODS FOR CONSIDERATION						
GAC	0.41	0.33	0.28	0.24	0.21	0.17
BAC	0.44	0.34	0.31	0.26	0.22	0.18

SOURCE: EPA, "Technology and Costs For The Removal of Trihalomethanes From Drinking Water" February, 1982. (97)

FIG.10 THM CONTROL COST (GROUP I)

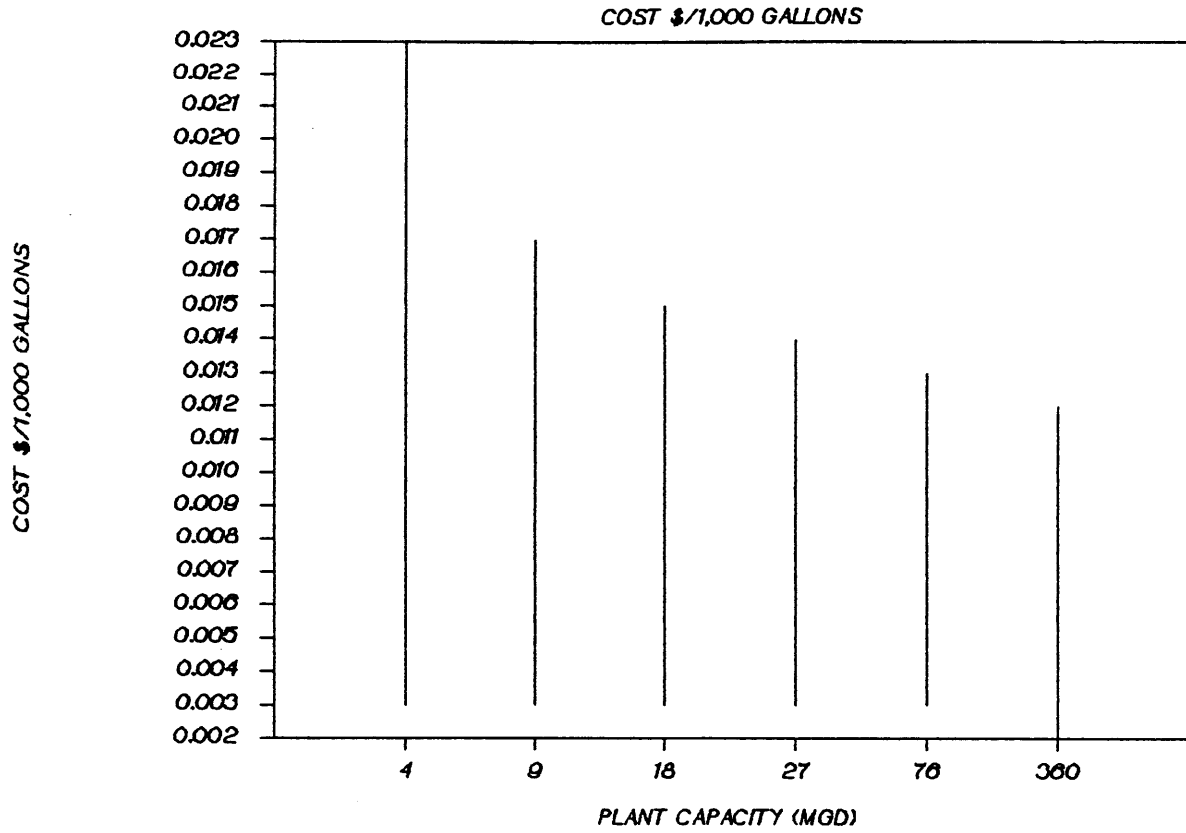


FIG.11 THM CONTROL COST (GROUP II&III)

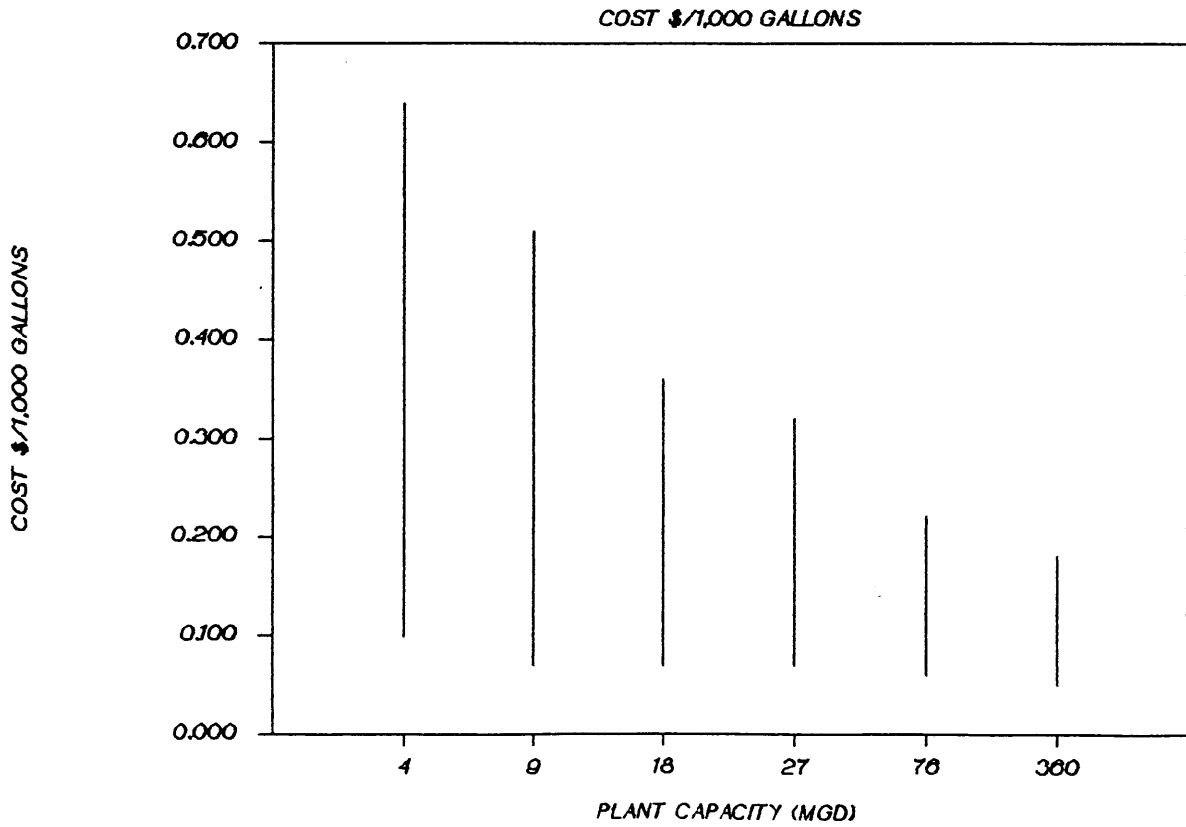
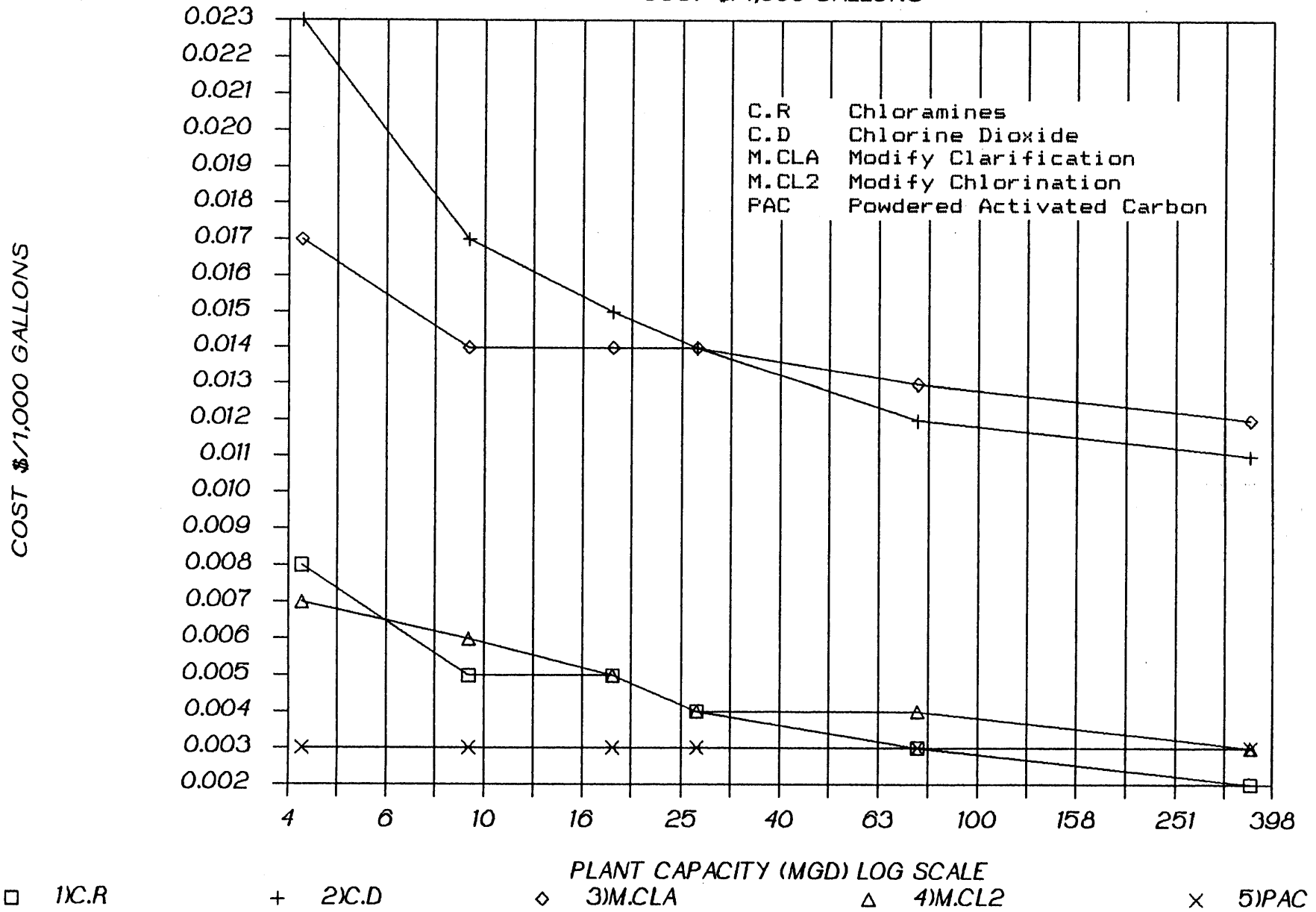


FIG.12 TREATMENT COST FOR THM CONTROL

COST \$/1,000 GALLONS



8.3. Question on alternative disinfectants. (17)

As described in the previous section, the EPA identified only chlorine dioxide and chloramine as acceptable alternative disinfectants. It is interesting that the EPA did not include the ozonation and GAC process in their best generally available treatment methods recommendation.

In fact, in 1980, the EPA requested the National Academy of Sciences to review the efficacy of disinfectant. Their conclusions were that only chlorine dioxide and ozone were acceptable alternative disinfectants. Chlorine dioxide is used in the USA primarily for taste and odor control rather than for disinfection. Because of the explosiveness of chlorine dioxide, it must be produced at the site of application by reduction of sodium chlorate or, as is usual in water treatment practice, by chlorination of sodium chlorite. Greenberg (17) indicates that adding chlorine dioxide alone resulted in no production of trihalomethanes but unfortunately the case is not that simple because other organic compounds are formed. Human health effects of these compounds are unknown. More obvious, and possibly more significant are the toxic effects of chlorine dioxide itself and their inorganic reaction products, the chlorite (ClO_2^-) and the chlorate (ClO_3^-) ions. Calabrese and his co-workers summarized that there is insufficient evidence to accept chlorine dioxide as a suitable replacement for chlorination as the prime means of disinfection at the present time.

8.4. ELIMINATION OF GAC FROM THE BEST GENERALLY AVAILABLE TREATMENT METHOD

The EPA's determination not to include GAC and BAC in Group I or II took into consideration costs that might be involved, in their explanation (5), but primarily was made due to the complexities of the modifications prior unit operations (i.e., disinfection) and in the logistics of the carbon replacement.

Is GAC really an expensive treatment system for human lives exposed to a carcinogen risk ?

This question will be reviewed in the next chapter.

Chapter 9

BENEFIT-COST ANALYSIS OF GRANULAR ACTIVATED CARBON

9.1. QUANTITATIVE ANALYSIS FOR EVALUATING BENEFITS AND COSTS

Page, Harris and Bruser (93) discussed the methodology of evaluating benefits and costs for GAC. They emphasized the difficulty of accounting to be satisfactory for the distributional or equity effects across generations. One approach that appears to be fair to future generations is the steady state comparison test, which was also used in both the National Academy of Sciences and the Council on Wage and Price Stability studies. The first seventy years or so after the installation of GAC can be considered as a transition period during which the cancer rate declines (Fig 13); during this time the benefits of GAC grow while the costs remain relatively constant. After seventy years the rate of benefits to costs remain fairly steady.

9.2. MODEL BUILDING

According to the methodology described in the previous section, Table 10 has been created.

The following is an explanation of each column.

Column 1: Year

A time horizon of 100 years was chosen in order to capture the stream of benefit.

Column 2: THM hazard people (refer to Figure 12)

In the year the GAC treatment started its operation, all the people who had been

supplied the THM contaminated water suffered from the potential carcinogenic risks. This number decreases according to the sum of the Natural Death and Excess Cancer Death number caused by THM.

Column 3: Natural Death

THM hazard people have a normal life expectancy of 70 years, and the entire generation of THM hazard people, consisting of a uniform number of people for all represented years, counts for a constant number of natural deaths from this group every year.

Column 4: Excess Cancer Death Number (refer to Figure 14) There are several reports about this risk estimate. (Table 11 & 12) This column counts the number of people of the THM hazard group who die due to the THM caused cancer.

Column 5: Number of Life Saved

According to the assumption of a 90% GAC THM removal ratio from the drinking water by GAC, this number is given as
$$POP. * Cancer Rate - Cancer Death Number \geq 0$$
These "number of lives saved" creates a minimum number for the first 5-6 years. This is because cancer death number (Column 4) includes 10% of excess cancer death numbers from the new generation born after the GAC

plant's operation.

Column 6: Maintenance and Operation Costs of the GAC Plant. This is constant, \$1.4 million in this case.

Column 7: Discount Rate

$$\frac{1}{(1+i)^n}$$

Column 8: Discount Maintenance and Operation

$$(\text{col.6}) * (\text{col.7})$$

Column 9: Discount Life Saved

$$(\text{col.5}) * (\text{col.7})$$

Fig 3 THM hazard people number

Small Size Plant Pop. <10,000

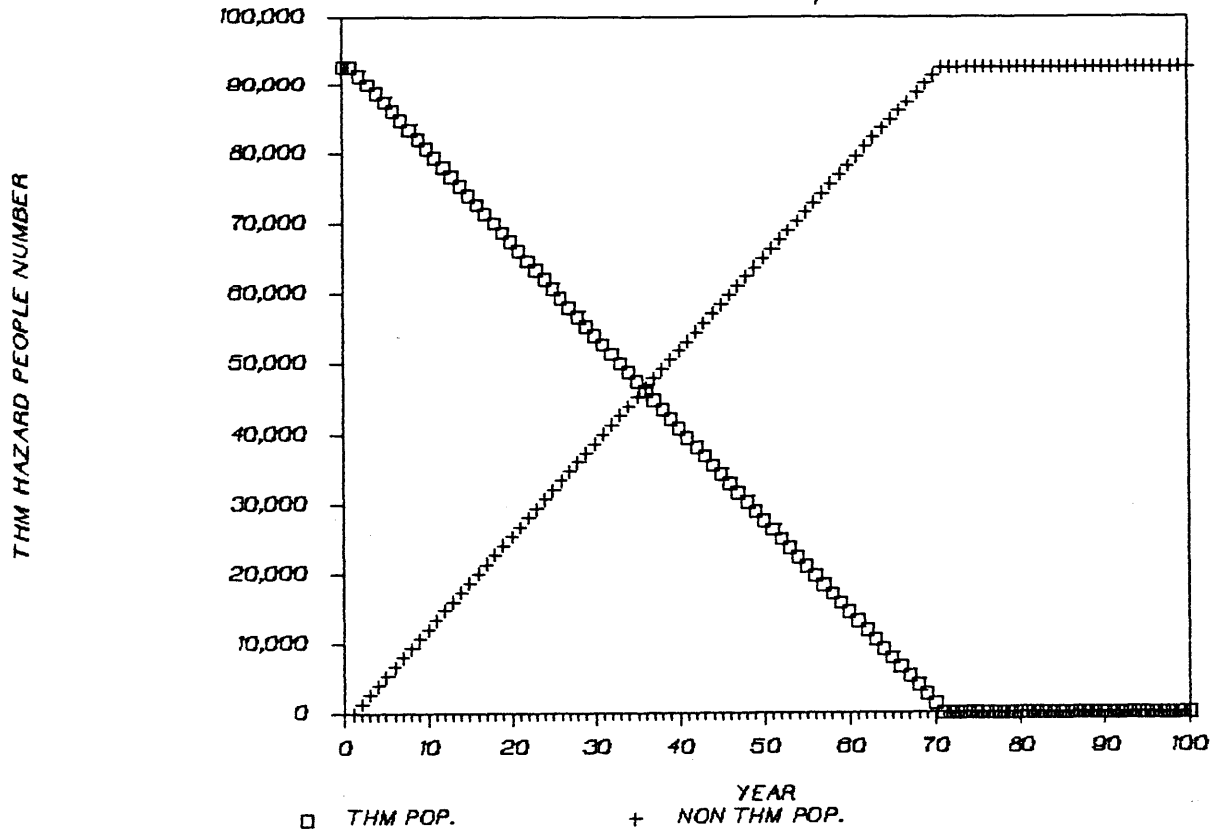


Fig 4 Death & Life Saved Number

Small Size Plant Pop. <10,000

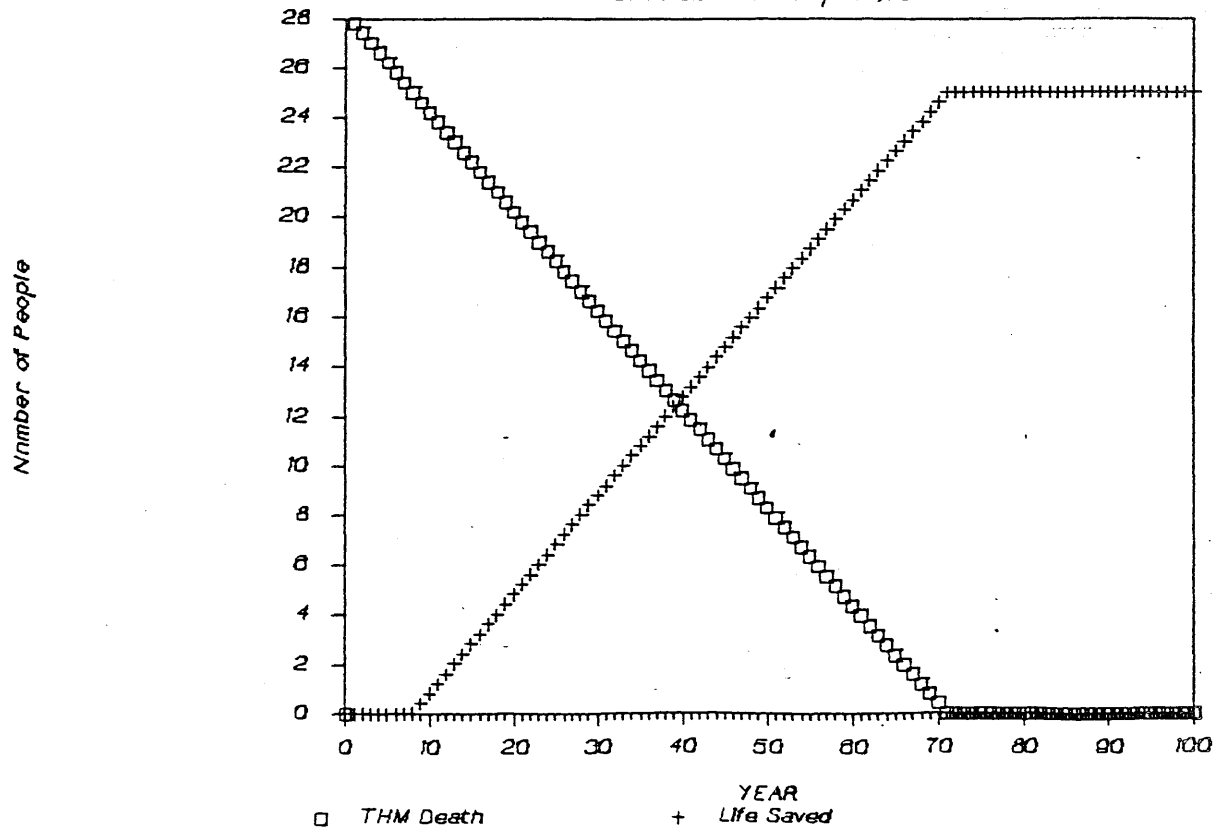


Table 10: Spread Sheet Analysis for GAC Cost Per Life Saved (small plant)

(1)	(2)	THMHazard Pop.		NO. of Plant	Discount			
		Natur'l Death	Excess Death		M&D Rate	M&D *1000	Life Saved	
	92,700	0	0.00	0.00				
1	92,700	1,310	27.81	0.00	1,400	1.0000	1,400	0.00
2	91,362	1,310	27.41	0.00	1,400	0.8264	1,157	0.00
3	90,024	1,310	27.01	0.00	1,400	0.7513	1,052	0.00
4	88,687	1,310	26.61	0.00	1,400	0.6830	956	0.00
5	87,350	1,310	26.21	0.00	1,400	0.6209	869	0.00
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
30	54,059	1,310	16.22	8.81	1,400	0.0573	80	0.50
31	52,733	1,310	15.82	9.21	1,400	0.0521	73	0.48
32	51,407	1,310	15.42	9.61	1,400	0.0474	66	0.46
33	50,081	1,310	15.02	10.00	1,400	0.0431	60	0.43
34	48,756	1,310	14.63	10.40	1,400	0.0391	55	0.41
35	47,431	1,310	14.23	10.80	1,400	0.0356	50	0.38
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
65	7,870	1,310	2.36	22.67	1,400	0.0020	2.85	0.05
66	6,557	1,310	1.97	23.06	1,400	0.0019	2.60	0.04
67	5,245	1,310	1.57	23.46	1,400	0.0017	2.36	0.04
68	3,933	1,310	1.18	23.85	1,400	0.0015	2.14	0.04
69	2,622	1,310	0.79	24.24	1,400	0.0014	1.95	0.03
70	1,311	1,310	0.39	24.64	1,400	0.0013	1.77	0.03
71	0	0	0	25.03	1,400	0.0012	1.61	0.03
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
95	0	0	0	25.03	1,400	0.0001	0.16	.00
96	0	0	0	25.03	1,400	0.0001	0.15	.00
97	0	0	0	25.03	1,400	0.0001	0.14	.00
98	0	0	0	25.03	1,400	0.0001	0.12	.00
99	0	0	0	25.03	1,400	0.0001	0.11	.00
100	0	0	0	25.03	1,400	0.0001	0.10	.00

(1) Discounted Cost/Life Saved \$687,022 (i=10 %)
(2) Steady State Cost/Life Saved \$ 55,935
(3) Population 92,700
(4) Excess mortality Rate 0.03 %
(5) Constant Death Number 1,310
(6) M&O Cost \$ 1.4 mil.

9.3. RISK ESTIMATES BASED ON ANIMAL AND EPIDEMIOLOGICAL EVIDENCE (93)

Page, Harris and Bruser summarized the risk estimates from animal and epidemiological studies of different researchers. Table 11 and Table 12 show the results.

Table 11: Summary of Risk Estimates from Animal Studies (93)

Model	Cancer per Mil. Population Annually	
	Surface area Method	Lifetime Accum-rated dose method
New Orleans	23	102
Miami	19	34
80-city survey of chloroform (250 ppb)	12	20

Table 12: Summary of Risk Estimates from Epidemiological Studies (93)

Model	Cancer per million population annually
Ohio (surface water)	140
Louisiana (Mississippi River water)	250
80-city survey of chloroform (250 ppb)	22-55
New York counties (chlorinated water)	240-340

As shown in Table 11 and Table 12 there is approximately one order of magnitude difference between the risk estimate based upon the epidemiological studies of the Mississippi River and chlorinated drinking water in the state of New York.

9.4. COST OF GAC TREATMENT

Page, Harris and Brusel analyzed the cost of removing the organic compounds with GAC. According to their analysis the annual costs per resident of GAC are shown in Table 13

Table 13: Annual Cost per Resident of GAC costs in 1978 dollars (93)

Increase in annual residential water bill	System size (population served)		
	Small 75,000- 100,000	Medium 100,000- 1,000,000	Large over 1,000,000
Standard cost			
9-min. contact time	16.20	10.50	7.10
18-min. contact time	23.00	15.00	11.40
High cost (25 % extra cost)			
9-min. contact time	18.50	11.90	7.90
18-min. contact time	26.10	17.00	12.70
Annual revenue requirements for standard costs, 18-min. contact time			
	1,418,310	2,632,000	10,259,000

9.5. RESULTS

Table 14 shows the setting sheet of the variables for the quantitative analysis.

Table 14: Setting Sheet for the Variables for the GAC Calculations

Category	Population	O & M (\$ million/yr.)	Excess Cancer Risk (per 1,000,000)
Large	1,193,000	10.3	20 - 300
Medium	263,000	2.6	20 - 300
Small	92,700	1.4	20 - 300

Figure 15-17 depicts the graphical presentation of the calculation results. Table 15-17 shows the calculation results. From these graphs if data is available about excess cancer risks, we are able to calculate the approximate cost/life saved in several discount rates. This cost-benefit analysis is problematic and raises controversial issues such as the ethics of measuring human value in terms of money.

Additional problems are as follows:

- (1) Only a few compounds have been adequately studied in animal tests and have been found to be carcinogenic. (93)
- (2) Effects vary according to age, but it is quite difficult to identify two independent target populations, which have a similar age structure.
- (3) Relations are assumed in the metabolism between rats and man.
- (4) Results are difficult to extrapolate from high doses in rats and low and long term effects in man.
- (5) Although the direct reaction of some chemicals with DNA has been correlated with the induction of tumors, it is becoming increasingly clear that other factors can also be involved in the formation of tumors. (54)

Fig 15 GAC Cost per Life Saved

Small Size Plant Pop.<10,000

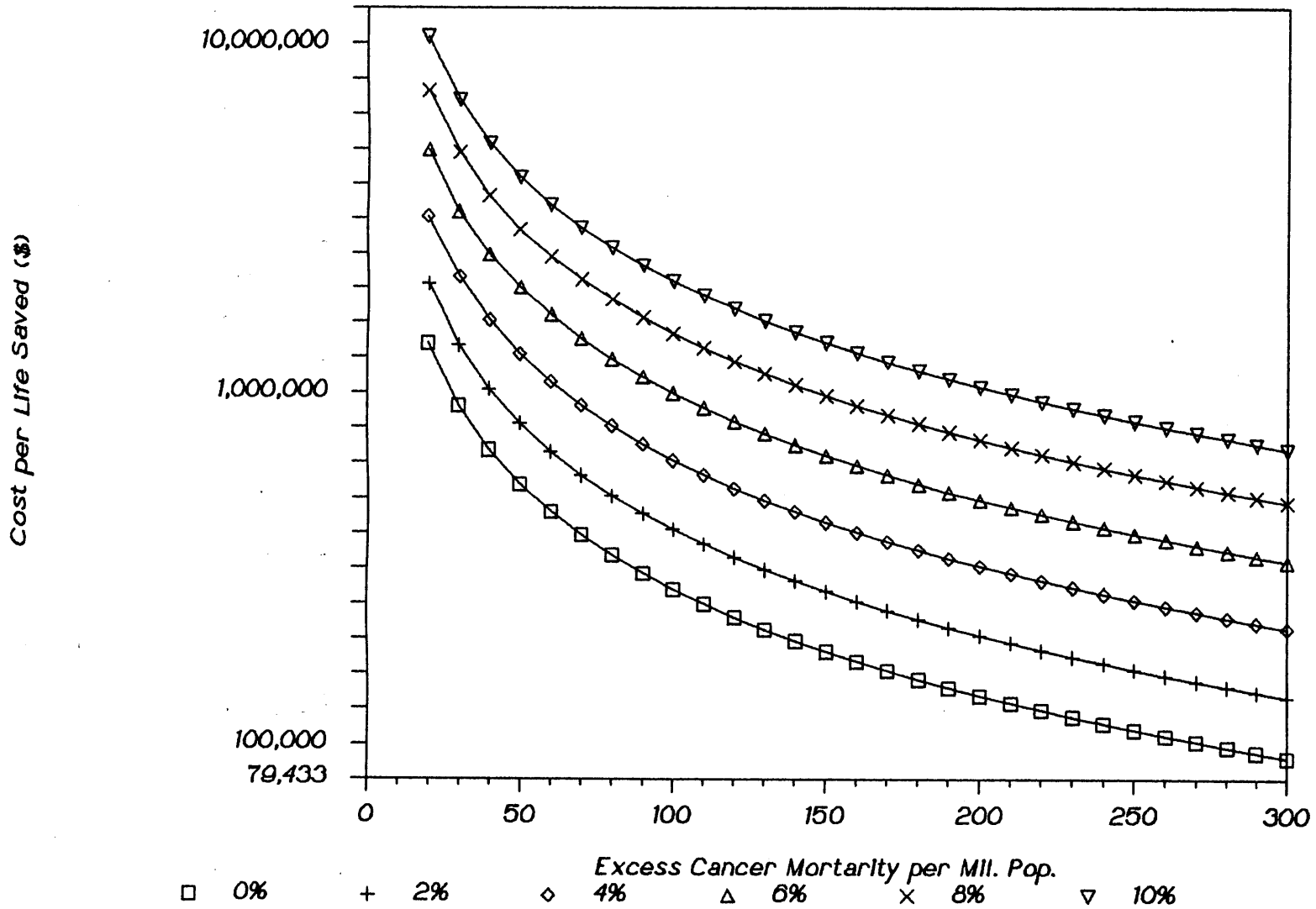


Fig 16 GAC Cost per Life Saved

Middle size 1 mil.-0.1 mil. Pop.

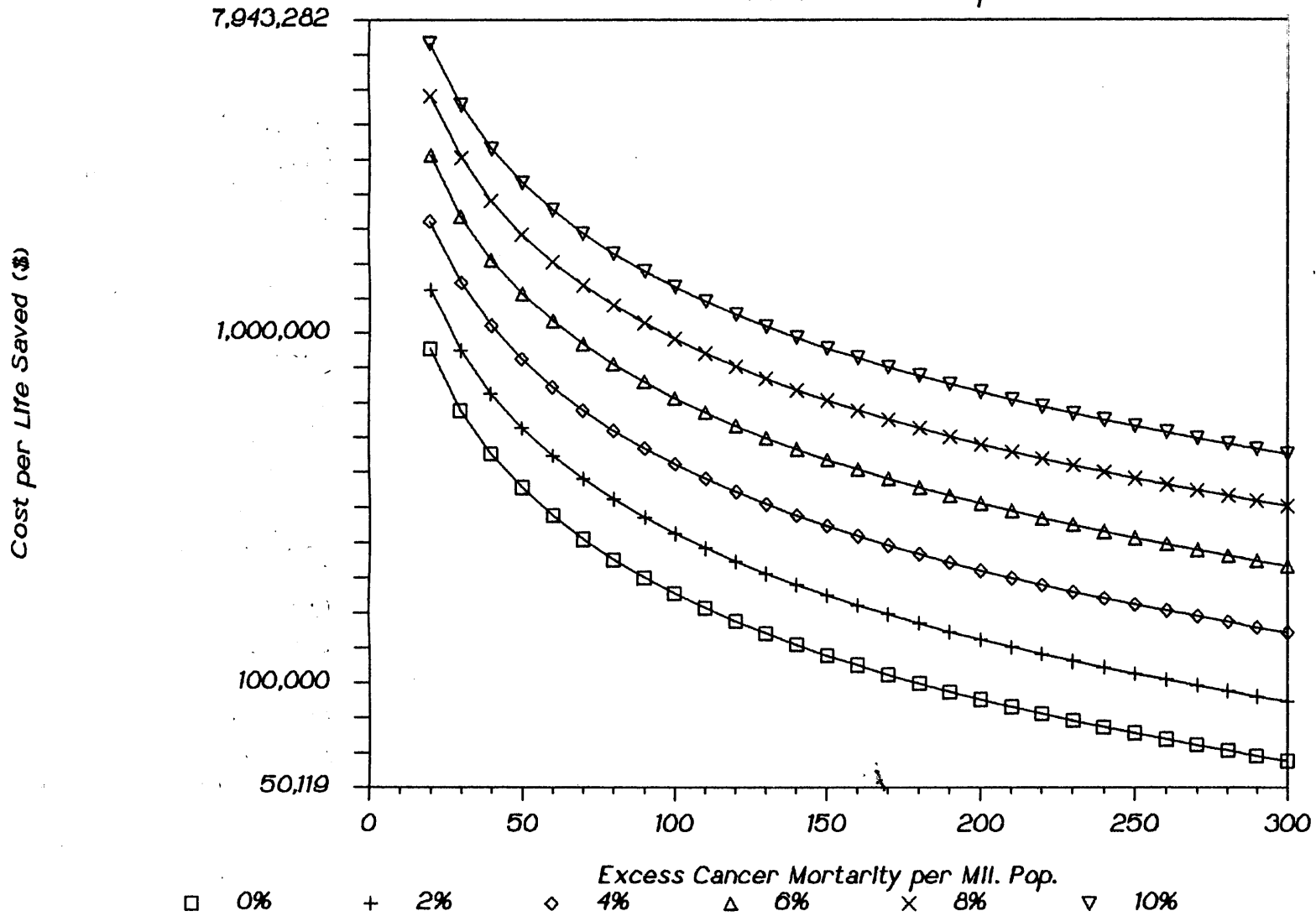
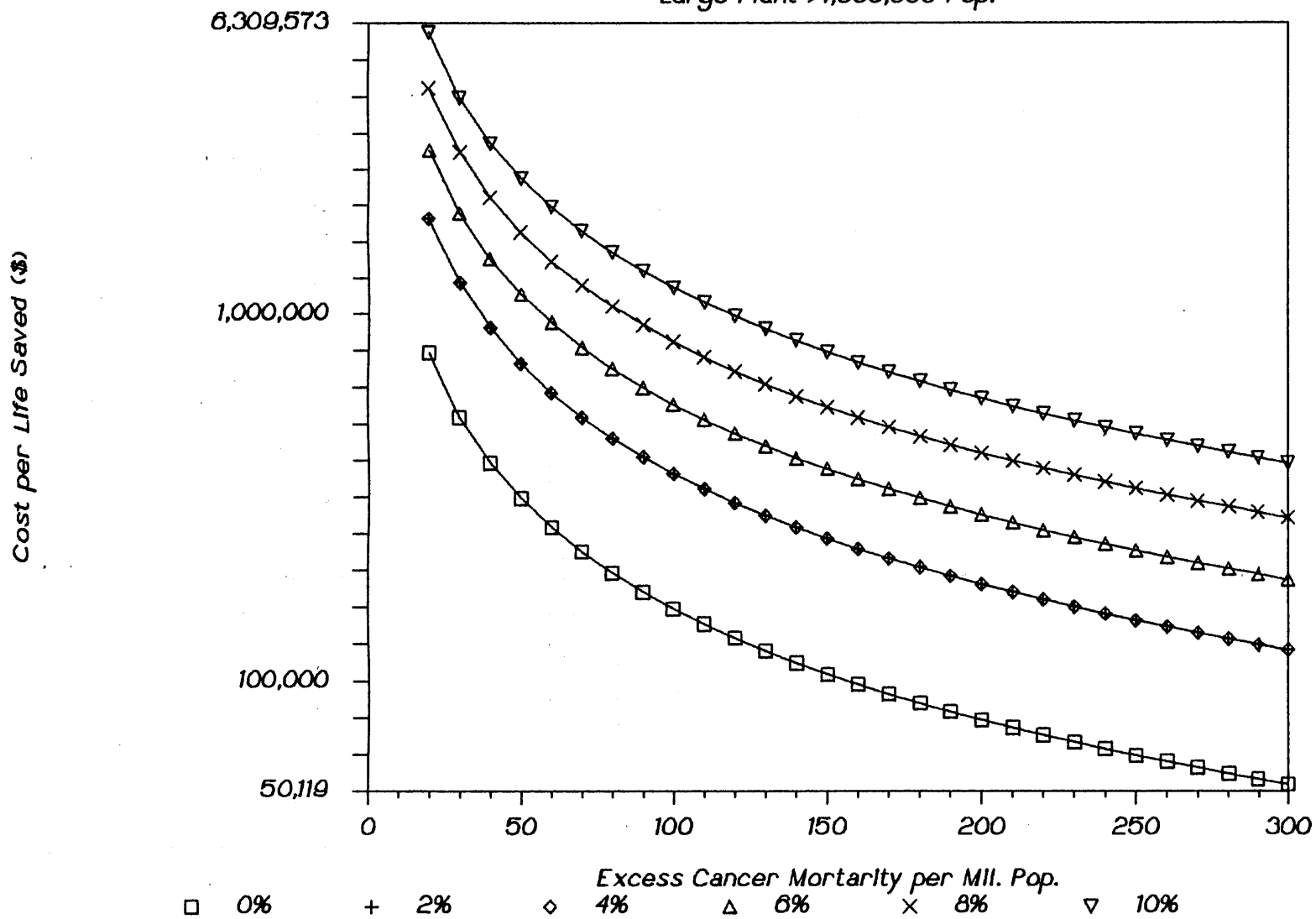


Fig 17 GAC Cost per Life Saved

Large Plant >1,000,000 Pop.

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**Table 15: GAC Cost per Life Saved (Data Table Calculation)
Small Size Plant**

Morta- lity rate	Discount rate					
	0.00%	2.00%	4.00%	6.00%	8.00%	10.00%
0.002%	1375254	2040777	3212955	4978520	7368729	10420286
0.003%	916770	1360347	2141556	3318134	4910846	6944095
0.004%	687527	1020132	1605856	2487941	3681905	5206001
0.005%	549982	816002	1284437	1989826	2944541	4163146
0.006%	458285	679916	1070157	1657749	2452966	3467910
0.007%	392787	582712	917100	1420552	2101841	2971314
0.008%	343664	509809	802308	1242654	1838497	2598867
0.009%	305457	453106	713025	1104289	1633675	2309187
0.010%	274891	407744	641598	993597	1469818	2077444
0.011%	249883	370630	583159	903031	1335753	1887836
0.012%	229043	339701	534459	827559	1224032	1729830
0.013%	211409	313531	493251	763699	1129499	1596133
0.014%	196294	291099	457931	708961	1048472	1481536
0.015%	183194	271659	427320	661522	978248	1382219
0.016%	171732	254648	400535	620013	916802	1295317
0.017%	161619	239638	376901	583388	862585	1218639
0.018%	152629	226297	355894	550832	814393	1150481
0.019%	144585	214359	337097	521703	771273	1089498
0.020%	137346	203616	320181	495487	732466	1034614
0.021%	130796	193895	304875	471768	697355	984957
0.022%	124842	185059	290961	450205	665436	939814
0.023%	119405	176990	278257	430517	636292	898597
0.024%	114422	169594	266612	412470	609577	860815
0.025%	109837	162790	255898	395866	585000	826056
0.026%	105605	156509	246008	380540	562313	793971
0.027%	101686	150694	236851	366350	541307	764263
0.028%	98047	145294	228348	353173	521801	736677
0.029%	94660	140266	220432	340904	503641	710993
0.030%	91498	135573	213043	329454	486692	687022

**Table 16: GAC Cost per Life Saved (Data Table Calculation)
Middle Size Plant**

Morta- lity rate	Discount rate					
	0.00%	2.00%	4.00%	6.00%	8.00%	10.00%
0.002%	899543	1334857	2101570	3256412	4819830	6815831
0.003%	599652	889793	1400776	2170366	3212147	4542080
0.004%	449706	667260	1050379	1627344	2408307	3405206
0.005%	359739	533741	840141	1301530	1926002	2723083
0.006%	299761	444728	699982	1084321	1604466	2268334
0.007%	256919	381148	599869	929172	1374798	1943514
0.008%	224788	333462	524784	812810	1202547	1699900
0.009%	199797	296373	466384	722307	1068575	1510422
0.010%	179804	266703	419665	649904	961397	1358840
0.011%	163447	242426	381440	590666	873706	1234819
0.012%	149815	222196	349586	541300	800630	1131469
0.013%	138281	205078	322632	499530	738797	1044019
0.014%	128394	190406	299529	463726	685797	969062
0.015%	119826	177690	279507	432697	639864	904099
0.016%	112329	166563	261987	405546	599673	847257
0.017%	105714	156746	246528	381590	564211	797103
0.018%	99833	148019	232787	360295	532688	752521
0.019%	94572	140211	220493	341242	504484	712633
0.020%	89837	133184	209428	324094	479101	676733
0.021%	85553	126826	199417	308580	456135	644253
0.022%	81658	121045	190316	294475	435257	614725
0.023%	78102	115768	182006	281598	416194	587766
0.024%	74842	110930	174389	269793	398720	563053
0.025%	71844	106480	167381	258933	382644	540317
0.026%	69075	102372	160912	248909	367805	519331
0.027%	66512	98568	154923	239627	354065	499899
0.028%	64132	95035	149361	231008	341306	481855
0.029%	61916	91747	144183	222983	329428	465055
0.030%	59848	88677	139350	215493	318341	449376

**Table 17: GAC Cost per Life Saved (Data Table Calculation)
Large size plant**

Mortality rate	Discount rate					
	0.00%	2.00%	4.00%	6.00%	8.00%	10.00%
0.002%	786197	1166659	1836763	2846091	4212511	5957007
0.003%	524093	777675	1224272	1896891	2807403	3969759
0.004%	393041	583183	918026	1422291	2104850	2976136
0.005%	314410	466487	734279	1137532	1683318	2379963
0.006%	261990	388691	611781	947692	1402297	1982514
0.007%	224546	333121	524283	812092	1201568	1698623
0.008%	196464	291444	458659	710393	1051021	1485705
0.009%	174622	259029	407618	631293	933930	1320103
0.010%	157148	233097	366785	568014	840257	1187621
0.011%	142852	211880	333377	516239	763615	1079227
0.012%	130938	194198	305536	473094	699747	988899
0.013%	120857	179238	281979	436587	645705	912468
0.014%	112216	166414	261787	405295	599384	846956
0.015%	104727	155300	244288	378175	559239	790179
0.016%	98175	145576	228975	354446	524112	740499
0.017%	92393	136995	215465	333508	493118	696664
0.018%	87254	129368	203455	314896	465567	657700
0.019%	82656	122544	192710	298244	440917	622838
0.020%	78517	116402	183039	283257	418732	591462
0.021%	74773	110845	174289	269697	398660	563074
0.022%	71369	105793	166335	257370	380412	537267
0.023%	68261	101181	159072	246115	363752	513705
0.024%	65412	96953	152415	235798	348480	492106
0.025%	62791	93063	146290	226307	334429	472235
0.026%	60372	89472	140636	217545	321460	453893
0.027%	58131	86148	135402	209433	309451	436909
0.028%	56051	83061	130541	201900	298300	421139
0.029%	54114	80186	126015	194886	287919	406456
0.030%	52307	77504	121791	188340	278229	392753

CHAPTER 10

CONCLUSION

10.1. CONCLUSION

I discussed two types of technology for the control of trihalomethane precursors in drinking water.

- (1) The Application of disinfectant chemicals which react less with the insertion of organic materials in water. These technologies are modified chlorination such the case of Huron, chlorine dioxide and ozonation.
- (2) The elimination of the organic material from water before reacting the chemicals. GAC is a typical example of this category.

Table 18: Comparison of Each Technology

Method	Strength	Weakness
Change the point of chlorination	cheap	no removal of organic matter
Chlorine dioxide	most desirable for no polluted water	if polluted, not desired
Ozonation	long history in Europe no production of THM	organic end products unknown use of electricity
GAC	Eliminate the THM precursor taste & odor removal	most expensive

Each of these technologies have strengths and weaknesses. (Table 18) Huron's case study suggests to us it is necessary to change the chlorination point following recarbonation process. Chlorine dioxide is desirable for application to non-polluted waters in which its bactericidal value can be utilized more fully. The ozonation process has a long history in Europe, but the organic end-products of ozonation and their health significance are unknown. GAC has a good performance record for removing TOC and THM, but it costs 10 to 20 times more than the other alternatives. All of these technologies except GAC may produce by-products not present in the source water, as long as substantial quantities of background organic material are present in the source water. As to the biggest disadvantage of cost comparison with other alternative disinfectant, we should note that GAC also contributes to up-grading the taste of water. Other methods do not.

As discussed in Chapter 7, the EPA used CWSS data for their analysis in technology and costs study. Because of a small number of concentration of THM, usually ppb order, it is quite difficult to detect it but it is not a question whether or not the large differences exist between CWSS and NOMS data. The presence of algae adds to the additional uncertainty to this detection technique. That is, algae also produces THM precursors (87), and during the period of water shortage, usually in the summer, it is most likely to have an extraordinary growth phase. Consequently, these factors

contribute to the THM fluctuation.

There are other problems other than this source water contamination problem. People usually do not consider the distribution system as a source of contamination. The pipes can be asbestos/cement, lead, galvanized iron or plastic and there are polymeric and coal tal coating on pipe. All of these are capable of contaminating the water as it passes through.

The EPA proposed two regulations in 1978 to limit contaminants in drinking water. The EPA specified GAC or its equivalent to be installed in water plants when MCL exceeds 100 ppb for THMs. This regulation won the subject of strong criticism from water utilities. The EPA has decided to reformulate the proposal. Consequently; the GAC system was excluded from Group I. It should not be deleted from the GAC regulation as originally proposed because we have doubts about the precise risk estimates, the source water quality, and the THMs level itself. It is urgent to find the real risk estimate on chlorination by-products. The Agency should regard this risk estimate as a measure to install GAC plants rather than as a measure to prolong or eliminate the installation of GAC plants.

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