ABSTRACT

WILLIAM S. M'COY. Use of The Flavor Profile Method To Solve Taste and Odor Problems In Water Supplies. (Under the Direction of DR. FRANCIS A. DIGIANO)

The Flavor Profile Method (FPM) was evaluated for use as a practical tool to aid water managers in controlling taste and odor in water supplies. A sensory panel using students was organized and trained. Water samples from throughout the Orange Water and Sewer Authority water system were analyzed by the sensory panel using the FPM.

The FPM is useful in investigating the source of taste and odor problems and in monitoring the effectiveness of treatment processes in removing tastes and odors. The FPM is effective in eliminating the influence of outside odors on the results. A trained sensory panel using the FPM is able to detect presence of musty and chlorinous odorants in water samples in concentrations above a threshold value. Results from the sensory analysis of samples indicate an enhancement of the chlorinous flavor intensity in samples that were chlorinated with a musty odorant present.

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Chapter 1

INTRODUCTION

Objectionable taste and odor is one of the primary water quality problems facing water managers. Numerous episodes of taste and odor outbreaks extending across the world are cited in the literature, with the earthy-musty odors produced by actinomycetes and blue-green algae being by far the most common. Utilities have found these outbreaks difficult to predict and the cause of the taste and odor hard to prevent and treat.

The American Water Works Association (AWWA) Research Foundation has included minimizing taste and odor in drinking water as one of 18 major research topics in their 5 Year Plan (1). Other indicators of the problem's importance include sessions dedicated to taste and odor at the 1984 AWWA Water Quality Technology Conference and the 1985 AWWA Annual Conference.

Among the many methods used by utilities to measure the intensity of the odor, the Threshold Odor Number (TON) method as described in Standard Methods (2) is the most common. However, this method suffers several drawbacks.

It has been noted to give inconsistent and sometimes inaccurate results. Moreover, it is not a practical tool for pinpointing a taste and odor problem because it cannot be used to identify and distinguish one source of taste and odor from another (3,4,5,6).

Problems with the TON method prompted the Metropolitan Water District of Southern California (MWDSC) to search for a new method that would aid in identifying and solving taste and odor problems throughout their system. MWDSC in conjunction with Arthur D. Little, Inc. modified the Flavor Profile Method (FPM) for use by the water industry as a replacement for the TON method. The FPM had been used for years by the food, beverage, and pharmaceutical industries (3).

The FPM is a descriptive method and is influenced by the total flavor of a sample, which includes taste, odor, and feeling factors. A group of trained panelists individually analyzes samples for aroma and flavor-by-mouth under controlled conditions. The panel discusses the individual findings, resolves any conflicts, and agrees to a flavor profile for the sample. This flavor profile is a description of all flavors, the order that they were perceived, and the intensity of each (7).

The FPM is a sensory technique and, as a result, is subjective. The Method's purpose is not to determine concentrations of odorants and be used as a replacement for our analytical instruments, but to detect presence of an odorant and to aid in evaluating water treatment effectiveness.

Use of the FPM by the water industry is limited at this time to a few of the larger utilities and a research project at Drexel University. MWDSC uses the FPM extensively for routine monitoring throughout their system and as an aid in solving specific taste and odor problems (3,8,9). Drexel University is using the FPM as part of a research project on taste and odor. The Drexel project includes use of the FPM by the Philadelphia Water Department, The Philadelphia Suburban Water Company, and the Societe Lyonaisse des Eaux et de l'Eclairage (1,8,10).

This research was undertaken to obtain some practical experience with the FPM. The following objectives were established:

1. to organize and conduct a sensory panel using the Flavor Profile Method.

2. to evaluate use of the Flavor Profile Method by water managers as a detector of and as an aid in controlling earthy-musty and chlorinous odorants in water supplies. This objective was accomplished with samples taken from selected locations in the Orange Water and Sewer Authority water supply system.

Chapter 2

LITERATURE REVIEW

Physiology and Chemistry of Taste and Smell

Flavor is a combination of taste from the tongue, odors from the nose, feeling factors from the mouth and nose, and aftertastes. When a sample is tasted, we evaluate its flavor. When the sample is smelled, we assess only its odors and feeling factors from the nose. Feeling factors include burning, cooling, gritty, numbing, astringent, etc. (7).

Odor is perceived when air is drawn through the nostrils to the olfactory area (Figure 1). According to the stereochemical theory of odor as presented by Amoore (11), this area contains nerve endings and receptor sites. A primary odorant fits into a receptor site, similar to the site specific enzyme reaction, and triggers a nerve signal through the olfactory bulb to the brain.

The seven primary odorants are listed in Table 1. All other odors are complex and are a combination of two or

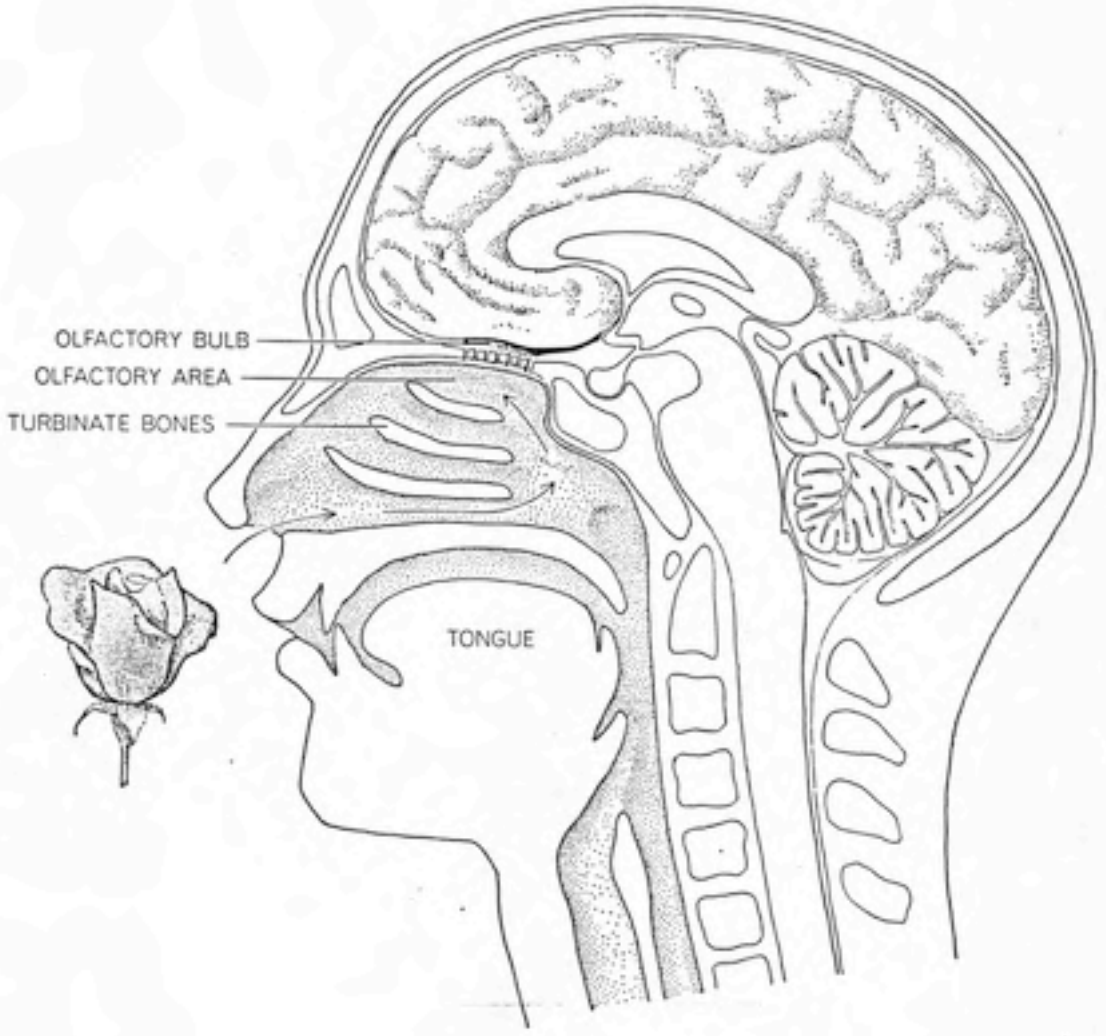


Figure 1. The anatomy of smell (Amoore, 11)

Table 1. The seven primary odors (Amoore, 11)

PRIMARY ODOR	CHEMICAL EXAMPLE	FAMILIAR SUBSTANCE
CAMPHORACEOUS	CAMPHOR	MOTH REPELLENT
MUSKY	PENTADECANOLACTONE	ANGELICA ROOT OIL
FLORAL	PHENYLETHYL METHYL ETHYL CARBINOL	ROSES
PEPPERMINTY	MENTHONE	MINT CANDY
ETHEREAL	ETHYLENE DICHLORIDE	DRY-CLEANING FLUID
PUNGENT	FORMIC ACID	VINEGAR
PUTRID	BUTYL MERCAPTAN	BAD EGG

more primary odorants. To be an odorant, a molecule must be volatile to reach the olfactory area. Odor is perceived during tasting because volatiles rise behind the tongue to the olfactory area. An odorant must be water soluble to penetrate the moist skin of the olfactory area. Finally, an odorant must be soluble in lipids to reach the nerve endings (11).

Taste is influenced by only four factors: sweet, sour, salty, and bitter. These taste factors are perceived when specific taste buds on the tongue are chemically stimulated (Figure 2) (3).

Occurrence and Contol of Taste and Odor In Water Supplies

Causes of Taste and Odor. The sources of taste and odor may be divided into three groups: natural organics, synthetic organics, and inorganics (Table 2). Odor from natural organics may be produced by the decay of organisms, by metabolites, or by organic chloramines. Industrial discharges or spills are usually the source of odor from synthetic organics. Odor producers in the last group, inorganics, are limited to hydrogen sulfide, free chlorine, and inorganic chloramines. Other inorganics

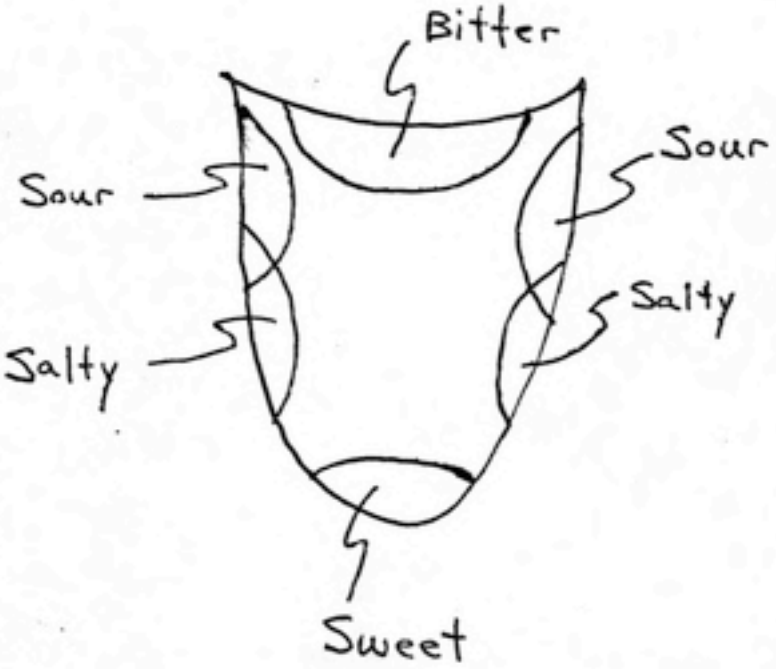


Figure 2. The anatomy of taste.

Table 2. Typical causes and descriptions of odors

Cause	Description	Ref.
Natural Organics		
Decaying Algae	Grassy, Septic, Fishy Decayed Vegetation	(12)
Geosmin	Earthy, Musty	(13)
MIB	Earthy, Musty	(3)
Synthetic Organics		
Benzene	Sweet	(14)
No. 2 Fuel Oil	Gasoline	(14)
Trichloroethylene	Strong Chlorinated Solvent	(14)
Dodecanal	Spicy, Green Vegetation	(8)
Ethylene Glycol	Mild, Sweet	(14)
Inorganics		
Hydrogen Sulfide	Rotten Egg, Sewer	(12)
Free Chlorine	Chlorinous	(15)
Monochloramine	Chlorinous	(15)
Dichloramine	Swimming Pool, Bleachy	(15)

such as salts and metal ions may cause objectionable taste (12).

When two or more odorants are together in a sample, we may perceive an odor description and intensity entirely different from what we detect with the individual odorants. The odor intensity will change by one of three phenomena (16):

1. Additivity- sum of the individual intensities
2. Synergism - more than the sum of the individual intensities
3. Antagonism- less than the sum of the individual intensities

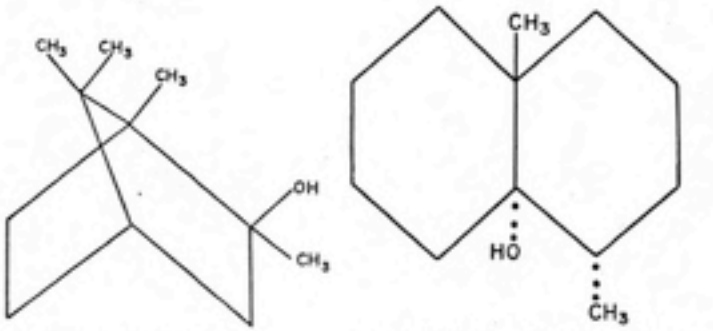
Earthy-Musty and Chlorinous Odorants. The earthy-musty odor seems to be the most prevalent cause of taste and odor problems throughout the world: from here in the United States to The Netherlands (17), Japan (18), Israel (19), and Finland (20). These odors can be produced by any one of five compounds (21,22):

MIB (2-methylisoborneol)
geosmin (trans-1,10-dimethyl-trans-9-decalol)
IPMP (2-isopropyl-3-methoxypyrazine)
IBMP (2-isobutyl-3-methoxypyrazine)
TCA (2,3,6-trichloroanisole)

MIB and geosmin are the most common of the earthy-musty odorants. Of the five, they are the only compounds charged with causing problems in water supplies. Geosmin

is a metabolite of actinomycetes (genus Streptomyces) and blue-green algae (genera Oscillatoria, Lyngbya, Symploca, and Anabaena). MIB is also a metabolite of Streptomyces and blue-green algae (genera Oscillatoria and Lyngbya) (23,18). Both compounds are saturated cyclic tertiary alcohols (Figure 3) (23).

The ability of the senses to detect MIB and geosmin at very low concentrations is one of the reasons these compounds are so troublesome. Figure 4, which is based on work performed by Krasner et al. (3) at MWDSC, shows a sensory panel's perceived intensity of earthy-musty odor at various MIB concentrations. Intensity as a function of the logarithm of concentration is a straight line relationship as predicted by the Weber-Fechner Law (5). This is an empirical law and, interpreted, means that as the concentration of an odorant increases, the perceived intensity of the odor will be less than that predicted by a linear relationship. From the graph, we see that 1 to 3 ng/l of MIB in taste and odor free water can be perceived by the human senses. Even in the samples, which contain background odorants, 3 to 5 ng/l MIB is detected. Researchers have found geosmin to have an even lower threshold odor concentration than MIB (17).



2-methylisoborneol

Trans-1,10-dimethyl-trans-9-decalol
(geosmin)

Figure 3. The structure of MIB and geosmin (Rosen et al., 21)

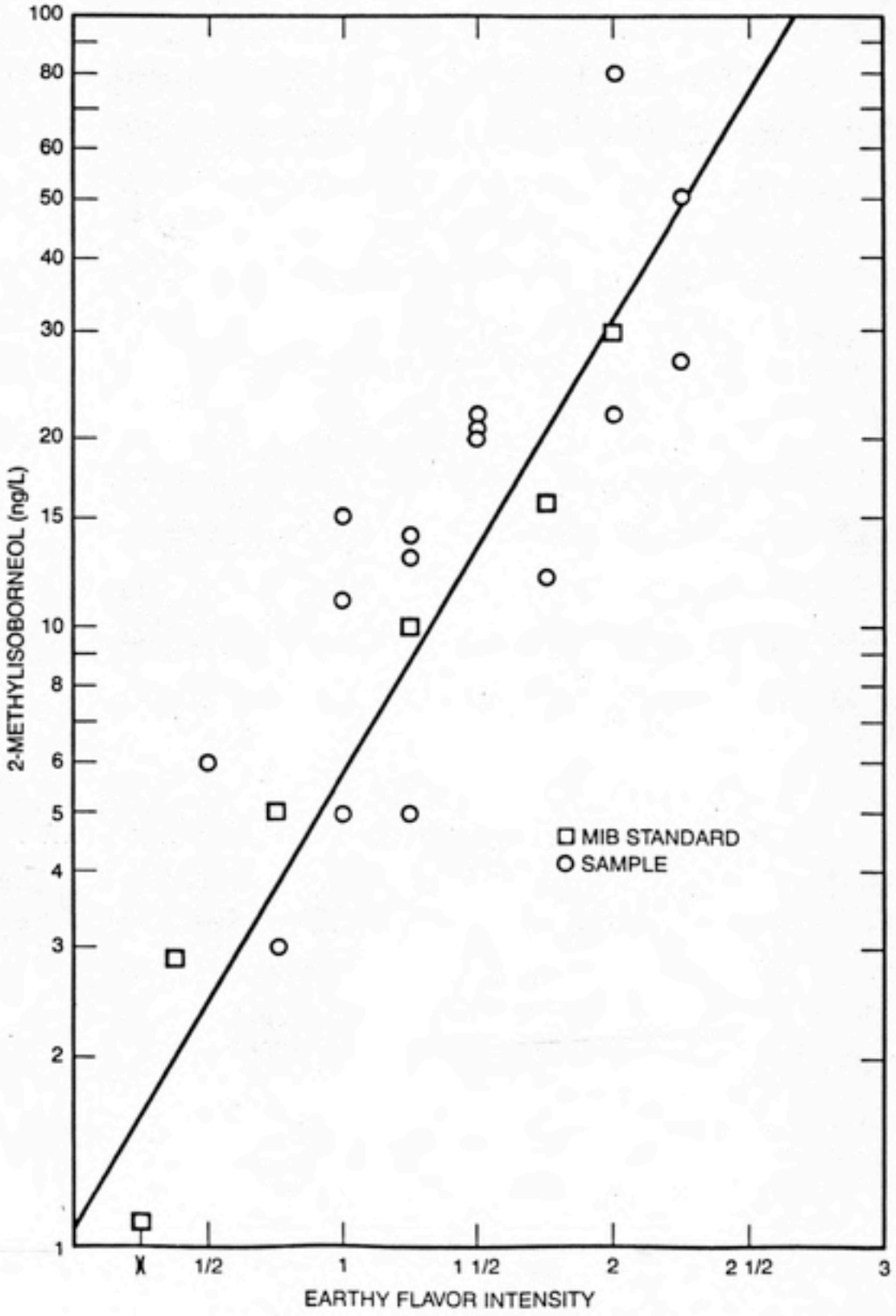


Figure 4. Correlation of earthy flavor intensities with MIB concentrations (Krasner et al., 3)

Chlorinous odors are a concern, especially in the United States, due to the widespread use of free chlorine and inorganic chloramines as drinking water disinfectants. Krasner and Barrett (15) found monochloramine to be relatively non-odorous: concentrations up to 3 mg/l as Cl2 had a slight intensity at most. Concentrations of monochloramine above 3 mg/l contained significant amounts of dichloramine, a strong odorant. They found that dichloramine above 0.5 mg/l as Cl2 had an objectionable bleachy, swimmimg pool-like odor. The odor intensity of free chlorine falls in between the two chloramines. The threshold odor concentration for free chlorine was found to be about 0.3 mg/l as Cl2. Figure 5 is a plot of intensity vs. concentration for one component of free chlorine, hypochlorous acid. Hypochlorite exhibited the same chlorinous odor and similar intensities.

Control of Taste and Odor. Water utilities use a variety of methods to treat taste and odors at the plant. Some methods are: chemical oxidation with chlorine, chloramines, chlorine dioxide, ozone, or potassium permanganate; adsorption with powdered or granular activated carbon; and stripping by aeration. The best treatment to use depends on the situation, but, in general, carbon adsorption is thought to be the most

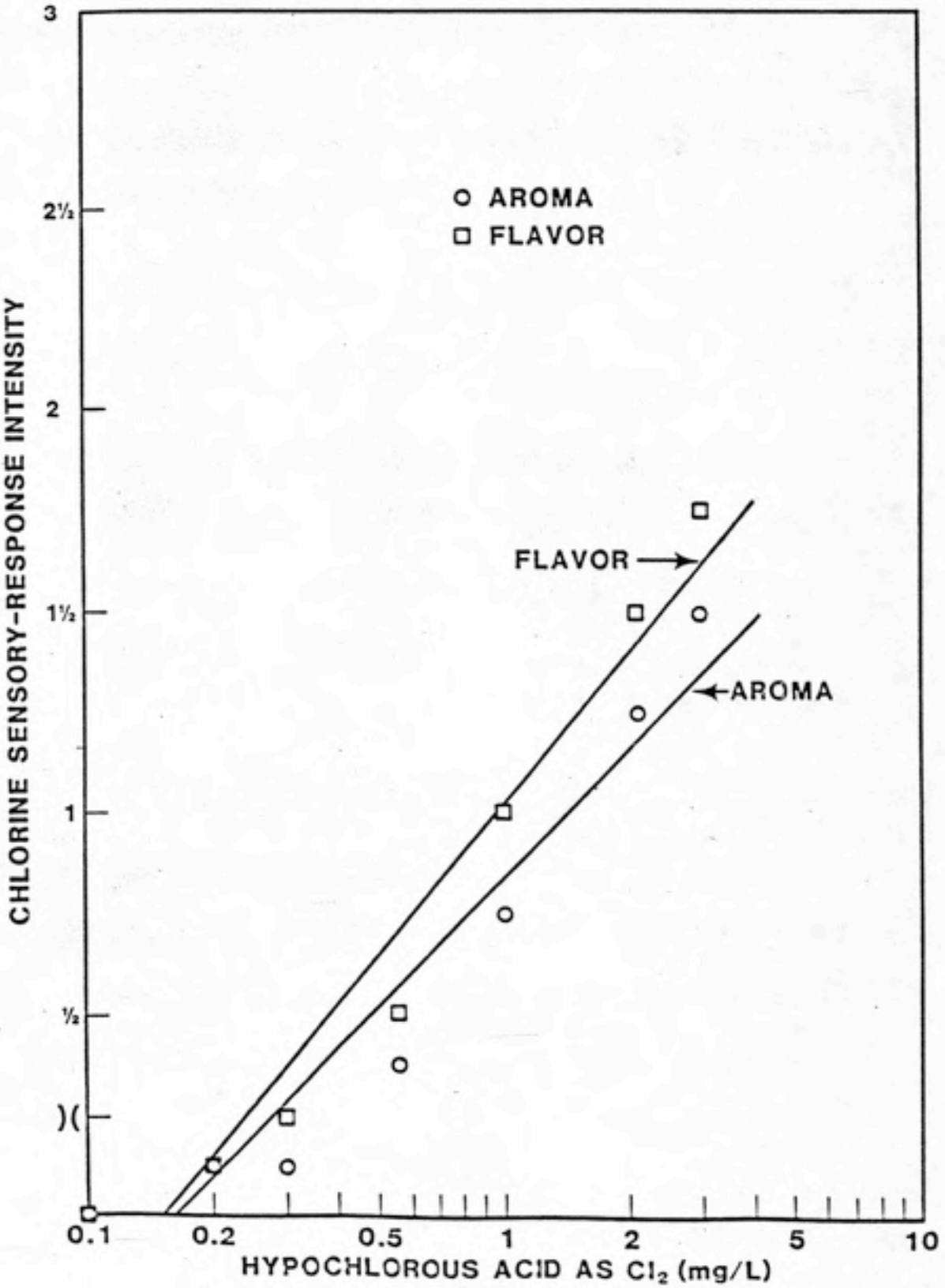


Figure 5. Concentration-versus-sensory response curves for hypochlorous acid (Krasner and Barrett, 15)

effective (8). Rebhun et al. (24) found that chlorination reduced the earthy-musty odors produced by cultures of Oscillatoria, but many studies of natural waters note an intensification of the odor (25,24,4). McGuire et al. (4) suggest that chlorine effectively oxidizes other odorants in the sample leaving earthy-musty as the predominant odorant.

Treatment at the plant may be the best method of control for a large water supplier, such as Cincinnati, whose source is difficult to protect. But for other utilities there may be a more cost effective solution. The cost of treatment is illustrated in the following example. A 30-mgd water treatment plant experiencing problems with earthy-musty odors from MIB and geosmin spent $150,000 in 1981 on powdered activated carbon (PAC) and potassium permanganate ($KMnO_4$) just to reduce the odor level. This cost was 50% of their total chemical costs for the year (26). This utility and others having control over their source water may benefit by attending to the cause of the problem in addition to treatment at the plant.

Numerous methods exist to control the cause of natural taste and odor problems including: application of algacides, biological oxidation, and reservoir

destratification. Algalcides such as copper sulfate will destroy blue-green algae which is a source of food for another producer of earthy-musty odors, Streptomycetes (27). Biological oxidation involves the application of Bacillus species to consume the odorous compounds produced by actinomyces (27,28). The objective of reservoir destratification is to interupt the life cycle of planktonic taste and odor producers. For producers attached to the bottom, this method is not effective (8).

Good watershed and water storage system management can be very effective in reducing taste and odor. Control of industrial discharges and organic and nutrient loads into source waters will reduce synthetic and natural odor producers, respectively. Reservoirs that cause taste and odor problems may be bypassed temporarily so raw water to the treatment plant is of good quality (8).

MWDSC has a unique and very effective approach to solving taste and odor problems. They combine sensory evaluation, analytical measurements, microbial culturing and analyses, and field sampling and observations to identify the odorant and the cause (4). Sensory evaluation is with the FPM. The analytical technique is

the closed loop stripping analysis (CLSA) with GC/MS. This sensitive instrumental method is necessary to detect the low concentrations of many odorants. Many of MWDSC's solutions focus on the odor's cause and have included: treatment of an Oscillatoria bloom with copper sulfate (29) and implementing a new procedure for repair of fabric-covered reservoirs (9).

Sensory Methods Used By Water Utilities

The Threshold Odor Number (TON) method has been the most frequently used sensory technique in the water industry. The method involves repeated dilutions of a sample until the tester can barely detect the faintest odor (threshold odor) (2). Due to the Method's design, the most intense odor will control the result. This is acceptable in instances of gross contamination, but often we are concerned with a less intense odor that is more objectionable or with multiple odorants. Other problems with the TON method are the alteration of odorant characteristics with dilution and inconsistent results, since one person can conduct the test but each person's odor sensitivity is different (3,4).

Many other techniques are used by utilities for sensory

monitoring. One example is a method used by the Atlanta Water Works. Air is bubbled through a vessel containing raw water (Figure 6), the odor is stripped out, and exits through the top for sensory evaluation (25). This "continuous odor monitor" is located at the plant, so the sensory evaluation is performed by under uncontrolled conditions. Background odors in the plant would make detection difficult. One would expect that the results from this method are inconsistent and unreliable.

The Flavor Profile Method

The FPM is a versatile sensory technique that applies well to the water industry. The Method is descriptive in that it characterizes the entire flavor of the sample, not just the most outstanding intensity as with the TON method. Description of the flavor helps the water manager identify its cause and reporting the entire flavor allows treatment of a less intense but more objectionable odor. The Method lends itself well to assessing the impact to taste and odor by treatment processes or any other stimulus. Since it is based on the use of a trained panel, the Method is consistent and reproducible. Finally, samples are tested in the same

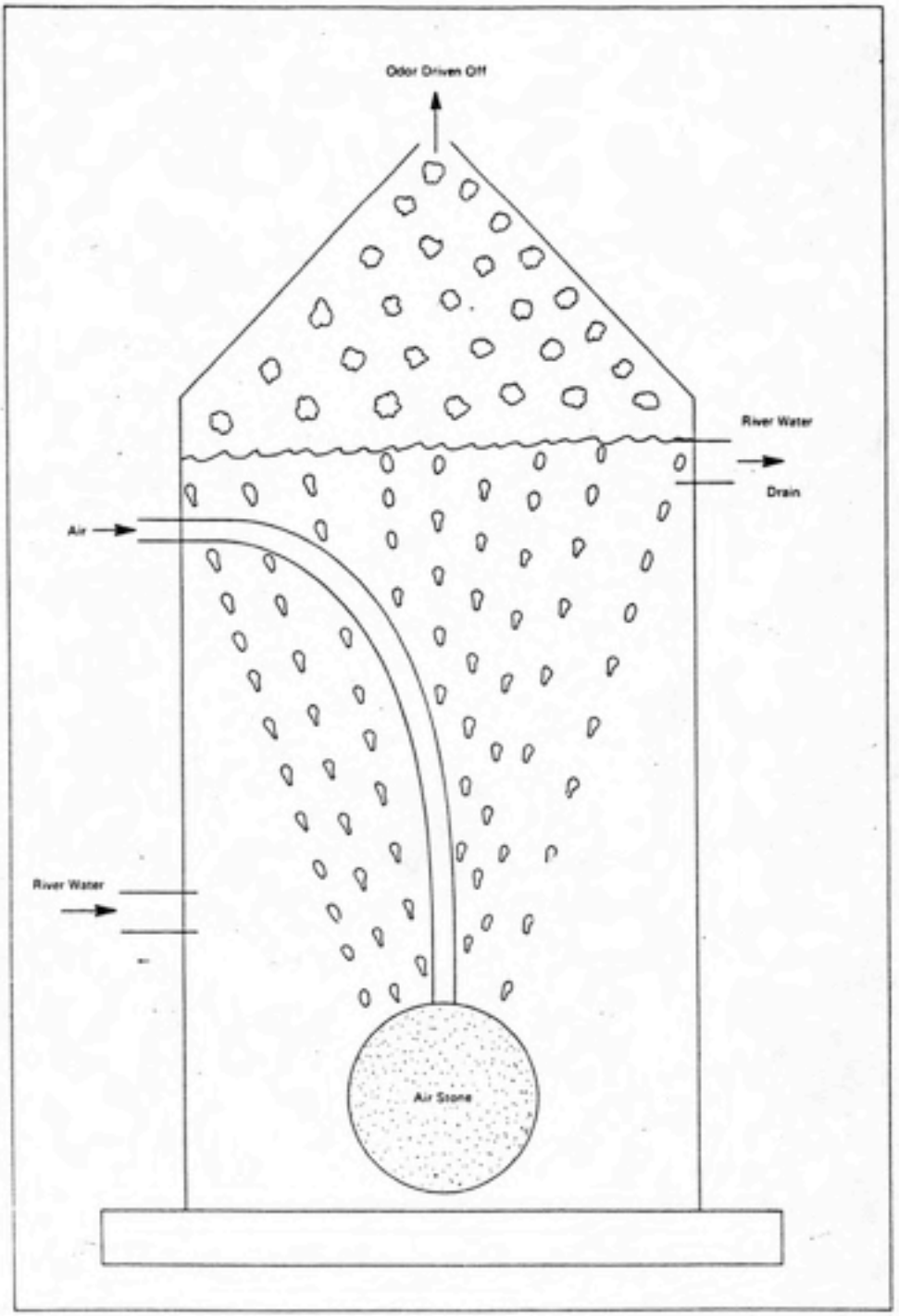


Figure 6. Continuous odor monitor (AWWA, 25)

fashion consumers ingest the product: in contrast to the TON method, which alters the sample through dilution. Cairncross and Sjostrom (30) developed the FPM in 1949 and since then it has been used in the food, beverage, and pharmaceutical industries. Being dissatisfied with the TON method, MWD and Arthur D. Little, Inc., a consultant having extensive experience in the flavor evaluation field, adopted the FPM for use in the water industry (3). The principle of the Method is that a sample is analyzed by a trained panel for aroma or odor and for flavor (by mouth). Each panel member describes all flavors and notes the intensity of every description. The panel discusses the individual results, resolves any discrepancies, and arrives at a composite flavor profile for the sample (7). A description of each important element of the FPM follows:

1. Selection of The Panel.

A minimum of four panelists is required, but at least six people should be trained in case of absences. Panel members are motivated, intelligent, and have normal flavor sensitivity. They may be selected from employees or volunteers or may be hired specifically for this purpose (7).

Members are selected by a screening process consisting of three steps. First, they are tested for taste recognition. The chemicals listed in Table 3 are dissolved in taste and odor free water and presented to the prospective panelists in odorless plastic cups. An acceptable result is recognition of all four basic tastes. Flavor intensity depends on temperature, so it is important for all samples to be at a consistent temperature (7). The Philadelphia Water Department substitutes the taste recognition test with a standardized scratch and sniff test that detects olfactory problems instead of taste sensitivity . The test is called the University of Pennsylvania Smell Identification Test (UPSIT) (31) and is available from Sensonics, Inc. (408 S. 47th St., Philadelphia, PA 19143, tel. 215-471-4117) (32).

Second, the prospective panel members are tested for odor recognition (32). A series of odor reference standards are presented to the panel for identification. The standards used by the Philadelphia Water Department are listed in Table 4. The chemicals and concentrations used as standards should be checked against references on chemical toxicity for the protection of the panelists. A scoring system as that developed by Caul (7) may be used:

Table 3. Taste reference standards (Philadelphia Water Dept., 32)

TASTE STANDARD	COMPOUND USED	CONCENTRATIONS
Sweet	Table Sugar	2.5%, 5%, 10%, 15%
Sour	Citric Acid (reagent grade)	0.025%, 0.05%, 0.10%, 0.20%
Salty	Sodium Chloride (reagent grade)	0.2%, 0.4%, 0.7%, 1.0%
Bitter	Quinine Hydrochloride Dihydrate	0.0005%, 0.001%, 0.002%, 0.004%

The standards are dissolved in T & O-free water.

Table 4. Odor reference standards (AWWA, 8)

PHILADELPHIA WATER DEPARTMENT

TASTE AND ODOR PANEL

Odor reference standards are used to train the panelists and develop consistency among the panel. Specific quantities of a product or chemical are placed in a 500 ml. Erlenmeyer, usually with 200 ml. of odor free water, and sniffed at room temperature.

ODOR DESCRIPTIVES	ODOR REFERENCE STANDARDS[1]
Almond, sweet	500 ppb benzaldehyde
Bleach, sweet	monochloramine (60 ppm chlorine, 20 ppm ammonia)
Chlorinous	2 ppm free chlorine
Cucumber	75 grams of cucumber
Cucumber	200 ppb nonenal
Earthy, musty, potato	25 ppt geosmin
Fruity, sweet	200 ppb nonanal
Garlic	75 grams of garlic
Geranium	geranium flowers or leaves
Grassy	2 grams of fresh grass
Grassy	500 ppb 3-Hexen-1-ol
Hay, straw	dry hay
Hexanal	2,000 ppb hexanal
Medicinal, sweet	500 ppb m-Xylene
Moth balls	several crystals of p-Dichlorophenol
Musty, earthy, peaty	50 ppt 2-methylisoborneol
Onion	75 grams of onion
Pepper, musty	75 grams of green pepper
Perfumy, sweet	1,000 ppb methylisobutyl ketone
Rubber hose	water that was heated with rubber hose in it
Rubber hose, shoe polish	500 ppb cumene
Septic	2 grams of grass after several days
Septic, sludge	paper mill sludge
Spicy	3-4 cloves
Vegetation, decomposing	2 grams of grass after several days
Varnish, paint	industrial varnish plant effluent

[1] Current list of reference standards as of November, 1984.

5 points for exact identification
4 points for association (vinegar for acetic acid)
3 points for description (fishy for cod liver oil)
2 points for vague description (cooling for camphor)

Using 20 odor standards, a score of 70 is desirable. Fewer odor standards may be used.

Third, an odor intensity test is given. Various concentrations of an odor reference standard in taste and odor free water are smelled by the prospective panelists using the procedures for evaluating odor described later in this section. The samples should contain several concentrations in the threshold range. A response very much different from the known threshold value would be unacceptable (32).

The prospective panelist may be interviewed before a final decision is made (7). The interview is used to find out if the person is motivated and intelligent. Also, he or she cannot be dominating or must be willing to assume an equal voice with the other panel members, and he or she must be in good health (7).

The selected panelists are trained before they begin the first assignment. Training includes classroom instruction on the physiology of taste and smell and the

mechanics of the FPM. Using the FPM procedure described later in this section, the panel spends several sessions producing flavor profiles of the taste standards, odor standards, and water samples from local supplies.

Prior to beginning a FPM assignment, the panel must be oriented to the nature of the taste and odor problem being investigated. The results should be more thorough if the panel knows the types of tastes and odors to expect (7). Krasner (33) found that prior knowledge of the sample identity did not significantly bias the panelist's response.

2. The Panel Leader

The panel leader, an equal member of the panel, should be a regular employee with a knowledge of chemistry. The leader makes all the preparations for the panel sessions to include: scheduling the panel, cleaning the glassware, collecting the samples, preparing the standards, purchasing needed supplies, preparing the samples for the panel, moderating the panel discussion, presenting the results to management, and selecting and training new panel members. The leader's opinions during panel discussions carry no more weight than that of the

other panelists, but he or she is responsible for ensuring individual participation (7).

3. The Testing Area

The area used to conduct the sessions must be clean, quiet, well lit, free of outside odors, and temperature controlled. A board to record the results and a large table to seat all the panelists is necessary. Members of the panel must not eat or smoke 15-30 minutes prior to testing. To ensure that no outside odors are present, panelists cannot wear perfume, cologne, or any cosmetic with a significant odor; and they must wash their hands with odor-free soap (Ivory) (3).

4. Sample Collection and Preparation

Glassware must be odor-free. One of the following two cleaning procedures is recommended: 1) wash in warm tap water and detergent, rinse five times with warm tap water, then rinse three times with taste and odor free water, or 2) wash with detergent, rinse with tap water, rinse with acetone, then bake @ 180 degrees C overnight. Rubber gloves should not be worn during either procedure. Taste and odor free water can be bottled spring water or

distilled, deionized, carbon-filtered water. Bottles cleaned using the first procedure should be filled with 100-200ml of taste and odor free water before storage (3,34).

Samples are collected in glass bottles with Teflon-lined caps. If the sample is from a tap; remove aerators, let it run for five minutes, then rinse the bottle several times from the spigot. Samples must be kept on ice or refrigerated @ 4 degrees C until tested. The refrigerator should not be used for chemical storage. Samples must be tested no more than 24 hours after collection (3).

The FPM specifies that all analyses be performed on samples at room temperature (25 degrees C). The Philadelphia Water Department modified the procedure for odor analysis so the sample is heated to 45 degrees C. The reason for heating the sample is to enhance the odors as happens during cooking and bathing. The sample is analyzed from a stoppered flask to contain the odors. If odor analysis is performed on samples at room temperature, then 2 ounces of the liquid is given to the panelist in an odorless plastic cup and covered with a watchglass. Taste is also analyzed from plastic cups and should be from the same cups and sample used for odor

analysis, only if both taste and odor samples are at room temperature (3,34).

Quality control of sample collection, sample preparation, glassware cleaning, and the panel calibration consists of a taste and odor free water sample, a duplicate sample, and an odor reference standard sample of certain concentration, all included with the set of "unknown" samples. If odor is analyzed from heated samples, then two sets of samples are used so no more than three panelists use each flask. Odor intensity will diminish after continued use. The number of samples analyzed during each session should be limited so as not to cause fatigue or extend beyond one hour.

5. Analysis of Odor

For samples to be analyzed at room temperature; the cup is swirled, the watchglass is removed, then the panelist sniffs the sample a few times with their hands below the table. The senses become fatigued after a few sniffs so additional smelling will not detect the odor. The panelist comes back to a troublesome sample later (3).

After each sample is smelled, the descriptions of all odors in the order they are perceived and the intensity of each description are noted. Flavors perceived first and last are usually the most important. Descriptions or "character notes" are agreed upon and listed by the panel. If a panelist detects a character note that is not listed and the other members of the panel do not perceive it, then that person must bring in a reference standard for the new note. This system will expand the flavor vocabulary of all panelists. The character notes used by the Philedelphia Water Department (34) are listed in Appendix A. The intensity scale is listed in Table 5. An intensity rating corresponds to a specific concentration of a reference standard as determined by the panel (3).

Between samples the panelists should clear their senses by sniffing taste and odor free water. Strong flavors can dull the senses so samples should be analyzed beginning with the least flavorful to the most flavorful (3).

If samples are analyzed for odor at 45 degrees C, only the method of smelling will change. The stoppered flasks will be in water baths at the time of testing. Without

Table 5. Flavor intensity scale (Krasner et al., 3)

Intensity	Scale
Threshold (recognition)	)(
Very slight	½
Slight	1
Slight to moderate	1½
Moderate	2
Moderate to strong	2½
Strong	3

touching the flask's neck, it is shaken vigorously to release the aromatics; the stopper is removed; and, while holding the bottom of the flask, the sample is sniffed a few times (34).

6. Analysis of Flavor

Samples are always analyzed for flavor after odor analysis. This order is helpful because the odor analysis will alert the taste-tester of what to expect in the flavor (7). Water that may contain pathogens should not be tasted. The panel should agree on what type of waters are safe.

Flavor is analyzed by sipping the sample, rolling it over the entire tongue to contact all taste areas, and then swallowing. The liquid should be "slurped" to release aromatics to the olfactory area. One or two more sips are taken; then the panelist writes down all descriptions in the order perceived, with intensities. The senses are cleared between samples with taste and odor free water and unsalted crackers (3).

7. The Flavor Profile

The individual findings are compiled into a flavor profile after each panel member completes their analyses of odor and flavor. Each panelist recites their results for a sample as the panel leader writes them on the board. After all individual results for the sample are recorded, a discussion takes place to arrive at a composite profile for that sample. Samples may be analyzed again if necessary. No person, including the panel leader, is dominant during the discussion. If only 50% of the panel perceives a character note, the description is assigned a threshold value. If less than 50% of the panel detects a characteristic note, an "other" is recorded with description but no intensity. Figure 7 is an example of the individual responses and the final, composite result called the flavor profile (3,7).

8. Panel Scheduling

Panel sessions can be scheduled any time of the day except one-half hour after meals and near the end of the day. A study has shown that sensitivity to flavor is indifferent between morning and afternoon. Tasting is

FLAVOR PROFILE METHOD

Taste X **or Odor** ___ **Date** 7/8/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Ruthy	Bill	Pam	Anne	Desc.	Int.
Pinegate	Cl ½	Cl)(	Mu ½	Cl ½	Mu ½-1	Mu	1
	Mu 1		Cl ½			Cl	½
Carolina Inn	Mu ½	Mu ½	Cl 1	Mu ½	Mu ½	Mu	½
	Cl ½	Cl ½	Mu ½			Cl	)(
Taste and Odor Free Water	------	-----	-----	-----	Mu ½	-----	-----
Finished Water @ WTP	Cl ½	Bi ½	Mu½	Mu 1	Bi 2	Mu	½
	Mu ½	Cl ½	Cl ½	Cl ½		Cl	½
						Other-	Bi
Finished Water @ WTP	? 1	Mu 1	Mu 1	Mu 1	Mu 1	Mu	1
		Cl ½		Cl ½	Cl ½	Cl	½

Figure 7. Example of panel session results

not appealling after meals and work pressure may be a problem at the end of the day (7). Frequent testing is necessary to keep senses sharp; the MWDSC panel meets three days per week (8).

Taste and Odor Research Being Conducted By Drexel University

Drexel, in association with the Philadelphia Suburban Water Company (PSWCo), the Philadelphia Water Department (PWD), and the Societe Lyonaisse des Eaux et de l'Eclairage (SLEE) is conducting a project dealing with taste and odor. The objectives are: 1) to identify taste and odor producing compounds, 2) to evaluate the effectiveness of various treatment processes in removing these compounds and publish the results in a manual, 3) to develop odor reference standards for use with the FPM, and 4) to make an inter-laboratory comparison of the FPM (10,35).

To identify taste and odor producing compounds; PSWCo, PWD, and SLEE are performing the FPM sensory analysis on water samples from local supplies. The samples were also analyzed by CLSA and simultaneous distillation extraction (SDE). Compounds identified from the instrumental analysis and flavor descriptions from the sensory

analysis are being correlated using the statistical method of factor analysis. The result will be a listing of odor descriptions and the compound(s) that may cause that odor (8).

That portion of the research dealing with treatment of taste and odor is aimed at developing a manual for use by utilities with taste and odor problems. Drexel is evaluating the effectiveness of coagulation and filtration, chlorination, chloramination, oxidation with chlorine dioxide, oxidation with potassium permanganate, adsorption with PAC, adsorption with GAC, and air stripping on a wide range of synthetic and natural odorous compounds; all of these methods are being evaluated on a bench scale. Preliminary results, which do not include treatment by GAC, show PAC adsorption to be the most effective (8,10).

The results of this study are to be presented at the 1986 AWWA Annual Conference. The project director is Dr. I. H. Suffet at Drexel University (36).

Chapter 3

EXPERIMENTAL METHOD AND DESIGN

Preparation For Panel Session

The work required prior to conducting a panel session includes: washing glassware, gathering other materials, collecting samples, mixing standards, and preparing all samples for presentation to the panel. The glassware used for collecting samples and mixing standards were 32 oz. flint glass bottles w/ screw cap (Fisher Scientific # 02-883EE). The caps were Teflon lined. For odor analysis, 500 ml Wheaton 900 amber glass bottles w/ ground glass stoppers (Fisher Scientific #02-918B) were used. These stoppered bottles helped to contain the volatile odorants. Tinted glass is not necessary; clear bottles could be used instead. Plastic cups were covered by watch glasses (75 mm diameter).

All glassware was cleaned by washing in warm tap water and detegent, rinsing five times with warm tap water,

then rinsing three times with taste and odor free water. The detergent used was Sparkleen from the Fisher Scientific Co. and a Scotch-Brite Kitchen Scrub-Sponge from the 3M Corp. was used to scrub the outside of the glassware. The inside of the bottles were scrubbed with a tube brush. The taste and odor free water used throughout the project was Spring Water from Rainbow Water Service, Durham, NC. Several brands of locally available spring and distilled water were tasted by the panel and the Rainbow Spring Water was found to be the most pleasing.

The analysis of taste was performed from 3-1/2 oz. yellow plastic cups (Solo Cup Co. # P35A). The Solo cups, with the exception of the clear type, are considered the only brand that do not impart an odor (34). To keep track of the sample identity during tasting, the cups were placed in a numbered circle on a cardboard mat. For odor analysis, the stoppered bottles were numbered with a yellow china marker. The bottles containing samples for odor analysis were placed in two water baths 20 minutes prior to testing. These baths were filled with taste and odor free water and kept the samples at 45 degees C.

Prior to testing, the panelists washed their hands with

Ivory brand soap. The salt free crackers used to clear the senses between tasting were Keebler Sea Toast.

Panel Training

Prospective panelists were recruited through notices posted in the School of Public Health and were offered payment of $4.00 per hour. A limited number of people responded and we were well into the warm weather when the earthy-musty odor is predominant. Therefore, the screening and training processes were combined into three sessions. Those people without normal olfactory and taste sensitivity would be identified during these combined sessions.

The first training session involved classroom instruction and identification of odor and taste reference standards. The classroom instruction covered the project objectives, the physiology of taste and smell, and the mechanics of the FPM. Next, panelists identified reference standards. Odor reference standards used were: 2 mg/l hexanal (Aldrich Chemical Co. # 11,560-6) as leafy, 0.5 mg/l trimethylamine (Aldrich # T7,272-9) as rotten fishy, 0.5 mg/l benzaldehyde (Fisher Scientific # B-240) as almond, 0.5 mg/l 3-hexen-1-ol (Aldrich # H1,290-0) as grassy, 0.5

mg/l cumene (Aldrich # 18,579-5) as rubber hose, 1% cod liver oil (Hain Pure Food Co., Los Angeles, CA) as fishy, 375 g/l garlic as garlic, 25 ng/l geosmin (US Environmental Protection Agency, Cincinnati, OH) as earthy-musty, 50 ng/l MIB (US Environmental Agency, Cincinnati, OH) as earthy-musty, and 1 mg/l as Cl2 free chlorine (prepared from NaOCl, Eastman Kodak Co. # 18309) as chlorinous. Taste reference standards used were: 0.1% citric acid (Aldrich # C8,315-5) as sour, 0.002% quinine monohydrochloride dihydrate (Aldrich # 14,592-0) as bitter, 0.7% salt as salty, and 10% sugar as sweet. All chemicals were diluted in taste and odor free water.

The second and third training sessions were used to develop the panel's sensitivity to different intensities of odor reference standards. The standards used were MIB and free chlorine and concentrations ranged from 1 to 80 ng/l for MIB and from 0.1 to 5 mg/l as Cl2 for free chlorine.

Panel Calibration

The intensity vs. concentration curve for a reference standard need not be the same for two different panels. A panel is specific to the utility it serves, in that its

results cannot be compared to those obtained by a different panel serving another utility. The panel will seek its own intensity vs. concentration curves, but must remain consistent to these curves from session to session.

The calibration of the panel was checked using odor reference standards. A known concentration of either MIB or free chlorine was included as a sample during both flavor and odor analyses at each session. MIB was not measured, so the concentration was calculated from dilutions of a known quantity from a 1 ml vial. The MIB stock solution was stored at 4 degrees C. If the panel was well-trained and had good sensitivity, the plot of intensity vs. logarithm of concentration for each standard would yield a staight line.

Application of the FPM to the Orange Water and Sewer Authority

The FPM was applied to the Orange Water and Sewer Authority (OWASA) water system in a manner similar to how a utility would use the Method to aid in solving taste and odor problems. OWASA delivers approximately 8 mgd of treated water to the Chapel Hill and Carrboro area. The

raw water supply is University Lake, which is a protected source that holds 630 million gallons and has a surface area of 210 acres. The sample location from University Lake is shown in Figure 8. Samples were taken at depths above and below the thermocline with a Kemerer bottle. The raw water is pumped to the OWASA Water Treatment Plant where it undergoes conventional treatment and disinfection with free chlorine. The plant is designed to treat 10 mgd. A process flow diagram is shown in Figure 9 and includes possible points of chlorine addition. Raw water and finished water samples from the treatment plant were taken from remote taps in the plant's laboratory. Settled water samples were taken from the end of the sedimentation basins. Over filter samples were taken from off the top of the filters, which is immediately after pre-filter chlorination. The purpose of taking a settled water and over filter sample was to determine the effect of chlorination on taste and odor. Filtered water samples were taken from a tap off the filtered water effluent piping.

An outline of the OWASA water distribution system is shown in Figure 10. The two sample points are the Carolina Inn and Pinegate Apartments. These points were used because Carolina Inn is near the center of Chapel

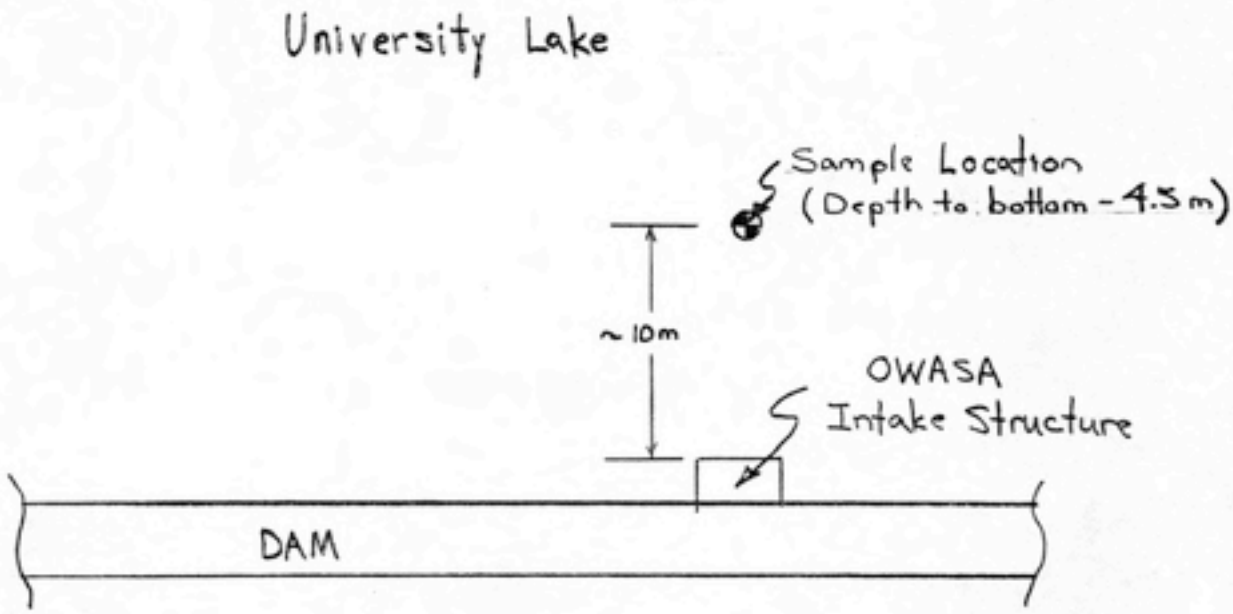


Figure 8. University Lake sample location (plan view)

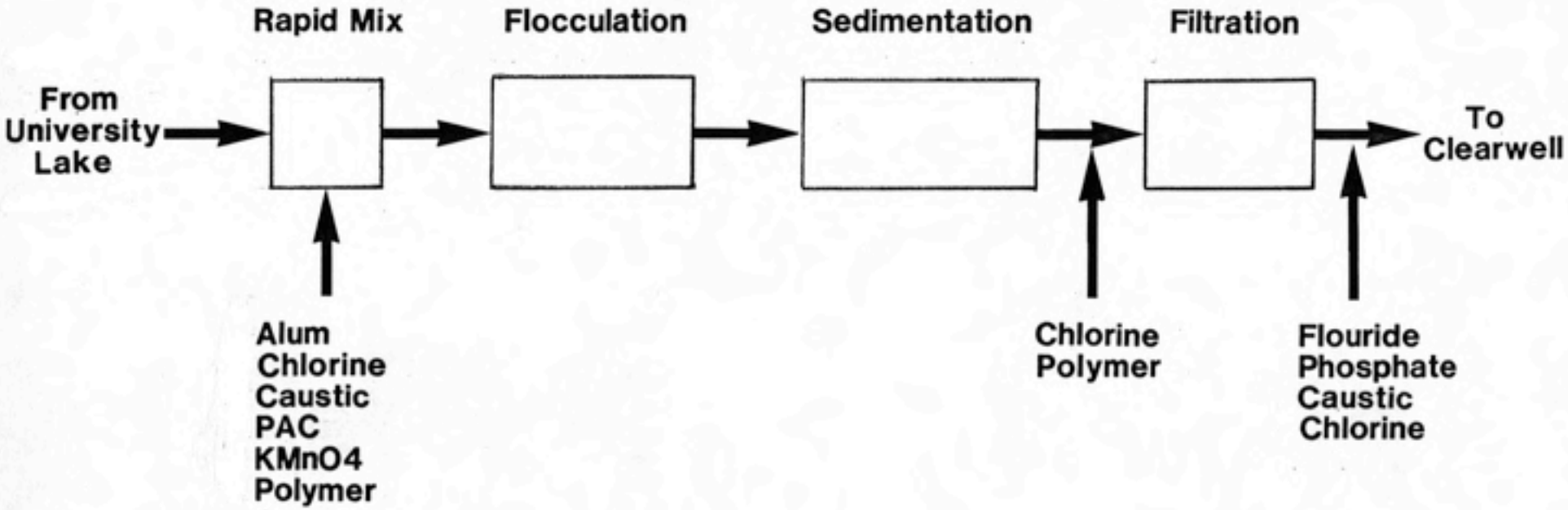


Figure 9. OWASA Water Treatment Plant process diagram with possible points of chemical addition

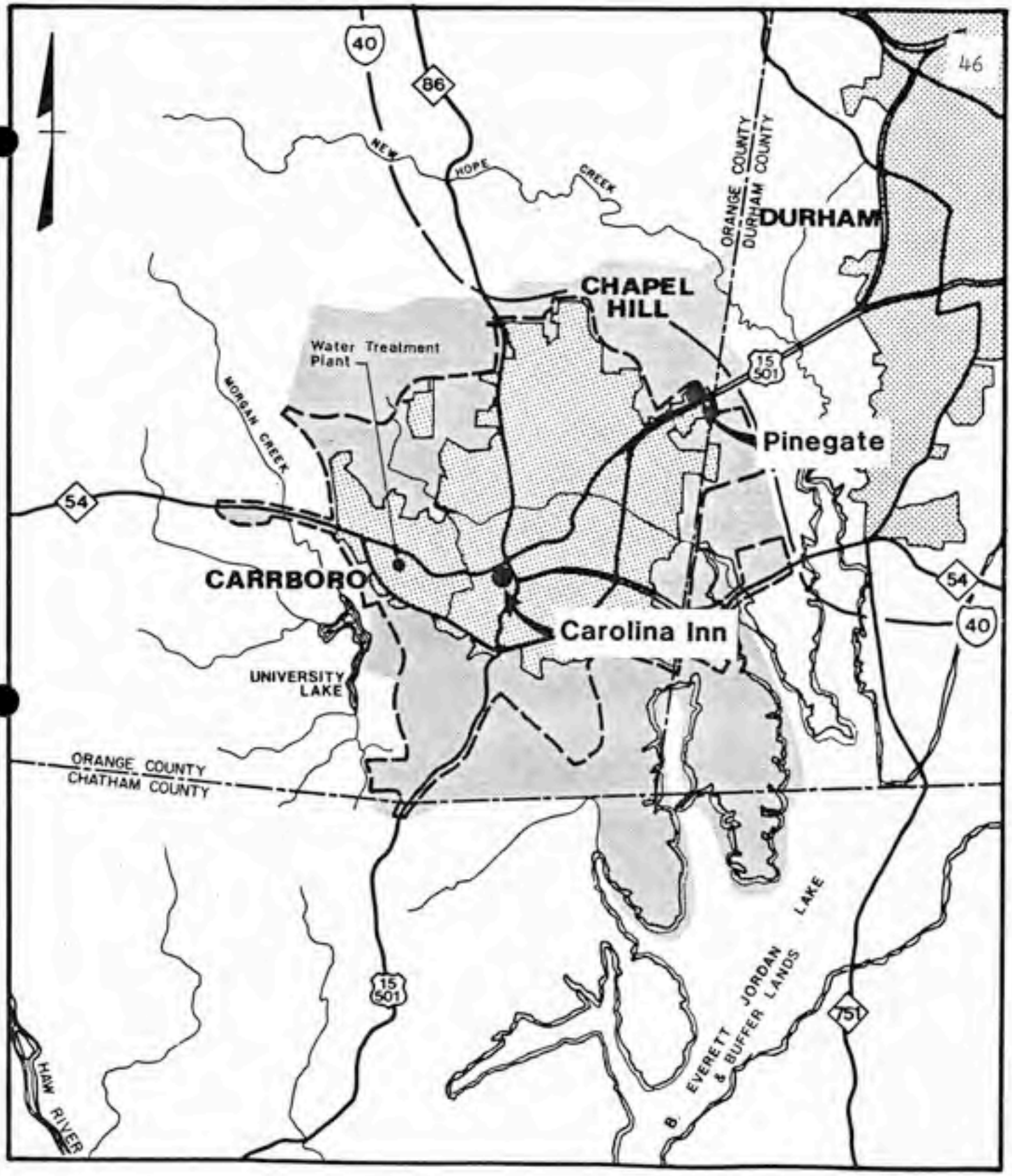


Figure 10. OWASA distribution system sample locations (OWASA, 37)

Hill and near the water treatment plant and Pinegate is at the edge of the distribution system. Neither of the two locations is on a "dead end" line.

To evaluate use of the FPM with bench-scale jar testing, several raw and settled water samples were dosed with powdered activated carbon (PAC) and chlorine in the laboratory. The PAC used for the jar tests was Watercarb (Husky Industries) and was obtained from OWASA. The PAC was dried overnight at 102 degrees C before weighing. The water samples were measured into 500 ml wide mouth amber glass bottles w/ Teflon-lined caps including a control sample that would not be dosed with PAC. The appropriate amount of PAC was added to each sample. All samples were mechanically rotated for the specified time; including the control, which rotated for 70 minutes. All samples were then centrifuged and the liquid decanted. After centrifuging, appropriate samples were dosed with chlorine and placed in the dark for two hours before measuring free chlorine residual.

Sensitivity of the panel to chlorinous flavors was determined by plotting intensity vs. free chlorine concentration. Sources of chlorinous odors other than free chlorine should not be present in OWASA water or in

the free chlorine standards, or present in insignificant concentrations. Measurement of monochloramine in OWASA drinking water at the School of Public Health found only 0.13 mg/l as Cl2. Taste and odor free water containing 3 mg/l as Cl2 of free chlorine had only 0.10 mg/l as Cl2 of monochloramine. These monochloramine concentrations are well below the flavor and odor thresholds (38). The other possible source of chlorinous odor, chlorinated phenols, should not be present in the OWASA water system. Since the water supply is protected and receives no industrial discharges, it would not contain phenols.

Table 6 lists all samples collected and subjected to sensory analysis. Chlorinated samples and the chlorine reference standard were analyzed for free chlorine concentration. All measurements of free chlorine and monochloramine were made using the DPD Ferrous Titrimetric Method (2).

Table 6. List of samples

Date	Sample
7/8/85	Raw Water @ WTP (O), Finished Water @ WTP (D), Carolina Inn, Pinegate
7/11/85	Raw Water @ WTP (O), Settled Water @ WTP (D), Filtered Water @ WTP, Finished Water @ WTP, 5 ng/l MIB Standard
7/19/85	Raw Water @ WTP (O), University Lake @ 1m depth (O), 2m depth (O) (D), and 3.5m depth (O), 0.5 mg/l as Cl2 Free Chlorine Standard (D)
7/24/85	Finished Water @ WTP, Carolina Inn, Pinegate (D), 3 ng/l MIB Standard
8/6/85	Raw Water @ WTP (O), Settled Water @ WTP (O), Filtered Water @ WTP, Finished Water @ WTP (D), 0.9 mg/l as Cl2 Free Chlorine Standard
8/14/85	Raw Water @ WTP (O), University Lake @ 1m depth (O) (D), 2m depth (O), and 3.5m depth (O), 25 ng/l MIB Standard (D)
8/21/85	Raw Water @ WTP (O) (D), Raw Water @ WTP treated w/ 15 ppm PAC for 40 min (O), 15 ppm PAC for 90 min (O), 30 ppm PAC for 40 min (O), 30 ppm PAC for 90 min (O), 2.9 mg/l as Cl2 Free Chlorine Standard (D)
9/4/85	Raw Water @ WTP (O), Settled Water @ WTP (O), Over Filter @ WTP (O), Filtered Water @ WTP (O) (D), 5 mg/l as Cl2 Free Chlorine Standard (D)
9/11/85	Raw Water @ WTP (O), Raw Water @ WTP treated w/ 30 ppm PAC for 40 min (O), 30 ppm PAC for 90 min (O), 60 ppm PAC for 40 min (O), 60 ppm PAC for 90 min (O), 9 ng/l MIB Standard (O)(D)

Note: (D)- this sample was also a duplicate.
(O)- this sample was analyzed only for odor.

Table 6 (cont.)

Date	Sample
9/18/85	Settled Water @ WTP (O), Settled Water treated w/ 5 mg/l as Cl2 Chlorine (O), Settled Water treated w/ 60 ppm PAC for 90 min (O), Settled Water treated w/ 60 ppm PAC for 90 min then 5 mg/l as Cl2 Chlorine (O), 25 ng/l Geosmin Standard (O), 25 ng/l Geosmin Standard treated w/ 1 mg/l as Cl2 Chlorine (O), 0.9 mg/l as Cl2 Free Chlorine Standard (O)
9/25/85	Raw Water @ WTP (O), Raw Water treated w/ 5 mg/l as Cl2 Chlorine (O), Raw Water treated w/ 60 ppm PAC for 90 min (O), Raw Water treated w/ 60 ppm PAC for 90 min then 5 mg/l as Cl2 Chlorine (O), 25 ng/l Geosmin Standard (O), 25 ng/l Geosmin Standard treated w/ 1 mg/l as Cl2 Chlorine (O), 1.0 mg/l as Cl2 Free Chlorine Standard (O)
10/2/85	0.3 mg/l as Cl2 Free Chlorine Standard, 0.9 mg/l as Cl2 Free Chlorine Standard (D), 2 ng/l MIB Standard, 5 ng/l MIB Standard, 15 ng/l MIB Standard

Note: (D)- this sample was also a duplicate.
(O)- this sample was analyzed only for odor.

Chapter 4

RESULTS AND DISCUSSION

Panel Training

In the first training session, the prospective panelists were given taste and odor reference standards for identification. The results of this session are shown in Table 7. The panel had no problem identifying the taste reference standards, although the bitter, sour, and salty standards could not be swallowed because of their strength.

The panel was able to identify the more familiar odor reference standards, such as: cod liver oil, garlic, geosmin, MIB, and chlorine. The other odor standards, which are used by the Philadelphia Water Department (see Table 4), were very difficult to describe. 3-hexen-1-ol at the recommended concentration did not have a perceptable odor. Benzaldehyde at the recommended concentration did not smell like almonds. The panel's

Table 7. Results of first training session (5/29/85)

ODOR

Reference Standard	Response Anne	Wendy	Pam	Bill
Hexanal (leafy)	sweet	grass	candy	fruit
Trimethylamine (rotten fish)	fish	fish	glucose	bad
Benzaldehyde (almond)	chemical	paint thinner	rubber	chemical
3-hexen-1-ol (grassy)	bland	-----	-----	------
Cumene (rubber hose)	chemical	varnish	plastic cement	chemical
Cod liver oil (fishy)	fish	fish	cod fish	kitchen
Garlic (garlic)	garlic	garlic	garlic	onion
Geosmin (earthy,musty,dirty)	dirty	dirt	geosmin	musty
MIB (earthy,musty,dirty)	dirty	dirt	paper	musty
Chlorine (chlorinous)	slightly flourinated	chlorine	chemical	chlorine

TASTE

Citric Acid (sour)	lemon juice	lemon sour	sour	lemon juice
Quinine (bitter)	bitter	bitter	bitter	bitter
Salt (salty)	salty	salty	salty	salty
Sugar (sweet)	sugar	sweet	sweet	sugar

difficulties in the first session seemed to be due to some poor odor reference standards and not to any abnormal olfactory sensitivity.

The results of the second and third training sessions are shown in Appendix B. In these sessions the panelists were given various concentrations of the reference standards MIB and free chlorine to evaluate odor and flavor (by mouth). The objective was to ensure that the panel's response for intensity was consistent with the known threshold values of these standards. Using the results of Krasner and Krasner and Barrett (Figures 4 and 5) as a guide, the results show our panel to be very sensitive to low concentrations of these reference standards.

Additional training would be desirable, but, as mentioned previously, time was limited and the regular sessions had to begin. Based on the three training sessions, all prospective panelists were considered to have normal flavor sensitivity. The panelists are listed in Table 8.

Table 8. Panelists used to conduct the FPM

Name	Age	Sex	Occupation
Anne Caston	28	F	Student
Pam Reitnauer	30	F	Student
Bill Dowbiggin	23	M	Student
Wendy Fuscoe	28	F	Student
Ruthy Deer (part-time)	28	F	Student
Ronnie Karanjia (part-time)	24	M	Student

Panel Calibration

The panel responses to the MIB standard are shown in Figure 11. Each point represents the composite flavor profile for that sample. The solid lines are the lines of best fit. The results show that the panel is sensitive to changes in MIB concentration. Also, the panel response follows the Weber-Fechner Law very closely, since the linear regression model is a function of the logarithm of concentration. The regression models are shown in the figure; Y is the panel response and X is the sample concentration. For odor, a better fit of the data was found with a regression model having response as a function of concentration squared. The reason for this deviation from the Weber-Fechner Law was the influence of the point at X=25 and Y=2. If this point is removed, the regression model shown in the figure is the best fit.

The results in Figure 11 also show that the panel's taste sensitivity to MIB is equal to its odor sensitivity. A test for equality of slopes and intercepts and for coincidence found that the two best fit lines are statistically the same lines.

When the word "taste" is used in the results it is meant

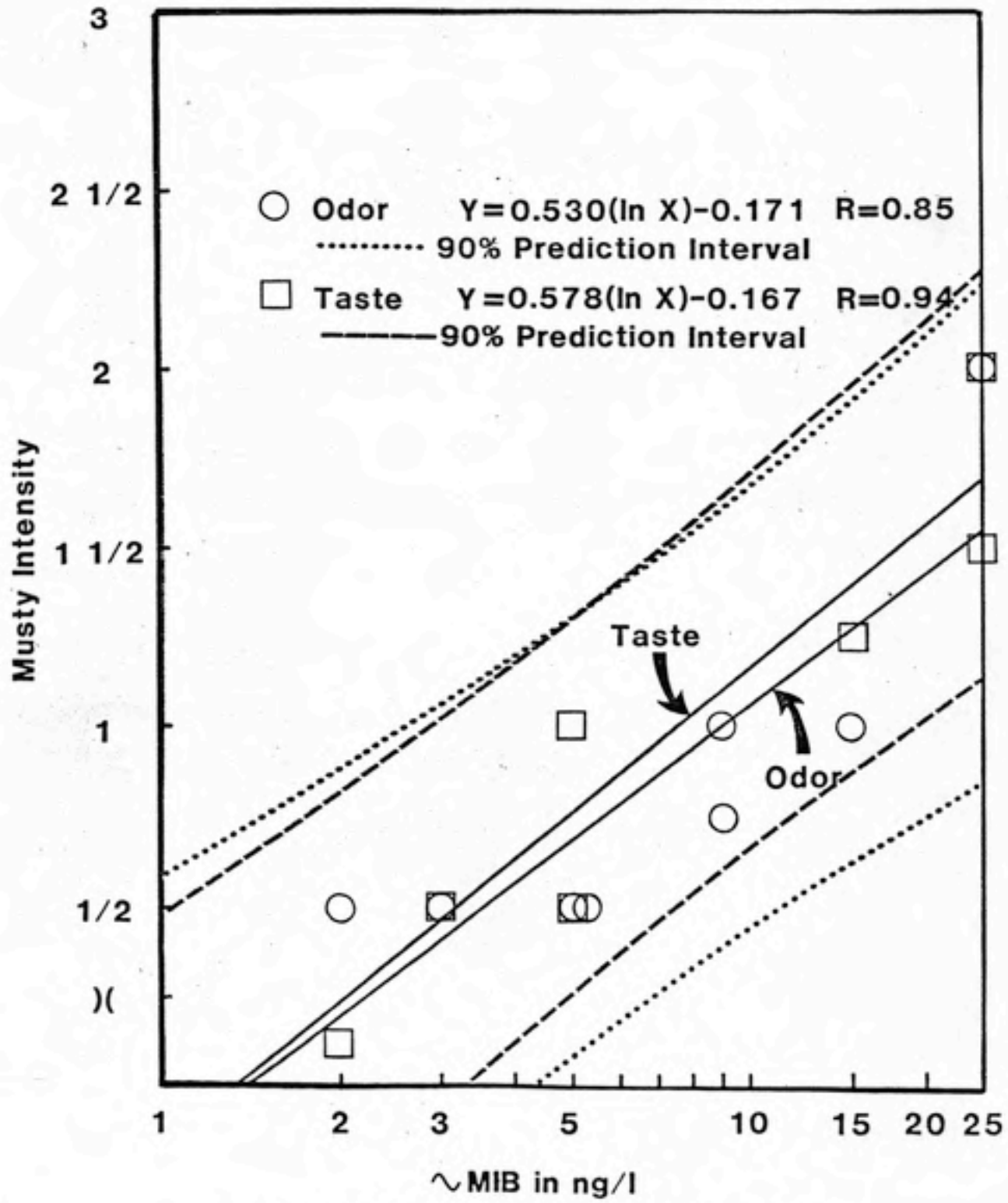


Figure 11. Panel calibration with MIB standards

to include the entire flavor of the sample; i.e. tastes, odors, feeling factors, and aftertastes.

The dashed and dotted lines in Figure 11 are the bounds for the 90% prediction intervals. Appendix D contains an explanation of how these prediction intervals were calculated. With these prediction intervals, a person may predict, with 90% confidence, the upper and lower limits of the intensity response for a single flavor profile (a single point on the graph), given the odorant concentration. The more commonly used confidence intervals predict the limits of response for the mean of many identical samples. The prediction intervals, as opposed to the confidence intervals, were plotted because in a taste and odor investigation many times a utility will produce a single flavor profile for many different samples rather than take the extra time and expense of producing many flavor profiles for each sample and using the mean response value. Thus, the variability of a single flavor profile result will be of more concern to a utility.

The prediction intervals reinforce an important point made in Chapter 1, that is, the FPM is a subjective technique. The intervals for the MIB standards span one

intensity unit. This is a large amount of variability considering the entire intensity range spans only three units. The results in Figure 11 are very similar to those obtained by MWDSC for MIB (Figure 4).

The results indicate a threshold odor and flavor for MIB of 2 ng/l. This value may not be accurate, because only the concentration of the 1 ml vial of MIB was known with certainty; errors in dilution could have occurred. Also, the concentration of the MIB stock solution may have been reduced by biological activity during storage, even though it was kept at 4 degrees C.

The results for the free chlorine standard are shown in Figure 12. The pH of the free chlorine standards ranged from 6.5 to 6.9. Therefore, hypochlorous acid was the predominant species of free chlorine. The panel has a very low odor sensitivity to changes in free chlorine concentration, since the odor points are scattered and the correlation coefficient for the best fit line is low. As a result, the 90% prediction interval spans 1-1/2 intensity units. The panel could not discern different concentrations of free chlorine through taste. The best fit line is horizontal, indicating no influence of concentration on response.

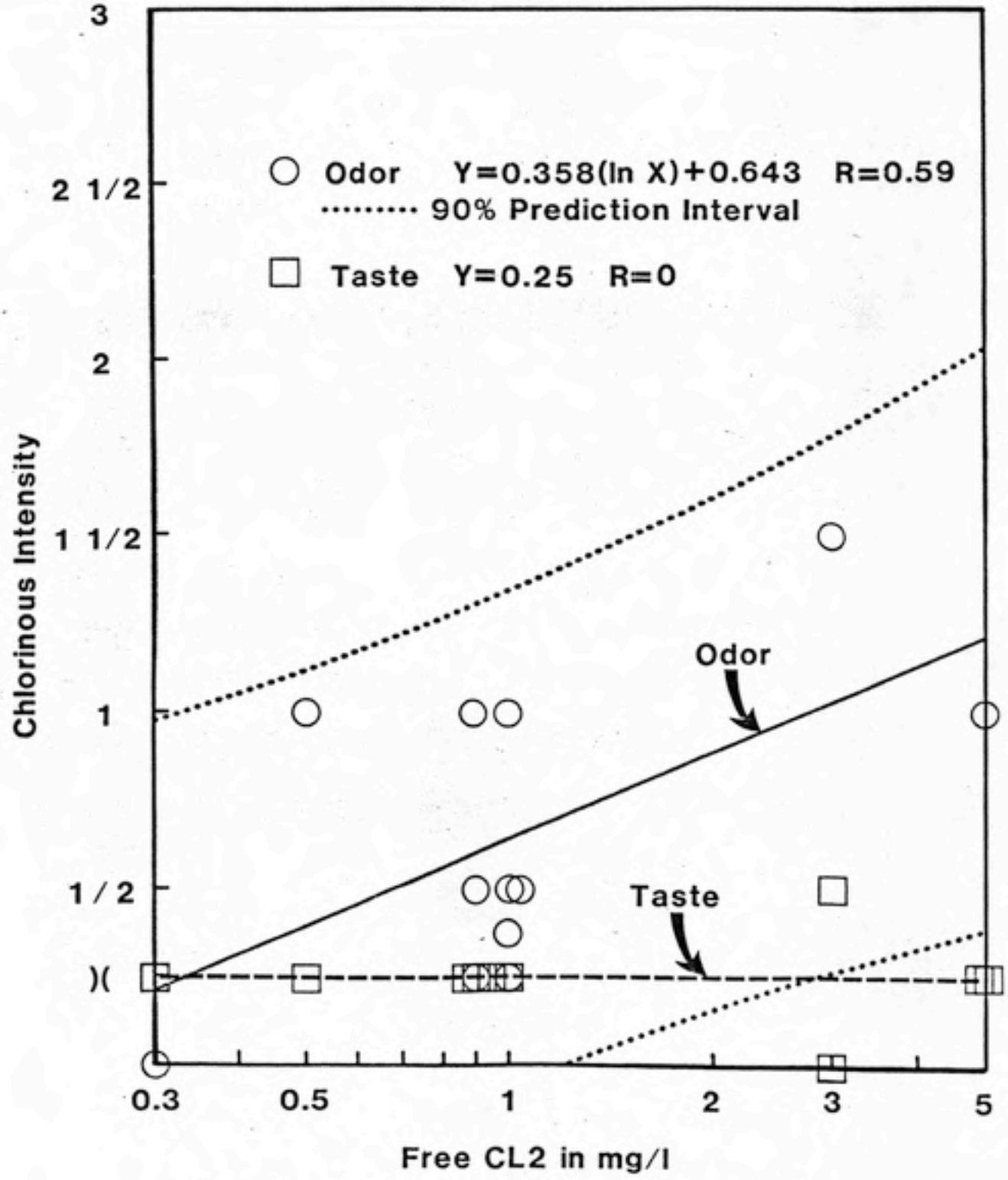


Figure 12. Panel calibration with free chlorine standards

Although the results given in Figure 12 show that the panel cannot distinguish one level of chlorination from another, the panel could distinguish presence of chlorine from control samples containing no chlorine. The panel was able to detect presence of free chlorine in concentrations above 0.3 mg/l as Cl2. With the exception of one point at 3 mg/l, the panel gave positive responses. The panel's inability to detect changes in free chlorine concentration made it impossible to determine the threshold odor or flavor concentrations.

Drexel University's panels have started to analyze free chlorine standards and also report problems with panel sensitivity to concentration changes. However, MWDSC's panel developed good sensitivity to various concentrations of hypochlorous acid (Figure 5), and even found taste to be more sensitive than odor. More extensive training with the free chlorine standards than was possible in this research should develop the panel's sensitivity, as it did at MWDSC.

Other Quality Assurance Samples

Two other quality assurance samples were used in each

session: a blank of taste and odor free water and a duplicate sample. Listed in Table 9 are the panel responses to the blank. Except for two responses, one being 1/2 intensity unit and the other a note with no intensity, the panel consistently found no flavor. Even though the panel was insensitive to varying concentrations of free chlorine, as shown in Figure 12; they are able to detect presence, or, as demonstrated in Table 9, absence of the chlorinous odorant.

Table 10 lists a comparison of samples and their duplicates. In all cases, the description of the sample and its duplicate are identical. Except for one sample, on 7/7/85, all pairs vary by no more than 1/2 intensity unit.

The quality assurance samples also served as a check on the cleanliness of materials. Based on the results, it was assumed that the glassware cleaning, sample preparation, and sample analysis procedures were effective in eliminating outside odors.

Application To OWASA

The results presented thus far show that the panel was

Table 9. Panel response to taste and odor free water

DATE	ODOR	TASTE
7/8/85	None	None
7/11/85	None	None
7/19/85	None	None
7/24/85	None	None
8/6/85	None	Bitter
8/14/85	None	Bitter 1/2
8/21/85	None	None
9/4/85	None	None
9/11/85	None	None
9/18/85	None	None
9/25/85	None	None
10/2/85	None	None

Table 10. Panel response to duplicate samples

Date	Response: Sample	Response: Duplicate	
7/7/85	Cl* 1-1/2	Cl 1-1/2	(Odor)
	Mu** 1	Mu)(	
	Cl 1/2	Cl 1/2	(Taste)
	Mu 1/2	Mu 1	
7/11/85	Mu 1	Mu 1	(Odor)
	Cl)(	Cl 1/2	
	Mu 1	Mu 1	(Taste)
	Cl)(	----	
7/19/85	Mu 1-1/2	Mu 2	(Odor)
	Bitter)(	Bitter)(	(Taste)
7/24/85	Cl 1	Cl 1/2	(Odor)
	Mu 1/2	-----	
	Cl 1/2	-----	(Taste)
	Mu 1/2	Mu 1	
8/6/85	Cl 1-1/2	Cl 1	(Odor)
	Mu 1/2	Mu	
	Cl 1	Cl 1	(Taste)
	Mu)(	Mu)(	
8/14/85	Mu 1	Mu 1	(Odor)
	Dirt 1-1/2	Dirt 2	(Taste)
8/21/85	Ea*** 1-1/2	Ea 1-1/2	(Odor)
	Cl 1/2	----	(Taste)

* Cl = Chlorinous
** Mu = Musty
*** Ea = Earthy

Table 10 (cont.)

Date	Response Sample	Duplicate	
9/4/85	Cl 1-1/2	Cl 1	(Odor)
	Cl)(	Cl)(	(Taste)
9/11/85	Mu 1	Mu 1/2 - 1	(Odor)
9/18/85	Cl 1/2	Cl)(- 1/2	(Odor)
9/25/85	Cl 1	Cl 1/2	(Odor)
10/2/85	Cl)(	Cl 1/2	(Odor)
	Cl)(	Cl)(	(Taste)

sensitive to changes in the MIB standard concentration. However, this is not sufficient proof that the panel could detect, quantitatively, a musty odorant in the presence of other odorants. The effect of one odorant on another in olfactory response is not known in most cases. As seen in Figure 4, MWDSC found the panel to be sensitive to changes in MIB concentration in natural waters, which contain background odorants. However, it was not possible in this research to determine whether the panel could detect changes in MIB concentration in natural waters, because closed-loop stripping analysis of the actual MIB concentration was not available.

The FPM was applied to samples from the OWASA water system strictly as a tool to detect presence or absence of an odorant and to perceive tastes and odors; in effect, the FPM was used to simulate the response of consumers of OWASA water. Figures 13 and 14 show the panel response to samples taken at various depths in University Lake and a sample of raw water after being pumped to the plant. The musty odor is present throughout the oxygenated layer of the lake. It may also have been present in the deoxygenated hypolimnion, but was masked by the strong hydrogen sulfide odor found below the thermocline. Also, the musty odor does not

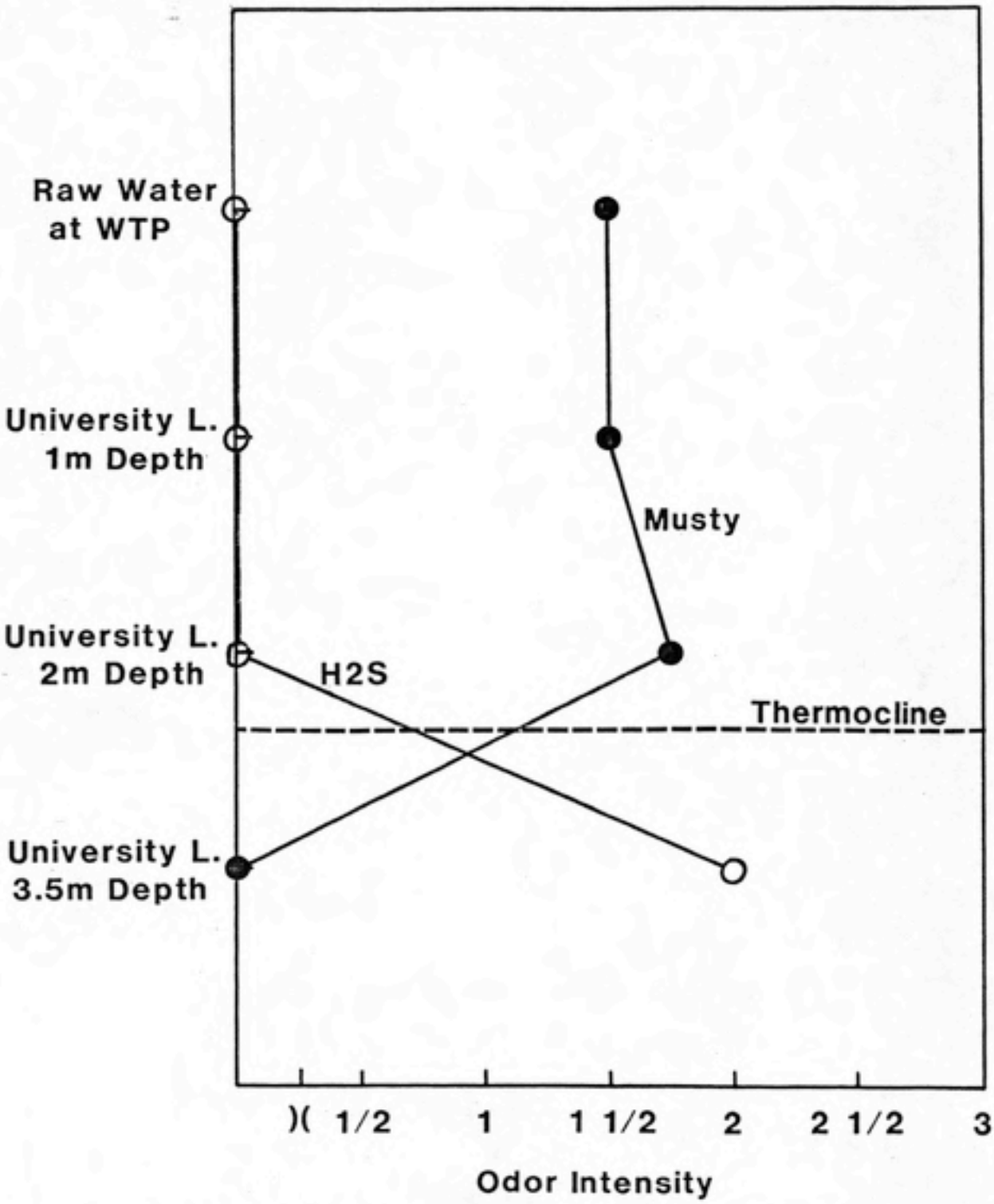


Figure 13. Odor descriptions and intensities for water source on 7/19/85

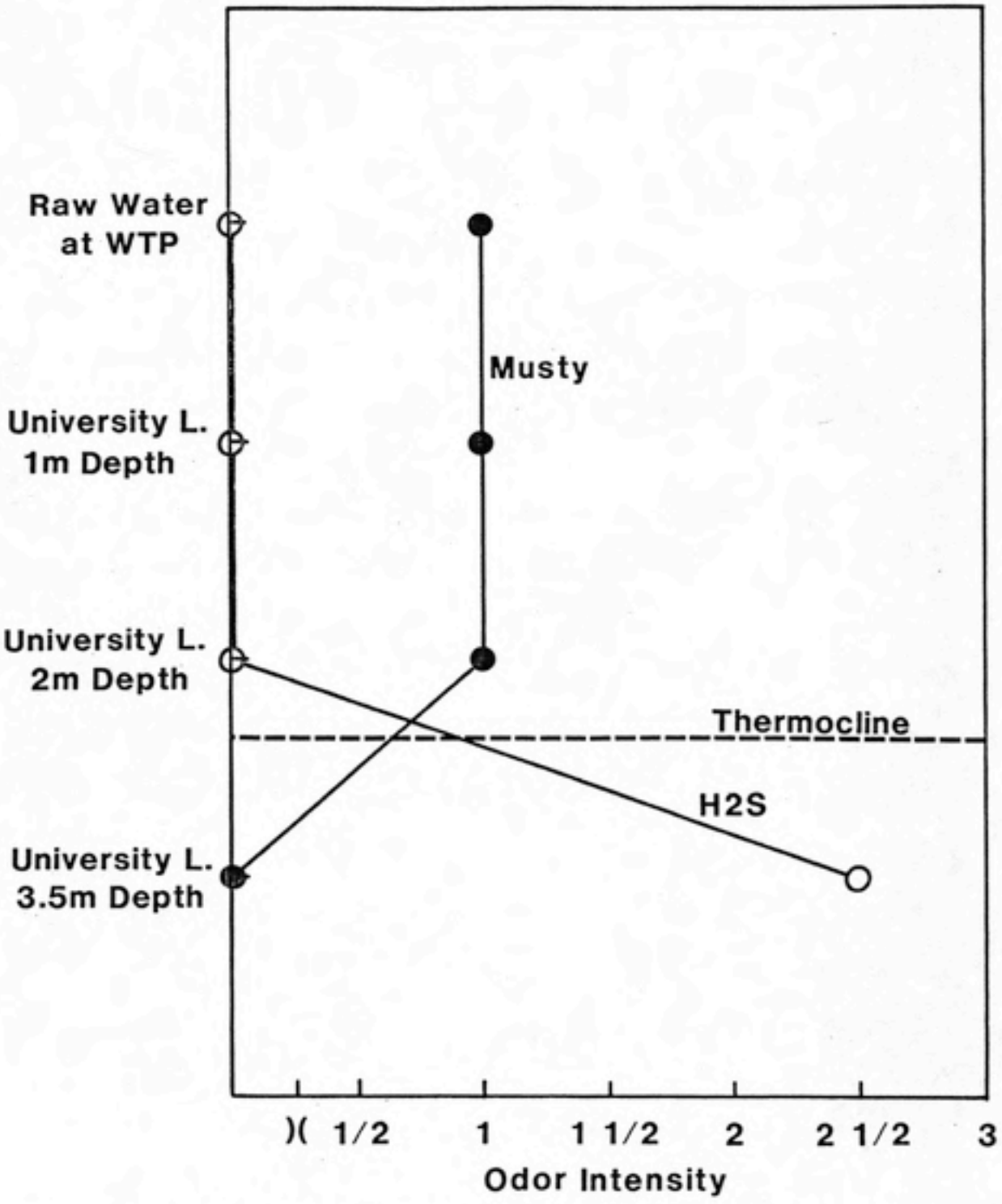


Figure 14. Odor descriptions and intensities for water source on 8/14/85

change in character or intensity as water is pumped to the plant.

The presence of a musty odorant in the lake was confirmed about a month after these samples were taken. One sample of raw water from the treatment plant was sent to MWDSC for closed-loop stripping analysis. The water contained 2 ng/l MIB and 4 ng/l geosmin. The concentrations of MIB and geosmin in the lake were probably higher earlier in the summer, since the musty odor intensities reported by the panel were greater.

The method of sampling at various depths and using the FPM could be used by utilities with adjustable intakes as an additional parameter when deciding from what level to draw water.

Figures 15-17 exhibit the flavor profiles for samples from the water treatment plant on three different days. Points of chlorine addition are also shown. The results in Figures 15 and 16 show that the musty odor is either removed by filtration or chlorination or is masked by chlorination. To distinguish the effect of chlorination from that of filtration, an additional sample was taken from above the filters, but after chlorination. As seen in Figure 17, the chlorination process eliminates the

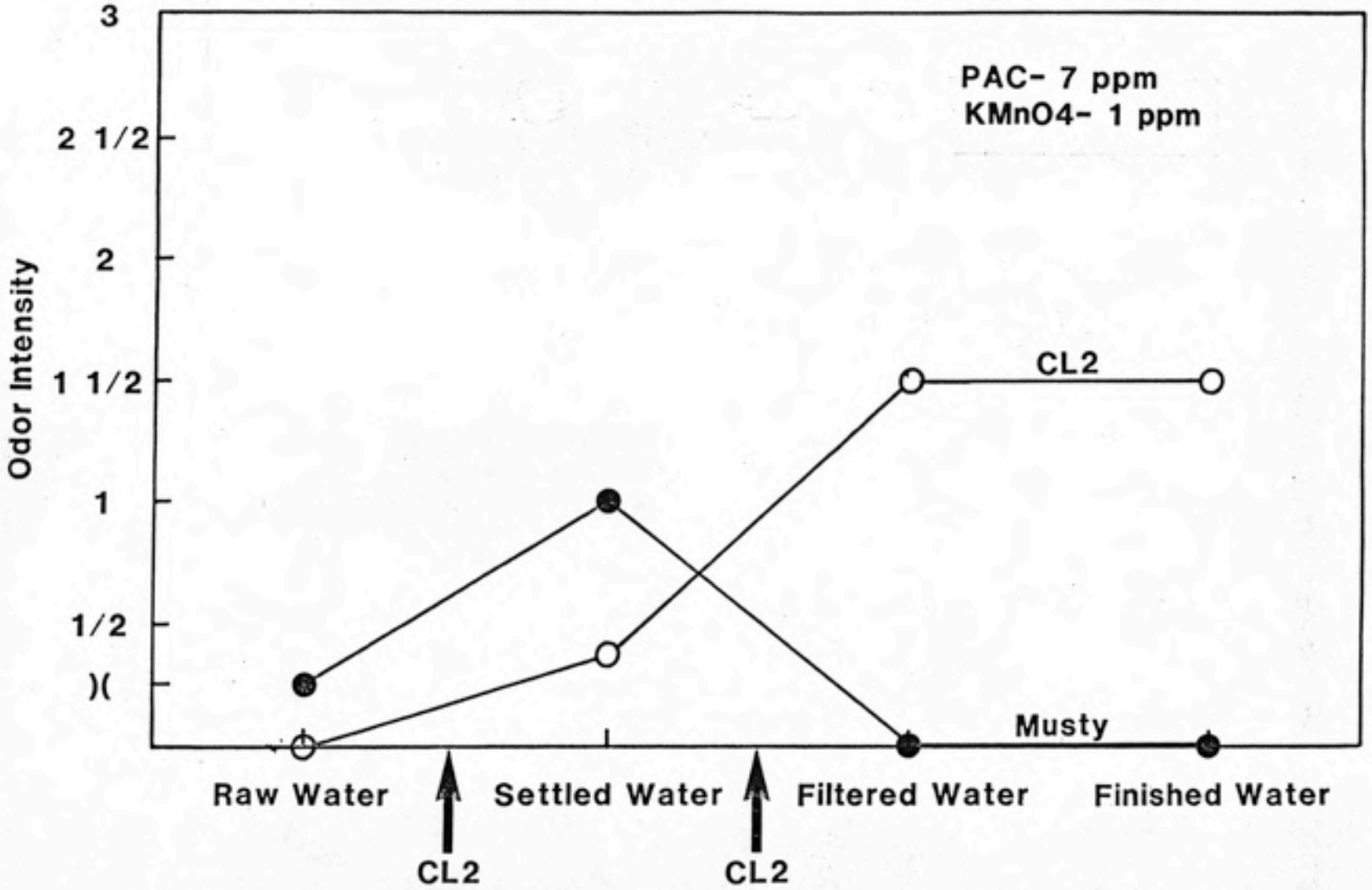


Figure 15. Odor descriptions and intensities through water treatment on 7/11/85

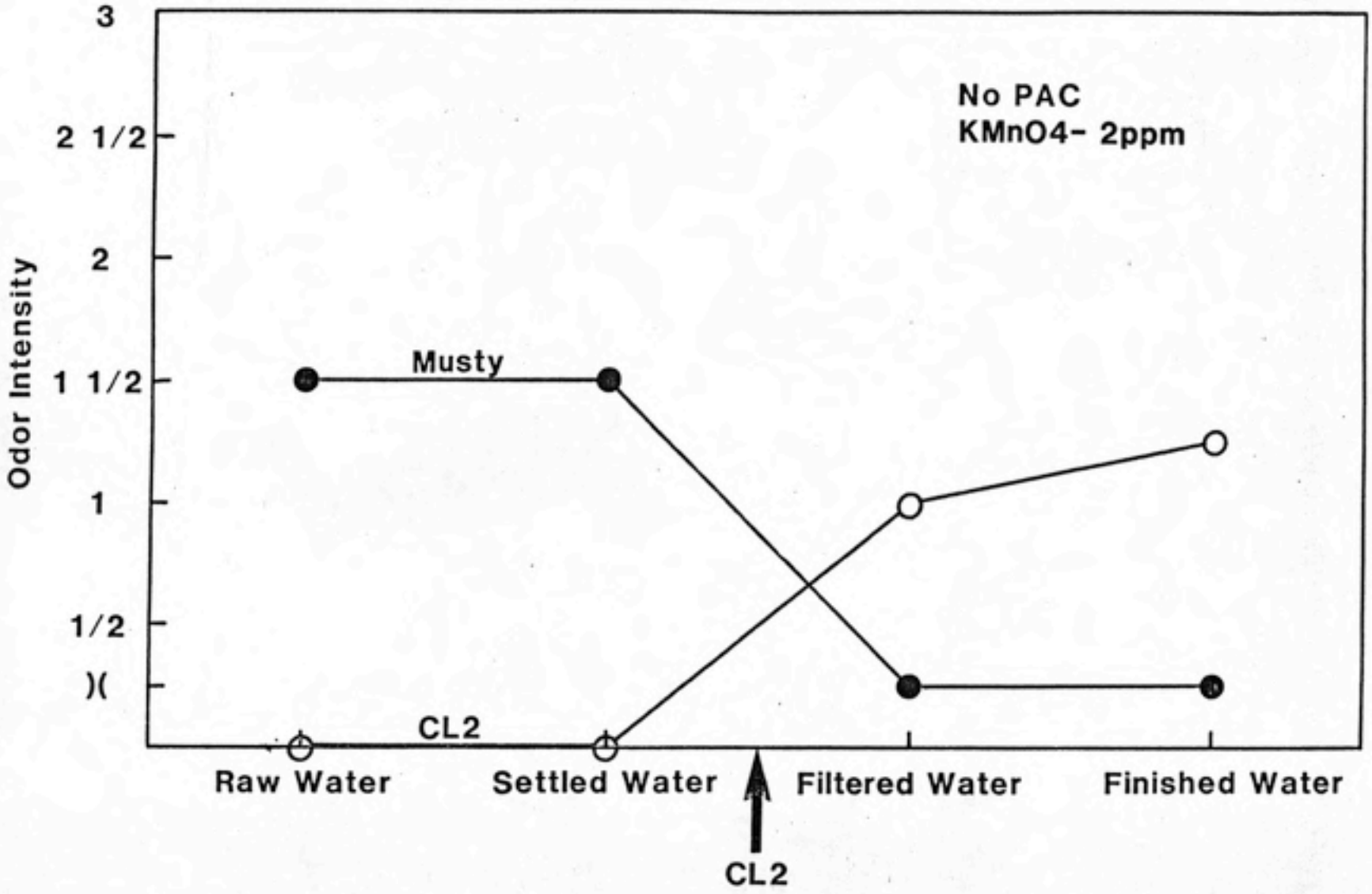


Figure 16. Odor descriptions and intensities through water treatment on 8/6/85

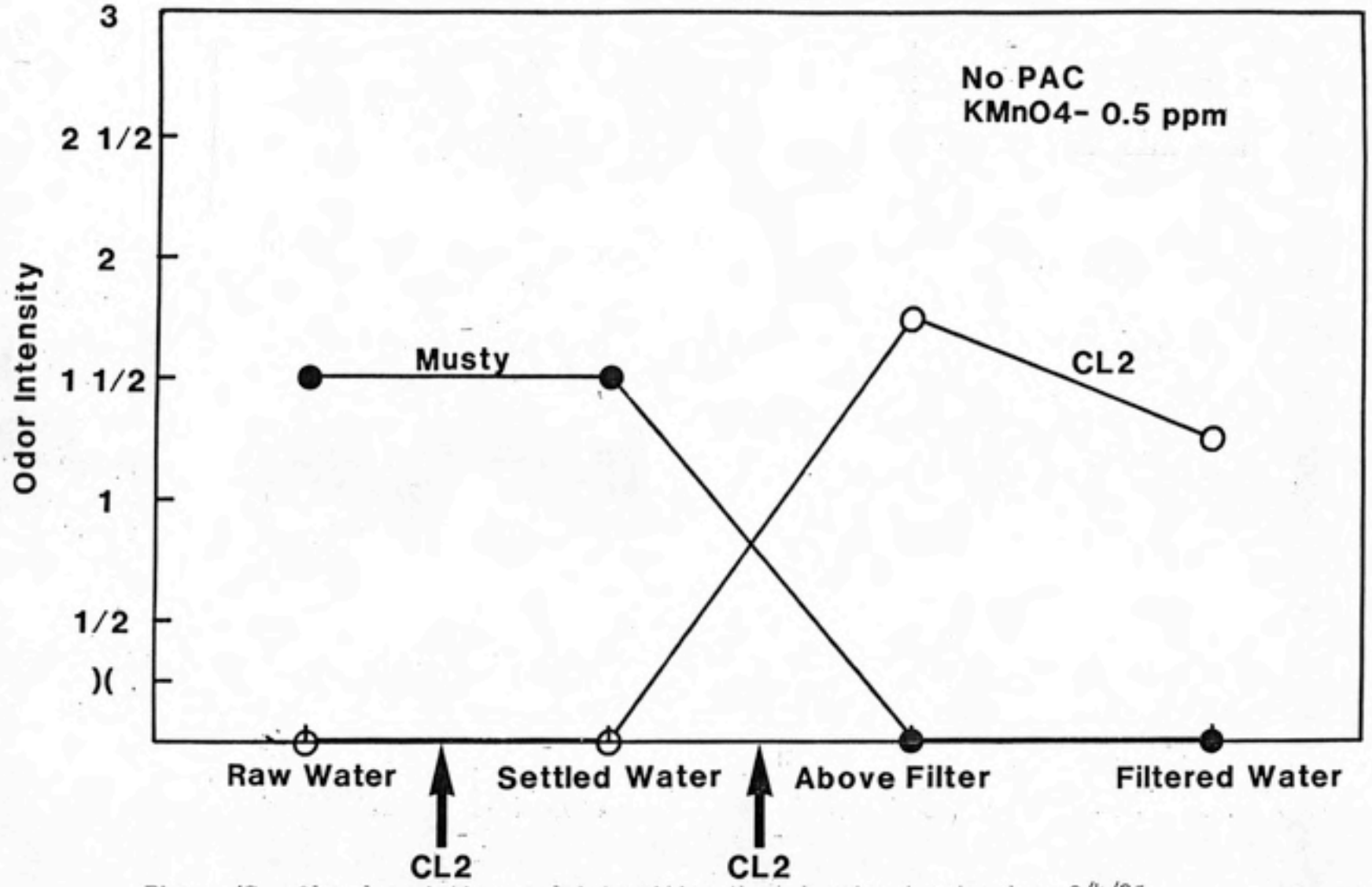


Figure 17. Odor descriptions and intensities through water treatment on 9/4/85

panel's response to musty odor and replaces it by a response to chlorinous odor. Thus, chlorine is either oxidizing or masking the musty odorant. Figures 15-17 also show the concentrations of PAC and potassium permanganate added in the rapid mix basin. These treatments did not appear to be effective, since the musty odor did not decrease between the raw and settled water points.

The results presented in Figures 15-17 illustrate the usefulness of the FPM in practice. A utility could perform sensory analysis by the FPM on samples from throughout their treatment plant to aid in evaluating process effectiveness in removing tastes and odors.

The results in Figures 18 and 19 track the flavor profile from the water treatment plant through the distribution system. Both earthy-musty and chlorinous odors are persistent to the far end of the distribution system. Free chlorine measurements in mg/l as Cl2 are shown in Figure 18. Even though the free chlorine residual drops to 0.1 mg/l as Cl2 the panel response to chlorinous intensity is high. This tends to confirm the panel's insensitivity to changes in chlorine concentration, or, as discussed later, may indicate the occurrence of a

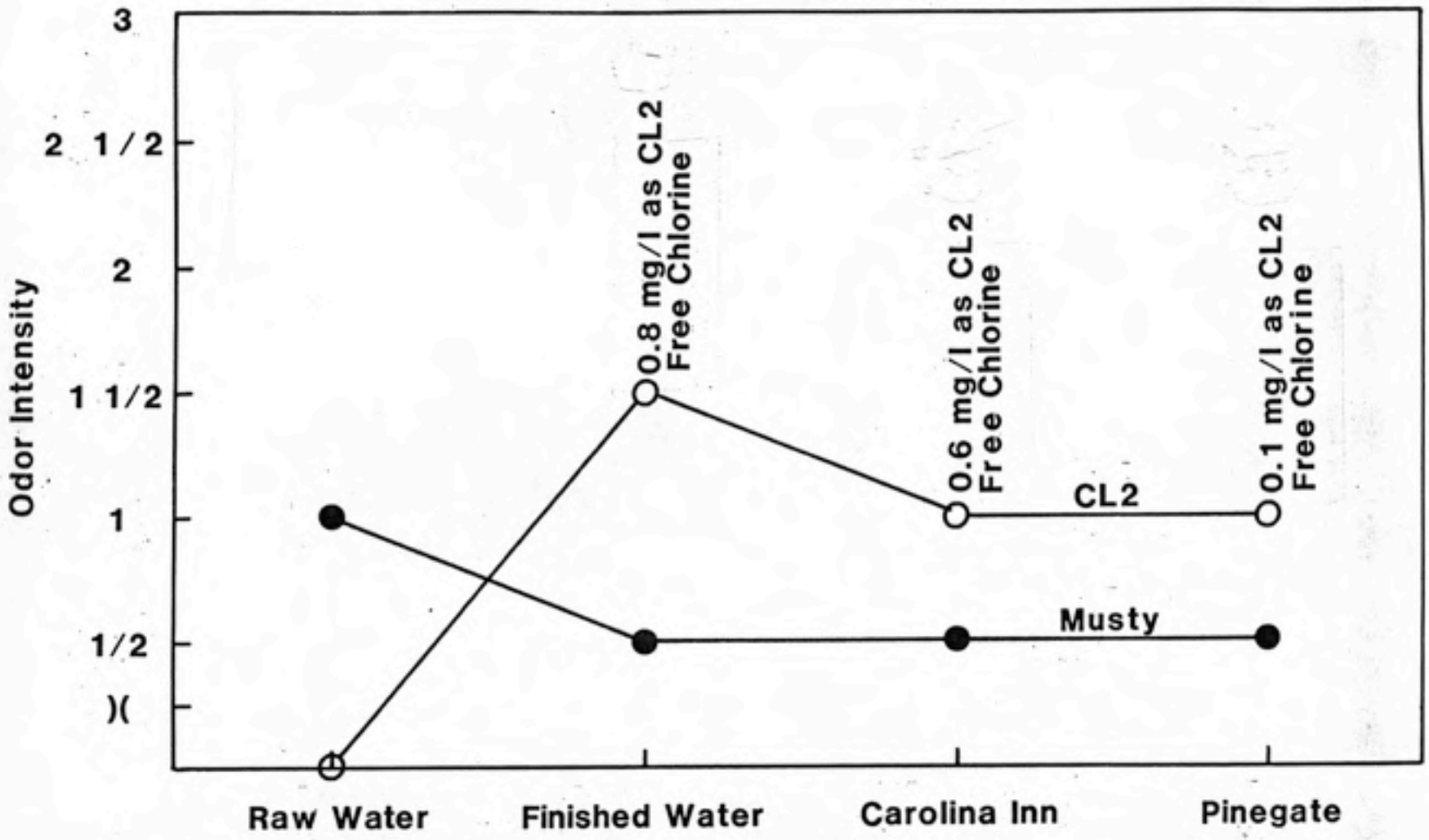


Figure 18. Odor descriptions and intensities through water treatment and distribution on 7/7/85

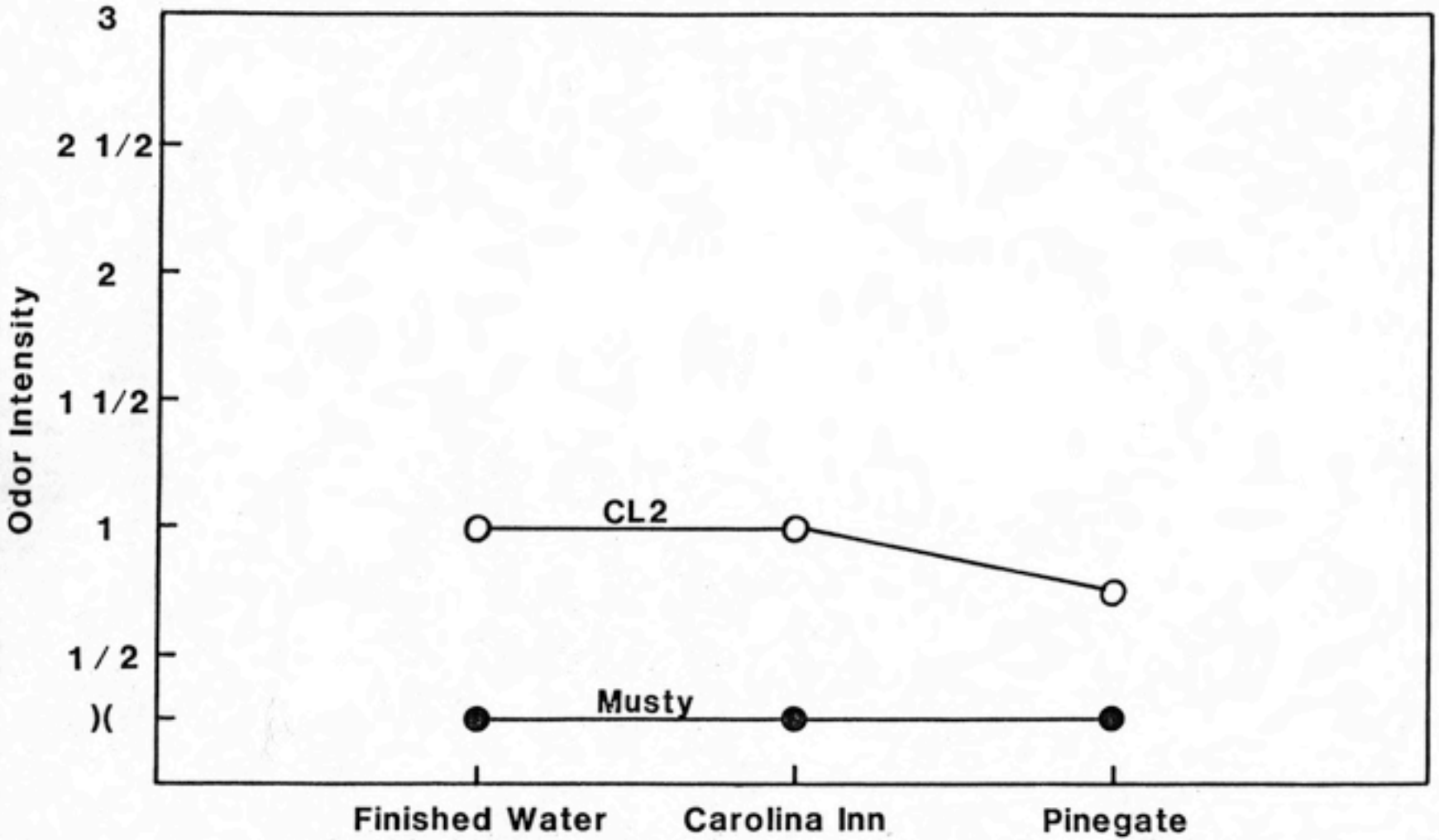


Figure 19. Odor descriptions and intensities through water distribution on 7/24/85

reaction between chlorine and the musty odorant to form some by-product.

Samples from the system can be taken by a utility and analyzed by the FPM to isolate trouble spots. Also, samples from the distribution system will reveal how the consumer perceives the water.

Jar tests were run, dosing raw water with PAC at various concentrations and contact times (CT). The results, shown in Figures 20 and 21, demonstrate the effectiveness of carbon adsorption in removing earthy-musty odorants. Complete removal of the musty odor does not appear feasible because of the high doses required. However, complete removal is not necessary. MWDSC found that the consumers would not complain if they were able to reduce the musty odor to an intensity of 1/2 (33).

The FPM could also be used with jar tests simulating other water treatment processes, such as, coagulation and sedimentation. In addition to analyzing the effectiveness of existing treatment in removing taste and odor, these results show that utilities could use the FPM with jar tests to evaluate changes in removal effectiveness brought about by modifying a process or adding a new process.

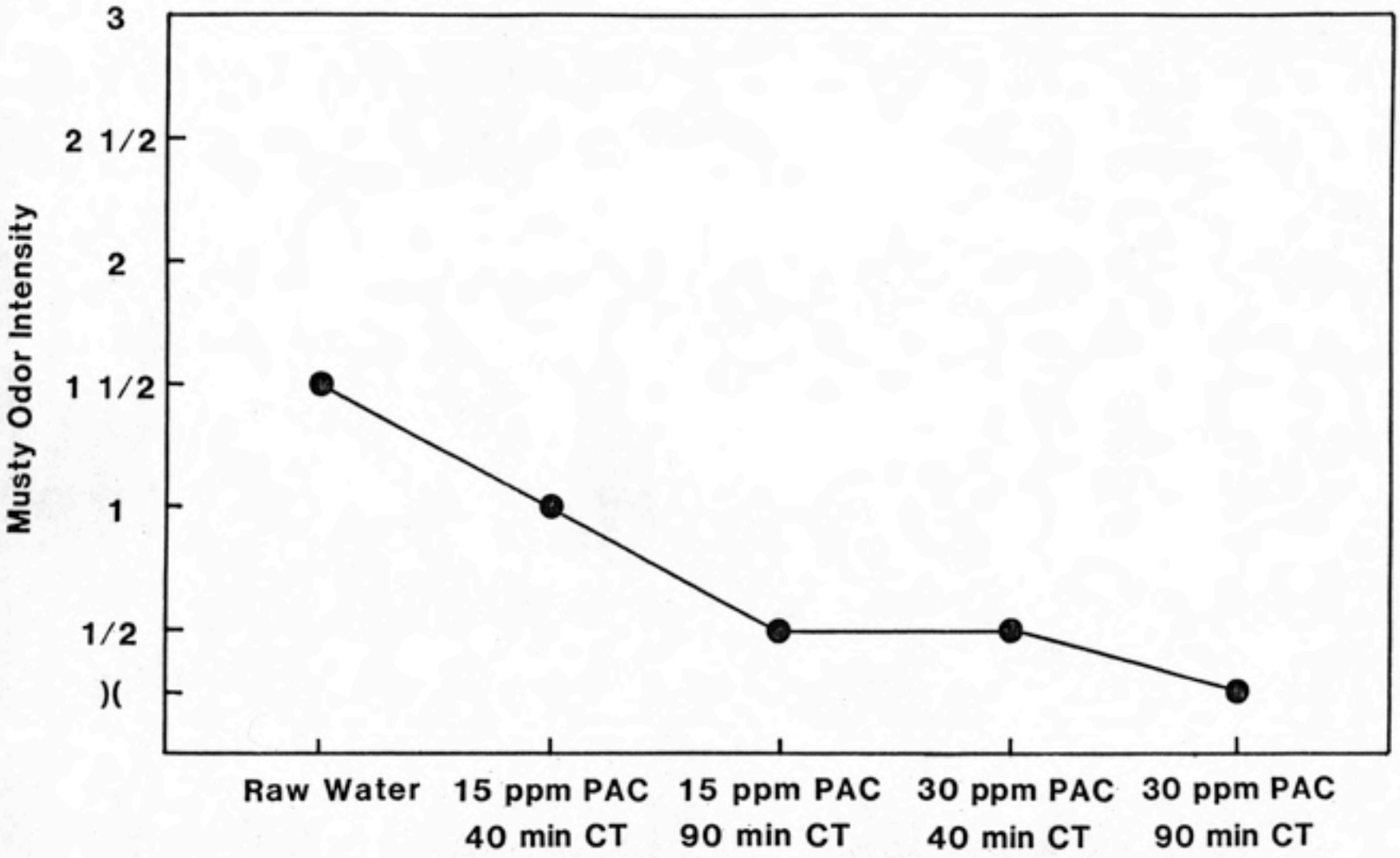


Figure 20. Bench-scale treatment of raw water with 15 and 30 ppm powdered activated carbon

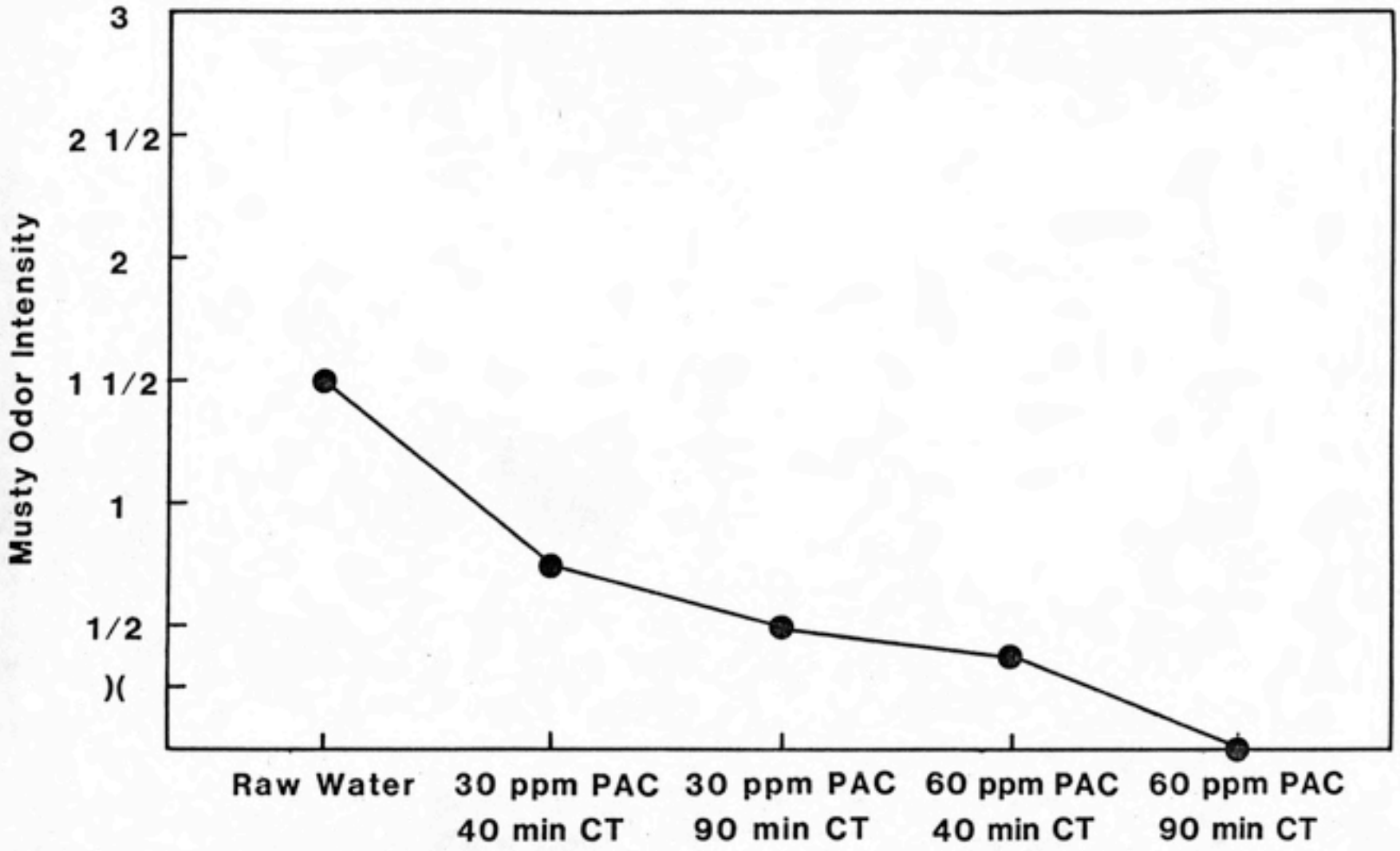


Figure 21. Bench-scale treatment of raw water with 30 and 60 ppm powdered activated carbon

Effect of Musty Odorant On Chlorinous Flavor Intensity

During the course of this research, some trends were noticed concerning the interaction of earthy-musty and chlorinous odorants. These results are not meant to be conclusive, but may indicate possible topics for further research.

All field and reference standard samples that contained a musty odorant when chlorinated are plotted in Figure 22. The data are very scattered and the best fit line is not very significant (very low correlation coefficient). The panel continued to be insensitive to changes in chlorine concentration, the same as with the free chlorine standards. A test of equality of slopes and intercepts and of coincidence for the two best fit lines found that odor is more sensitive than taste for the chlorinous odorant.

The best fit line for odor from Figure 22 is plotted in Figure 23 with the best fit line for odor from Figure 12. These two lines represent samples chlorinated with and without musty odorant present. A test of equality of

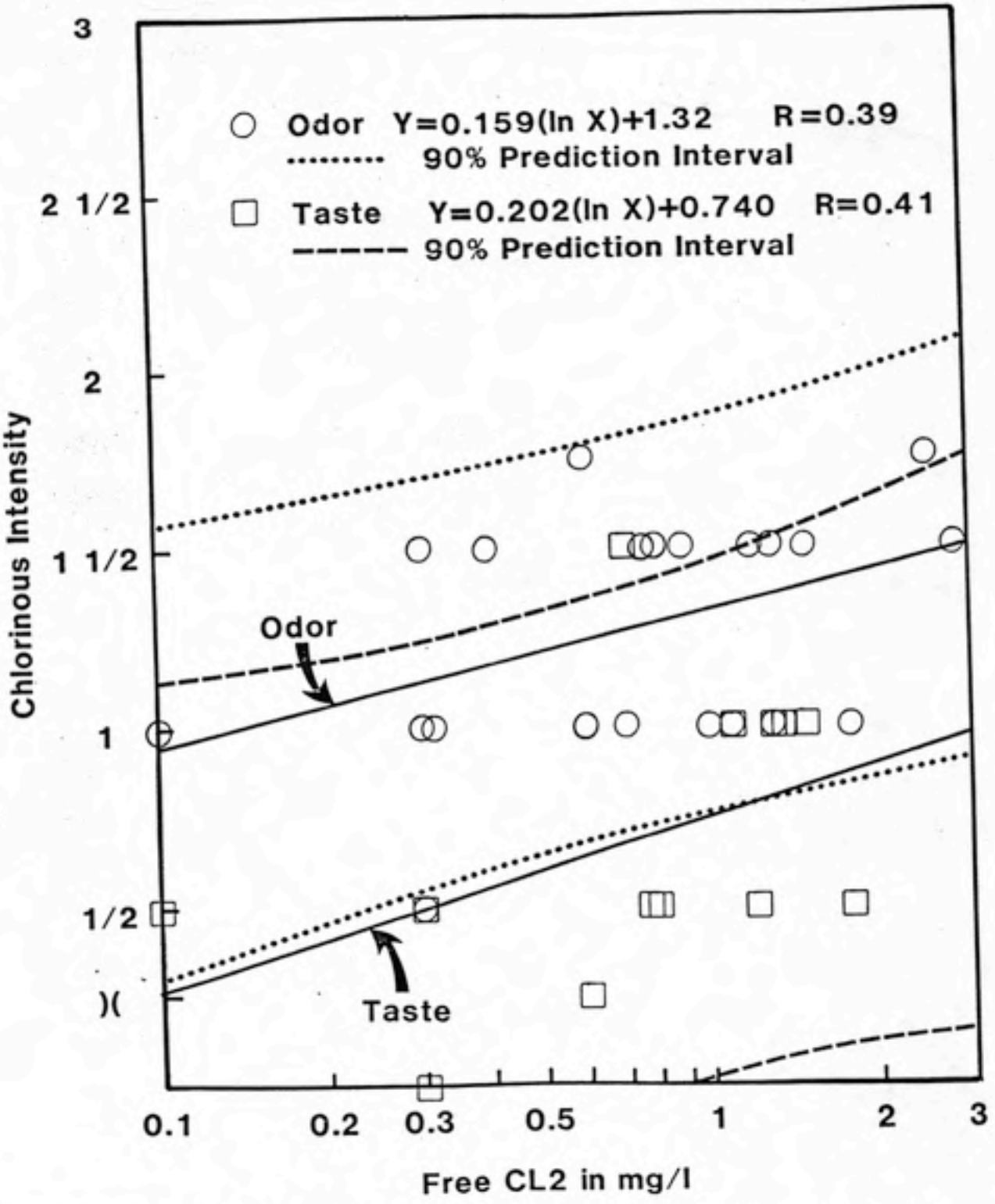


Figure 22. Field samples and standards chlorinated with musty odorant present

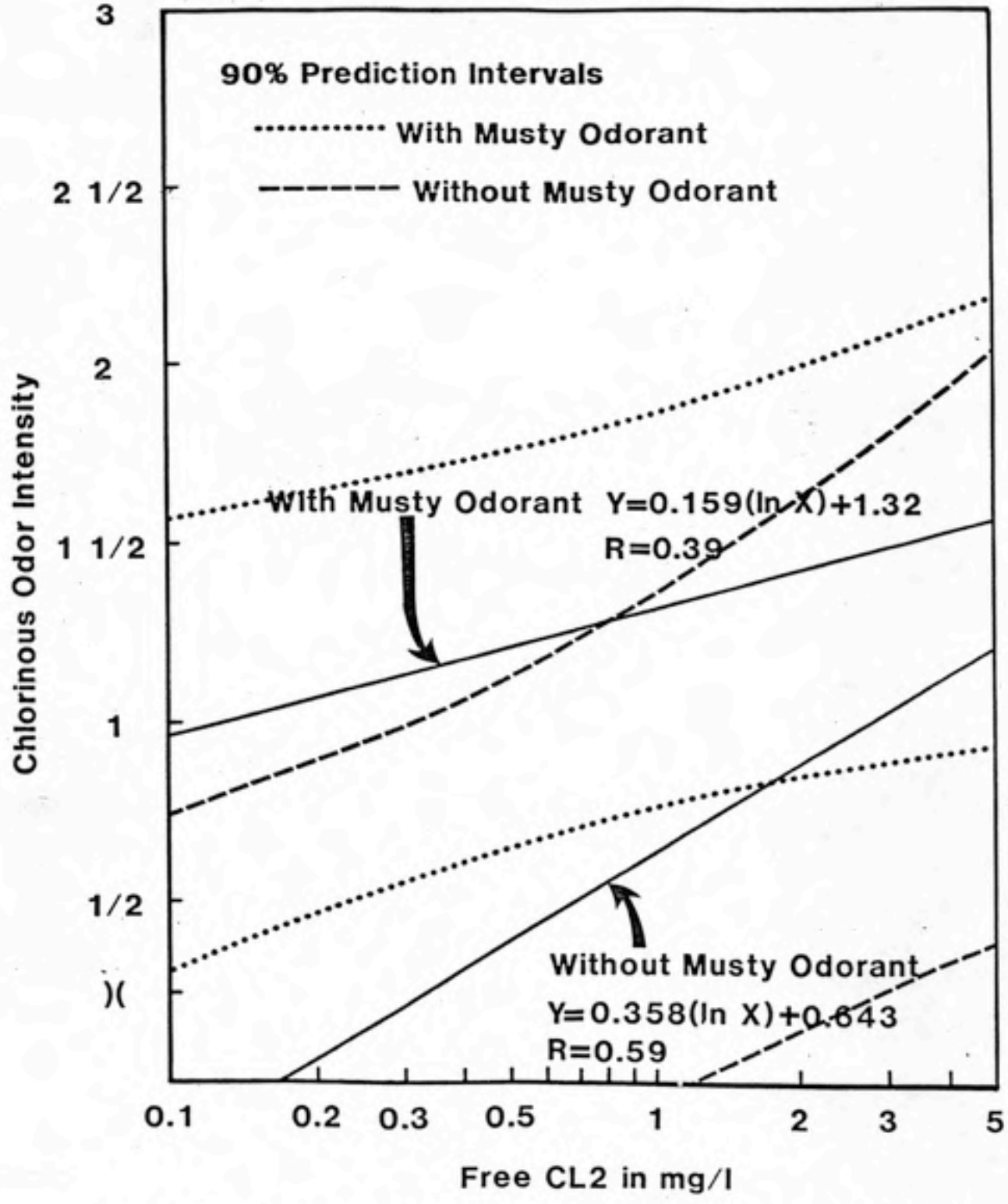


Figure 23. Comparison of samples chlorinated with and without musty odorant present

slopes and intercepts and of coincidence found that the line for samples containing the musty odorant lies above the other line. Although both lines have low correlation coefficients, a trend is observed in that for a given concentration of free chlorine the chlorinous intensity is higher if a musty odorant is present. This trend would take on greater significance if the panel had been trained sufficiently to be sensitive to changes in free chlorine concentration.

A possible explanation for the enhancement of chlorinous odor in the presence of a musty odorant is a reaction between chlorine and the musty odorant to form a more odorous by-product. If this reaction were taking place it would suggest that water treatment must remove the musty odorant prior to chlorination to produce acceptable chlorinous odor intensities in the finished water.

Manpower and Cost Required To Implement The FPM

An evaluation of the technical merits of the FPM would be incomplete without also considering the manpower required, and thus, the expense to a water utility. A utility could implement the FPM by training five employees or customers as panelists. At least three of

these panelists would have to be present at a panel session. The time requirement for panel sessions is 30-45 minutes per day, three days per week. The panel leader, a regular employee of the utility with a background in chemistry, would be required one-half-time for a smaller utility and full-time for a larger utility to perform his or her many duties.

If properly performed, the TON method requires the same manpower as the FPM; a panel should be used to analyze dilutions and a panel leader is needed to prepare samples and organize the sessions. However, the FPM produces much more useful information for the same expense.

The manpower requirements can be translated into costs and combined with the material costs to estimate the total cost to implement the FPM. This is done below for a utility of OWASA's size.

Panel Leader- \$12/hr x 20 hr/wk = \$240/wk
Panelists (4)- \$8/hr x 9 hr/wk = \$ 72/wk
Materials = \$ 10/wk
\$322/wk

Plant Flow- 6 mgd x 7 days/wk = 42 mg/wk

Cost/1000 gal- \$322/wk x wk/42,000 1000 gal
= \$0.0077/1000 gal

The O&M and labor costs of treatment for the OWASA water

treatment plant is $0.31/1000 gal. Therefore, the cost of implementing the FPM for a 6 mgd plant is approximately 2.5% of the cost of treatment.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

A sensory panel using the FPM was able to detect presence of musty and chlorinous odorants in water samples in concentrations above a threshold value. The threshold value for 2-methylisoborneol (MIB) in taste and odor free water, the musty odor standard in this research, was 2 ng/l. The accuracy of this value is uncertain because of possible errors during dilution of the 1 ml vial if MIB and possible biodegradation of the MIB stock solution. The threshold value for free chlorine could not be determined because the results were erratic. This showed the panel's insensitivity to the different concentrations of free chlorine.

The FPM produced consistent and reproducible results with the earthy-musty odorant, MIB, in taste and odor free water. The results from the sensory evaluation of the MIB standards could be predicted by the Weber-Fechner Law, which is a staight line relationship between intensity and the logarithm of concentration.

The FPM was effective in eliminating the influence of

outside flavors on the results. The results from the quality assurance samples showed that the procedures for sample collection, glassware cleaning, sample preparation, testing area selection, and panel testing were adequate in preventing the introduction of foreign odors.

Additional sensory panel work is needed to investigate the possible enhancement of chlorinous odors in samples chlorinated with a musty odorant present. This research was inconclusive, since the panel could not perceive changes in the chlorinous flavor intensity. Further work must first develop the panel's sensitivity to changes in free chlorine concentration.

The FPM is an effective tool for use by utilities as an aid in making water management decisions from the water source to the consumer's tap. The FPM was shown to be useful for analyzing the occurrence of taste and odor in the raw water source, the removal of taste and odor through water treatment at the OWASA plant, and for the persistence of problems in the distribution system. By describing all the flavor characteristics of a sample, the FPM can monitor multiple odorants and is well suited for investigations on the cause of taste and odor and the

effects of treatment processes. The FPM also simulates how the consumer perceives the water quality.

A utility can organize and conduct a sensory panel using the FPM. This research was successful in implementing the FPM using equipment and materials that are available to any utility. Using the materials, procedures, and manpower described in this paper, a utility can incorporate the FPM into their regular water quality monitoring program.

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Appendix A

Typical Flavor Descriptions and Abbreviations (Philadelphia Water Department, 34)

SYMBOL	DESCRIPTION
Af	an aftertaste
Bi	bitter
Che	chemical
Cha	chalky
Cl	chlorinous
Cu	cucumber
Dr	drying sensation (for taste)
Ea	earthy, peaty
Fi	fishy
Fl	flowery/perfumy
Fr	fruity
Ge	geramium
Gr	grassy, freshly cut
Hay	old grass, hay-like
Hc	hydrocarbon, petroleum
I	iodine
Med	medicinal
Met	metallic
Mo	moldy, damp cellar
Mu	musty, decomposing
No	no odor/taste
On	oniony
Ph	phenolic
Pl	plastic
Pp	pig-pen
Ru	rubber hose
Sa	salty, briny
Se	septic
Sl	slick (for taste)

SYMBOL	DESCRIPTION
So	sour
Sp	spicy
St	stale
Su	rotten eggs, H_2S, sulfurous
Sw	sweet
Veg, dec.	vegetation, decomposing
Veg. green	vegetable, green
Veg. root	vegetable, root
We	wet paper
?	Has a odor/taste but can not identify. Should be described as well as possible.

Other specific descriptions allowed if none on the list is suitable.

	TYPE MOUTH-FEEL
Ast	astringent
Coo	cooling
Bit	biting
Bur	burning

Appendix B

Results From Training Sessions

Second Training Session

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 6/4/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Pam	Bill		Desc.	Int.
0.3 mg/l as Cl2 Free Chlorine Standard	Cl 1½	Cl 1	Cl 1	Cl 1			
0.5 mg/l as Cl2 Free Chlorine Standard	Fish 2	Cl 2	Cl 2½	Cl 1½			
				Mu			
1.0 mg/l as Cl2 Free Chlorine Standard	Cl 2½	Cl 2½	Cl ½	Cl 2½			
5.0 mg/l as Cl2 Free Chlorine Standard	Cl 2-2½	Cl 3	Cl 1½	Cl 2			
2.0 ng/l MIB Standard	Mu ½	Dirt 1	-----	Ea)(			
5.0 ng/l MIB Standard	Mu ½	Dirt 2	Mu 1	Mu ½			
30 ng/l MIB Standard	Dirt 1	Dirt 2½	Mu 1½	Mu 1½			
80 ng/l MIB Standard	Dirt 1½	Dirt 3	Mu 2	Mu 2			
Taste and Odor Free Water	-----	----	----	----			

Second Training Session

FLAVOR PROFILE METHOD

Taste X **or Odor** ___ **Date** 6/4/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Pam	Bill		Desc.	Int.
0.3 mg/l as Cl2 Free Chlorine Standard	Cl 1½	Cl ½	Cl ½	Cl ½			
0.5 mg/l as Cl2 Free Chlorine Standard	Dirt ½	Cl ½	----	Cl 1			
1.0 mg/l as Cl2 Free Chlorine Standard	Cl ½	Dirt ½	Cl 1	Bitter)(			
5.0 mg/l as Cl2 Free Chlorine Standard	Cl ½	Cl ½	Cl ½	Cl 1½			
2.0 ng/l MIB Standard	Dirt ½	Dirt 1	Soil)(	----			
5.0 ng/l MIB Standard	----	Dirt 1½	Soil ½	Geos 1			
30 ng/l MIB Standard	Dirt 1	Dirt 2½	Mu 1½	Geos 2½			
80 ng/l MIB Standard	Bi 1½	Dirt 2½	Mu 2	Geos 3			
Taste and Odor Free Water	Dirt ½	----	----	----			

Third Training Session

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 6/21/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Pam	Bill		Desc.	Int.
0.1 mg/l as Cl2 Free Chlorine Standard	Mu ½	Cl ½	Cl ½	Cl ½-1			
0.2 mg/l as Cl2 Free Chlorine Standard	Cl ½	Cl)(	Cl ½	Cl)(-½			
0.3 mg/l as Cl2 Free Chlorine Standard	Mu 1	Cl ½	Cl 1	Cl)(-½			
1.0 ng/l MIB Standard	----	Mu 1	----	Mu 1			
2.0 ng/l MIB Standard	Mu 1	Mu ½	Mu ½	Mu½			
5.0 ng/l MIB Standard	----	Mu 1½	Cl ½	Mu)(			
Taste and Odor Free Water	----	----	-----	------			

Third Training Session

FLAVOR PROFILE METHOD

Taste X **or Odor** ___ **Date** 6/21/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Pam	Bill		Desc.	Int.
0.1 mg/l as Cl2 Free Chlorine Standard	Bi 1	Cl ½	----	Cl 1			
0.2 mg/l as Cl2 Free Chlorine Standard	Dirt ½-1	Cl)(	Cl ½	Cl 1			
0.3 mg/l as Cl2 Free Chlorine Standard	Dirt ½	Cl ½	Cl 1	Cl ½ Mu			
1.0 ng/l MIB Standard	Bi ½	Mu 1	Mu ½	Geos 2			
2.0 ng/l MIB Standard	Sweet ½	Mu ½	Mu ½	Geos 1			
5.0 ng/l MIB Standard	----	Mu 1½	Mu ½	Geos 2			
Taste and Odor Free Water	-----	------	------	Bi)(			

Appendix C

Results From Regular Panel Sessions

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 7/8/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Ruthy	Bill	Pam	Anne	Desc.	Int.
Finished Water @WTP	Cl 1	Cl ½	Cl ½	Cl 1½	Cl 1½	Cl	1½
	Mu 1	Mu ½	Mu 1			Mu	1
Pinegate	Mu ½	Mu ½	Cl 1	Cl 1	Cl 1	Cl	1
			Mu 1			Mu	½
Taste and Odor Free Water	------	Mu)(	------	----	-----	------	----
Finished Water @ WTP	Cl 1	Cl1	Cl ½	Cl 1	Cl 1½	Cl	1½
			Mu)(	Mu ½		Mu	)(
Carolina Inn	Cl 1	Cl 1½	Cl 1	Mu 1	Cl 1	Cl	1
		Mu ½				Mu	½
Raw Water @ WTP	Mu 1	Mu 1½	Mu 1	Mu ½	Mu 1	Mu	1
			Free Chlorine Measurements				
			Pinegate- 0.1 mg/l as Cl2				
			Carolina Inn- 0.6 mg/l as Cl2				
			Finished Water @ WTP- 0.6 mg/l as Cl2				

FLAVOR PROFILE METHOD

Taste X **or Odor** ___ **Date** 7/8/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Ruthy	Bill	Pam	Anne	Desc.	Int.
Pinegate	Cl ½	Cl)(	Mu ½	Cl ½	Mu ½-1	Mu	1
	Mu 1		Cl ½			Cl	½
Carolina Inn	Mu ½	Mu ½	Cl 1	Mu ½	Mu ½	Mu	½
	Cl ½	Cl ½	Mu ½			Cl	)(
Taste and Odor Free Water	------	-----	-----	-----	Mu ½	-----	-----
Finished Water @ WTP	Cl ½	Bi ½	Mu½	Mu 1	Bi 2	Mu	½
	Mu ½	Cl ½	Cl ½	Cl ½		Cl	½
						Other-	Bi
Finished Water @ WTP	? 1	Mu 1	Mu 1	Mu 1	Mu 1	Mu	1
		Cl ½		Cl ½	Cl ½	Cl	½

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 7/11/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Wendy	Anne	Bill	Ruthy	Desc.	Int.
Finished Water @ WTP	Cl 1 Mu)(	Cl ½	Cl 1½	Cl 1-1½ Mu)(	Cl 2	Cl Other-	1½ Mu
Settled Water @ WTP	Mu 1	Mu 1 Cl)(	Mu ½	Mu ½ Cl ½	Mu 1½ Cl)(	Mu Cl	1)(
5.0 ng/l MIB Standard	Mu ½	Mu 1	Mu ½	Mu ½	Mu ½ Cl)(	Mu ½	
Taste and Odor Free Water	------	-----	-----	-----	-----	----	----
Settled Water @ WTP	Mu 1	Mu 1-1½ Cl ½	Cl ½ Mu ½-1	Cl ½ Mu ½	Mu 1	Mu Cl	1 ½
Filtered Water @ WTP	Cl 1 Mu)(	Cl 1½	Cl 2-2½	Cl ½	Cl 1	Cl	1½
Raw Water @ WTP	Mu)(	Mu ½	----	Mu)(	Mu ½	Mu	)(
		Free Chlorine Measurements					
			Settled	Water- 0.0 mg/l	as Cl2		
			Filtered	Water- 1.5 mg/l	as Cl2		
			Finished	Water- 1.2 mg/l	as Cl2		

FLAVOR PROFILE METHOD

Taste X **or Odor** ____ **Date** 7/11/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Wendy	Anne	Bill	Ruthy	Desc.	Int.
5.0 ng/l MIB Standard	Mu 1	Mu 1	Mu ½	Mu 1	Mu 1	Mu	1
Settled Water @ WTP	Mu ½ Cl)(	Mu 1 Cl)(	Mu 1½ Cl)(	Mu ½ Cl)(	Mu 1	Mu Cl	1)(
Taste and Odor Free Water	------	-----	Bi ½	----	-----	------	-----
Filtered Water @ WTP	Cl ½	Mu 1	Cl 1	Cl 1 Mu)(-½	Cl 1	Cl Other-	1 Mu
Finished Water @ WTP	Cl 1 Mu ½	Mu 1 Cl)(	Mu 1 Cl ½	Mu ½ Cl 1	Cl ½ Mu)(	Cl Mu	½ ½
Settled Water @ WTP	Mu ½	Mu 1	Mu ½-1	Mu 1½	Mu 1 Cl ½	Mu	1

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 7/19/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Ruthy	Pam	Bill	Desc.	Int.
0.5 mg/l as Cl2 Free Chlorine Standard	Cl 1	----	Cl 1	Cl 1	Cl)(	Cl	1
University L. 1m Depth	Mu 1	Mu 1	Mu 1½	Mu 2	Mu 1	Mu	1½
Taste and Odor Free Water	-----	-----	------	------	-----	------	-----
University L. 2m Depth	Mu 1½-2	Mu 1½-2	Mu 2	Mu 2½	Mu 1½-2	Mu	2
Raw Water @ WTP	Mu 1	Mu 1	Mu 1½	Mu 1	Mu 1 Fl ½	Mu	1½
University L. 3.5m Depth	Su 2	Su 1½	Su 1½-2 Mu ½	Su 2	Su 1½ Mu 1	Su Other-Mu	2
University L. 2m Depth	Mu ½	Mu 1½	Mu 1½	Mu 1½	Mu 1 Fl ½	Mu	1½

FLAVOR PROFILE METHOD

Taste x **or Odor** ___ **Date** 7/19/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Ruthy	Pam	Bill	Desc.	Int.
0.5 mg/l as Cl2 Free Chlorine Standard	Bi 1½	Bi 1½	----	------	Cl)(	Bi	)(
Taste and Odor Free Water	------	-----	-----	------	Mu ½	------	----
0.5 mg/l as Cl2 Free Chlorine Standard	Bi)(	Bi)(	Cl)(	-----	Cl)(	Bi	)(
					Bi ½		

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 7/24/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Pam	Bill		Desc.	Int.
Pinegate	Cl 1½	Cl 1	Cl 1-1½	Cl 1		Cl	1
		Mu ½	Mu ½	Mu ½-1		Mu	½
Carolina Inn	Cl 1	Cl ½	Cl 1	Cl ½		Cl	1
			Mu ½	Mu)(		Mu	)(
Taste and Odor Free Water	------	------	------	-------		------	-----
Pinegate	Cl 1	Cl)(	Cl 1	Cl)(-½		Cl	½
			Mu)(				
3.0 ng/l MIB Standard	-----	Mu ½	Mu 1	Mu)(		Mu	½
		Cl)(					
Finished Water @ WTP	Cl 1	Cl 1	Cl 1	Cl ½		Cl	1
		Mu)(	Mu ½	Mu)(		Mu	)(
			Free Chlorine Measurements				
			Finished Water- 1.1 mg/l as Cl2				
			Carolina Inn- 0.7 mg/l as Cl2				
			Pinegate- 0.3 mg/l as Cl2				

FLAVOR PROFILE METHOD

Taste X **or Odor** ___ **Date** 7/24/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Anne	Wendy	Pam	Bill		Desc.	Int.
Carolina Inn	Mu 1½	Cl 1	Cl 1½	Cl 1-1½		Cl	1½
			Mu)(			Mu	½
Finished Water @ WTP	Cl 1	Cl 1	Cl 1	Cl ½-1		Cl	1
		Mu)(	Mu)(			Mu	)(
Pinegate	Cl)(	Cl 1	Cl 1	Cl ½		Cl	½
	Mu ½	Mu 1	Mu ½	Mu ½		Mu	½
3.0 ng/1 MIB Standard	Bi 1½	Mu ½-1	Mu ½	Mu)(		Mu	½
Taste and Odor Free Water	Bi)(	-----	-----	-----		------	-----
Pinegate	Mu 1	Mu 1-1½	Mu 1	Cl)(		Mu	1
				Mu ½			

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 8/6/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Wendy	Bill	Ronnie	Anne	Desc.	Int.
Finished Water @ WTP	Cl 1½	Cl 1½	Cl 1½	Cl 1	Cl 1½	Cl	1½
	Mu ½		Mu ½	Mu 1		Mu	½
Settled Water @ WTP	Mu 2	Mu 1	Mu 1½	Mu 1½	----	Mu	1½
		Cl ½					
1.0 mg/l as Cl2 Free Chlorine Standard	Cl 1	Cl ½	Cl 1	Mu ½	Cl 1	Cl	1
Taste and Odor Free Water	------	-----	Mu ½	------	-----	------	-----
Finished Water @ WTP	Mu 1	Cl 1½	Cl 1	Cl ½	Cl 1½	Cl	1
	Cl 1		Mu 1			Other-	Mu
Filtered Water @ WTP	Cl 1½	Cl 1	Cl 1	Cl 1	Cl 1½	Cl	1
	Mu)(		Mu)(	Mu 1		Mu	)(
Raw Water @ WTP	Mu 1½	Mu 1½	Mu 2	Mu 1	Mu)(	Mu	1½
			Free Chlorine Measurements				
			Filtered Water- 1.8 mg/l as Cl2				
			Finished Water- 1.3 mg/l as Cl2				

FLAVOR PROFILE METHOD

Taste X **or Odor** ___ **Date** 8/6/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Wendy	Bill	Ronnie	Anne	Desc.	Int.
Finished Water @ WTP	Cl $\frac{1}{2}$	Cl 1	Cl $\frac{1}{2}$-1	Mu 1	Cl 1	Cl	1
	Mu)(	Mu 1	Mu)(			Mu)(	
Taste and Odor Free Water	------	------	Bi)(	-----	Bi)(	Other-	Bi
1.0 mg/l as Cl2 Free Chlorine Standard	-----	-----	Cl)(	Cl $\frac{1}{2}$	Cl $\frac{1}{2}$	Cl)(	)(
Finished Water @ WTP	Cl 1	Cl 1	Cl $\frac{1}{2}$	Cl 1	Cl 1	Cl	1
	Mu)(	Mu)(	Mu)(		Mu)(	Mu	)(
Filtered Water @ WTP	Cl 1	Cl $\frac{1}{2}$	Cl $\frac{1}{2}$	Cl $\frac{1}{2}$	Cl $\frac{1}{2}$	Cl	$\frac{1}{2}$

FLAVOR PROFILE METHOD

Taste ____ **or Odor** X **Date** 8/14/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Anne	Ronnie	Bill		Desc.	Int.
University L. 1m Depth	Mu 2	Mu 1	Mu 1	Mu ½		Mu	1
University L. 3.5m Depth	Su 2	Su 2½	Su 3	Su 1½		Su	2½
Raw Water @ WTP	Mu 1	Mu 1	Mu)(	Mu 1-1½		Mu	1
University L. 1m Depth	Mu 1	Mu 1½	Mu ½	Mu ½		Mu	1
Taste and Odor Free Water	------	------	-----	-----		-----	----
University L. 2m Depth	Mu 2	Mu 1½	Mu ½	Mu ½-1		Mu	1
25 ng/l MIB Standard	Soil 2	Di 2½	Veg Dec	Di 1½-2		Di Other-	2 Veg Dec

FLAVOR PROFILE METHOD

Taste X **or Odor** ____ **Date** 8/14/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Anne	Ronnie	Bill		Desc.	Int.
Taste and Odor Free Water	Bi)(	Bi 1	Bi 1	Bi)(-½		Bi	½
25 ng/l MIB Standard	Soil 1½	Soil 1½	Soil 1½	Mu 1½-2		Di	1½
	Mu ½						
25 ng/l MIB Standard	Di 2	Di 2	Di 2	Mu 2		Di	2
	Mu 1						

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 8/21/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Anne	Ronnie	Wendy		Desc.	Int.
Raw Water @ WTP 15 ppm PAC 90 min	Mu ½	Mu)(	Mu 1	----		Mu	½
Taste and Odor Free Water	------	-----	-----	-----		-----	----
Raw Water @ WTP 15 ppm PAC 40 min	Mu 1	Mu)(	Mu 1	Mu 1½		Mu	1
Raw Water @ WTP	Mu 1½	Mu 1	Veg dec1	Ea 2		Ea	1½
Raw Water @ WTP 30 ppm PAC 90 min	Su ½ Mu ½	Su ½ Mu)(	Su)(	Mu ½		Mu Su	)(½
Raw Water @ WTP 30 ppm PAC 40 min	Mu 1	Mu ½	Mu ½	Mu ½		Mu	½
Raw Water @ WTP	Mu 1½	Mu 1½	Veg dec1	Mu 1½		Ea	1½
3.0 mg/l as Cl2 Free Chlorine Standard	Cl 1½	Cl 1½	Cl 1	Cl 1½		Cl	1½

FLAVOR PROFILE METHOD

Taste X **or Odor** ____ **Date** 8/21/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Anne	Ronnie	Wendy		Desc.	Int.
3.0 mg/l as Cl2 Free Chlorine Standard	Cl ½	Cl 1	Cl)(	----		Cl	½
Taste and Odor Free Water	------	------	------	-------		----	----
3.0 mg/l as Cl2 Free Chlorine Standard	-----	-----	Bi 1	----		-----	----

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 9/4/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Anne	Pam	Ronnie	Bill	Desc.	Int.
Filtered Water @ WTP	Cl 1	Cl 1-1½	Cl 1	Cl ½	Cl)(-½	Cl	1
Above Filter @ WTP	Cl ½-1	Cl 2-2½	Cl 1½	Cl 2	Cl 1	Cl	1½-2
Filtered Water @ WTP	Cl)(-½	Cl 1½-2	Cl 1	Cl 1	Cl 1-1½	Cl	1½
Settled Water @ WTP	Ea 1½	Ea 1½	Mu 1	Mu ½	Mu 1½	Mu	1½
Raw Water @ WTP	Mu 1½	----	Mu 1½	----	Mu 1½	Mu	1½
Taste and Odor Free Water	------	-----	------	Mu)(	-----	-----	-----
5.0 mg/l as Cl2 Free Chlorine Standard	Cl ½	Cl 1½	Cl 1½	Cl ½-1	Cl ½	Cl	1
			Free Chlorine Measurements				
			Above Filter- 0.6 mg/l as Cl2				
			Filtered Water- 0.3 mg/l as Cl2				

FLAVOR PROFILE METHOD

Taste X **or Odor** ____ **Date** 9/4/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Anne	Pam	Ronnie	Bill	Desc.	Int.
5.0 mg/l as Cl2 Free Chlorine Standard	-----	Cl $1\frac{1}{2}$	Cl)(	----	Cl)($-\frac{1}{2}$	Cl	)(
		Bi)(			Bi)(	Other-	Bi
Taste and Odor Free Water	-----	Cl $\frac{1}{2}$	----	-----	-----	-----	-----
		Bi)(					
5.0 mg/l as Cl2 Free Chlorine Standard	Bi $\frac{1}{2}$	Bi)(	Cl)(	----	Cl $\frac{1}{2}$	Cl	)(

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 9/11/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Bill	Ronnie	Anne	Pam		Desc.	Int.
Raw Water @ WTP 60 ppm PAC 40 min	Mu 1	Mu ½	-----	Mu)(		Mu	)(-½
Raw Water @ WTP 30 ppm PAC 40 min	Mu 1	Mu 1	Mu)(	Mu ½		Mu	½-1
9.0 ng/l MIB Standard	Mu 1½	Mu ½	Di 1	Di 1		Mu	1
Raw Water @ WTP 60 ppm PAC 90 min	------	-----	-----	Mu)(		----	----
Raw Water @ WTP 30 ppm PAC 90 min	Soil ½	Mu ½	----	Mu ½		Mu	½
Raw Water @ WTP	Mu 1 Fl)(-½	Veg Dec1	Soil 1½	Soil 1½		Mu	1½
Taste and Odor Free Water	-----	-----	-----	------		----	----
9.0 ng/l MIB Standard	Mu ½-1	Mu 1	Mu ½	Mu ½		Mu	½-1

FLAVOR PROFILE METHOD

Taste ____ **or Odor** X **Date** 9/18/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Anne	Pam	Bill	Ronnie	Desc.	Int.
25 ng/l Geosmin Standard + 1.0 mg/l Chlorine	Cl 1	Cl 1-1½	Cl 1½	Cl 1-1½	Cl 2	Cl	1½
				Mu)(			
Settled Water @ WTP 60 ppm PAC 90 min	Mu ½	Mu ½	Mu ½	Mu ½	Mu ½	Mu	½
	Veg dec1	Veg dec1	Veg dec1	Veg dec1	Veg dec1	Veg dec	1
25 ng/l Geosmin Standard	Mu ½-1	Mu ½	Mu ½	Mu ½	Mu)(	Mu	½
Settled Water @ WTP 60 ppm PAC 90 min +5.0 mg/l Chlorine	Cl 1	Cl 2½	Cl 2	Cl 1	Cl 1	Cl	1½
				?)(	Mu)(		
Settled Water @ WTP +5.0 mg/l Chlorine	Cl 1½	Cl 3	Cl 2½	Cl 1	Cl)(	Cl	1½-2
Taste and Odor Free Water	------	-----	------	-----	-----	-----	----
0.9 mg/l as Cl2 Free Chlorine Standard	Cl)(	Cl 1½	Cl ½	Cl)(	----	Cl	)(-1
			Mu)(	Mu)(	Mu)(	Mu	)(
0.9 mg/l as Cl2 Free Chlorine Standard	Sw ½	Cl 1	Cl)(-½	Cl ½	Cl)(	Cl	½
Settled Water @ WTP	Mu 1½	Sea Water 2	Mu 2	Mu 2	Mu 2	Mu	1½
				Fl ½			
		Free Chlorine Measurements					
		S.W. +5.0mg/l Chlorine - 2.5 mg/l as Cl2					
		S.W. 60 ppm PAC 90 min +5mg/l Chl- 2.8 mg/l as Cl2					
		25 ng/l Geos. +1mg/l Chl- 0.9 mg/l as Cl2					

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 9/25/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Pam	Wendy	Anne	Bill	Ronnie	Desc.	Int.
1.0 mg/l as Cl2 Free Chlorine Standard	Cl ½	Cl 1-1½	Cl ½-1	Cl ½-1	Cl 1	Cl	1
1.0 mg/l as Cl2 Free Chlorine Standard	Cl ½	Cl)(	Cl ½	Cl)(-½	Cl ½	Cl	½
25 ng/l Geosmin Stand. + 1.0 mg/l Chlorine	Cl 1 Mu ½	Cl1	Cl 1	Cl ½-1 Mu ½	Mu 1	Cl Mu	1 ½
Raw Water @ WTP 60 ppm PAC 90 min +5 mg/l Chlorine	Cl ½ Mu)(	Cl ½	Cl 1-1½	Cl ½	Cl ½	Cl	½
Raw Water @ WTP +5 mg/l Chlorine	Cl 1 Mu ½	Cl 1	Cl 1½-2	Cl ½-1 Di)(	Cl 2	Cl Other-	1½ Mu
Raw Water @ WTP	Mu 2½	Mu 1 Veg dec	Se 2	Se 2	Se 1½	Se	2
Raw Water @ WTP 60 ppm 90 min	Veg dec	½ Se 1	Se 1½	Se 1-1½	Veg dec½	Se	1-1½
25 ng/l Geosmin Stand.	Mu ½	Mu)(	----	----	----	Other-	Mu
Taste and Odor Free Water	-----	------	Mu)(	?)(	----	-----	----
		Free Chlorine Measurements					
		R.W.+5 mg/l Chlorine- 0.4 mg/l as Cl2					
		R.W. 60ppm PAC 90 min+5mg/l Chl- 0.6 mg/l as Cl2					
		25 ng/l Geos.+1mg/l Chlorine- 1.0 mg/l as Cl2					

FLAVOR PROFILE METHOD

Taste ____ or Odor X **Date 10/2/85**

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Pam	Anne	Ronnie		Desc.	Int.
0.9 mg/l as Cl2 Free Chlorine Standard	Cl)(	Cl ½	Cl)(	Cl)(		Cl	)(
2 ng/l MIB Standard	Mu 1	Mu ½	Mu)(	----		Mu	½
0.9 mg/l as Cl2 Free Chlorine Standard	Cl)(	Cl 1	Cl ½	Cl ½		Cl	½
Taste and Odor Free Water	------	-----	------	Cl)(		----	-----
15 ng/l MIB Standard	Ea 1½	Mu 1	Di 1	Mu ½		Mu	1
5 ng/l MIB Standard	Mu ½	Mu ½	Mu)(	----		Mu	½
0.3 mg/l as Cl2 Free Chlorine Standard	----	Cl ½	Cl ½	----		Other-	Cl

FLAVOR PROFILE METHOD

Taste X **or Odor** ___ **Date** 10/2/85

Sample I.D.	Panel Desc., Order, Int.					Flavor Profile	
	Wendy	Pam	Anne	Ronnie		Desc.	Int.
0.3 mg/l as Cl2 Free Chlorine Standard	Cl ½	Cl)(	Cl ½	Mu)(		Cl	)(
0.9 mg/l as Cl2 Free Chlorine Standard	Cl)(	Cl)(	Cl ½	Se 1		Cl	)(
2 ng/l MIB Standard	Mu ½	Mu)(	Mu)(	---		Mu	)(
5 ng/l MIB Standard	Mu 1	Mu ½	Mu ½ Bi ½	Mu ½		Mu	½
15 ng/l MIB Standard	Mu 1½	Mu 1	Mu 1	Mu 1½		Mu	1-1½
0.9 mg/l as Cl2 Free Chlorine Standard	Cl)(	Cl)(	Cl)(	Mu)(		Cl	)(
Taste and Odor Free Water	-----	-----	Bi)(	----		-----	-----

Appendix D
Calculation of Prediction Interval
(Kleinbaum and Kupper, 38)

Prediction Interval is given by

$$\bar{Y} + \hat{\beta}_1 (X_0 - \bar{X}) \pm t_{n-2,1-\alpha/2} S_{Y/X} \sqrt{1 + 1/n + (X_0 - \bar{X})^2 / (n-1) S_x^2}$$

where

n = number of observations
$\bar{Y}$ = sample mean of Y's
$\bar{X}$ = sample mean of X's
$\hat{\beta}_1$ = slope of best-fit line
X_0 = value of X at which interval is being calculated
$t_{n-2,1-\alpha/2}$ = $100(1-\alpha)\%$ point of the t distribution with $n-2$ degrees of freedom
$S_{Y/X}$ = estimate of common variance (σ^2)
S_x^2 = sample variance of the X's