Disinfection Alternatives and Sustainability: Energy Optimization, Disinfection Efficiency, and Sustainability

Gary Hunter [1], Andy Shaw [1], Dr. Leonard W. Casson [2], and Dr. Joe Marriott [2]
[1]Black & Veatch, 8400 Ward Parkway, Kansas City, MO 64114
[2]Department of Civil and Environmental Engineering,
944 Benedum Engineering Hall, University of
Pittsburgh, Pittsburgh, PA 15261

ABSTRACT

The dramatic rise in energy and chemical costs is spurring additional focus on optimizing efficiency of wastewater disinfection processes. At the same time, sustainability of disinfection in an increasingly-urbanized world will depend in part on the ability to reuse treated effluent as a resource instead of a waste product.

Following the terrorist attacks of September 11, 2001, and devastation of Hurricane Katrina, the engineering design paradigm was broadened to include safety, security and a response to all hazards. The "3-S Design Concept" for drinking water and wastewater infrastructure systems was developed

The "3-S Design Concept" can be used to provide practical guidance for the design and operation of disinfection processes and treatment systems in today's economic environment in a manner that embraces sustainable solutions that benefit future generations instead of short-sighted solutions with hidden future costs. Sustainability incorporates a triple bottom line approach incorporating economic, environmental, and social factors in to the selection of a UV disinfection system.

INTRODUCTION

The Clean Water Act (1972 and 1977) established the basis for regulating pollutant discharges into the waters of the United States. This Act contains many provisions regulating pollutant discharges and surface water quality in the United States. This act has also been modified by numerous revisions and amendments since it was enacted in 1972.

The National Pollutant Discharge Elimination System (NPDES) permit program (authorized by the Clean Water Act) regulates point sources that discharge pollutants into waters of the United States in an effort to control water pollution. The NPDES permit program contains the following programs which regulates sanitary wastewater and stormwater runoff.

- Secondary Treatment Standards;
- Water Quality Based Permitting;
- Combined Sewer Overflows (CSOs);
- Sanitary Sewer Overflows (SSOs);
- Municipal Separate Storm Sewer Systems;
- National Pretreatment Program; and
- Biosolids.

Disinfection of either treated sanitary wastewater or stormwater (through CSOs) is a key unit process used by the wastewater treatment industry to meet NPDES permit requirements and protect the receiving water (and downstream drinking water treatment plant intakes).

The public health and environmental benefits of practicing wastewater disinfection in the United States are very clear. On September 11, 2001, the possibility of an international terrorist attack within the continental United States became a reality. The most recent terrorist attacks targeting the United States have been directed at constructed facilities and infrastructure (e.g., the World Trade Center in New York City, the Pentagon, selected Postal facilities and Congressional Offices). Although these attacks seemed to initiate terrorism in the continental United States, numerous domestic terrorism attacks and incidents have occurred in the United States since the early 1950's. In addition to intentional attacks, the impacts of hurricane Katrina on the Gulf Coast of the United States highlighted the risks and safety issues associated with remediation and recovery of infrastructure systems following a major disaster. Thus, the current focus of preparing for "All Hazards" instead of focusing on intentional attacks or accidental discharges.

To address these hazards the "3-S design guidance" was developed in response to this paradigm shift.

- Safety
    - o Public Health Protection Through Regulatory Compliance
    - o Workers and Surrounding Community Protection

- Security – *"All Hazards"*
    - Vulnerability Assessments
    - Emergency Response/Operation Plans
- Sustainability
    - Infrastructure Design Support Systems
    - Environmental Considerations

Literature has discussed safety and security related to disinfection systems, therefore this paper will focus on aspects related to sustainability.

SUSTAINABILITY BACKGROUND

The United States and other countries have begun to embrace the sustainability concept. This concept is best defined by the following statement from the Bruntland Commission Report.

> *"Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs"* Bruntland, 1987.

That same report reminds us of the following:

> *"Sustainable Development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made consistent with future as well as present needs"* Bruntland, 1987.

Life Cycle Management (LCM) is an integrated concept used for managing the total life cycle of goods and services towards more sustainable production and consumption. Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all states of its life cycle. The international organization for Standardization (ISO) has standardized this framework with the ISO 14040 on Life Cycle Assessment (UNEP, 2008).

Engineers are being challenged to determine how to best incorporate sustainability and sustainable concepts into drinking water and wastewater infrastructure systems. Presently, the primary method for sustainability incorporation has been to include green building concepts into utility buildings. These green building concepts have been developed and certified by the Leadership in Energy and Environmental Design (LEED). The effort to incorporate sustainability has raised the following questions among academics and consulting engineers:

- Can sustainability (i.e., LCM and LCA) be incorporated into standard engineering design of infrastructure systems?
- What is the best, most practical and meaningful way to incorporate sustainability into the engineering design and operation of the drinking water and wastewater infrastructure?
- What is the best approach to incorporate sustainability concepts into engineering design?

In addition to the 3-S Design Concept, the sustainability triangle for drinking water and wastewater infrastructure was adapted from the sustainability literature (UNEP, 2008) and is shown in Figure 1.

Figure 1. *Sustainable Infrastructure Triangle (Adapted from UNEP, 2008)*

CARBON FOOTPRINT

One of the aspects of a LCA is the determination of the carbon footprint of the disinfection system. The first consideration in developing a carbon footprint is the "boundaries" for the assessment. By this is meant a clear definition of what activities, processes, emissions and timescales should be included in the calculation. The actual boundaries selected for the assessment depend on the purpose of the assessment. For example, if the carbon footprint will be used to assess the plant as part of a wider local or regional program that looks at a variety of utilities and activities then it is important that the utility follows a standard protocol to ensure that an "apples for apples" comparison is made and that emissions are not double-accounted. If the purpose of the carbon foot printing exercise is to look at reducing onsite emissions, to provide opportunities to sequester carbon or to sell carbon offsets, then the utility may want to broaden the assessment to include significant biogenic emissions (i.e. emissions that are considered to be part of the natural carbon cycle) that are not usually included in standard protocols.

The most significant source of greenhouse gas emissions for most wastewater treatment facilities is the indirect emission of CO_2 due to the use of electricity to provide aerobic treatment. These emissions can usually be calculated easily as most facilities have good measurements of their electricity use. An important consideration for wastewater treatment plants that provide nitrification is the emission of nitrous oxide (N_2O) which is usually emitted in very small quantities but is; however, 300 times more potent than

CO_2 and so it can be a significant contribution to the overall carbon footprint of the plant. The paper will discuss the conditions that influence N_2O emissions and give guidance on preventing excessive emissions.

Once a carbon footprint has been calculated for a facility, this baseline number can be used as a measurement to assess steps to reduce the carbon footprint – such as the use of co-generation using digester gas - or the increase in carbon footprint due to requirements for improved effluent quality.

SUSTAINABLILITY

Sustainability as a concept is somewhat difficult to implement and determine as shown on Figure 2. A large number of factors can be examined to establish the costs or rankings for economic, environmental and social area of sustainability.

DISINFECTION ALTERNATIVES

Design of disinfection systems can become challenging, as there may be a number of end uses, each with its own set of disinfection requirements. Since 1935, chlorination has been the most common method of wastewater disinfection. Despite its effectiveness, chlorine use has more recently been questioned for several reasons: chlorine transport from the chemical manufacturer to the point of use carries quantifiable risks, chlorine gas can be toxic, hypochlorite solution is corrosive, chlorine residual in treatment plant effluent can harm aquatic systems, and chlorine addition to wastewater can result in formation of undesirable DBPs.

Chlorine Gas.

Gaseous chlorine is the most common means of disinfecting wastewater in the United States. Design parameters and dosing requirements for its use are well established. The equipment is fairly reliable, easy to operate, and is familiar to many wastewater treatment staff as it is the current means of disinfection at the four plants. Typical gaseous chlorine facilities are comprised of a cylinder storage area equipped with cradles, scales, gas detectors, and an overhead crane. Evaporators and chlorinators transfer the chlorine from the cylinders and disperse a dose of chemical into the wastewater. An emergency scrubber is generally installed to capture and neutralize any chlorine gas leaks. Chlorine contact basins are provided to ensure adequate time for disinfection.

Perhaps the most substantial drawback associated with the use of chlorine gas is the safety risk. Chlorine is a toxic gas that can be harmful or fatal if inhaled. In 1988, the Uniform Fire Code (UFC) was revised to include the requirement that if more than 150 pounds of chlorine is stored at a given time, the facility must be equipped with

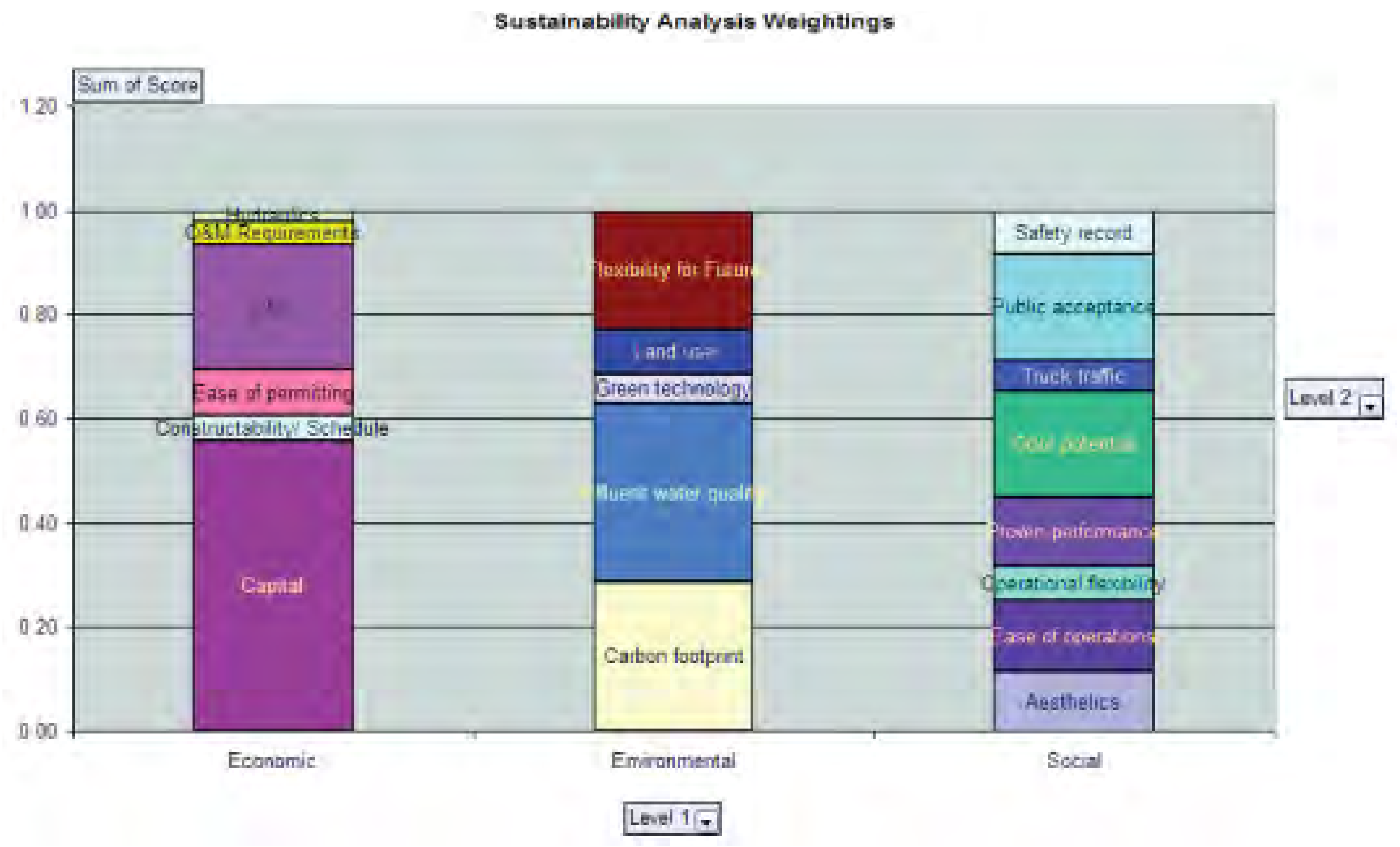


Figure 2. *Economic, Environmental and Social Factors used in Sustainability Analysis.*

safety systems to contain and treat chlorine gas in the case of an accidental leak. Options include chlorine scrubbers and cylinder containment vessels. Facilities constructed before this requirement was adopted may at the discretion of the local fire marshal be exempt until they are modified or expanded.

In 1992, the Occupational Safety and Health Administration (OSHA) put forth the requirements of its Process Safety Management (PSM) rule (29 CFR 1910.119). Utilities that operate gas chlorine systems are required to comply with this regulation, given the threshold quantities (TQs) of chlorine used and stored onsite. The TQs are 1,500 pounds for chlorine and 1,000 pounds for sulfur dioxide. The rule contains the compliance requirements for 13 plan elements that apply to the facilities. Compliance with the rule requires the development of written policies, procedures, and records for each of these plan elements. All of these factors increase training budgets for wastewater treatment plant staff.

Disinfection with gaseous chlorine typically has a lower operating cost than other methods. Therefore, there has in the past been little or no economic incentive for utilities to switch to another method. When the costs of various options are similar, the non-economic factors sway utilities away from using chlorine/sulfur dioxide gas disinfection.

Sodium Hypochlorite.

Sodium hypochlorite is a liquid disinfection agent which has proven to be reliable in the inactivation of fecal coliforms and bacterial pathogens. Sodium hypochlorite typically achieves performance levels equal to that of chlorine gas. Its effectiveness may be attributed to the fact that sodium hypochlorite disassociates in solution to form hypochlorous acid, which is the same disinfecting agent formed when chlorine gas is introduced into solution. When sodium hypochlorite is used for disinfection, sodium bisulfite is typically used for dechlorination. Since sodium hypochlorite and sodium bisulfite is delivered in liquid form and is not a listed Hazardous Air Pollutant under the Clean Air Act Amendments of 1990, its use as a dechlorinating agent does not mandate the implementation of an emergency scrubber.

A typical sodium hypochlorite feed system will consist of a bulk storage tank, day storage tanks, metering pumps, and a calibration column used to pace the metering pumps. Sodium hypochlorite is typically delivered in a 10 to 15 percent solution strength in bulk quantities. Because its solution strength degrades slowly over time, bulk quantities are usually not stored for periods longer than 60 days. To determine the minimum bulk storage requirements, a 15 to 30 day storage period at annual average flow conditions is typically used.

On-Site Generation of Sodium Hypochlorite.

On-site sodium hypochlorite generation has been a proven technology since the 1930s. This process uses salt or a brine solution and electric power to generate chlorine. If salt is used, it is dissolved in a brine solution which is diluted and then passed across electrodes powered by a low voltage current. This process produces a dilute hypochlorite of 0.8 percent in solution. On-site hypochlorite generation requires the construction of a brine tank, rectifier, electrolytic cells, a product tank, metering pumps and controls. In 2002, Black & Veatch conducted a survey on the use of on-site generation hypochlorite in the wastewater industry. Results of this survey found that there were less than 10 wastewater facilities using this form of disinfection with the largest facility having a peak design flow less than 25 mgd. Recent improvements to the technology have allowed the production of 12.5 percent solution resulting in an increase of facilities using on-site generation. This process is receiving interest from many communities as operating costs are about one half of that of a sodium hypochlorite system.

Alternatives to disinfection with chlorine gas and hypochlorite have been developed to avoid some of these problems. However, chlorine use will not be completely discontinued in the near-term, because a chlorine residual is still desired and/or required for many end uses.

Table 1
Ozone Doses required for Various Disinfection Targets*

Effluent Quality	Absorbed Ozone Dosage for 2.2 cfu/100mL total coliform	Absorbed Ozone Dosage for 70 cfu/100 mL total coliform	Absorbed Ozone Dosage for 200 cfu/100 mL fecal coliform
Filtered Secondary	35 to 40	15 to 20	12 to 15
Filtered and Nitrified	15 to 20	5 to 10	3 to 5

*From Stover et.al. 1981

Disinfection Alternatives to Chlorine

Alternative disinfectants such as ultraviolet (UV) light, ozone, chlorine dioxide, and chloramines are often considered in reuse and recharge applications, primarily to address chlorine residual and/or DBP issues, i.e. trihalomethane (THM), haloacetic acids (HAA), and nitrosodimethylamine (NDMA) formation. Below is a brief discussion of the disinfection technologies and some of the concerns with respect to reuse and recharge applications.

- *UV*. UV disinfection has been used at many installations, but water must be relatively free from substances that absorb at 254 nm to ensure disinfection. Since many reuse facilities employ filtration, UV can be a good fit. One of the key limitations with UV is that there is no form of residual disinfectant following treatment. For many reuse facilities, a residual chlorine concentration is desirable to control biological growth in the distribution system. In addition, many end users require a residual. For example, for golf course irrigation, the reuse water may be delivered to storage ponds prior to application. To control biological and algal growth in the pond as well as for public health concerns due to potential public access, chlorine residual is desirable. With UV, there is a potential for regrowth in open storage ponds. A key feature of UV relates to DBP formation. UV eliminates the formation of THMs and is one of the few proven technologies to reduce NDMA. When UV is used to treat NDMA the required dosage is approximately 1,000 mJ/cm^2 which is significantly greater than the dosage range used in reuse (60 to 140 mJ/cm^2) and for basic level (20 to 40 mJ/cm^2) disinfection (USEPA).
- *Chlorine Dioxide*. Chlorine dioxide does not promote the formation of THMs and is a highly effective bactericide and viricide. It has been used successfully for a number of years as a disinfection alternative at water production facilities. It minimizes the formation of disinfection byproducts that are regulated under the Safe drinking water act and byproducts that are regulated by standards in the receiving stream. Research is being conducted on the use of chlorine dioxide at wastewater treatment facilities for minimizing the formation of disinfection byproducts as well. A review of literature indicates that while chlorine dioxide is effective, it is several times more expensive than chlorine; consequently, it has not found widespread use as a disinfectant at WWTPs.
- *Ozone*. Ozone has not been widely used for disinfection of WWTP effluents. In the early 1970's, utilities in the US first recognized the need for adding ozone as a disinfectant to treated wastewater effluent. As early as 1981, researchers began to examine the application of ozone as part of the water reclamation process. Early research indicated that the following ozone doses were required to achieve the specific levels of disinfection (Table 1).

Concentration/time (CT) values for many of the early facilities ranged from 20 to 150 mg/L•minute. The literature indicates that the most significant factors that influence the ozone dose requirements are effluent chemical oxidation demand (soluble COD), influent bacteria density, and target effluent bacteria density. Results from recent studies (Snyder 2007, Hunter 2007) indicate that at ozone doses near 3 mg/L, bacteria concentrations can be reduced to at or below detection limits. These studies have also found that bromate (a DPB from ozone) can be formed. Further research is being completed to optimize bacteria removal with bromate formation.

- *Ozone*. Ozone has not been widely used for disinfection of WWTP effluents. In the early 1970's, utilities in the US first recognized the need for adding ozone as

- *Chloramination*. Monochloramine is an effective disinfectant which is formed through the reaction of chlorine with ammonia. In fully nitrifying activated sludge systems it can be rapidly formed by adding a controlled amount of ammonia (NH3) ahead of chlorine addition. The benefits of chloramination are (1) chlorine is immediately tied up with ammonia which prevents the formation of organochloramines which are non-germicidal and require extremely high dosages of chlorine to get effective disinfection, and 2) chloramines minimize the formation of THMs as well as other potential DBPs. The exception is NDMA which has been identified as a potential byproduct created with chloramination as well as chlorination. Najam and Trussell found that NDMA concentrations of 700 ng/L or higher were observed when using chloramines for disinfection. The complicating factor for monochloramine disinfection is that after dechlorination, monochloramine will be destroyed and ammonia will be released. Depending on the effluent discharge point, the release of ammonia can impact nitrogen permit compliance as well as cause ammonia toxicity concerns.

■ *Peracetic Acid*. Paracetic Acid is a promising new disinfectant that is being evaluated more frequently as a disinfection alternative. Researchers debate whether PAA's disinfection action occurs due to active oxygen release or the hydroxyl radical. Regardless, it is an effective disinfectant that is not mutagenic or carcinogenic, decomposes to harmless acetic acid, oxygen, and water, and thus does not yield harmful DBPs. In addition, no subsequent processes, i.e. dechlorination, are required. The main disadvantages are the increase of organic content in the treated effluent, the potential for microbial regrowth caused by the remaining acetic acid, the limited efficiency against viruses and parasites, and the strong dependence on wastewater quality. Literature indicates that peractic acid has mostly been used for discharges to marine waters which have less stringent discharge limitations when compared to reuse and recharge requirements. It may not be cost competitive when high doses are required, i.e., to meet CA standards of 2.2 CFU/100 mL total coliforms and >5 log inactivation of polivirus. It has been shown that under the right conditions (high PAA dosages, sufficient contact times, and adequate concentration of organic and mineral constituents in the final effluent) halogenated byproduct formation may be a problem. Aquatic toxicity issues and costs for full-scale operation are not well-documented. While, PAA shows promise as a disinfectant, many questions remain to be answered prior to its full-scale application.

CASE STUDY FOR SUSTAINABILITY

Several disinfection alternatives were considered for secondary effluent as for the wet weather flow from a secondary wastewater treatment facility. The following list of criteria was used in the development of five disinfection alternatives.

- Maximum Primary Treatment Capacity – 135 mgd
- Average Daily flow – 30 mgd
- Secondary Treatment Capacity
  - o Sustained Daily Flow – 55 mgd
  - o Peak Flow – 75 mgd
- Maximum Secondary Bypass Wet Weather Flow – 80 mgd (receives primary treatment)

Design guidance for the chlorination system was based on State requirements and on disinfecting waters with similar characteristics. The following criteria were used in developing the disinfection alternatives:

- A hypochlorite dosage of 6 mg/L for secondary flow and 12 mg/L for bypassed primary flow.
- Ten wet weather bypassing events per disinfection season.
- Contact chambers sized for 15 minutes of detention time at peak flow and 30 minutes minimum at average daily flow.
- Storage of enough chemicals for 15 days with three bypassing events.

Alternative 1—Liquid Sodium Hypochlorite and New Contact Basins

This alternative would include a new sodium hypochlorite system to disinfect all flows discharged from the plant. The total of these flows would be 135 mgd (80 mgd of wet weather flow and 55 mgd of secondary treated wastewater). A new chemical feed building would be constructed to store chemical and to house the chemical feed equipment. New chlorine contact chambers would be constructed as well. The existing basin has 15 minutes of detention time at 49 mgd; therefore, it does not have sufficient capacity for 55 mgd of secondary treated wastewater. New basins would be built, one for secondary treated flow and one for primary treated flow, and the existing basin would not be used. Each basin allows different hypochlorite dosages; the dosage for primary treated flow is greater than for flow that has received secondary treatment.

Alternative 2 —Ultraviolet Disinfection Using Medium Pressure Lamps

This alternative would involve construction of a UV facility to house the equipment (lamps, ballasts, PLC, and electrical cabinets) to treat 135 mgd of plant effluent. Flow would be diverted from the plant effluent and secondary bypass sewers into the UV disinfection building. Primary and secondary effluent would be combined in an influent channel before they pass through the UV reactor.

Alternative 3—Ultraviolet Disinfection Using Low Pressure – High Intensity Lamps

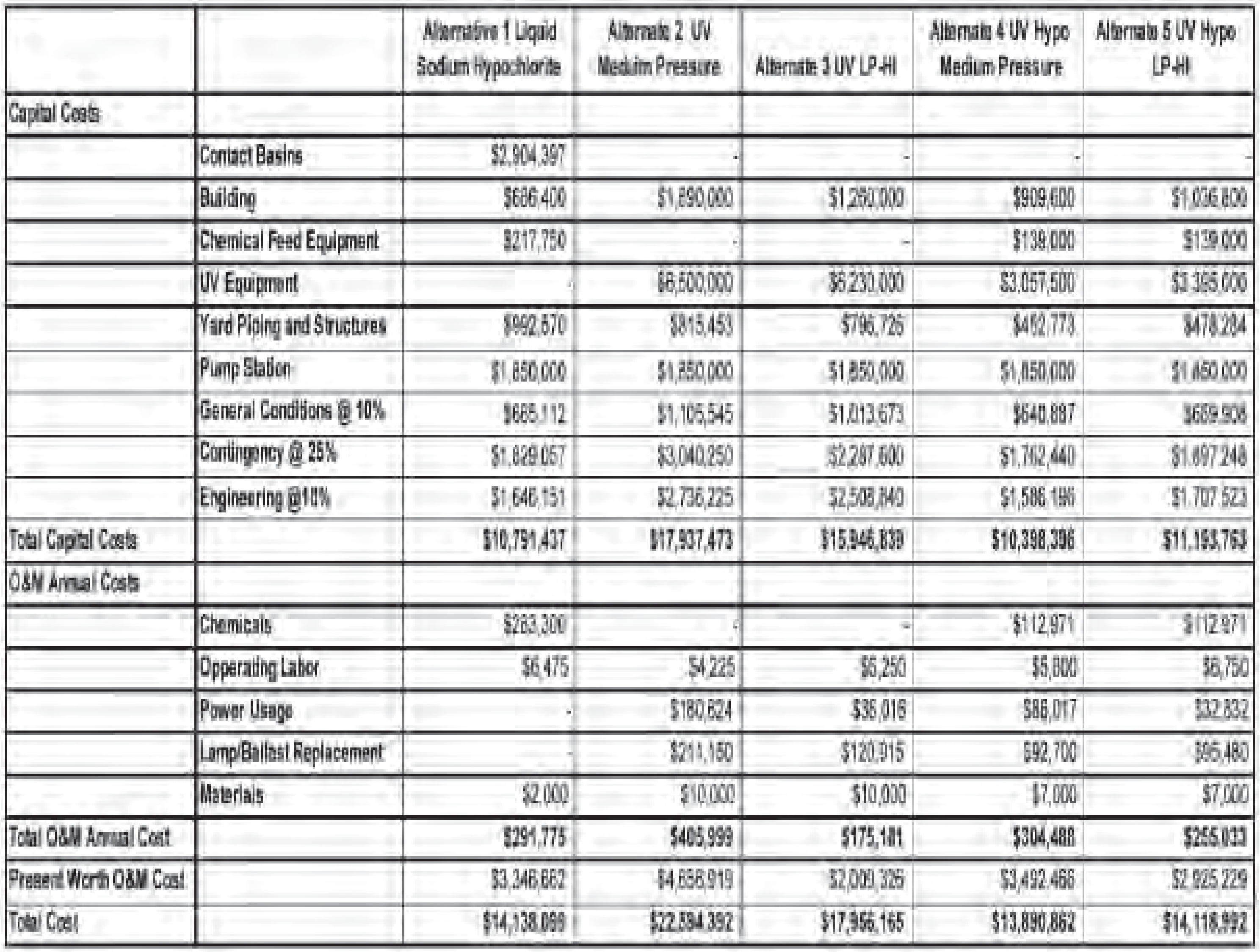
This alternative will involve the construction of a new facility to treat the 135 mgd of blended plant effluent with low pressure – high intensity UV lamps. Flow diverted from the plant effluent and secondary bypass sewers into the UV disinfection building would be blended in an influent channel before passing through the UV channels.

Alternative 4 —Medium Pressure UV Disinfection and Liquid Sodium Hypochlorite

This alternative combines two of the technologies discussed above. Ultraviolet disinfection would be used on the secondary flow. Liquid sodium hypochlorite would be used to treat wet flow that receives only primary treatment. Enough sodium hypochlorite would be stored on-site to treat flow from two wet weather events. Because UV disinfection would be used only on flows that have received secondary treatment, the equipment needs are significantly less than if it were to be used on flows that have received only primary treatment in addition to the flows that have received secondary treatment. The UV system needed would be considerably smaller than would be needed to treat the entire plant flow.

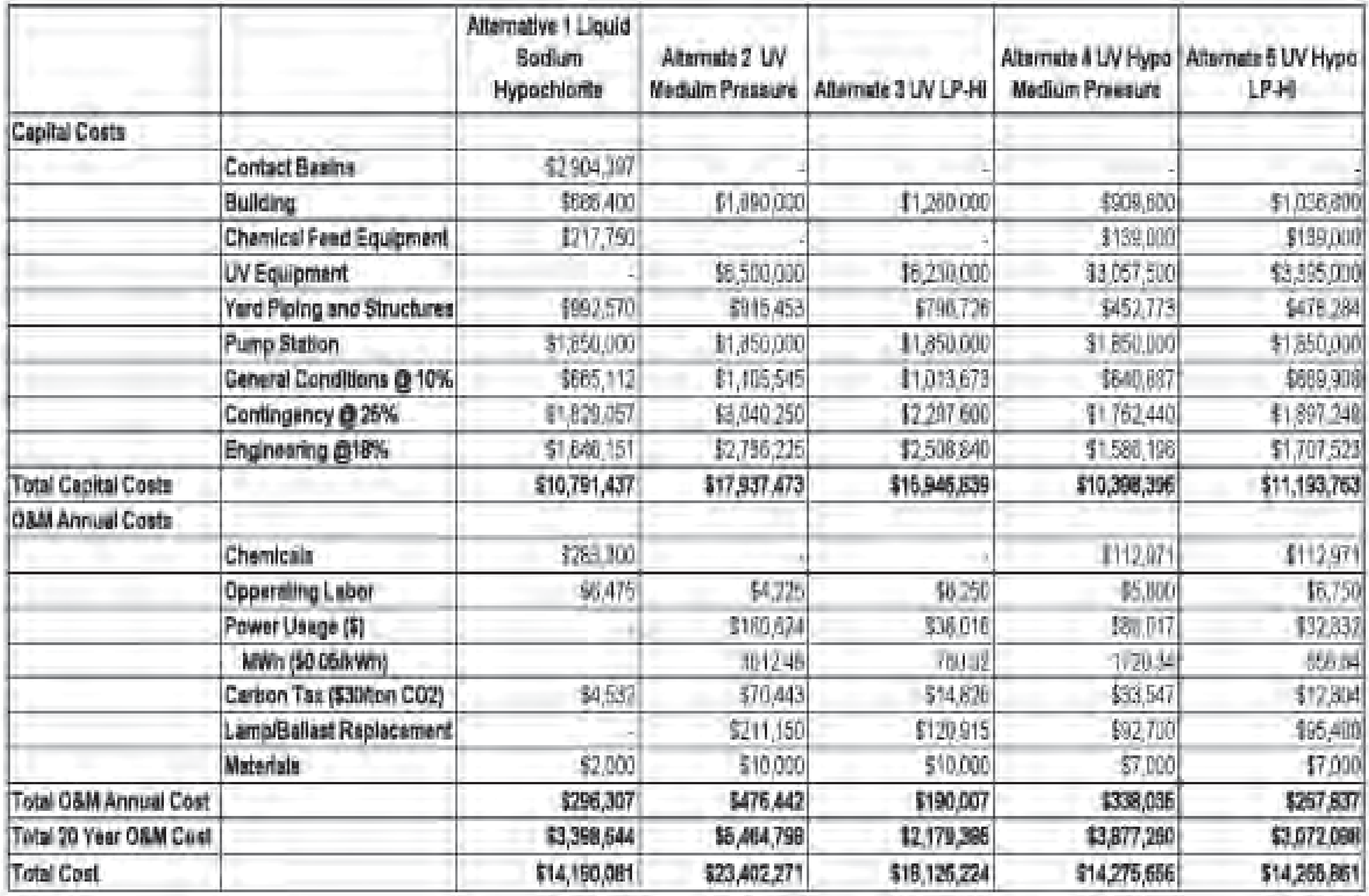
Alternative 5—Low Pressure – High Intensity UV Disinfection and Liquid Sodium Hypochlorite

This alternative combines two of the technologies discussed above. Ultraviolet disinfection would be used on the secondary flow. Liquid sodium hypochlorite would be used to treat wet flow that receives only primary treatment. Enough sodium hypochlorite would be stored on-site to



		Alternative 1 Liquid Sodium Hypochlorite	Alternate 2 UV Meduim Pressure	Alternate 3 UV LP-HI	Alternate 4 UV Hypo Medium Pressure	Alternate 5 UV Hypo LP-HI
Capital Costs						
	Contact Basins	$2,904,397	-	-	-	-
	Building	$686,400	$1,890,000	$1,260,000	$909,600	$1,036,800
	Chemical Feed Equipment	$217,750	-	-	$139,000	$139,000
	UV Equipment	-	$8,500,000	$6,230,000	$3,057,500	$3,386,000
	Yard Piping and Structures	$992,570	$815,453	$796,726	$492,773	$478,284
	Pump Station	$1,850,000	$1,850,000	$1,850,000	$1,850,000	$1,850,000
	General Conditions @ 10%	$665,112	$1,105,545	$1,013,673	$640,887	$689,908
	Contingency @ 25%	$1,829,057	$3,040,250	$2,287,600	$1,762,440	$1,697,248
	Engineering @10%	$1,646,151	$2,736,225	$2,508,840	$1,586,196	$1,707,523
Total Capital Costs		$10,791,437	$17,937,473	$15,946,839	$10,398,396	$11,193,763
O&M Annual Costs						
	Chemicals	$283,300	-	-	$112,971	$112,971
	Opperating Labor	$6,475	$4,225	$6,250	$5,800	$6,750
	Power Usage	-	$180,624	$36,016	$86,017	$32,832
	Lamp/Ballast Replacement	-	$211,150	$120,915	$92,700	$95,480
	Materials	$2,000	$10,000	$10,000	$7,000	$7,000
Total O&M Annual Cost		$291,775	$405,999	$175,181	$304,488	$255,033
Present Worth O&M Cost		$3,346,662	$4,656,919	$2,009,326	$3,492,466	$2,925,229
Total Cost		$14,138,099	$22,594,392	$17,956,165	$13,890,862	$14,118,992

Table 1. *Development of Present Worth Cost for Disintection Alternatives*



		Alternative 1 Liquid Sodium Hypochlorite	Alternate 2 UV Medium Pressure	Alternate 3 UV LP-HI	Alternate 4 UV Hypo Medium Pressure	Alternate 5 UV Hypo LP-HI
Capital Costs						
	Contact Basins	$2,904,397	-	-	-	-
	Building	$686,400	$1,890,000	$1,260,000	$909,600	$1,036,800
	Chemical Feed Equipment	$217,750	-	-	$139,000	$139,000
	UV Equipment	-	$6,500,000	$6,230,000	$3,057,500	$3,395,000
	Yard Piping and Structures	$992,570	$915,453	$798,726	$452,773	$476,284
	Pump Station	$1,850,000	$1,850,000	$1,850,000	$1,850,000	$1,850,000
	General Conditions @ 10%	$665,112	$1,105,545	$1,013,673	$640,887	$689,908
	Contingency @ 25%	$1,829,057	$3,040,250	$2,287,600	$1,762,440	$1,897,248
	Engineering @18%	$1,646,151	$2,736,225	$2,508,840	$1,586,196	$1,707,523
Total Capital Costs		**$10,791,437**	**$17,937,473**	**$15,946,639**	**$10,398,396**	**$11,193,763**
O&M Annual Costs						
	Chemicals	$263,300	-	-	$112,971	$112,971
	Opperating Labor	$6,475	$4,725	$8,250	$5,000	$6,750
	Power Usage ($)	-	$180,624	$38,016	$89,017	$32,837
	MWh ($0.06/kWh)		3012.46	780.32	1720.34	556.84
	Carbon Tax ($30/ton CO2)	$4,532	$70,443	$14,826	$33,547	$17,804
	Lamp/Ballast Replacement	-	$211,150	$120,915	$92,700	$95,400
	Materials	$2,000	$10,000	$10,000	$7,000	$7,000
Total O&M Annual Cost		**$296,307**	**$476,442**	**$190,007**	**$338,036**	**$267,837**
Total 20 Year O&M Cost		**$3,398,644**	**$5,464,798**	**$2,179,385**	**$3,877,260**	**$3,072,098**
Total Cost		**$14,190,081**	**$23,402,271**	**$18,126,224**	**$14,275,656**	**$14,265,861**

Table 2. *Disinfection Albernatives with Carbon Tax*

treat flow from two wet weather events. Because UV disinfection would be used only on flows that have received secondary treatment, the equipment needs are significantly less than if it were to be used on flows that have received only primary treatment in addition to the flows that have received secondary treatment. The UV system needed would be considerably smaller than would be needed to treat the entire plant flow.

DEVELOPMENT OF COSTS

Capital costs and operating costs were developed for each of the four disinfection alternatives to be considered further. Disinfection costs are for alternatives operated for 6 months during a year. Capital costs were developed from vendor information and from Black & Veatch experience with similar projects. The operation and maintenance costs are based on a 20-year life cycle and an annual interest rate of 6%.

Chemical costs for sodium hypochlorite and sodium bisulfite are $0.75 per gallon and $1.20 per gallon, respectively. Chemical use was based on 180 days of disinfection of secondary effluent and 10 wet weather events. The operating labor costs were based on a rate of $25 per hour.

Carbon tax at $30/ton was used to initially examine the carbon footprint of each disinfection alternative as shown in Table 2.

The initial development of the carbon tax did not include the cost of transportation of sodium hypochlorite or replacement costs for the UV systems. Therefore additional analysis needs to be completed to determine the overall impact of carbon foot print on the selection of the disinfection alternative. It is anticipated that after the cost of transporting the sodium hypochlorite is added in the present worth analysis, UV will become the most viable alternative available for selection.

Sustainability was examined by looking at environmental, social, and economic factors as they related to the Case history. The following are the issues that were evaluated as part of the sustainability evaluation that conducted for the project.

Environmental Sustainablity

- Disinfection by products were evaluated as part of a bench scale study – values were found to be below detection limits

- Land use – While site is land locked ..conceptual layouts for any of the disinfection alternatives could be implemented
- Green House Gas – Carbon Footprint only consider manufacturing – transportation of chemicals still needs to be included

Social Sustainability

- Health Effects - location of plant does not impact down stream drinking water intakes
- Nuisance factors - Hypochlorite requires more truck deliveries –for this example average of 7 truck loads per week
- Aesthetics - UV smaller footprint
- Safety - Hypochlorite transportation and handling issues
- Plant Operability - Size of plant, Staff Experience on Technology

Economic Sustability

- Capital Costs
- Annual Operating Costs
- Redundancy/Reliability/Equipment including Code and Cooling
- Construction Issues: Contingency, Soils, Timing (Weather), Electrical

CONCLUSIONS

The use of Sustainability principles is here to stay. The selection of the disinfection alternative will be impacted based on the use of sustainable principles which allow for consideration of environmental, social and economic factors.

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