AGENDA FOR THE
ENGLEWOOD CITY COUNCIL
STUDY SESSION
MONDAY, FEBRUARY 14, 2011
COMMUNITY ROOM
6:00 P.M.

I. **Sheridan Rebonding Proposal**
City Attorney Dan Brotzman and City Manager Gary Sears will discuss the Sheridan rebonding proposal.

II. **Ultraviolet Wastewater Disinfectant – 6:30 p.m.**
Utilities/WWTP Director Stu Fonda and WWTP Manager Dennis Stowe will discuss the ultraviolet disinfectant at the L/E Wastewater Treatment Plant.

III. **City Manager's Choice**

IV. **City Attorney's Choice**

Please Note: If you have a disability and need auxiliary aids or services, please notify the City of Englewood, 303-762-2407, at least 48 hours in advance of when services are needed. Thank you.

February 8, 2011

City of Englewood, Colorado
1000 Englewood Parkway
Englewood, CO 80110
Attn: Daniel L. Brotzman, City Attorney

Re: River Point at Sheridan

Ladies and Gentlemen,

The purpose of this letter is to request the consent of the City of Englewood, Colorado to the First Amendment to Declaration of Covenants Imposing and Implementing the River Point Public Improvement Fee (the "PIF Covenant Amendment").

As you know, the City of Englewood owns approximately 54.5 acres that are leased to the Sheridan Redevelopment Agency (the "Agency") pursuant to a Ground Lease dated November 27, 2006 (the "Ground Lease"), between the City of Englewood, as landlord, and the Agency, as tenant. The land that is the subject of the Ground Lease is part of the River Point at Sheridan commercial area that is being developed by Weingarten Miller Sheridan LLC, a Colorado limited liability company ("WMS"). The Ground Lease is for an initial 20-year term, with three 20-year renewal options. As consideration for the Ground Lease, the Agency paid rent of $4,190,000 for the initial 20-year term, with lesser amounts of rent to be paid for the ensuing three 20-year terms, and, since the land covered by the Ground Lease was part of the original Englewood Golf Course, the Agency agreed to redesign and rebuild, at its expense, a portion of the Englewood Golf Course Complex.

As contemplated by the Ground Lease, the Agency's leasehold interest in the land covered by the Ground Lease and the Agency's obligations thereunder were assigned to WMS pursuant to the Ground Lease Assignment and Assumption Agreement dated November 27, 2006, between the Agency, as assignor, WMS, as assignee, and the City of Englewood, as landlord.

In 2007, the Agency issued bonds to finance a portion of the River Point at Sheridan development as an urban renewal project under the Colorado Urban Renewal Law. In order to help pay the Agency's bonds and to pay the City of Sheridan for its added costs in providing municipal services to River Point at Sheridan, WMS, with the approval of the Agency, recorded the Declaration of Covenants Imposing and Implementing the River Point Public Improvement Fee on February 20, 2007 (the "Declaration"), which imposed a one-percent Public Improvement Fee (the "PIF") on sales of goods and services in River Point at Sheridan. The Declaration covers the property that is the subject of the Ground Lease and also the property that is owned by

WMS and by the larger retailers in River Point at Sheridan. By the terms of the Declaration, the PIF will end, as to the property that is the subject of the Ground Lease, when the Ground Lease ends, so as not to burden the property of the City of Englewood when control of that property is returned to the City at the end of the Ground Lease.

The Agency is now in the process of refinancing and restructuring its bonds issued in 2007. As part of this refinancing, a change is being proposed to remove from the Declaration the percentages of the PIF that are to be used by the Agency for debt service and for the costs of municipal services rendered by the City of Sheridan to River Point at Sheridan, which percentages currently are set forth in the Declaration. This change does not alter the amount of the PIF, the duration of the PIF or the area from which the PIF can be collected on sales of goods and services, all of which are set forth in the Declaration. Consequently, this change should have no effect on the City of Englewood or its property that is the subject of the Ground Lease.

Finally, in addition to changes to certain definitions in order to accommodate the present and future refinancings of the Agency's bonds and a change due to replatting of the River Point at Sheridan Subdivision, a change to the Declaration is being proposed that will allow WMS, as the tenant under the Ground Lease, to make future changes to the Declaration without the further consent of the City of Englewood so long as the Ground Lease is in effect and will make clear that the PIF shall never burden the City of Englewood's property that is the subject of the Ground Lease when control of that property is returned to the City at the end of the Ground Lease. Since the PIF will still end, as to the property that is the subject of the Ground Lease, when the Ground Lease ends, this change also should have no effect on the City of Englewood or its property that is the subject of the Ground Lease.

The PIF Covenant Amendment is enclosed herewith. As stated above, we believe that these changes to the Declaration will have no effect on the City of Englewood, its property, or the terms of the Ground Lease. Therefore, WMS hereby requests consent from the City of Englewood to execute and record the PIF Covenant Amendment. Please indicate such consent by executing the PIF Covenant Amendment in the place provided for your signature, having your signature notarized, and returning the executed PIF Covenant Amendment to Kutak Rock LLP, 1801 California Street, Suite 3100, Denver, Colorado 80202, Attn: Richard L. Buddin, Esq.

[Remainder of page intentionally left blank]

Very truly yours,

WEINGARTEN MILLER SHERIDAN LLC, a Colorado limited liability company

By: Weingarten Realty Investors, a Texas real estate investment trust
Its Manager and Member

By: _____
Name: M. Candace DuFour
Title: Sr. Vice President

February __, 2011

City of Englewood, Colorado
1000 Englewood Parkway
Englewood, CO 80110
Attn: Daniel L. Brotzman, City Attorney

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[Remainder of page intentionally left blank]

Very truly yours,

WEINGARTEN MILLER SHERIDAN LLC, a Colorado limited liability company

By: Weingarten Realty Investors, a Texas real estate investment trust
Its Manager and Member

By: _____
Name: _____
Title: _____

FIRST AMENDMENT TO DECLARATION OF COVENANTS IMPOSING AND IMPLEMENTING THE RIVER POINT PUBLIC IMPROVEMENT FEE

THIS FIRST AMENDMENT TO DECLARATION OF COVENANTS IMPOSING AND IMPLEMENTING THE RIVER POINT PUBLIC IMPROVEMENT FEE (this "PIF Covenant Amendment") is made as of March ____, 2011, by Weingarten Miller Sheridan, LLC, a Colorado limited liability company ("Declarant").

Recitals

This PIF Covenant Amendment is made with respect to the following facts:

A. Declarant executed that certain Declaration of Covenants Imposing and Implementing the River Point Public Improvement Fee which was recorded on February 20, 2007, at Reception No. B7021613 of the records of the Clerk and Recorder of Arapahoe County, Colorado (the "Original PIF Covenant").

B. As more fully set forth in the Original PIF Covenant, the PIF Covenant imposed a Public Improvement Fee on certain PIF Sales made within the PIF Property to be used as set forth in the PIF Covenant including, without limitation, for the payment of Public Financing to pay for certain public improvements of the commercial project in the City of Sheridan, Colorado, known as River Point at Sheridan.

C. Sheridan Redevelopment Agency ("Agency") in cooperation with Declarant and others has entered into a refunding of the initial Public Financing and, in connection with the refunding of the initial Public Financing, Agency and Declarant have agreed to amend and restate the PIF Agreement.

D. In connection with the refunding of the initial Public Financing, Declarant desires to amend the PIF Covenant as more particularly set forth herein below.

E. The Agency and the City of Englewood, Colorado desire to evidence that they have taken all appropriate action and do hereby consent to this PIF Covenant Amendment.

NOW, THEREFORE, Declarant amends the PIF Covenant as more particularly set forth herein below:

Section 1. Capitalized terms that are not defined in this PIF Covenant Amendment have the meaning defined in the Original PIF Covenant.

Section 2. The following definitions from Section 1 of the PIF Covenant are amended to read as follows:

> "Indenture" means an Indenture of Trust by and between the Agency and the Trustee, as the same may from time to time be in effect, including any supplement or amendment thereto, executed and delivered in connection with any Public Financing.

"PIF Agreement" means a Public Finance and Public Improvement Fee Agreement between the Declarant and the Agency, as the same may from time to time be in effect, including any supplement or amendment thereto, executed and delivered in connection with any Public Financing.

"PIF Covenant" means the Original PIF Covenant, as amended by this PIF Covenant Amendment.

"PIF Property" means the real property described on Exhibit A attached hereto. For the purpose of clarification, the PIF Property has not changed since the date of the Original PIF Covenant. Rather, the names and boundaries of certain lots and blocks and other property located within River Point at Sheridan Subdivision Filing No. 1 have changed as a result of replatting portions of the PIF Property as River Point at Sheridan Filing Nos. 2, 3 and 4.

"Trustee" means the bank or trust company duly incorporated and existing under and by virtue of the laws of any State or of the United States of America that is duly appointed and serving as Trustee under the Indenture.

Section 3. The first sentence of Section 8 of the Original PIF Covenant is deleted in its entirety and replaced with the following:

> "The Public Improvement Fee revenues generated pursuant to this PIF Covenant, after deduction of any collection fee under the Collecting Agent Agreement, shall be used to pay Public Financing Requirements in accordance with the terms of the Indenture and the PIF Agreement, Agency administrative costs, and to reimburse the City for the cost of providing municipal services to River Point."

Section 4. Section 16 Amendment by Declarant is deleted in its entirety and replaced with the following:

> Section 16. Amendment by Declarant. Subject to the provisions hereof regarding obtaining the prior written approval of the Agency and, if required by the Indenture, the Trustee, Declarant may amend the provisions of this PIF Covenant with the consent of the Owners who hold fee title to not less than seventy-five percent (75%) of the total acreage of the PIF Property; provided, however, that so long as the Englewood Lease remains in effect, the Tenant under the Englewood Lease shall have the sole right of consent as to the land subject to the Englewood Lease; and provided further, that no amendment to this PIF Covenant shall impose the Public Improvement Fee on the fee interest in the land subject to the Englewood Lease.

Section 5. Except as amended hereby, the terms and provisions of the Original PIF Covenant remain in full force and effect and are hereby ratified and confirmed.

IN WITNESS WHEREOF, Declarant has executed this PIF Covenant Amendment as of the date first set forth above.

WEINGARTEN MILLER SHERIDAN LLC,
a Colorado limited liability company

By: WEINGARTEN REALTY INVESTORS,
a Texas Real Estate Investment Trust,
Manager

By:_____
Name:_____
Title:_____
Date:_____

STATE OF TEXAS)
)ss.
COUNTY OF HARRIS)

The foregoing instrument was acknowledged before me this _____ day of March, 2011, by _____, as _____ of Weingarten Realty Investors, a Texas Real Estate Investment Trust, Manager of Weingarten Miller Sheridan LLC, a Colorado limited liability company.

Witness my hand and official seal.

My commission expires: _____

_____
Notary Public

CONSENT OF SHERIDAN REDEVELOPMENT AGENCY

SHERIDAN REDEVELOPMENT AGENCY,
a Colorado urban renewal authority

By:_____
Name:_____
Title:_____
Date:_____

STATE OF COLORADO)
)ss.
COUNTY OF ARAPAHOE)

The foregoing instrument was acknowledged before me this _____ day of March, 2011, by _____, as _____ of Sheridan Redevelopment Agency, a Colorado urban renewal authority.

Witness my hand and official seal.

My commission expires: _____ _____
Notary Public

CONSENT OF CITY OF ENGLEWOOD, COLORADO

CITY OF ENGLEWOOD, COLORADO, a
Colorado home rule municipal corporation

By: _____
Name: _____
Title: _____

STATE OF COLORADO)
)ss.
COUNTY OF ARAPAHOE)

The foregoing instrument was acknowledged before me this _____ day of March, 2011, by _____, as _____ of City of Englewood, Colorado, a Colorado home rule municipal corporation.

Witness my hand and official seal.

My commission expires: _____

_____
Notary Public

EXHIBIT A

Legal Description

RIVER POINT AT SHERIDAN SUBDIVISION FILING NO. 2, COUNTY OF ARAPAHOE, STATE OF COLORADO, ACCORDING TO THE REPLAT RECORDED DECEMBER 19, 2007, UNDER RECEPTION NO. B7158299, EXCEPTING THEREFROM LOT 2, BLOCK 6

RIVER POINT AT SHERIDAN SUBDIVISION FILING NO. 3, COUNTY OF ARAPAHOE, STATE OF COLORADO, ACCORDING TO THE REPLAT RECORDED MARCH 13, 2009 UNDER RECEPTION NO. B9025368

RIVER POINT AT SHERIDAN SUBDIVISION FILING NO. 4, COUNTY OF ARAPAHOE, STATE OF COLORADO, ACCORDING TO THE REPLAT RECORDED NOVEMBER 20, 2008, UNDER RECEPTION NO. B8128635

WEINGARTEN REALTY

2600 Citadel Plaza Dr., Suite 300
Houston, Texas 77008
800.688.8865
713.866.6950 Fax
www.weingarten.com

February 10, 2011

Mayor Jim Woodward
City Council Member At Large
1000 Englewood Parkway
Englewood CO 80110

Mr. Gary Sears
City Manager
1000 Englewood Parkway
Englewood CO 80110

Dear Jim and Gary:

Steve Richter, Chief Financial Officer, and I enjoyed meeting you last week and gaining a better understanding of your views and perspective for the City of Englewood and our shopping center there.

As we shared with you, on a combined basis, City Center Englewood (300,000 sf) and River Pointe at Sheridan (500,000 sf existing and 800,000 sf when completed) are the largest concentration of retail at one intersection in our portfolio of 312 shopping centers. We have a strong economic interest in making this a viable, synergic retail focus in the area. As we have seen in other situations, centers situated across the street from each other often do compliment each other. It is our intention to make that happen here. From a financial standpoint, we own each center with different partners. We are the managing partner in both partnerships, and we have a fiduciary responsibility to each partner as well as our public shareholders to maximize the operations of both centers.

Jim, thank you for the retailer void analysis you sent. I passed that along to our leasing team. Please do call us with any other suggestions or thoughts you may have and we will pass those along to our operations and marketing teams.

We welcome the opportunity to work with you to find ways to better enhance both centers.

Very truly yours,

WEINGARTEN REALTY INVESTORS

M. Candace DuFour
Sr. Vice President, Director of Acquisitions

MCD:jjs

People-to-People. Coast-to-Coast.

Weingarten Realty is the trade name of Weingarten Realty Investors (the "Trust") which is an unincorporated trust organized under the Texas Real Estate Investment Trust Act. Neither the shareholders of the trust, nor its trust managers, officers, employees or other agents are personally, corporately or individually liable for any debt, act, omission or obligation of the trust, and all persons having claims of any kind against the trust must look solely to the property of the trust for the enforcement of their rights.

BROWN AND CALDWELL

Technical Memorandum

1697 Cole Boulevard, Suite 200
Golden, Colorado 80401
Tel: 303-239-5400
Fax: 303-239-5454

Prepared for: Littleton/Englewood Wastewater Treatment Plant

Project Title: Ammonia Compliance Study

Project No: 136547

Technical Memorandum

Subject: Evaluation of Alternative Disinfection Methods to Comply with the Recent Proposed Ammonia Limits

Date: January 26, 2011

To: Chong Woo, LE WWTP Project Manager

Prepared by: Derya Dursun, Ph.D., Process Engineer

John Bratby, P.E., Ph.D., Regional Process Engineer

Reviewed by: Kirk Petrik, P.E., Supervising Engineer

APPENDICES

APPENDIX A – UV Dose Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa and Viruses

APPENDIX B - Definition of Each Criteria Used in the Comparison of Disinfection Alternatives

APPENDIX C – Quotes Received from UV Disinfection System Suppliers

APPENDIX D – O&M Cost Estimates of UV Disinfection System Suppliers

APPENDIX E - Cost Estimates for Construction Costs of UV and Ozone Disinfection Systems

APPENDIX F – Quotes Received from Ozone Disinfection System Suppliers

APPENDIX G – O&M Cost Estimates of Ozone Disinfection System Suppliers

This document was prepared solely for the Littleton/Englewood WWTP Staff in accordance with professional standards at the time the services were performed and in accordance with the contract between The City of Englewood and Brown and Caldwell dated January 7,2009. This document is governed by the specific scope of work authorized by The City of Englewood; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by the Littleton/Englewood WWTP Staff and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

EXECUTIVE SUMMARY

The Littleton and Englewood Wastewater Treatment Plant (L/E WWTP) received a renewed wastewater discharge permit effective September 30, 2009. The new permit requires L/E to meet discharge limits for multiple constituents, including new limits for E. coli and lower limits for ammonia. The changes in E. coli and ammonia limits are the result of new regulations adopted by the Water Quality Control Commission (Commission).

- March 2007 – Commission adopted more restrictive ammonia standards based on EPA's 1999 Ammonia Criteria.
- June 2005 – Commission switched from fecal coliform to E. coli as the regulated measure of bacteria in surface waters. The Division then developed an E. coli Total Maximum Daily Load (TMDL) for L/E's stream segment that set L/E's permit limit at the E. coli standard.

Both ammonia and E. coli have delayed effective dates. The permit allows L/E until January 1, 2014 to come into compliance with the E. coli limits, as it is a new constituent that was not in the previous permit. Because the changes in ammonia standards required significant improvements to wastewater treatment systems, the Commission granted a temporary modification of the standard that delayed the effective date of the new ammonia standards until January 1, 2011. The permit allows L/E three additional years to come into compliance with the new, lower ammonia limits.

An evaluation of the new ammonia limits and their impact to the facility indicates that the current ammonia removal treatment facilities are substantial enough, so no additional ammonia treatment is needed. This is good news as others, such as the Metro Wastewater Reclamation District, estimate they will spend $200 million to come into compliance. However, the new ammonia limits will impact the effectiveness and reliability of the existing liquid chlorine disinfection process, which removes fecal coliform and E. coli. The liquid chlorine disinfection process depends on the presence of certain levels of ammonia to provide effective disinfection and stable process control. Compliance with the new lower ammonia limits will reduce the ammonia to a level below the point where process stability is assured, consequently putting L/E at risk for permit violations.

Since the existing disinfection system cannot be expected to consistently meet permit limitations based on the newly adopted ammonia and E. coli regulations, an alternative form of disinfection that does not rely on chlorine and maintains adequate and controllable disinfection is needed. An evaluation was completed of all viable, non-chlorine, disinfection alternatives for the L/E facility. The report, entitled "Ammonia Compliance Alternative Study", identified UV as the selected alternative for its effectiveness, reliability, low cost (nearly one fourth of the second chosen option, ozone) and other reasons. UV technology has advanced and is now common in WWTP's, and it is the selected alternative in nearly all new installations.

L/E's current permit lays out a compliance schedule for design, construction, and startup of the UV system. This schedule identifies annual milestones that must be met in order to maintain compliance with the discharge permit. The first milestone, was due May 31, 2010 for a study to pilot different UV manufacturers, and a report on progress in securing funds to design and build the UV system. Subsequent reports are due in May of each year to describe progress and approval process for the UV design and construction, which is to be completed in 2013. The final report is set for December 31, 2013, which must summarize construction and startup activities for full compliance with the January 1, 2014 E. coli and ammonia limits.

Besides allowing L/E to maintain permit compliance, UV has other benefits, which include:

- Protection of safety and health - No transport, storage, or handling of toxic chemicals.

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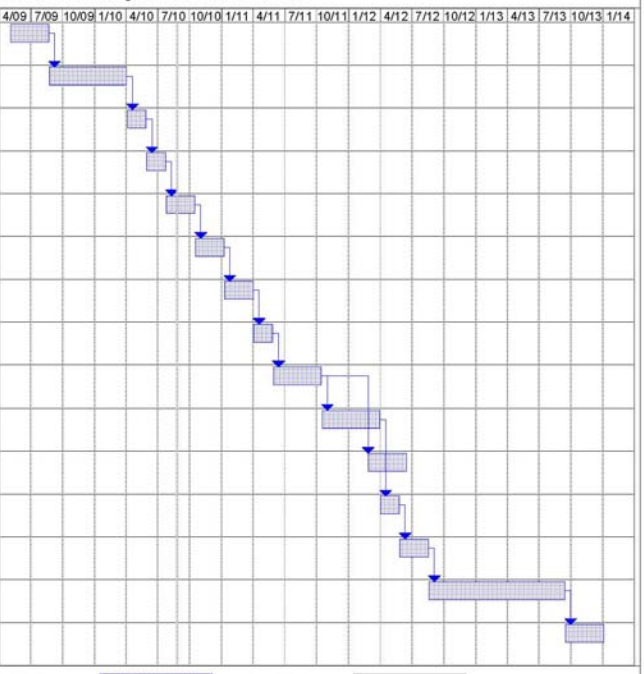
- No toxic disinfection by-products, which are becoming more of a water quality issue because of their impact on drinking water.
- No subsequent chemical removal (like dechlorination) needed, as UV disinfected water does not harm the aquatic life in the receiving stream.
- Lower cost – UV has a potentially lower annual operating cost than chlorine.
- Very effective at removing Cryptosporidium and Giardia, which are highly resistant to chlorination.
- No change in odor, pH, or color of the water.
- Easy to operate compared to chemical systems.

SCHEDULE - SUMMARY

The disinfection project schedule began with an evaluation of the impact of the new ammonia limits on the existing disinfection system. The Ammonia Compliance schedule which was approved by the Division and included in the discharge permit is shown below. The following evaluation of alternatives for the disinfection process was completed in October 2009. The Ammonia Compliance Alternative Study evaluated five different alternatives for the existing system: Chlorine Dioxide, Ozone, Peracetic Acid, Ultraviolet (UV), and Chlorination. UV was selected over the other alternatives because it offered significantly more benefits. Cost was one of the benefits and the planning level total project cost for installing UV disinfection was estimated at $10 million, well over half the cost of the second alternative, Ozone.

Ammonia / Disinfection Compliance Schedule

ID	Task Name	Duration	Start	Finish
1	Ammonia Compliance Alternative Study	4 mons	Mon 5/4/09	Fri 8/21/09
2	Pilot Test	8 mons	Mon 8/24/09	Fri 4/2/10
3	Pre Equipment Selection	2 mons	Mon 4/5/10	Fri 5/28/10
4	Prepare Site Application	2 mons	Mon 5/31/10	Fri 7/23/10
5	Process Site Application	3 mons	Mon 7/26/10	Fri 10/15/10
6	State Review Site Application	3 mons	Mon 10/18/10	Fri 1/7/11
7	Pre-Design and Approval	3 mons	Mon 1/10/11	Fri 4/1/11
8	State Approval	2 mons	Mon 4/4/11	Fri 5/27/11
9	Final Design	5 mons	Mon 5/30/11	Fri 10/14/11
10	State & Building Department Approval	6 mons	Mon 10/17/11	Fri 3/30/12
11	Owner Purchase Equpiment	4 mons	Mon 2/27/12	Fri 6/15/12
12	Bid Period	2 mons	Mon 4/2/12	Fri 5/25/12
13	Award	3 mons	Mon 5/28/12	Fri 8/17/12
14	Construction	14 mons	Mon 8/20/12	Fri 9/13/13
15	Startup	4 mons	Mon 9/16/13	Fri 1/3/14



Project: UltraViolet (UV) Disinfection
Date: Wed 8/25/10

Task | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress | Split | External Tasks | Project Summary | Group By Summary | Deadline

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AMMONIA COMPLIANCE ALTERNATIVES STUDY

1. INTRODUCTION

The prime objective of the Federal Clean Water Act (CWA) passed in 1972 is to make all waters of the United States fishable and swimmable. The CWA states that water quality standards should be evaluated and revised regularly based on progressive improvements in science and technology. In Colorado, action by the Water Quality Control Commission (WQCC) to establish water quality standards provides the basis for wastewater effluent limits.

The U.S. Environmental Protection Agency (EPA) updated water quality criteria for ammonia in 1999, and the WQCC adopted the revised ammonia standards for the South Platte River in March 2007. The EPA's 1999 ammonia standards are protective of waters with aquatic life use classification. To provide dischargers time to implement treatment system improvements in response to the new standards, the WQCC approved a temporary modification (Regulation 31, The Basic Standards and Methodologies for Surface Water) to the new state wide limits that is effective through December 2011. This temporary modification grants time for dischargers to plan and construct facilities or modify processes to meet the revised standards.

Wastewater treatment agencies generally must respond to the new effluent ammonia limits by evaluating their existing facilities to determine if additional treatment is necessary to achieve compliance. All improvements are subject to Regulation 22, Site Location and Design Approval Regulations for Domestic Wastewater Treatment Works and must be approved by the Colorado Department of Public Health and Environment (CDPHE), Water Quality Control Division (Division).

In evaluating the anticipated new effluent ammonia limits and their impact on the L/E WWTP, it was determined that the current treatment facilities have the capability to meet the anticipated effluent ammonia limits. However, a high degree of operational vigilance will be required to avoid treatment upsets that could affect ammonia removal through the treatment process. Another important consequence of lower ammonia limits is their affect on the disinfection process. The existing disinfection system at the Littleton/Englewood Wastewater Treatment Plant (L/E WWTP) will be impacted by the anticipated limits. The current disinfection process utilizes ammonia in combination with chlorine to achieve wastewater disinfection. When the lower ammonia standards are integrated into the L/E WWTP discharge permit, there will be less ammonia available for the disinfection process.

This report describes the impacts of lower effluent ammonia limitations on the existing L/E WWTP disinfection system and describes possible mitigation approaches and alternatives to the existing disinfection system.

2. EVALUATION OF THE EXISTING SYSTEM AT THE LITTLETON/ENGLEWOOD WASTEWATER TREATMENT PLANT

The L/E WWTP includes nitrifying trickling filters (NTF) for nitrification, and deep-bed denitrification filters for biological nitrogen removal. Based on previous studies and loading predictions of the NTF's, effluent ammonia concentrations after the NTF's should be less than 3 mg/l at about 20°C. Therefore the NTF's are capable of meeting the anticipated effluent ammonia limits. However, the lower effluent ammonia limits do require a high degree of care with centrate return and equalization to avoid spikes in the ammonia loading on the treatment process. Additionally, care will be required to limit the denitrification recycle so that the capacity of the NTF feed pumps is not exceeded.

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The L/E WWTP currently utilizes sodium hypochlorite (liquid bleach) as a disinfecting agent. Chlorinated effluent is held in chlorine contact tanks prior to dechlorination with sodium bisulfite and before discharge to Segment 14 of the South Platte River. The typical chlorine dosage is approximately 1.6 mg/l (2008 data) to meet the current permit limit for Fecal coliform bacteria of 245/100 ml (30-day geometric mean) and 490/100 ml (7-day geometric mean). Data presented in Figure 1 shows that effluent Fecal coliform bacteria levels for the period from 2004 through 2008 were consistently below permit limits. The new permit requires that *Escherichia Coli* (*E. coli*) limits be met, rather than Fecal coliform limits. This requirement will take effect on January 1, 2014. In anticipation of this, the L/E WWTP has also been monitoring *E. coli* levels. The new limit for *E. coli* is 126/#100 ml (30-day geometric mean) and 252/100 ml (7-day geometric mean).. In the last four years, the L/E WWTP has exceeded the new *E. coli* limits several times, as shown in Figure 2.

The Fecal coliform group of microorganisms includes all of the rod shaped bacteria that are non-spore forming, gram negative, lactose fermenting in 24 hours at 44.5°C, and which can grow with or without oxygen. Fecal coliform bacteria, members of the family *Enteriobacteriacae coli*, include *E. coli, Citrobacter* and *Klebsiella* species. *E. coli* is reported to be the most common Fecal coliform bacteria. Since *E. coli* is one of several organisms comprising the Fecal coliform group, one would expect that *E. coli* analytical values would be equal to or lower than Fecal coliform analytical values in a given sample. However, this presumption ignores variations in the sensitivity of the test methods employed and their ability to recover (as positives) organisms that may be stressed from exposure to a wastewater disinfection process. Previous lab results have indicated for WWTP's employing chlorination, compliance with an *E. coli* limitation may be more problematic than compliance with the current Fecal coliform limits.

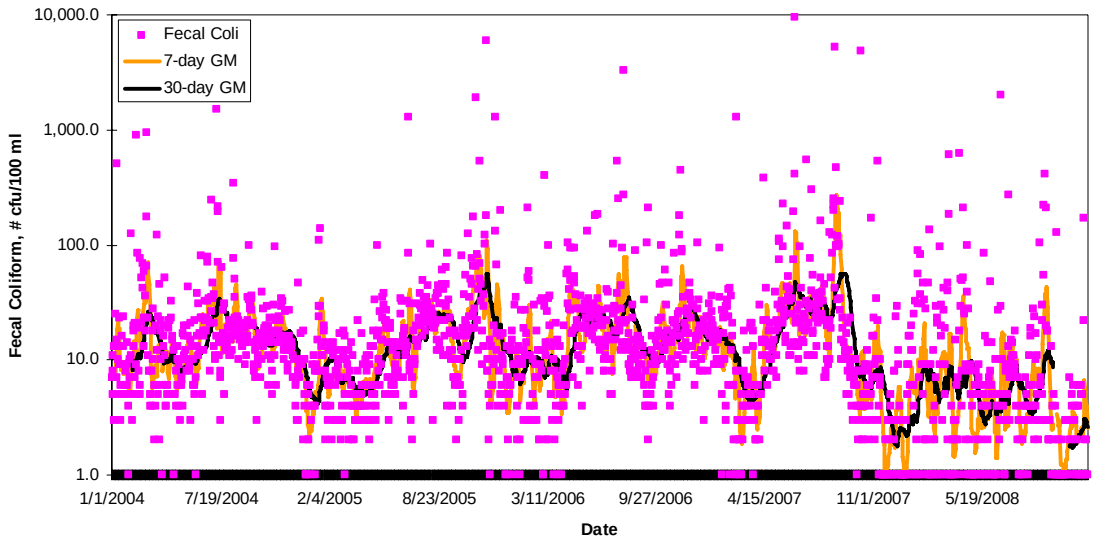

Figure 1. Historical Fecal Coliform Values at the Final Effluent in the L/E WWTP

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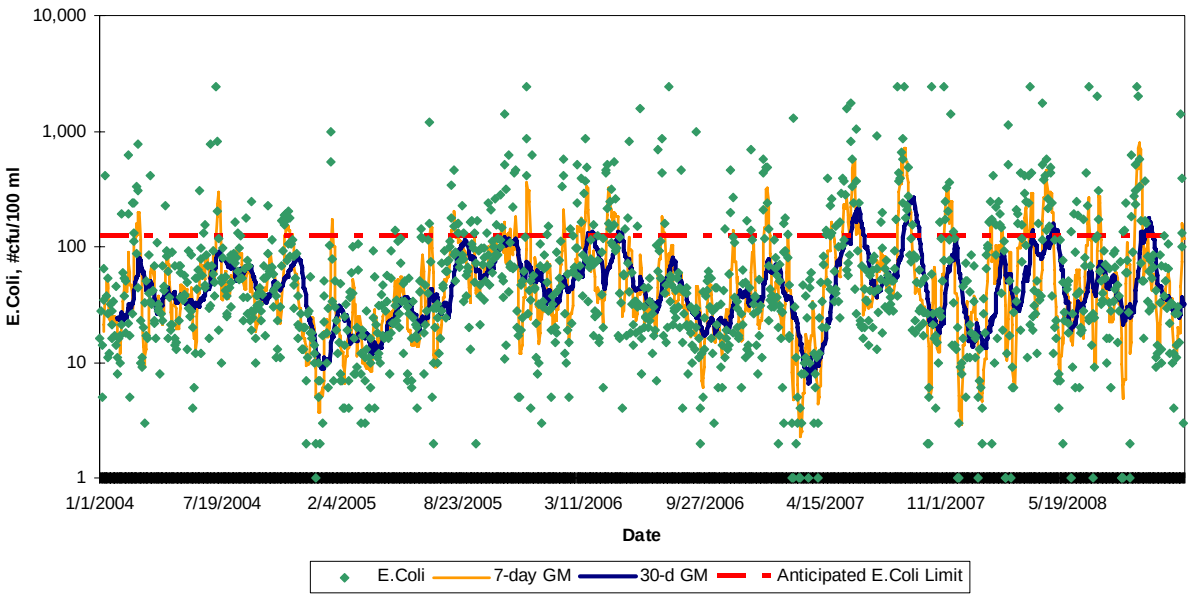

Figure 2. Historical E. coli Values at the Final Effluent in the L/E WWTP

3. RELATIONSHIP BETWEEN CHLORINE AND AMMONIA

Chlorine reacts with ammonia nitrogen to form chloramines, which are effective for the disinfection of treated wastewater effluents. When chlorine reacts with ammonia, monochloramine (NH_2Cl), dichloramine ($NHCl_2$) or trichloramine (NCl_3) are formed. The chloramine species formed depends upon the relative concentrations of chlorine and ammonia, and the pH and temperature of the water. The chemical reactions governing the formation of NH_2Cl, $NHCl_2$, NCl_3 are shown below:

$$NH_4^+ + HOCl \Leftrightarrow NH_2Cl + H_2O + H^+$$

$$NH_2Cl + HOCl \Leftrightarrow NHCl_2 + H_2O$$

$$NHCl_2 + HOCl \Leftrightarrow NCl_3 + H_2O$$

Monochloramine is the preferred chemical for disinfection due to the unpleasant taste and odors of dichloramines or trichloramines. In order to limit the amount of dichloramines and trichloramine formation and to promote the formation of monochloramines, chlorine to ammonia ratios of 3:1 to 5:1 are preferred.

The conceptual relationship between applied chlorine and nitrogen species is shown in Figure 3. Free chlorine residual will typically be present if the chlorine dose exceeds ten times the ammonia nitrogen concentration (on weight basis) in the water. This process is referred to as the *"breakpoint chlorination"* process, as shown in Figure 3.

When very low effluent ammonia concentrations are present, inordinately high chlorine dosages can be required due to the high chlorine to ammonia ratio and the formation of organic nitrogen –chlorine species which are ineffective as disinfectants. In this case, the solution is to add enough chlorine to exceed the breakpoint shown in Figure 3 and form free chlorine.

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Free chlorine species are strong oxidants and react at a much faster rate than combined chlorine. However, free chlorine also reacts with natural organic matter (NOM) such as humic acid and fulvic substances in the effluent to form such disinfection byproducts (DBP's) as total trihalomethanes (TTHM) and haloacetic acids (HAAs). Because of their potential adverse effect on human health, the USEPA has set drinking water standards for TTHM's and HAAs. Other DBP's that may be generated from the breakpoint chlorination process include cyanide and cyanogen chloride. Wastewater treatment plants in some states are already subject to regulatory limits on effluent DBPs.

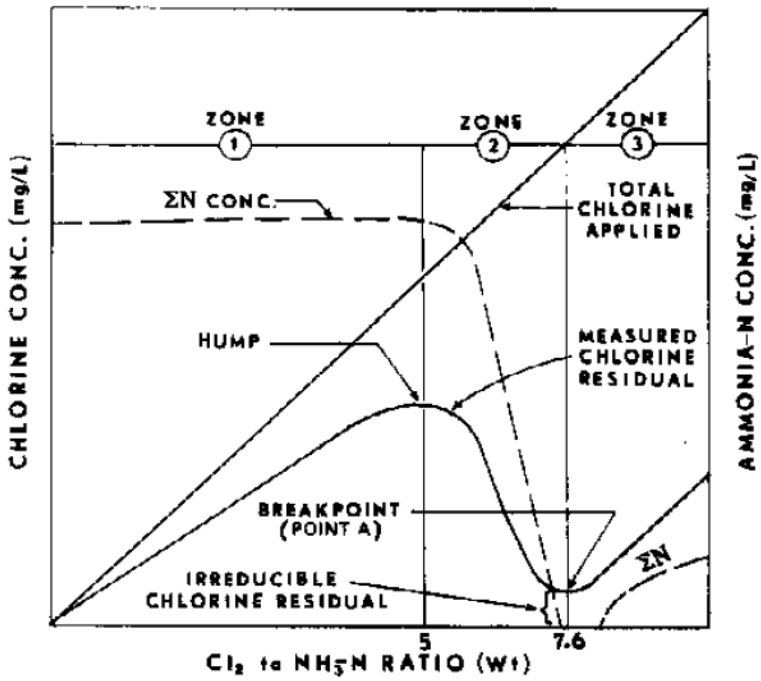

Figure 3. Theoretical breakpoint curve.
(Zone 1 is associated with the reactions of chlorine and ammonia to form Monochloramine;
Zone 2 is associated with an increase in dichloramine and the disappearance of NH_3;
Zone 3 is associated with the appearance of free chlorine after the breakpoint) (White, 1999).

4. CONTROL OF THE CHLORINATION AND DECHLORINATION PROCESSES

A significant issue with disinfection at the L/E WWTP is interference of chlorine disinfection by low ammonia concentrations. This will become more of an issue as the required level of disinfection increases, and effluent ammonia concentrations become lower. The current permit effluent ammonia limits are as low as 4.5 mg/l as nitrogen, on a 30-day average basis. The new permit has tiered ammonia limits, starting with a 30-day average flow up to 34 mgd, with the lowest 30-day average ammonia limit of 4.1 mg/l as nitrogen. The next tier is for 30-day average flows up to 42 mgd with the lowest 30-day average ammonia limit of 3.8 mg/l as nitrogen. The final tier is for 30-day average flows up to 50 mgd with the lowest 30-day average ammonia limit of 3.2 mg/l as nitrogen.

The lowest ammonia limits, for all tiered flows occur in the warmest months, from August through September. The warmest months are those when the plant produces the lowest ammonia concentrations.

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If effluent ammonia concentrations are at least 1 to 2 mg/l or greater, then control of the chlorine disinfection process is relatively straightforward. However, without corrective measures, the plant would produce effluent ammonia concentrations significantly less than 1 mg/l. The issue with very low ammonia concentrations is that the chlorination chemistry becomes unstable and control of the process is very difficult.

The L/E WWTP uses a state-of-the-art oxidation-reduction potential (ORP) system to control both chlorination and dechlorination. Figure 4 shows that the ORP of a chlorinated water changes significantly depending on the chlorine species that predominate. For example, the L/E WWTP maintains a chlorination ORP setpoint at 400 to 450 mV. This means that chlorination is stable, with maximum disinfecting potential when monochloramines are formed.

If ammonia concentrations are too low, then not enough ammonia is available to form chloramines and the chlorine added combines with organic material present in the effluent to form so-called organochloramines. These species have negligible disinfecting power. These chlorine species are also referred to as nuisance residuals, since they are ineffective for disinfection and seriously interfere with control of the disinfection process.

The interference with chlorination control is explained by Figure 4. With insufficient ammonia to form beneficial monochloramines at the setpoint of 400-450 mV, the chlorine chemical reactions proceed past the chlorination breakpoint until free chlorine is formed. This means that the ORP controller detects a high ORP (at around 700 mV) which corresponds with the presence of free chlorine. However, since the setpoint is 400-450 mV, the controller interprets the phenomenon as an excess of chlorine. Therefore the response is to reduce the chlorine dosage until the setpoint is reached – at which time it is likely that insufficient chlorine is being dosed, and fecal and E-Coli kills are inadequate and the permit is violated.

The solution to the above loss of control at the L/E WWTP is to bypass secondary effluent around the NTFs to increase the ammonia concentration to approximately 2 mg/l before disinfection. In principle this would work satisfactorily, except for two factors. The first is that in the summer months it is not possible to avoid nitrification in the secondary treatment process, despite appropriate control of the solids contact SRT down to low levels. Therefore, secondary effluent ammonia levels both entering, and bypassed around the NTFs are relatively low. This means that the blend of NTF effluent and bypass still remains too low for satisfactory control of the chlorination process.

The second issue is that the L/E WWTP utilizes in-line ammonia analyzers to control the bypass around the NTFs. These analyzers are difficult to calibrate and do not always produce accurate results. A film also tends to form on the surface of the probe, which necessitates regular cleaning if accurate results are to be obtained. Therefore, the ammonia analyzers must be checked and calibrated at least weekly to ensure accurate data is obtained. Despite diligent maintenance and calibration of the ammonia analyzers, control of the blended (NTF and bypass) ammonia to the setpoint of 2 mg/l is complicated even further.

An alternative to the above control process is to eliminate the issues with the ammonia bypass and allow the plant to reduce ammonia to low levels. This means that the ORP setpoint would now be approximately 700 mV. However, if nitrification is lost partially or totally then monochloramines would form because of the higher ammonia, the ORP would detect a lower value of around 450 mV and the chlorination system would immediately increase chlorine to achieve the original free chlorine setpoint. In addition this scenario will require a greater amount of chlorine for disinfection, thus annual chemical costs will be much higher.

Loss of nitrification is a real possibility, and has occurred by unknown and illicit discharges to the sewer system. Despite the best efforts of plant personnel, the causative agents have not been identified, nor the dischargers, but the effect is to paralyze the nitrifying organisms for a short time, but sufficient to cause sharp increases in effluent ammonia concentrations.

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The consequence of the loss of nitrification on the alternative chlorination control scenario would be a dramatic increase in dechlorination response. The current permit limits for total residual chlorine are an instantaneous daily maximum of 0.026 mg/l and a 30-day average of 0.0042 mg/l. It would be very difficult to maintain these limits under the scenario described and violations of the permit would be likely.

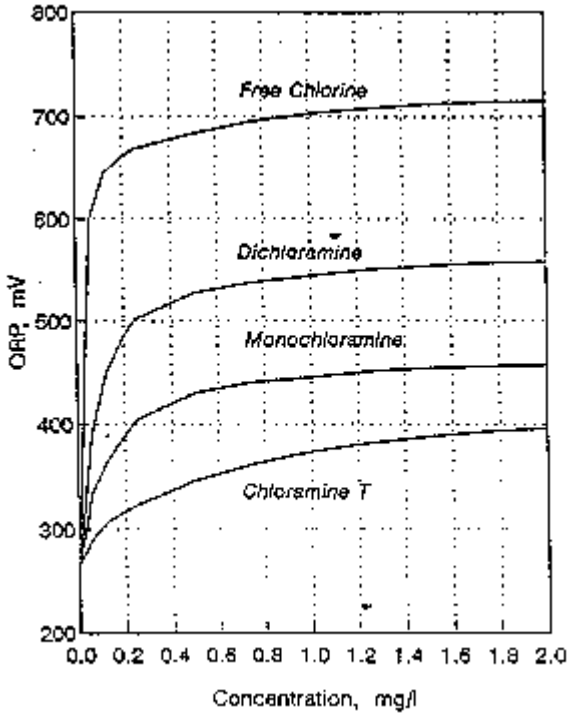

Figure 4. Redox Potential of Various Chlorine Compounds

4.1 Alternative to NTF Bypass for Ammonia Control

A further approach to remedy the low ammonia conditions and interference with the current chlorination control strategy is to eliminate the secondary effluent bypass around the NTFs, but still add ammonia for disinfection. The alternatives to accomplish this are described below:

One approach was adopted by the Phoenix 91st Avenue Wastewater Treatment Plant. This plant was converted to a nitrification-denitrification process, whereby the effluent ammonia concentration was reduced to 0.5 mg/l or less. Consequently, the chlorine dosages required to achieve adequate disinfection increased from 6 to 8 mg/l to 14 to 16 mg/l and sometimes above 30 mg/l. The issue was resolved by increasing effluent ammonia concentration by bypassing a small portion of primary effluent to the secondary clarifiers. This process resulted in effluent ammonia levels of 1 to 2 mg/l and reduced the required chlorine dosage to previous values. It was observed that the plug flow nature of the chlorine contact tanks and the initial mixing of the chlorine in the effluent flow enhanced the efficiency of the process significantly.

Although this alternative is theoretically feasible, it has several disadvantages. The practice of bypassing primary effluent or other in-plant streams such as centrate, provides a complicated control scenario because of the variable nature of these streams.

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A more straightforward approach would appear to be to add ammonia as a consistent concentrated chemical such as anhydrous ammonia. Anhydrous ammonia, NH_3, is commonly stored and transported as a liquid in pressure vessels. The vessels, or tanks, are generally equipped with evaporators, leak detectors, etc.

However, even with consistent anhydrous ammonia addition, this approach is complex. Table 2 shows an example of effluent ammonia data from the L/E WWTP. The L/E WWTP effluent ammonia levels are too low for effective disinfection, without extending beyond the breakpoint, anhydrous ammonia addition may be required to achieve a stable disinfection process using chlorine. Table 2 shows that a theoretical set point of 2.5 mg/l effluent ammonia would increase the ammonia for disinfection, while still maintaining the effluent ammonia below the assumed treated effluent limit of 3.3 mg/l.

Table 2. An Example of Ammonia Control in the L/E WWTP in case of Anhydrous Ammonia Addition

Date	Final Effluent Ammonia-N	Controlled Ammonia-N Based on Final Effluent
8/1/2007	1.54	1.85
8/2/2007	1.54	1.85
8/3/2007	1.49	1.85
8/4/2007	7.46	7.46
8/5/2007	0.66	1.85
8/6/2007	1.35	1.85
8/7/2007	1.16	1.85
8/8/2007	1.37	1.85
8/9/2007	1.29	1.85
8/10/2007	1.34	1.85
8/11/2007	1.28	1.85
8/12/2007	1.13	1.85
8/13/2007	1.1	1.85
8/14/2007	2.07	1.85
8/15/2007	1.06	1.85
8/16/2007	1.04	1.85
8/17/2007	1.4	1.85
8/18/2007	1.33	1.85
8/19/2007	0.76	1.85
8/20/2007	12	12.00
8/21/2007	0.35	1.85
8/22/2007	0.2	1.85
8/23/2007	2.4	1.85
8/24/2007	6.25	6.25
8/25/2007	2.14	1.85
8/26/2007	1.7	1.85
8/27/2007	1.21	1.85
8/28/2007	1.18	1.85
8/29/2007	1.24	1.85
8/30/2007	1.16	1.85
8/31/2007	1.15	1.85
Month Average	1.98	2.50
Anticipated Limit for August, mg/l: 3.3		
Target Limit, mg/l: 2.5		
Set Point Ammonia for Chlorination, mg/l: 1.85		

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A serious difficulty with this approach is due to the incidences of loss of nitrification described above. If ammonia is added to increase effluent ammonia to adequate levels for chlorination, and nitrification is lost during the month, then violation of the permit limit for ammonia becomes a real risk.

Besides natural diurnal variations in effluent ammonia levels, the denite filter backwash has instantaneous effects on the flow and loads which may easily cause further ammonia excursions. Taking into account the ORP related operational issues and the reliability issues of ammonia analyzers previously described, the control of the ammonia/chlorination/dechlorination system would be very difficult. A control system involving sophisticated feed-back loops would be required and, even then, the chance for chlorine, *E. coli*, or ammonia permit violations would be unacceptably high.

Therefore, it is likely that the drive to meet low effluent ammonia limits in the future would make it impractical to add ammonia to the effluent for the purpose of maximizing disinfection efficiency.

A further disadvantage of ammonia addition to maintain disinfection with chloramine species, is the formation of nitrosamines in the effluent. It has recently been found that chloramines are precursors to nitrosamines, a group of compounds considered to be extremely potent carcinogens (Mitch and Sedlak, 2002, 2004). The most studied nitrosamine in wastewater treatment is N-nitrodimethylamine (NDMA). The USEPA has established a 1 in 1,000,000 cancer risk at 0.7×10^{-6} mg/l for NDMA and the California Department of Health Services has set a drinking water notification level for NDMA at 10×10^{-6} mg/l. NDMA is formed when chloramines react with organic nitrogen containing precursors such as dimethylamine (DMA). DMA is present in fully nitrified effluents and also is a key component in cationic polymers commonly used for sludge thickening and dewatering. Depending on the levels of precursors in water, significant levels (up to 1000×10^{-6} mg/l) of NDMA may be formed from chloramination.

A significant amount of research has been conducted regarding how to alleviate the formation of NDMA in the chloramination process. Some researchers have suggested a sequential chlorination alternative which applies chlorination in a two-step process with the addition of ammonia. The first step is to provide first tier disinfection and the consumption of organic materials using free chlorine. In the second step, ammonia nitrogen is added to the effluent followed immediately by additional chlorine. Ammonia and chlorine doses are dependent on the disinfection requirements of the plant. This process might generate adequate chloramines for effective disinfection by adding chlorine and ammonia nitrogen in the required amounts. However, the presence of chloramines could still result in some NDMA formation, although probably less than with the conventional chloramination approach. Tests on the sequential approach have produced final NDMA concentrations exceeding 10×10^{-6} mg/l.

Even in the absence of chloramination, some researchers (Shreiber and Mitch, 2007) have suggested that, if breakpoint chlorination is conducted to achieve significant free chlorine residual in the presence of nitrite, nitrosamines and nitramines can form through a reaction between nitrite and hypochlorite.

Because of the issues described and the disadvantages of ammonia addition, both L/E plant staff and Brown and Caldwell consider this option to be impractical. Therefore, the addition of ammonia for chlorination control will not be evaluated any further in this report.

Because of these issues, many wastewater utilities have investigated and implemented alternative forms of disinfection.

5. ALTERNATIVE DISINFECTANTS

Potential alternative disinfectants to chlorination include chlorine dioxide, ozone, peracetic acid, and Ultraviolet (UV) light. These potential alternatives are briefly described and discussed below.

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5.1 Chlorine Dioxide

Chlorine dioxide (ClO_2), a synthetic yellow to brown colored gas at room temperature and atmospheric pressure, has been used as an alternative disinfectant in drinking water treatment to control the formation of regulated DBPs such as TTHMs. ClO_2 is a strong oxidant that is as effective as chlorine as a disinfectant against viruses and bacteria and more effective against *Giardia* and *Cryptosporidium*. It is a highly reactive oxidant and is usually generated onsite. The ClO_2 residual dissipates quickly and therefore another residual disinfectant (e.g., chloramine) may be necessary as the secondary disinfectant in potable water treatment applications. Although ClO_2 does not form any significant level of TTHMs with NOM, it generates an inorganic by-product, chlorite, which is a drinking water DBP regulated by USEPA. If the ClO_2 dosage needs to be relatively high (>1.5 mg/l) to achieve required bacteria kill, the chlorite limit of 1.0 mg/l would likely be exceeded as the conversion from ClO_2 to chlorite is approximately 70% (White, 1999). The chlorite ion can be neutralized by sulfite ion at low pH (5 to 6.5) with excess sulfite ion (10-fold) at a reasonable reaction time (15 minutes). At pH above 6.5 the reaction slows markedly (White, 1999). Since wastewater effluents have relatively high disinfectant demands, the use of ClO_2 as an alternative disinfectant may produce issues with DBPs such as chlorite that may be regulated in the future.

5.2 Ozone

Ozone (O_3), a bluish gas, is a highly reactive chemical with a high oxidation-reduction potential. Ozone is created when oxygen (O_2) is separated by an energy source into oxygen atoms, which then collide with each other to form a more stable configuration, which later forms O_3 gas. Its use in aqueous conditions usually leads to the simultaneous production of secondary oxidants, such as radical species (OH) which have a higher oxidation potential than molecular ozone (Paraskeva and Graham, 2002). The free radicals disintegrate the cell tissue of bacteria and act as a strong virucide. Ozone is also an effective disinfectant for protozans such as Giardia and Cryptosporidium.

The high oxidizing power of ozone, together with the absence of any halogen constituent has made ozone a valuable chemical in water and wastewater treatment. In wastewater treatment, ozonation has been used to meet the discharge requirements for coliform and virus inactivation since the 1970s. In recent years, ozonation has gained attention due to its ability to oxidize endocrine disrupting compounds (EDCs) and pharmaceuticals found in both drinking water and wastewater. The combination of microbial disinfection and trace contaminant oxidation make ozonation an attractive alternative for advanced wastewater treatment.

Ozone is more effective at inactivating some organisms than chlorine. The *E. coli* removal efficiency of ozone is comparable with that of chlorine. The other advantages of using ozone treatment include taste and odor control, oxidation of humic organic substances in water, and the destabilization of particles. Although ozone is a fast acting disinfectant, it is very unstable with a life span of only about 20 minutes.

Typically, there are three components to an ozonation system; an ozone generator, an ozone contactor and an ozone destructor. These components represent not only high capital costs but also high operation and maintenance costs, which can make ozone less attractive than other alternatives.

As the use of ozone for drinking water disinfection is a relatively common practice, the formation of organic (e.g., assimilable organic carbon (AOC), aldehydes, ketones) and inorganic (e.g., bromate) DBPs from ozonation has been well documented. Bromate is currently the only ozone generated DBP regulated in drinking water by the USEPA, which established a maximum contaminant level of 10 μg/l.

Ozone does not react with NOM to form THMs. The relatively high dissolved organic carbon concentrations found in most wastewater promote fast O_3 decomposition and increased hydroxyl radical exposures. As a result, relatively high O_3 dosages are required to meet disinfection requirements, potentially leading to increased DBP formation (Wert et al., 2007).

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In summary, even though O_3 provides superior disinfection efficiency, high capital and operating costs make this alternative less attractive than some other alternatives.

5.3 Peracetic Acid

Peracetic acid (CH_3CO_3H) is also known as peroxyacetic acid (PAA). It is an organic peroxy compound, which has strong oxidizing properties. It is produced by the reaction of hydrogen peroxide (H_2O_2) and acetic acid (CH_3COOH), to form the compound CH_3CO_3H. As shown in the following equilibrium reaction (Lefevre et al, 1992):

$$CH_3COOH + H_2O_2 \Leftrightarrow CH_3CO_3H + H_2O$$

PAA is a strong oxidant that has been widely used as a disinfectant or sterilizing agent in laboratories and in the beverage, food, medical, and pharmaceutical industries. Recent studies have shown that PAA treatment effectively inactivates many pathogenic and indicator microbes in wastewaters (Koivunen and Heinonen-Tanski, 2005). The disinfectant activity of PAA is based on the release of active oxygen. PAA disrupts the important components of cell membranes by its oxidative effect, and impedes cellular activity.

A potential advantage of PAA is that it is not known to produce significant amounts of toxic or mutagenic DBP's or chemical residues. PAA disinfection is beginning to be considered at some WWTP's as a substitute for chlorine-based disinfectants not only because of insignificant DBP production, but also because it is readily retrofitted to existing chlorine contact tanks (Rossi et al, 2007).

PAA has a wide spectrum of antimicrobial activity even in the presence of heterogeneous organic matter and is minimally affected by pH. PAA has been reported to remove total and Fecal coliform bacteria to the same extent as chlorine and to remove *E. coli* with greater efficiency (Mezzanotte et al, 2007). Moreover, PAA disinfection effectiveness does not seem to be influenced by total suspended solids concentration between 10 to 40 mg/l, with good disinfection efficiency reported with TSS concentrations as high as 100 mg/l.

Major disadvantages associated with PAA disinfection are the increase of organics in the effluent, potential microbial regrowth due to the existence of acetic acid (which is present both in the commercial solution of PAA and as a product of PAA decomposition) and reported reduced efficiency against some viruses and protozoa's (such as *Cryptosporidium* and *Giardia*).

In recent research, wastewater disinfection with PAA was investigated using a commercial compound that contains 12% PAA (PROXITANE WW-12). The most up to date results of this study demonstrates the successful performance of this product (Maziuk and Muessig, 2008). Although the high price of PAA has generally limited its use for wastewater disinfection, these recent studies have demonstrated that PAA disinfection is a viable alternative compared to chlorination, ozone or UV disinfection processes. If the use of PAA for wastewater disinfection were to increase, the production capacity would also increase which may lead to lower costs.

In summary, there are a number of unknown factors related to disinfection with PAA. Its effectiveness for virus and cyst inactivation is not completely understood. Commercial production of PAA is limited and its future availability may be an issue. Therefore, although this alternative does have positive attributes, it is considered a less attractive option when compared with other available alternatives.

5.4 Ultraviolet (UV) Light

Ultraviolet light, which is defined as electromagnetic radiation with wavelengths between 100 and 400 nanometers, is often utilized for wastewater disinfection. UV light occurs in nature as a component of the sun's radiation, although most of the sun's UV light is absorbed by the ozone layer in the earth's upper atmosphere and never reaches the earth's surface. UV light with wavelengths close to 260 nm have been shown to have optimal germicidal affect.

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UV disinfection systems use specialized lamps, which emit the majority of UV light within the germicidal wavelength range. Unlike chemical disinfecting agents, the UV disinfection mechanism is a physical process in which the radiation penetrates microorganism cells. The deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) within the cell are damaged by the absorbed radiation, their ability to replicate is destroyed, and the organism is inactivated. Short exposure times, usually 5 to 10 seconds are sufficient to inactivate most microorganisms, including *Giardia* and *Cryptosporidium*. Although very high *E. coli* removal efficiency has been reported with UV disinfection (White, 1999), some recent studies indicated that the UV light might be less effective for *E. coli* removal than for other coliform indicators (Antonelli et al., 2008). A copy of the research that investigated the required UV dose to achieve incremental log inactivation of bacteria, protozoa, and viruses is provided in Appendix A.

Several manufacturers have developed systems that align UV lamps in vessels or channels to provide wastewater disinfection. The lamps are similar to household fluorescent lamps except that the household lamps are coated with phosphorous that converts the UV light to visible light.

UV radiation has grown in popularity over the last 25 years as a method of disinfecting wastewater. Increasingly, UV systems are being used to meet relatively stringent effluent permit limits. The effectiveness of UV disinfection is impacted by water quality parameters that prevent UV radiation from reaching the target microorganisms. Wastewater characteristics such as turbidity, suspended solids concentration, and UV absorbing inorganic and organic compounds may significantly affect disinfection efficiency.

UV radiation is not known to produce any DBPs in wastewater (Oppenheimer et al, 1997). It is not affected by low ammonia concentrations and can easily be applied to secondary/tertiary effluents. UV disinfection efficiency is proven, its cost is comparable to that of chlorination (Antonelli et al, 2008), and existing chlorine contact tanks can often be converted to UV disinfection channels.

As the requirements for disinfection are often stringent, special attention must be devoted to the reliability of any proposed UV system. Design characteristics of the system, such as the number and the configuration of UV lamps and the provision of standby power, are critically important. Redundancy can be achieved by providing either standby bank of UV lamps per channel, or one or more standby channels, depending upon the size of the installation.

As UV disinfection systems are completely dependent on electric power, back up power is vital for the continuous operation.

6. COMPARISON OF ALTERNATIVES

A summary of factors affecting the applicability of the disinfection alternatives is presented in Table 3. This table is adapted from the table given in Rudd and Hopkinson (1989). Table 3 summarizes the important parameters in disinfection process selection excluding economic factors. Explanation of each parameter is provided in Appendix B.

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*Table 3. Comparison Table for Disinfection Alternatives**

Parameter	Chloramines	ClO_2	Ozone	Peracetic Acid	UV
Bacterial disinfection	good	good	good	good	good
Virucidial disinfection	poor	moderate	good	poor	moderate
Cyst disinfection	poor	good	good	poor**	good
Bacterial Regrowth	yes	yes	no	yes**	yes
Residual toxicity	toxic	toxic	none	toxic	none
Disinfection byproducts	yes	yes	minimal	unknown	none
Corrosive	yes	yes	yes	yes	no
Community safety risks	yes	no	yes	no	no
Operator safety risks	moderate	high	high	moderate	low
Transportation costs	substantial	no	no	substantial	no
System complexity	moderate	complex	complex	simple	simple
Process control	difficult	moderate	moderate	moderate	simple/moderate
Equipment reliability	good	moderate	moderate	good	moderate
Availability	good	good	good	poor (uncertain)	good
Plant size	all sizes	all sizes	medium-large	all sizes	all sizes
Pretreatment requirement	secondary	secondary	secondary	secondary	secondary
Homeland security	substantial	substantial	no	substantial	no
Residual removal	yes	yes	yes	unknown	no
O&M sensitive	high/moderate	high	high	high	moderate

** Description of each criterion can be found in Appendix B*

*** Limited research/based on best available information*

Each criterion presented in Table 3 was assigned to a weight factor from 1 to 5 (1-worst 5-best) to quantatively evaluate the disinfection alternatives. Table 4 presents the scores for each alternative. The weight factors listed in the table were determined based on the priority of each criterion. The weight factors were reviewed and revised in collaboration with the L/E WWTP Staff to provide a general overview of each alternative. The evaluation indicates that UV disinfection has highest score, followed by ozone.

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Table 4. Quantification of Non-Economic Factors of Disinfection Alternatives

Parameter	Weight Factor	Un-weighted Score					Weighted Score				
		Chlor-amines	ClO_2	O_3	Peracetic Acid	UV	Chlor-amines	ClO_2	O_3	Peracetic Acid	UV
Bacterial disinfection	5	5	5	5	5	5	25	25	25	25	25
Virucidial disinfection	4	2	3	4	2	3	8	12	16	8	12
Cyst disinfection	4	2	4	4	2	4	8	16	16	8	16
Bacterial Regrowth	3	2	2	4	2	2	6	6	12	6	6
Residual Toxicity	5	1	1	5	1	5	5	5	25	5	25
Disinfection Byproducts	3	2	2	4	4	5	6	6	12	12	15
Corrosive	2	1	1	1	1	5	2	2	2	2	10
Community safety risks	5	1	5	1	5	5	5	25	5	25	25
Operator safety risks	5	3	2	2	3	4	15	10	10	15	20
Transportation costs	3	3	1	1	3	1	9	3	3	9	3
System complexity	2	3	1	1	5	5	6	2	2	10	10
Process control	5	1	3	3	3	4	5	15	15	15	20
Equipment reliability	4	5	3	3	5	3	20	12	12	20	12
Availability	5	5	5	5	2	5	25	25	25	10	25
Homeland Security	3	2	2	4	2	5	6	6	12	6	15
Residual Removal	5	1	1	3	3	5	5	5	15	15	25
Total Score							156	175	207	191	264

** Scale: 1-worst, 5-best*

7. COST ESTIMATES

The highest scoring alternatives, UV and Ozone, were subjected to an economic evaluation. Descriptions of these disinfection alternatives have already been provided in Section 5. In this Section the UV and ozone disinfection alternatives are evaluated in detail including cost estimates and the results of the evaluation are presented. The design criteria developed for each alternative in conjunction with the cost evaluation are presented below.

7.1 Design Criteria

Disinfection systems are typically designed to meet disinfection requirements at peak hourly design flows. A summary of the flow conditions in the Littleton/Englewood WWTP are summarized below:

- Plant Capacity, current : 36.3 mgd
- Plant Capacity, after the completion of the expansion project: 50 mgd
- Peak Hourly Flow Rate, after the completion of the expansion project: 100 mgd

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The disinfection requirement established in the current Littleton/Englewood CDPS permit is based on 245 organisms/100 ml for Fecal Coliform bacteria on a 30-day average. The permit limits for total residual chlorine are a daily maximum of 0.026 mg/l and a 30-day average of 0.0042 mg/l. Based on current trends within the water quality regulatory community, it is anticipated that the Fecal Coliform bacteria limit may be replaced with *E. coli* bacteria limit of 126 organisms per 100 ml. The residual chlorine limit is not expected to change. Therefore the Littleton/Englewood WWTP disinfection design criteria used for the cost evaluation are as follows:

- *E. coli* bacteria: 126 organisms/100 ml (30-day average)
- Residual chlorine: 0.0042 mg/l (30-day average)

7.2 UV Disinfection Design Criteria

The CDPHE design guidelines (CDPHE, 2002) recommended a minimum contact time under peak hourly flow conditions of between 5-7 seconds and minimum design UV dose of 30,000 $\mu W/cm^2/sec$ (or 30 mJ/cm^2) at 70 percent of new lamp output.

The applicability of the UV Disinfection system is strictly related with three major factors. The first factor is primarily determined by the manufacturer, the second is established by design and operation and maintenance and the third one has to be controlled in the treatment facility. These three critical factors are listed below:

- **Hydraulic properties of the reactor:** Ideally, a UV disinfection system should have a uniform flow with enough axial motion (radial mixing) to provide uniform exposure to the UV radiation. The path that an organism takes in the reactor determines the amount of UV radiation it will be exposed before inactivation. Thus, a reactor must be designed to eliminate short-circuiting and/or dead zones, which can result in ineffective disinfection.
- **Intensity of the UV radiation:** Age of the lamps, lamp fouling and the configuration and placement of lamps in the reactor affect the intensity of the UV radiation.
- **Wastewater characteristics:** These include the flow rate, suspended and colloidal solids concentrations, initial bacterial density, UV transmittance (UVT), and other physical and chemical parameters. Both the concentration of the total suspended solids and the concentration of particle-associated microorganisms determine how much UV radiation ultimately reaches the target organism. The higher these concentrations, the lower the UV radiation absorbed by the organisms.

Various wastewater characteristics and their effects on UV disinfection are given in Table 5.

Table 5. Wastewater Characteristics Affecting UV Disinfection Performance

Wastewater Characteristic	Effects on UV Disinfection
Nitrite	Minor effect, if any
Nitrate	Minor effect, if any
Biochemical Oxygen Demand (BOD)	Minor effect, if any. Although, if a large portion of the BOD is humic and/or unsaturated compounds then UV transmittance may be diminished
Hardness	Affects solubility of metals that can absorb UV light. Can lead to the precipitation of carbonates on quartz tubes
Humic Materials, Iron	High absorbency of UV radiation
pH	Affects solubility of metals and carbonates
TSS	Absorbs UV radiation and shields embedded bacteria

During UV disinfection system design, the first step in determining an appropriate UV dose is to perform UVT and collimated beam testing on the WWTP effluent. These analyses provide information about the UV dose and associated microorganism kill results characteristic of the particular wastewater. The UVT test

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determines how much of the UV light produced by the UV lamps will actually reach the microorganisms. The collimated beam test is site-specific and results can be used to generate a dose/response curve characteristic of the Littleton/Englewood effluent. This information can then be utilized to establish the appropriate design dose.

Since the dose/response curve has not been developed for the L/E WWTP yet, for the purpose of this initial evaluation, UV dose of 35 mJ/cm^2 is assumed to be adequate to meet the *E. coli* limit of 126 organisms/ml. This dosage has to be modified based on the initial analyses prior to design.

Typically UV disinfection systems are designed for "the worst case scenario". This suggests the system is designed to provide the intended or design UV dose under a combination of worst case situation such as old lamps, dirty lamp sleeves, and poor wastewater quality. Under regular conditions, the system may supply UV dosages higher than the design dose and the system can be turned down to provide the design dose. In addition to designing for the worst case operating condition, UV systems are usually provided with one bank of lamps out of service. This also grants the capability to provide 130 to 150 percent of the design dosage under the worst case conditions if all of the banks, including the redundant bank, are used, provided that the power supply is sized to accommodate the requirements of the worst-case scenario. For the purpose of this study, the parameters that will be used in the evaluation of the UV disinfection system are given in Table 6.

Table 6. Summary of the Littleton/Englewood WWTP UV Disinfection Design Criteria

Parameter	Design Value
Effluent *E. coli* Bacteria	126 organisms/100 ml
Minimum UV Dose at Peak Hour Flow	35 mJ/cm^2
Minimum UVT	65%
Total Suspended Solids	10 mg/L
Lamp Age Factor	98%
Sleeve Fouling Factor	85%

7.3 Ozone Disinfection Design Criteria

Ozone must be generated on-site since it is unstable and decomposes to elemental oxygen rapidly after generation. The effectiveness of the ozone disinfection system depends on the susceptibility of the target organisms, the contact time and the concentration of the ozone. Figure 5 indicates the ozonation process which includes feed-gas preparation, ozone generation, ozone contact and ozone destruction.

Air or pure oxygen is used to feed gas source and is passed to the ozone generator at a set flow rate. The energy source for production is generated by electrical discharge in a gas that contains oxygen. Generators manufactured by different companies have unique characteristics.

The electrical discharge method is the most common energy source used to produce ozone. Extremely dry air or pure oxygen is exposed to a controlled, uniform high-voltage discharge at a high or low frequency. After generation ozone is fed into a down flow contact chamber containing the wastewater to be disinfected. The main purpose of the contactor is to transfer ozone from the gas bubble into the bulk liquid while providing sufficient contact time for disinfection. The commonly used contactor times are diffused bubble positive pressure injection, negative pressure (Venturi), mechanically agitated and packed tower. Because ozone is consumed quickly, it must be contacted uniformly in a near plug flow contactor.

The off gases from the contact chamber must be treated to destroy any remaining ozone before release into the atmosphere. Therefore, it is essential to maintain an optimal ozone dosage for better efficiency. The ozone off gases that are not used, are sent to the ozone destruction unit or is recycled.

The key process design parameters are dose, mixing type and contact time. An ozone disinfection system strives for the maximum solubility of ozone in wastewater, as disinfection depends on the transfer of ozone

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to the wastewater. The effectiveness of disinfection depends on the ozone dose, effluent quality, the transfer efficiency of the ozone system, and contact time. Ozone disinfection is generally used after at least secondary treatment to minimize the costs. In addition to disinfection, another common use for ozone in wastewater treatment is color removal and odor control.

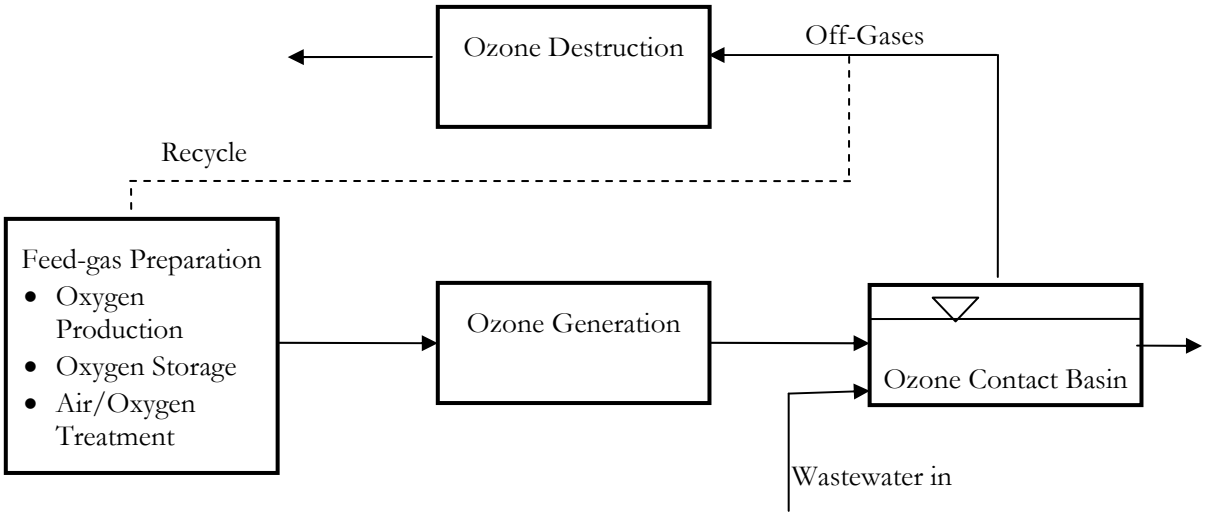

Figure 5. Ozone Disinfection Process Diagram

Since the ozone dose has not been developed for the L/E WWTP yet, for the purpose of this initial evaluation, minimum ozone dose of 3 mg/l is assumed to be adequate to meet the *E. coli* limit of 126 organisms/ml. This dosage has to be modified based on the initial analyses prior to design.

Ozone disinfection systems, like UV are designed for "the worst case scenario". The system should be able to meet the effluent *E. coli* limits when the flow is high and the effluent water quality is poor. The power supply of the system must be sized appropriately to accommodate the requirements of the worst-case scenario. The parameters that will be used in the evaluation of the ozone disinfection system are given in Table 7.

It is critical that all ozone disinfection systems are pilot tested and calibrated prior to installation to ensure that they meet discharge permit requirements for the particular sites.

Table 7. Summary of the Littleton/Englewood WWTP Ozone Disinfection Design Criteria

Parameter	Design Value
Effluent *E. coli* Bacteria	126 organisms/100 ml 126
Minimum Ozone Dose at Peak Hour Flow	3 mg/l
Total Suspended Solids	10 mg/L

7.4 Facility Requirements and Costs for UV Disinfection

Since the proper operation and maintenance (O&M) of a UV disinfection system ensures sufficient UV radiation transmitted to the organisms, all surfaces between the UV radiation source and the target organisms must be clean, and the ballasts, lamps and reactor must be functioning at peak efficiency. Cleaning has to be performed regularly by mechanical wipers or chemicals.

Chemical cleaning is most commonly done with citric acid. The average lamp life ranges from 8,760 to 14,000 working hours and the lamps are usually replaced after 12,000 hours of use. The ballast must be compatible with lamps and should be ventilated to protect it from excessive heating, which may shorten its life or even

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result in fires. Although the lifecycle of ballasts is approximately 10-15 years, they are usually replaced every 10 years.

The annual operating costs for UV disinfection include power consumption, cleaning chemicals and supplies, miscellaneous equipment repairs, replacement of lamps, ballasts and sleeves, and staffing requirements.

The cost of UV disinfection systems depends on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected. A UV disinfection system will be pilot tested with two different UV manufacturers. This will ensure reliable design criteria will be used specific to the LE effluent and it will allow the operators and other plant staff the experience to recommend a specific manufacturer.

The UV system could be installed in the existing chlorine contact tanks at the L/E WWTP. To accommodate the water depth requirements and to maintain hydraulic head conditions throughout the system, some modification would be required. A back up generator or other secondary power supply would also be required.

The anticipated construction and O&M costs associated with installation and use of a UV disinfection system at the L/E WWTP are shown in Table 8. Brown and Caldwell requested quotes from three different UV disinfection system manufacturers (Trojan, Wedeco, IDI-Degremont). These quotes can be found in Appendix C. The details of the calculation of O&M costs are supplied in Appendix D. Appendix E presents more information on the construction cost estimates of the UV disinfection system.

Table 8. Anticipated UV Disinfection System Costs

Cost Item	Construction Cost	20-Year Present Worth (2009 dollars*)
Construction Cost Estimate	$7,500,000	
Total Project Costs (assumption 25% for Engineering, Construction Services, and Change Contingency)		$10,000,000
Annual O&M Cost at Start-up		$120,000
Total Present Worth O&M Costs*		$1,500,000
Total 20-year Present Worth Cost*		$9,000,000

** Represents 2009 present worth cost amortized over 20 years*

7.5 Facility Requirements and Costs for Ozone Disinfection

Ozone disinfection requires onsite ozone generation system which includes storage tanks, filters, vaporizers and related instruments & valves and ozone generators. Although, existing chlorine building may be utilized to some extend, new construction may be inevitable.

Ozone generation uses significant amount of electrical power. Thus constant attention must be given to the system to ensure that power is optimized for controlled disinfection. There must be no leaking connections in or surrounding the ozone generator. Also, ozone should be diffused into the wastewater as effectively as possible.

Ozone in gaseous form is explosive once it reaches a concentration of 240 g/m^3. Although, the ozone concentration generally stays between 50-200 g/m^3, extreme caution is needed when operating the ozone gas systems.

Because the concentration of ozone generated from either air or oxygen is so low, the transfer efficiency to the liquid phase is a critical economic consideration. Therefore, the contact chambers used are usually very deep and covered.

The cost of ozone disinfection systems is dependent on the manufacturer, the site, the capacity of the plant, plant's effluent limitations and the characteristics of the wastewater to be disinfected. The overall cost of an

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ozonation system is also largely determined by the capital and O&M expenses. The annual operating costs for ozone disinfection include power consumption, supplies, miscellaneous equipment repairs, and staffing requirements. A summary of the ozone disinfection system cost is shown in Table 9. Brown and Caldwell contacted with several ozone manufacturers. Appendix F summarizes the responses and quotes received from ozone manufacturers. More information on the construction costs of Ozone Disinfection is provided in Appendix E. The O&M costs could not be calculated for all manufacturers due to uncertainties of electricity consumption. Anticipated O&M Costs can be found in Appendix G for the manufacturers that supplied the information on electricity consumption and operational and maintenance requirements.

Table 9. Anticipated Ozone Disinfection System Costs

Cost Item	Construction Cost	20-Year Present Worth (2009 dollars*)
Construction Costs	$33,300,000	
Total Project Costs (assumption 25% for Engineering, Construction Services, and Change Contingency)		$41,500,000
Annual O&M Cost at Start-up		$2,300,000
Total Present Worth O&M Costs*		$28,800,000
Total 20-year Present Worth Cost*		$62,100,000

** Represents 2009 present worth cost amortized over 20 years*

7.6 Advantages and Disadvantages

Table 10 facilitates the comparison of UV and Ozone Disinfection side by side by presenting the advantages and the disadvantages of each system.

Table 10. Advantages and Disadvantages of UV and Ozone Disinfection System

UV Disinfection		Ozone Disinfection	
Advantages	Disadvantages	Advantages	Disadvantages
Effective at inactivating most viruses, spores and cysts	Low dosage may not effectively inactivate some viruses, spores and cysts	More effective than chlorine in destroying virus and bacteria	Low dosage may not effectively inactivate some viruses, spores and cysts
UV is a physical process rather than a chemical disinfectant which eliminates the need to generate, handle, transport, or store toxic/hazardous or corrosive chemicals	Organisms can sometime repair and reverse the destructive effects of UV through a repair mechanism	Utilizes a moderate contact time (10-30 min) (compared to chlorine)	More complex technology, requiring complicated equipment and efficient contacting system
No residual effect	A preventive maintenance program is necessary to control fouling of tubes	No harmful residuals that need to be removed	Requires corrosion resistant material since it is very reactive and corrosive
User friendly for operators	Turbidity and TSS in the wastewater can render UV disinfection ineffective.	No re-growth	It is not economical for wastewater with high levels of TSS, BOD or COD
It has a shorter contact time when compared with other disinfectants (approximately 20-30 sec with low pressure lamps)	UV Disinfection is not as cost effective as chlorination, but costs are competitive when chlorination/dechlorination is used.	Since it is generated on-site, there are fewer safety problems associated with shipping and handling	It is extremely irrigating and possibly toxic, so off-gases from the contactor must be destroyed to prevent worker exposure
UV Disinfection equipment requires less space than other methods		Elevates the dissolved oxygen concentration of the effluent that can eliminate the need for re-aeration	The cost of treatment can be relatively high in capital and in power intensiveness

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8. SUMMARY AND RECOMMENDATIONS

Various alternatives for disinfection at the L/E WWTP have been considered to address the problems that might occur due to the changes in effluent ammonia limitations. These include chloramination using sodium hypochlorite and ammonia, chlorine dioxide, ozone, PAA, and UV disinfection. Because of disadvantages with chloramination, chlorine dioxide, ozone and PAA treatment, UV for disinfection appears to be the most desirable option for the L/E WWTP. UV disinfection's insensitivity to future low effluent ammonia levels, the absence of disinfection byproducts that could become regulatory issues in the future, and the relatively low cost make UV disinfection an attractive alternative. The L/E WWTP should start performing UVT and collimated beam testing immediately to determine the anticipated minimum UV design dose that is required for disinfection. Preliminary pilot plant tests are recommended by the LE staff to the implementation of the system and the development of costs.

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Appendices have been included with the original Littleton/Englewood report dated October 6, 2009 only, due to the amount of referenced material/paper.

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City of Littleton

Agenda

Special Meeting

Littleton City Council

Tuesday, February 8, 2011

7:30p.m.

1. Study Session Topics

a) 7:00 p.m. Discussion of Ammonia Treatment Proposal Re: Littleton/Englewood Wastewater Treatment Plant

1a

b) 8:00 p.m. Status Report on Lighting Ordinance

1b

RECESS

RECONVENE

c) 9:00 p.m. 2011 Contractual Service Agreements

1c

d) Announcements

Study Session will be held in the Community Room and will be televised on cable channel 8.
Special Meetings may be scheduled by the City Council as needed.