Analysis of initial effluent degradation : a study at two Montana water treatment plants
by Karen Elizabeth Bucklin

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering
Montana State University

Abstract:
The initial effluent from a granular media filter after a backwash is of higher turbidity than the effluent later in the filter run. Various theories have been put forward to explain this phenomenon, known as' "filter ripening", and to determine the source of these higher turbidity readings. Several studies have shown that during this period of higher, turbidity an increase occurs in the numbers of microorganisms, including Giardia, which pass through the filter. The research conducted here attempts to answer these questions and is unique because the post backwash "filter ripening" stage has been examined in two operating municipal water treatment plants, whereas previous studies have mainly been conducted within pilot plant scale studies.

Turbidity samples were collected during the post backwash period, both as grab samples and by continuously recorded monitoring. Microbiological samples were gathered at the same sample points, and were analyzed for total coliforms, injured coliforms, and heterotrophic plate count. Raw water characteristics, water treatment and chemical additions, and total plant effluent characteristics were monitored.

Incidences of higher ' than normal turbidity were evidenced at both plants, as has been shown to occur in pilot studies, during the post backwash filter ripening phase. These periods of high turbidity readings were found to show a two peak characteristic. Microbiological sampling showed no relationship between the higher turbidities and a corresponding increase in bacterial numbers. The chlorinated backwash water used in an operating water treatment plant seems to negate the relationship between the turbidity and bacterial numbers. This study also confirmed the higher recovery rates for chlorine injured coliforms using MT-7 agar, as compared to m-Endo agar, during the post backwash period. This effect was most pronounced during the initial portions of the filter run, and tapered off as the filter run progressed.

The data collected for this study confirms a dual peaked turbidity post backwash filter effluent characteristic in a full scale plant setting, but raises sane questions concerning the origins of these peaks. The data also provides sane guidelines for the minimization of these turbidity peaks.

These findings are applicable to the operation of existing water treatment plants, to provide guidelines for the production of a low turbidity effluent. It also raises questions concerning the practicality of filter-to-waste design for the post backwash filter period, in terms of the assumption of bacterial numbers being associated with turbidity during this period in the filter run.'

ANALYSIS OF INITIAL EFFLUENT DEGRADATION: A STUDY AT TWO MONTANA WATER TREATMENT PLANTS

by

Karen Elizabeth Bucklin

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Environmental Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1989

APPROVAL

of a thesis submitted by

Karen Elizabeth Bucklin

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Nov. 20, 1989
Date

Howard S. Lang(?)
Chairperson, Graduate Committee

Approved for the Major Department

22 Nov 1989
Date

Theodore E. Lang
Head, Major Department

Approved for the College of Graduate Studies

Dec. 15, 1989
Date

Henry L. Parsons
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Dean of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature ______________________

Date 12/19/89

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF TABLES - Continued

Table | Page

LIST OF FIGURES

LIST OF FIGURES - Continued

Figure | Page

LIST OF FIGURES - Continued

Figure | Page

LIST OF FIGURES - Continued

Figure | Page

LIST OF FIGURES - Continued

Figure | Page

ABSTRACT

The initial effluent from a granular media filter after a backwash is of higher turbidity than the effluent later in the filter run. Various theories have been put forward to explain this phenomenon, known as "filter ripening", and to determine the source of these higher turbidity readings. Several studies have shown that during this period of higher turbidity an increase occurs in the numbers of microorganisms, including Giardia, which pass through the filter. The research conducted here attempts to answer these questions and is unique because the post backwash "filter ripening" stage has been examined in two operating municipal water treatment plants, whereas previous studies have mainly been conducted within pilot plant scale studies.

Turbidity samples were collected during the post backwash period, both as grab samples and by continuously recorded monitoring. Microbiological samples were gathered at the same sample points, and were analyzed for total coliforms, injured coliforms, and heterotrophic plate count. Raw water characteristics, water treatment and chemical additions, and total plant effluent characteristics were monitored.

Incidences of higher than normal turbidity were evidenced at both plants, as has been shown to occur in pilot studies, during the post backwash filter ripening phase. These periods of high turbidity readings were found to show a two peak characteristic. Microbiological sampling showed no relationship between the higher turbidities and a corresponding increase in bacterial numbers. The chlorinated backwash water used in an operating water treatment plant seems to negate the relationship between the turbidity and bacterial numbers. This study also confirmed the higher recovery rates for chlorine injured coliforms using MT-7 agar, as compared to m-Endo agar, during the post backwash period. This effect was most pronounced during the initial portions of the filter run, and tapered off as the filter run progressed.

The data collected for this study confirms a dual peaked turbidity post backwash filter effluent characteristic in a full scale plant setting, but raises some questions concerning the origins of these peaks. The data also provides some guidelines for the minimization of these turbidity peaks.

These findings are applicable to the operation of existing water treatment plants, to provide guidelines for the production of a low turbidity effluent. It also raises questions concerning the practicality of filter-to-waste design for the post backwash filter period, in terms of the assumption of bacterial numbers being associated with turbidity during this period in the filter run.

CHAPTER 1

INTRODUCTION

It is well known that the initial effluent turbidities of a recently backwashed filter are higher than the turbidities later in the filter run (Amirtharajah, 1985; Chen, 1986; Yapijakis, 1982; Francois and Van Haute, 1985). The period of higher than average effluent turbidities is followed by a period during which the turbidities begin to slowly improve. This phenomenon, frequently called "filter ripening", has been often noted, but has not been extensively studied.

Concern about the intial portion of the filter run is due to the association of high turbidities with high particle counts (McCoy and Olson, 1986), and with high numbers of microorganisms (Logsdon and Rice, 1985; Logsdon, et al., 1985). Other studies, however, show a variable correlation between turbidity and bacteriological parameters (Reilly and Kippin, 1983; McCoy and Olson, 1986).

Regardless of the numbers of organisms associated with turbidity, high turbidities are undesirable due to the implications for disinfection. Turbidity is believed to: (1) serve as a carrier for nutrients that can result in biological activity and water quality degradation (Herson et al., 1984), (2) exert a significant demand upon the disinfectant used, resulting in a lower disinfectant residual in the distribution system (Ridgway and Olson, 1982), and (3) provide a matrix to "shield", or transport microorganisms into the distribution system (LeChavallier et al., 1984). Additionally, several studies have concluded that due to the large number of injured organisms present in drinking water, enumeration of coliforms has been underreported (McFeters, et al., 1982; LeChevallier and McFeters, 1985; McFeters and Camper, 1983; LeChevallier, et al., 1983; O'Connor, et al., 1984).

Several studies have tried to characterize and to determine the causes of the initial effluent degradation and the subsequent filter ripening period. Research by Amirtharajah and Wetstein (1980), has indicated that the period of effluent degradation is due to the backwash water remnants. Work done by Francois and Van Haute (1985), indicates that a large part of the poor quality effluent is a function of the influent water. The filter improvement period, or the period during which the effluent quality improves has been characterized by O'Melia and Ali (1978), and by Payatakes et al. (1981) as related to the accumulation of influent particles within the media over time.

The use of a filter-to-waste period at the beginning of a filter run was commonly used to control the quality of the filter effluent up to the 1930's. The procedure has not routinely been designed in newer plants but has gotten increasing attention due to concern over possible transmission of Giardia cysts. This practice may only be sufficient to avoid the initial effluent degradation peaks, since the filter ripening period generally takes place over an extended period of time. Another method of protecting the effluent quality is the injection of a polymer into the backwash water (Cranston, 1986; Harris, 1970; Yapijakis, 1982).

The polymers adsorb to the filter media, serving to "precondition" the filter.

There is a paucity of information from actual water treatment facilities investigating the period of filtration following a backwash. Most of the studies which deal with the post backwash period of the filter run have been conducted in pilot scale studies.

The research conducted herein provides a view of the post backwash filter effluent in full scale water treatment plants, and develops a hypothesis for this period, based upon observations and data collected as well as upon the literature available. In addition, some guidelines for the operation of water treatment facilities are presented, with the goal of minimizing the turbidities and bacteriological numbers associated with the post backwash period.

CHAPTER 2

RESEARCH OBJECTIVES

The overall objective of this research was to characterize the post backwash filter ripening phase of dual media filters in full scale water treatment plants. This is important in order to develop operational methods or design guidelines which minimize the magnitude and the duration of this period. The individual research objectives were:

1. To confirm the occurrence of high turbidity, bacteria and particles in the initial effluent from a filter and its association with the backwash water remnants.

2. To determine the magnitude of the components to initial degradation from the backwash water remnants and the improving phase.

3. To determine the severity of initial degradation in relation to current standards for drinking water (1 ntu) and future standards (0.2 ntu).

4. To determine the changes in initial degradation over a year with seasonal changes in raw water quality including temperature and treatment chemicals.

5. To compare the initial degradation from a conventional plant as contrasted with a direct filtration plant.

6. To develop design and operational guidelines that would minimize the detrimental effects of initial degradation.

CHAPTER 3

LITERATURE REVIEW

As mentioned earlier, there is a real lack of information regarding the initial stages of filtration in full scale water treatment plants. The only plant scale study which has focused on the initial degradation phase of a filter run reported in the literature is a 1982 report by Qureschi. An additional study which has been carried out in a municipal water treatment facility is a study in 1970, by Leslie Harris. However, Harris' investigation does not concentrate on the initial degradation of the filter effluent following a backwash. Rather, he investigated the minimization of the total filter effluent degradation by the use of coagulants in the backwash water remnants. There is much more information in the literature dealing with the mechanisms of filtration, including the mechanics of the improving effluent quality of a filter over time. There is a fair amount of data available from studies carried out on pilot plant filters, which chronicles the occurrence of high turbidity, high bacterial counts and high numbers of Giardia cysts in filter effluent during the period of time following a filter backwash.

In addition, there is a quite a bit of material covering the occurrence of coliforms, injured coliforms, heterotrophic organisms, and particle counts in water systems, and the correlation of this data with turbidity.

Initial Degradation of Filter Effluent

Amirtharajah and Wetstein (1980), with work done using a pilot scale filter, showed that the initial effluent quality from a filter used over several filter runs could be divided into three portions; the lag period, the rising limb culminating in two turbidity peaks, and the long receding limb (Figure 1). They proposed that the lag period was due to the clear backwash water remaining in the underdrain system up to the bottom of the filter media, that the rising limb was due to particles derived during collisions of the settling media at the end of the backwash, and that the receding limb was due to the dispersion of the media-derived particles from the filter with the influent, and the accumulation of influent particles within the media pores. The rising limb consists of two separate turbidity peaks; the first corresponding with the turbidity of the backwash water remnants remaining within the media, and the second corresponding with the backwash water remnants standing above the filter media, up to the backwash water gutter, following backwash.

The three stages of the initial effluent degradation have different characteristics in terms of particle concentrations. In general, the first turbidity peak, associated with the backwash water remnants within the filter media, has a quality which is characterized by the last stages of the backwashing operation. The second turbidity peak,

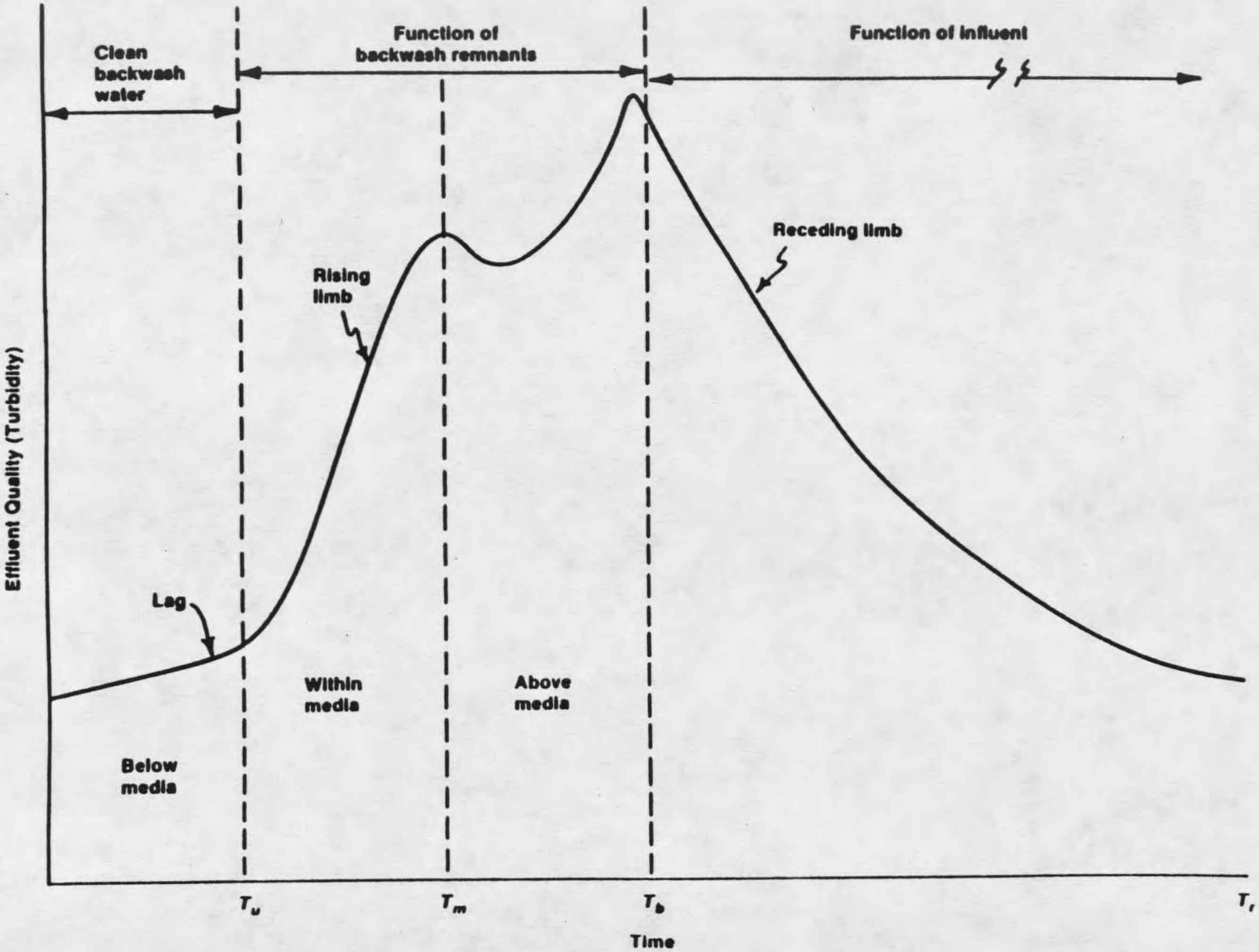

Figure 1. Characteristics of Initial Effluent Quality (Amirtharajah and Wetstein, 1980).

associated with the backwash water remnants remaining above the filter media, is the poorest quality water.

Amirtharajah (1982) has developed a model which characterizes the quality of the backwash water. The model assumes a surface renewal mechanism for particle detachment from fluidized grains to the backwash water. It is shown that the concentration of particles, C, in the backwash water are represented by;

$$C = Ke^{-(vt/d)}$$

in which ; v = backwash water velocity, t = time, d = diameter of collectors, and K = coefficient. This result indicates an exponential distribution of particles in the backwash water, and serves as a rationale for the dominance of the second turbidity peak during initial degradation.

Qureshi (1982), ran a series of plant-scale investigations at the Fridley Water Treatment Plant for the City of Minneapolis, in which filters were subjected to various backwashing rates. The study concluded that a higher initial degradation resulted when filters were backwashed at sub-fluidization rates. He also confirmed the existence of two turbidity peaks during the initial filter effluent degradation phase, and their relationship to the backwash water remnants as proposed by Amirtharajah and Wetstein (1980).

Qureshi's study was carried out, it should be noted, in a softening plant with alum addition. Turbidities from individual filters ranged from 0.5 to 1.9 ntu during the first hour of operation, while the typical turbidity during mature filter operation from one hour to 50 hours was in the range of 0.2 to 0.5 ntu. Qureshi attempted to minimize the initial degradation turbidities by addition of polymer to the backwash water.

In 1985, Francois and Van Haute described the filter ripening phase, modifying Amirtharajah and Wetstein's theory. Their experiments were carried out using a pilot scale plant utilizing domestic waste water with alum in conjunction with a non-ionic polymer. They theorize that the peak turbidity is more related to the influent water than to the backwash remnant water (95% influent vs. 5% remnant). Their research indicated that the ripening period of the filter is simultaneous with a change in the pore structure of the filter bed, and that the initial turbidity breakthrough was due to the breakdown of the initially placed weak hydroxide flocs within the pores of the media due to the rapid increase of velocity gradients as particles begin to accumulate within the media pores. The loosely deposited flocs are scoured back into suspension in fairly large amounts.

Another conclusion from Francois and Van Haute's study was that by overdosing the coagulant during the initial stages of filtration, the filter ripening peak can be reduced. They attributed this to an increased blocking rate of the media pores and dead zones.

Therefore, they summarize that the major degradation turbidity peak is assumed to be due to a lack of filter efficiency, caused by an inadequate pore structure and the passage of the initial weak flocs through the filter media. The rate of pore blocking was suggested to be strongly influenced by the chemical pre-treatment of the raw water.

Studies by Payatakes, et al. (1981), and O'Melia and Ali (1978), have shown that the improving phase of filter ripening is due to the accumulation of particles within the media flow channels. O'Melia and Ali suggested an association of the improving phase of filter ripening with the formation of particle chains, or dendrites, on the media during the initial stages of filtration. They used a pilot-scale study, with a polymer coagulant system. Payatakes, et al. (1981) showed, with simplified visual experimental data, that the main mechanism causing alteration of the geometry of flow channels within the filter could be throat clogging. This throat clogging resulted in an increase of local capture efficiency and explains the improving phase of filter ripening.

O'Melia and Ali (1978) developed an equation to model the improving phase of filtration due to the accumulation of particles and the formation of dendrites and particle chains within the media pores. The constantly accumulating particles within the media are thought to continually improve the effluent quality by the improved capture of the influent particles by the dendrites.

The equation which O'Melia and Ali developed includes both the collection efficiency of the original filter grain as well as displaying the collector efficiency of the filter grain and its associated particles collected during filtration:

$$nr = (A*n) + (N*Ap*np)*(dp/dc)^2$$

Where: nr = Single collector efficiency of a particle and its retained particles.

A = Collision efficiency factor.

n = Single collector efficiency.

N = Number of particles that act as collectors.

Ap = Collector efficiency factor of retained particles.

np = Collection efficiency of a retained particle.

dp = Diameter of suspended particles.

dc = Diameter of collector.

Cranston (1987) modified Amirtharajah and Wetstein's theory of filter ripening, calling the events the "filter ripening sequence". In the filter ripening sequence, three stages are characterized (Figure 2). The three stages are: the remnant stage, the influent mixing and particle stabilization stage, and the filter media conditioning stage. The remnant stage is associated with the backwash water remnants remaining within the underdrains, media, and above the media after backwash. Cranston noted that a peak of high turbidity may occur at this stage due to particles sheared off the media at the beginning of the filtration cycle, or at the end of the backwash, as the media particles collide with each other. The influent mixing and particle stabilization stage occurs as the influent water disperses into the coagulant-free remnant water above the filter media. This stage is characterized by the large peak in turbidity, and the cause is the partial stabilization of the previously destabilized influent particles, as they interact with the non-coagulated backwash water. The third

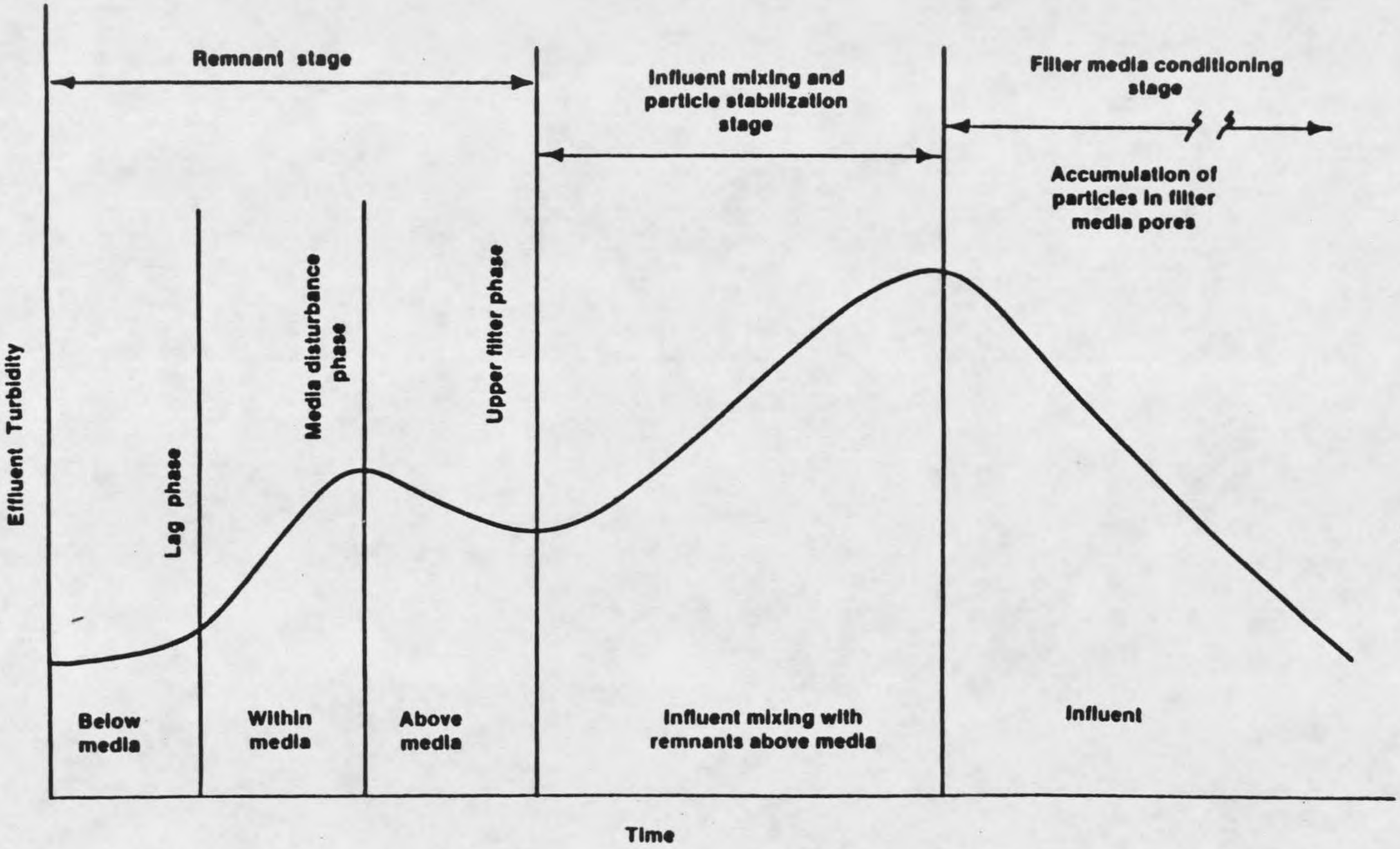

Figure 2. "Filter Ripening Sequence" (Cranston, 1987).

stage is the filter media conditioning stage, and is characterized by the accumulation of particles within the filter media, and the increased efficiency of particle removal.

Cranston also found that the use of coagulants in the backwash water as a means of reducing the magnitude and the duration of the filter ripening sequence can be very effective. He also stated that the mechanism by which this treatment becomes effective is by virtue of the fact that the coagulated backwash water remnants above the filter help to prevent the stabilization of the initial influent particles as they interact with the backwash water remnants. The coagulants or species created by the coagulants also tend to adsorb to the filter media, accelerating the particle accumulation within the media pores.

The addition of polymers to backwash water as a means of minimizing the filter ripening stage of filtration is a widely accepted idea and practice which is in use in some water treatment facilities. Several works on the subject include Harris' study at the Conta Costa County water treatment plant in California, in 1970, and Yapijakis'(1982) and Chen's (1986) experiments, using pilot plants. These studies indicate that the addition of polymer to the backwash water serves to minimize the filter ripening duration and magnitude, under both pilot and full scale studies.

Occurrence of Microorganisms in the Filter Ripening Period

One of the major problems facing the water industry today is giardiasis. Amirtharajah (1986) has recently summarized the rationale for development of mandatory filtration and disinfection regulations based on the possible transmission of Giardia cysts and viruses. Logsdon, et al. (1985) in a recent pilot scale study concluded that Giardia cyst concentrations may be higher than usual during the first portion of a filter run, and that operators should consider a filter-to-waste period at the start of a new run. Logsdon indicated that a 0.2 to 0.3 ntu rise in turbidity can be associated with rises in Giardia cyst concentrations by factors of twenty to forty. Since the ingestion of only ten Giardia cysts have been shown to cause an infection (Lin, 1985), it is quite possible that the initial degradation phase of filtration will transmit sufficient cysts to cause an infection. Some giardiasis outbreaks from filtration plants have been linked circumstantially with possible cyst transmission during the filter ripening period (Logsdon, 1985).

Logsdon and Rice (1985), in a related study, also confirmed the passage of high concentrations of Klebsiella occurred during the initial portions of a filter run, when dechlorinated backwash water was used. The Klebsiella concentrations rose sharply, as the filter run began following backwash, and then slowly declined, at about the same time as the turbidity concentrations. They went on to report that when chlorinated water was used for the backwash, no organisms were recovered for the first ten minutes of the filter run, after which the bacterial concentrations resumed as in the dechlorinated runs. Logsdon and Rice account for the low numbers of Klebsiella during the first ten minutes of the run as a result of chlorine injury to the organisms. They noted that injured and lysed organisms are a source of food for other organisms in the system, and that some injured organisms may recover to reproduce and colonize the distribution system. Logsdon and Rice concluded that the passage of bacteria during the initial filtration phase is likely to be masked by chlorination.

Al-Ani, et al.,(1984), in a pilot scale study, had similar results to Logsdon's work with Giardia and Klebsiella recovered from filter effluent. The studies of this group found that turbidity is a good indicator of bacterial and Giardia removal from filtered water, on a percentage basis. Their research, however, did not investigate the initial portions of the filter run, sampling only at 30 and 60 minutes into the filter run.

In a recent study, McCoy and Olson (1986), determined that the water quality degradation within municipal drinking water systems occurred because of intermittent short duration events that resulted in high turbidity, particle counts, and heterotrophic plate counts. They found that particle counts and turbidity were directly proportional, but that there was no predictable relationship between particle counts or turbidity and bacteriological quality. Similar results were reported earlier in 1983 by Reilly and Kippin, and in 1984, by O'Connor et al.. Reilly and Kippin concluded, from a study conducted on municipal water distribution systems, that standard plate counts (SPC) exhibited no relationship with coliform counts when the SPC was less than 50 organisms / ml.. In addition, the SPC was not dependent on low-level turbidity and varied with respect to free chlorine residuals.

O'Connor, et al. (1984), reported that there was a lack of correlation between direct cell counts and turbidity in water from distribution systems in Missouri. They also said that; "...turbidity is of no value for estimating plate or coliform counts in drinking waters."

Hudson (1981, pp7), used operating data from the Vitelma filtration plant in Bogota, Colombia, to show that bacterial counts in filtered water declined as the turbidity of the filtered water declined. This conclusion is also upheld by McCormick and King (1982), who reported that in pilot scale studies of direct filtration: "A filtered water turbidity of 0.10 ntu, which met the AWWA goal, resulted in practically complete removal of algae and coliform bacteria."

The turbidity of filtered water, whether directly proportional to microbial counts or not, is still considered a good surrogate parameter by which overall water quality can be measured. Turbidity is thought to: (1) serve as a carrier for nutrients that can result in biological activity and resultant water quality degradation (Herson, et al., 1984); (2) exert significant disinfection demand that can result in loss of disinfectant residual in the distribution system (Ridgway and Olson, 1982); and (3) provide a matrix to transport microorganisms through or introduce organisms into the system (LeChevallier, et al., 1984). Because of these effects and other pragmatic and economic considerations, turbidity measurements will continue to play a major role in drinking water regulations based on health criteria (Amirtharajah, 1986).

Incidence of Injured Organisms

As Logsdon concluded from his filter studies, discussed above, in which Klebsiella were not detected during the first ten minutes of the filter runs that were preceded by chlorinated backwash cycles, injured organisms may account for the poor recovery rates. Injured organisms present in the filter effluent may result in; (1) underestimation of the "true" bacterial count present in the water, and an overestimation of the water quality, (2) physiological recovery of the organisms, followed by regrowth in the distribution system, and a subsequent increased disinfectant demand, and (3) use of the injured organisms as "food" for the growth of other organisms present in the drinking water.

The problem of injured coliforms in drinking water has been researched by Gordon McFeters in several studies and by Mark LeChevallier, both from Montana State University. As noted by LeChevallier and McFeters (1984): "The effectiveness of the coliform group of bacteria as indicators of water quality is largely related to their efficiency of enumeration."

Not only is chlorine a source of injury, but environmental factors such as heat, freezing, sunlight, pH, and transition metals present in the water can also cause injury (LeChevallier and McFeters, 1985). Another source of repressed total coliform counts is biological interactions (LeChevallier and McFeters, 1985). The frequency of coliform detection decreases when Standard Plate Count levels exceed 500-1000 colony forming units / ml.

Several studies have shown that the enumeration of coliforms in drinking water by membrane filtration, with incubation on m-Endo medium, (the standard method most often used), often grossly underestimates the actual numbers of coliforms present. McFeters, et al., (1986), reported a 97.4% rate of injury among coliforms detected in drinking water after backwashing of a filter (Table 1). Injury rates of >90% were reported by McFeters, et al., in 1982, in coliforms recovered from the distribution system in Bozeman, MT. The average injury rate reported in this study, using m-Endo agar was 60% (Table 2).

The accurate detection of the coliform numbers present in a treated water is important in order to detect possible problems within a water treatment system. The incidence of waterborne morbidity has steadily increased over the past 20 years in the United States (McFeters, et al., 1986). The increased accuracy of enumeration of coliforms is an important tool in the prevention of waterborne disease, due to the fact that most outbreaks have been traced to deficiencies in water treatment systems and inadequate or interrupted chlorination (McFeters and Camper, 1983). Early detection of increased coliform numbers may help to "head off" waterborne disease outbreaks.

A medium developed expressly for the recovery and enumeration of coliform bacteria from drinking water is MT-7, designed to be used much the same as m-Endo, as a membrane filter medium. This medium has been proven to recover as many as three times (LeChevallier, et al., 1983) as many coliforms as m-Endo agar, the standard method (APHA, 1985), from drinking water in Bozeman, MT (Figures 3 & 4). In another study, MT-7

Table 1. Detection of Injured Coliforms in Three New England Water Treatment and Distribution Systems.*

Sample No.	Sample Source	No. of Samples	No. of Confirmed Colonies per 100 mL detected on: m-Endo LES	MT-7	% Injury	% False Negative
1	Throughout System	71	0.3	9.5	96.8	79
2	Water Leaving Treatment Plants	46	0.2	5.7	96.5	69
3	Filter Backwash	1	18	136	86.7	
4	After Backwash	1	5	42	97.4	82
5	Pipe Break	28	0.9	35.3	97.4	82
6	1 wk After Pipe Break	11	0	67.5	100	100
7	After Dis-infection of New Main	1	0	11	100	100

* Adapted from McFeters, et al. (1986).

Table 2.. Media and the Recovery of Injured and Healthy Coliforms from Water. [a*]

Medium	% Recovery (range)[b] Injured	Healthy	% Deoxycholate or Related Compounds
Group I			
Triple sugar iron	181	106	0
Nutrient alginate	125	88	0
Minerals modified glutimate	99	106	0
Tergitol 7	86 (71-101)	99	0
Boric acid	84	92	0
TLY + o.1% Tween 80	72	ND[c]	0
Group II			
Lactose broth	72 (47-98)	102	0
m-Endo	66 (30-102)	93	0.1:0.005[f]
Lauryl tryptose	56 (34-79)	98	0.01[f]
Levines EMB	42 (37-47)	119	0
3V	39	95	NA[g]
Purple serum	38	56	0
EE	38	106	2.0[d]
Brilliant green bile 2%	34 (18-51)	106	2.0[d]
Deoxycholate lactose	26	94	0.05
Group III			
Eosin methylene blue	24 (7-42)	102	NA
Violet red bile	12	99	1.5[e]
m-FC at 44.5 C	7 (4-10)	105	1.5[e]
MacConkey	5	97	0.1[e]
GN	4	71	0.05
TLY-D	2	82	0.10
XLD	0	40	0.25

[a] Coliforms tested include: Escherichia coli (two strains), K. pnemonia, C. freundii, and Enterobacter aerogenes.

[b] (Percent recovery) = ((CFU selective medium)/CFU TLY) * 100). Injury was between 90 and 99%. The range for injured coliforms is calculated from seven repetitions, using five coliforms over a 1 year period.
TLY = tryptic soy broth without dextrose, i% lactose, 0.3% yeast extract and 1.5% agar.

[c] ND, not done.

[d] Oxgall.

[e] Bile salts.

[f] Lauryl sulfate.

[g] NA, Not Available.

* Adapted from McFeters, et al. (1982).

recovered 8 to 38 times the number of coliforms from drinking water distribution systems in New England communities (McFeters, et al., 1986). These studies show that the possible passage of injured organisms during filter ripening has important effects not only in relation to overall finished water quality but also influences the possible regrowth of organisms in the distribution system.