Sludge Dewatering System Upgrade at the Bath Wastewater Treatment Facility

May 10th, 2019

Bath Wastewater Treatment Facility (Portland Press Herald 2018)

Humboldt State University
ENGR 481 - Wastewater Treatment - Spring 2019

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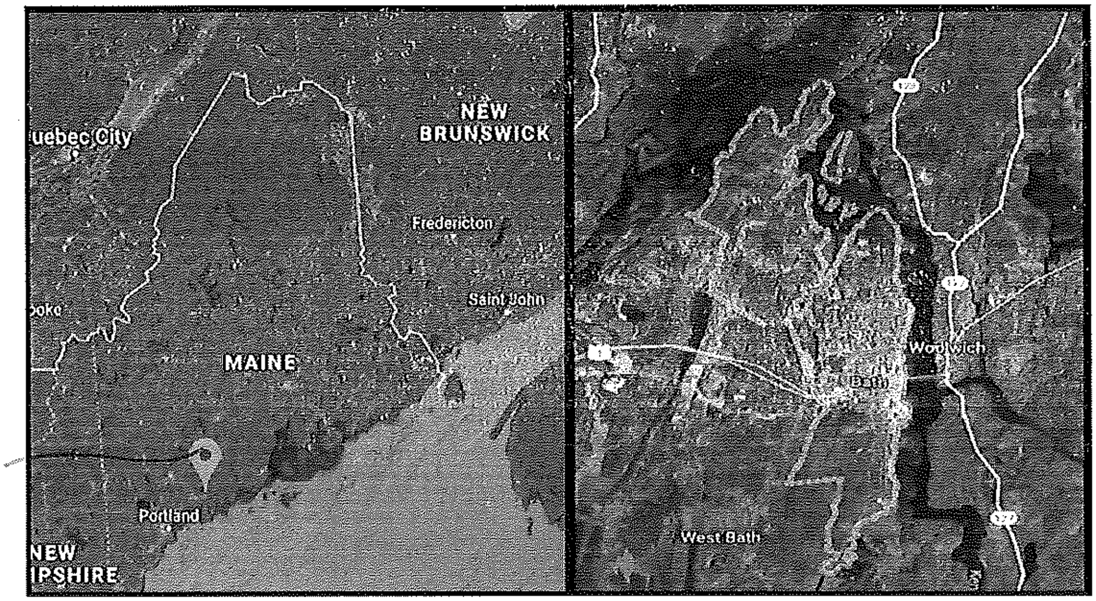
1 Introduction

The City of Bath is a small community in southern Maine that is preparing to conduct a major overhaul to its sewage collection system and wastewater treatment facility (Figure 1).



NEED LABEL

NOT THE BEST QUALITY IMAGE

Figure 1: The City of Bath is located in south-eastern Maine along the Kennebec River (Google Earth 2019).

The Bath Wastewater Treatment Plant (BWWTP) is owned and operated by the City of Bath. The facility is located on the edge of a residential area along the west bank of the Kennebec River, which is the receiving water for the treated effluent (Figure 2).

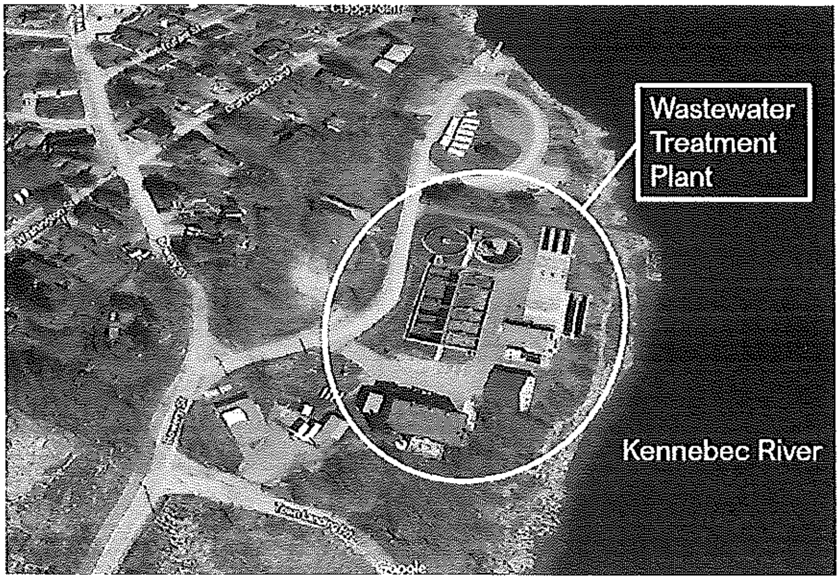


Figure 2: Aerial view of the BWWWTP (Google Earth 2019).

The sewage collection system and treatment facility upgrades are warranted due to combined sewer overflow (CSO) abatement issues throughout the city, and because some of the system components at the BWWTP have reached the end of their useful lives (Bryan Levitt, personal communication, 2019). Funding has been obtained and allocated specifically to update the sewer collection infrastructure, correct city-wide CSO abatement issues, and rehabilitate the wastewater treatment facility (Bath City Hall 2018). These upgrades will be funded primarily through the United States Department of Agriculture (USDA). The City will receive $2.3 million through a USDA Rural Development Grant, $6.5 million through a USDA Water and Waste Disposal Direct Loan (The Associated Press 2018; Portland Press Herald 2018), and the City itself will contribute $1 million to the project (Bath City Hall 2018).

One of the areas of concern at the BWWTP is the sludge dewatering system, which is over 25 years old and has reached the end of its useful life (Bryan Levitt, personal communication, 2019). The facility spends over $100,000 annually on repairs for the machine. Acquiring a new system that will require less maintenance is on the list of priorities for the facility upgrade. The Superintendent of the facility would like the new system to produce solids with minimal moisture content in order to minimize the cost of landfill disposal, and for the sake of environmental stewardship. Another concern is reducing the odor associated with sludge dewatering because neighbors in the adjacent residential area have complained about odor, in the past.

1.1 Background

The City of Bath experiences maximum temperatures of around 80°F in the summer and minimum temperatures of around 10°F in the winter (Weather Spark 2019). Rain falls year-round in Bath. The wettest month is October which receives around 4.3-in, and the driest month is January, with about 1.5-in. Snowfall generally occurs between November and March. December and January experience the most snow, each with around 1.5-in liquid equivalent.

The original Bath sewer system was entirely combined (Dwinal, et al. ~~Edgerton, and Swett~~ 2015). Several separation projects were conducted in the 1980's, 1990's, and 2000's, but several reaches of the sewer system remain combined (Dwinal, Edgerton, and Swett 2015). There are currently four locations within the city that experience CSO events, which has been reduced from 31 in 1971 (Bath City Council 2009). As a result of the combined sewer network, the BWWTP influent flowrate and quality is highly variable.

The BWWTP was constructed in 1971 (Bath City Council 2009) when the population of the city was around 9,700 (World Population Review 2019). An upgrade to the sludge dewatering system was installed in 1993 and that system continues to be in operation currently (Dwinal, Edgerton, and Swett 2015). The facility provides service for residential, commercial, institutional, and industrial customers, and it accepts sewage from septic systems at a rate of $110 per 1000-gal (WPCF 2019).

1.2 Purpose and Scope

The purpose of this project was to develop an informed recommendation for the optimal sludge dewatering system for the impending upgrade at the wastewater treatment facility in the City of Bath. The analysis was limited to sludge dewatering technologies that are commonly used at municipal wastewater facilities.

1.3 Goals and Objectives

The objective of this project was to develop a recommendation for the City of Bath regarding the most appropriate sludge dewatering technology for their wastewater treatment facility. This was achieved by maintaining correspondence with the Superintendent of the facility to gain an understanding of important criteria and factors constraining the upgrade, as well as analyzing the ability of appropriate technologies to meet the needs of the community. The overall goal was to recommend the system that would present the most benefits and the fewest challenges for the BWWTP operators and Superintendent.

2 Basis of Design

The attributes and specifications of the most appropriate sludge dewatering system for Bath are dependent on the current and projected population, variations in influent flow and sludge loading rates, projected changes in the service area, water use, or population, and any observed effects of local trends, including water conservation efforts and attributes of industrial pretreatment.

2.1 Population

LOST 1000 IN THE LAST 40 YEARS.

The population of Bath was 8,317 as of July 1st, 2017 (US Census Bureau 2019). The city does not have any colleges or industries that significantly impact the temporal flowrate or characteristics of the wastewater.

TOURISM ?

2.2 Projected Changes in Service Area, Water Use, and Population

The population of Bath experienced a brief period of growth in the early to mid-20th century, but the population has been declining since the 1970's (population.us 2019). The average annual decline has become larger each decade since the 1980's, and the city has experienced a 2.3% decline since 2010 (Table 1) (population.us 2019; US Census Bureau 2019).

Table 1: Population trends in Bath, Maine over the past half-century (US Census Bureau 2019; population.us 2019).

Decade	Average Annual Growth Rate (%)
1970-1980	-0.57
1980-1990	-0.37
1990-2000	-0.63
2000-2010	-1.13
2010-2017	-2.3

The population is projected to continue declining into the mid 2030's, and it has an estimated decrease of 7.5% between 2016 and 2036 (Table 2).

Table 2: Projected population in Bath, Maine over the next two decades (State of Maine Economist 2019).

Year	Projected Population
2021	8159
2026	8020
2031	7850
2036	7656

Despite the declining population trend, the current upgrade at the BWWTP accounts for a population increase (Bryan Levitt, personal communication, 2019). The new system components will be designed to handle flows experienced on the most recent highest discharge days, and the dewatering system will be designed with redundancy so it can handle unexpected growth (Bryan Levitt, personal communication, 2019).

PERHAPS PLANNING ON WETTER AND WARMER WEATHER?

2.3 Flows

The BWWTP capacity is 3.5-mgd with peak flow of 7-mgd and wet weather peak of 15-mgd. The combined sewer system creates a significant fluctuation in flow between dry weather (1-mgd) and wet weather (17-mgd) (City of Bath 2009). As of 2009, the facility treated an annual average of 2.2-mgd (Dwinal, Edgerton, and Swett 2015). When the influent is greater than 7-mgd, wa~~s~~ter is passed through grit removal and stored in an overflow tank before it is disinfected and released into the river.

Material that is sent through the dewatering system is a co-settled mixture of primary sludge with an average of 3% solids and secondary waste activated sludge (WAS) with an average of 0.33% solids (City of Bath 2016). The mixture produces an average solids content of 0.53% which is treated with a dry polymer before it is sent through the belt filter press. Although the population and service area are not expected to increase, the facility intends to upgrade the system with increased capacity (Table 3).

Table 3: Existing and estimated unthickened sludge production rates (City of Bath 2016).

Condition	**Solids Production**		**Hydraulic Loading**
	Dry Pounds per Day	**Dry Pounds per Week**	**Average Gallons per Day**
Existing Condition			
Average Day	1,458	10,206	32,809
Maximum Month	2,192	15,344	48,728
Design Condition			
Average Day	2,470	17,290	54,896
Maximum Month	3,766	26,362	83,703

PERHAPS THE OTHER PLANT UPGRADES WILL RESULTS IN MORE SOLIDS REMOVED FROM WASTEWATER ?

The design loading rate for the new sludge dewatering system is based on an operating schedule of 8 hours per day, five days per week. The design loading rates are higher than the current average (Table 4).

Table 4: Current and design loading rates (City of Bath 2016).

Parameter	**Current**		**Design**	
	Average Day	**Max Month**	**Average Day**	**Max Month**
Required hydraulic loading rate (GPM)	96	143	161	245
Required solids throughput (lb/hr)	225	384	432	659

2.4 Effects of Water Conservation, Industrial Pretreatment, or Other Trends

There are no recent or planned changes in the City of Bath that pertain to water conservation or industry that would impact the wastewater treatment facility (Bryan Levitt, personal communication, 2019).

3 Regulatory Requirements

The liquid effluent from the BWWTP is discharged into the surface waters of the Kennebec River and the solids are disposed of in the Bath landfill (Bryan Levitt, personal communication, 2019). Quality standards for the liquid and solid waste streams are set by regulatory bodies at the State level, and the liquid effluent standards must also satisfy national standards dictated by the EPA.

3.1 Permits and Agency Approvals Required

The BWWTP effluent is subject to quality standards set by the National Pollutant Discharge Elimination System (NPDES), which was created in 1972 as part of the Clean Water Act (CWA) (USEPA 2019). The State of Maine has assumed the program from the federal government through a process defined by CWA Section 402 (b) and Title 40 of the Code of Federal Regulations (CFR) Part 123 (USEPA 2019). The state issues CWA-compliant permits under the Maine Pollutant Discharge Elimination System (MEPDES) (State of Maine Department of Environmental Protection 2016). This permit defines standards for effluent water quality, in addition to the required frequency for each analysis and the standard methods used for the analyses.

Municipal biosolids disposal into landfills is regulated by the Bureau of Remediation and Waste Management branch of the Maine Department of Environmental Protection (Victoria Eleftheriou, personal communication, 2019). The agency requires that municipal wastewater biosolids are tested annually using the Toxicity Characteristic Leaching Procedure (TCLP) (Maine Department of Environmental Protection 2015a). If the processes that create the solid waste stream change or the composition of the waste stream changes, additional T~~L~~CPs may be required.

TCLP

3.2 Water Quality Standards

The BWWTP currently operates under the 2016 MEPDES permit (Bryan Levitt, personal communication, 2019). The permit specifies secondary-treated effluent standards for BOD_5, TSS, settlable solids, fecal coliforms, residual chlorine, pH, and mercury (Table 5) (State of Maine Department of Environmental Protection 2016). When the influent to the facility exceeds 7-mgd, a waiver for daily maximum BOD_5 and TSS for CSO-related bypass events comes into effect and the concentration of BOD_5 and TSS can be as high as 50-mg/L (State of Maine Department of

Environmental Protection 2016). The next MEPDES permit will be issued in 2021 (Bryan Levitt, personal communication, 2019). In addition to tighter restrictions on the current water quality parameters, the next permit is expected to define standards for nutrients and microplastics, as well as per- and polyfluoroalkyl substances (PFAS), although the details of these standards or whether they will be addressed is unclear at this time (Bryan Levitt, personal communication, 2019).

Table 5: Secondary effluent water quality requirements for the BWWTP (State of Maine Department of Environmental Protection 2016).

Effluent Characteristic	**Discharge Limitations**		
	Monthly Average	**Weekly Average**	**Daily Maximum**
BOD_5	30-mg/L	45-mg/L	50-mg/L
BOD_5 % Removal	85%	-	-
TSS	30-mg/L	45-mg/L	50-mg/L
TSS % Removal	85%	-	-
Settleable Solids	ODD NUMBER -	-	0.3-mg/L
Fecal Coliforms	15/100-mL	-	50/100-mL
Total Residual Chlorine	0.1-mg/L	-	0.3-mg/L
pH (Std. Units)	-	-	6.0-9.0 SU
Mercury (Total)	30.9-ng/L		46.3-ng/L

3.3 Biosolids Standards

The BWWTP sends its biosolids to the Bath Landfill (Bryan Levitt, personal communication, 2019). Solids were previously shipped 90 miles away to Soil Preparation, Inc to be used as soil amendments (City of Bath 2009), but the facility switched to landfill disposal to save money (Bryan Levitt, personal communication, 2019). Municipal sludge is generally not considered to be toxic waste (deLara et al. 2007), but the moisture content must be low enough to be compliant with Title 40 CFR Sections 264.314 and 265.314 in order to be disposed of in municipal landfills (EPA 2019c). EPA Method 9095B (Paint Filter Test) is used to demonstrate compliance, and sludge with at least 20% solids will usually pass the test (EPA 2019a). The regulated constituents for municipal biosolids disposal into Maine landfills include metals and organic compounds (Table 6). If the facility were to switch back to beneficial reuses, it would have to comply with PFAS regulations that are expected to come into effect in the summer of 2019 (Miller 2019), as well as Class A or B biosolids regulations outlined in 40 CFR Part 503 (Davis 2010).

Table 6: Maximum concentration of contaminants for disposal in Maine landfills (Maine Department of Environmental Protection 2015b).

Contaminant	**Regulatory Level (mg/L)**
Arsenic	5.0
Barium	100.0
Benzene	0.5
Cadmium	1.0
Carbon tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100.0
Chloroform	6.0
Chromium	5.0
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
Cresol	200.0
2,4-D	10.0
1,4-Dichlorobenzene	7.5
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
2,4-Dinitrotoulene	0.13
Endrin	0.02
Heptachlor (and epoxide)	0.008
Hexachlorobenzene	0.13
Hexachlorobutadine	0.5
Hexachloroethane	3.0
Lead	5.0
Lindane	0.4
Mercury	0.2
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitrobenzene	2.0
Pentrachlorophenol	100.0
Pyridine	5.0
Sleenium	1.0
Silver	5.0
Tetrachloroethylene	0.7
Toxaphene	0.5
Trichloroethylene	0.5
2,4,5-Trichlorophenol	200.0
2,4,6-Trichlorophenol	2.0
2,4,5-TP (Silvex)	1.0
Vinyl Chloride	0.2

ARE YOU SURE NO μg/L

4 Existing Facilities

The BWWTP utilizes grit screening, primary treatment, aeration, secondary treatment, and chlorine disinfection (Figure 3).

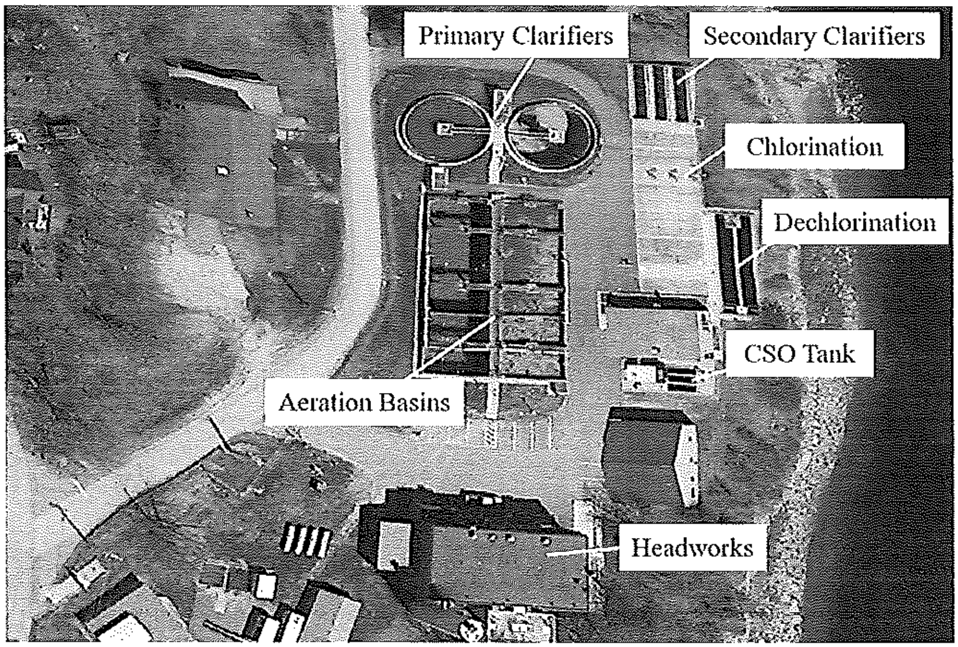


Figure 3: system components of the BWWTP (Modified Google Earth 2019).

4.1 Headworks

The wastewater treatment train begins at the headworks, which are located indoors (City of Bath 2009). The grit removal system includes an automated rake bar rack that removes about 15% of total grit from the water. This is collected and sent to the landfill. The city's licence requires a minimum pH of 6, and sodium hydroxide is added to the water after grit removal raise pH when necessary.

GRIT OR SOLIDS ?

4.2 Clarification and Aeration

After it leaves the headworks building, water is pumped underground to two primary clarifiers (City of Bath 2009). These clarifiers are cylindrical and include skimmer arms that remove oil, grease, and other floatables from the surface of the water. Solids that settle in the primary clarifiers are pumped from the bottom of the tanks and transferred to aerobic co-settling tanks.

The effluent from the primary clarifiers is pumped back underground and into one of two aeration basins (City of Bath 2009). One aeration basin is kept on-line at all times and uses blowers that operate for 24 hours each day. The second aeration basin provides redundancy for the aeration system and serves the double purpose of storing pre-treated wastewater during high flows so the facility can avoid direct release into the river. During low-flow periods in the summer one aeration basin remains empty at all times. In the winter both basins are kept full to keep the pipes clear of ice in case excess flow needs to be directed into the extra basin for storage.

UN TREATED ?

IMPOSSIBLE THEY ARE THIS SMALL !

After aeration, water is pumped into three, 165-gal tanks for secondary clarification (City of Bath 2009). Solids that settle are scraped from the bottom of the tanks, and the return activated sludge (RAS) gets recirculated through the aeration basin while the WAS is mixed is sent to one of two aerobic co-settling tanks for thickening (City of Bath 2019).

Clarification and aeration are skipped altogether under high flow conditions. During these times excess flow is routed into one of the aeration basins and into the CSO tanks, chlorinated, and released into the Kennebec River (City of Bath 2019).

4.3 Sludge Dewatering

Sludge is currently dewatered on the second floor of a building with a belt filter press that was installed in 1993 (Dwinal, Edgerton, and Swett 2015). A mixture of primary sludge and undigested WAS is thickened with a dry polymer in co-settling tanks (Bryan Levitt, personal communication, 2019) and then post-treated with lime in a pug mill for alkaline stabilization before it is dewatered (City of Bath 2019). The belt filter press system has reached the end of its useful life, and it costs the city over $100,000 annually to keep the machinery operational. Depending on variations in the sludge quantity and quality, dewatering currently occurs approximately 8 hours per day, one to two days per week (City of Bath 2016) with an average weekly operating rate of 8.54 hours (Bryan Levitt, personal communication, 2019). The sludge is dewatered to 26-28% solids, which are stored in two dumpsters that each have a capacity of 20-yd^3. About 30-yd^3 of dewatered solids are produced each week (City of Bath 2009; Dwinal, Edgerton, and Swett 2015).

4.4 Disinfection

The facility uses chlorine disinfection in the form of sodium hypochlorite (bleach) (City of Bath 2009). Sodium bisulfite is used for dechlorination before the water is discharged into the Kennebec River or recirculated through the faciity ~~to~~ to be used for chemical injections. The City stores the bleach in a 3,000-gal tank and uses about 25,000-gal each year. The sodium bisulfite is stored in a 2,500-gal tank, and the facility uses about 13,00-gal each year.

5 Development of Preliminary Alternatives

Four sludge dewatering technologies were selected for consideration to replace the belt filter press at the BWWTP. The alternatives were analyzed using criteria and constraints that were communicated by Bryan Levitt, Superintendent of the BWWTP.

5.1 Screening Mechanisms

The initial screening process involved considering the ability of each alternative to meet the project constraints. The alternatives that met the constraints were analyzed in more depth (Section 6) and the Pugh Method was used to select the best alternative design based on the project criteria (Section 7).

5.1.1 Constraints

Constraints for the sludge dewatering system include aspects of the system that must comply with economic and regulatory restrictions. The economic restrictions were developed based on the amount of money that was allotted to the dewatering technology upgrade, and the maximum acceptable annual cost of operation and maintenance (O&M). The regulatory restrictions relate to the maximum moisture content permissible for solid waste disposal in the Bath landfill. Constraints include:

- **Capital Cost:** The capital cost of the dewatering equipment must remain below $1.1 million.
- **Operation and Maintenance Cost:** The annual cost of O&M must remain below $500,000.

- **Moisture Content:** The processed sludge must be dewatered to a minimum solids content of 20% to ensure compliance with Title 40 CFR Sections 264.314 and 265.314.

5.1.2 Criteria

Criteria for the sludge dewatering upgrade were identified by the BWWTP Superintendent based on desirable aspects of the future system. These criteria describe the most important aspects to consider for the new sludge dewatering system. They were not ranked or weighted by the client, so the Pugh Method was used to select the preferred design alternative. Criteria include:

- **Capital Cost:** The lower the capital cost the better.
- **Operation and Maintenance Cost:** The lower the annual O&M cost the better. The BWWTP prefers designs that require $100,000 per year or less (Bryan Levitt, personal communication, 2019).
- **Moisture Content:** The dryer the sludge the better. Dryer sludge is more environmentally friendly because it reduces the amount of eventual landfill leachate, and it also reduces the attraction of pathogen vectors (Brad Finney, personal communication, 2019). Less moisture in sludge also reduces the volume and space necessary for storage, and reduces the total mass of the processed sludge. Reduced mass is an economic benefit since the landfill charges on a per-mass basis for disposal.

DRIED SLUDGE HELPS WITH THIS ALSO

- **Odor:** The less odor the better. The facility is located on the edge of a neighborhood, and residents have complained about the odor in the past. The BWWTP is interested in minimizing the odor as much as possible (Bryan Levitt, personal communication, 2019).
- **Ease of Operation:** Fewer operator hours required on a weekly basis is better. Operators will be free to engage with other aspects of daily operation and maintenance at the facility when the amount of time required to operate the sludge dewatering system is minimized.

5.2 Description of Alternatives

Four technologies were selected for consideration based on their widespread use for municipal sludge dewatering. These include a heat dryer, a solid bowl centrifuge, a screw press, and a belt filter press. Drying beds are a fifth popular technology (Davis 2010, deLara et al. 2007) that was not considered because the BWWTP lacks adequate space, and the below-freezing winter temperatures would not support desirable evaporation rates. The ability of each alternative to meet the project constraints was analyzed as the first step in the selection process.

Many costs associated with the various technologies were reported in dollars per dry ton of solids (DTS) produced. To convert the average weekly average sludge production of 30-yd^3 reported by the BWWTP, it was assumed that the density of dewatered sludge is 1050-kg/m^3 (deLara et al. 2007). The BWWTP was found to produce an annual average of 1,638,000-kg (1806-ton) of dry sludge. In addition, costs reported for dewatering technologies were specific to design loading rates that were not equal to the loading rate at the BWWTP. For each design alternative cost analysis, the assumption was made that there is a linear relationship between solids loading rate or hydraulic loading rate and cost. Finally, all costs were brought to their present value using the RSMeans historical construction cost index (Appendix A).

5.2.1 Heat Drying

Heat dryers use evaporation as the sludge dewatering mechanism (Figure 4). Two types exist - indirect and direct dyers (Water Environment Federation 2014). Indirect dryers use steam, hot water, or oil as a conductive heat transfer fluid that is separated from the sludge by a metal wall (Water Environment Federation 2014). Direct dryers send hot gas through a vessel to come in contact with cool sludge and evaporate moisture through convection. Most heat dryer installations in municipal wastewater plants within the last two decades have been direct rotary driers (EPA 2019b). Heat drying is most efficient when the sludge is dewatered through another method (such as a belt press) prior to drying (deLara et al. 2007). It is most appropriate to use heat drying at facilities that have the ability to use fuel generated on-site (such as methane from anaerobic digesters) (deLara et al. 2007), and at facilities that will benefit from an increased operating cost in exchange for marketable, Class A biosolids (EPA 2019b).

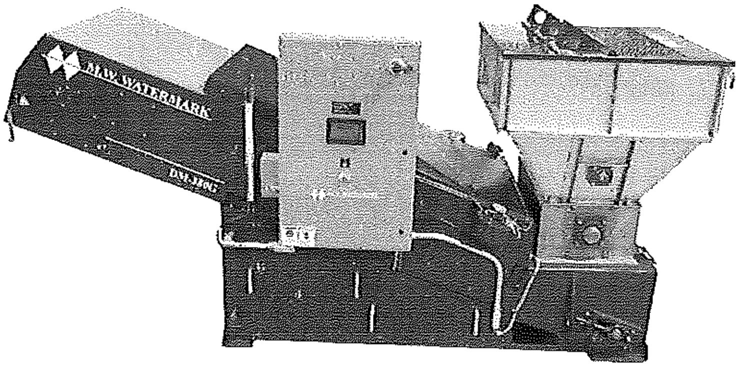


Figure 4: Image of a continuous heat dryer (M.W. Watermark 2019).

Constraint Analysis

Heat drying systems require a higher capital investment and higher O&M costs than other sludge dewatering technologies, but they produce higher quality solids with lower moisture content than many technologies. Due to the high projected capital and O&M costs, and the lack of need for Class A biosolids, heat drying was determined to be infeasible for the BWWTP upgrade.

- **Capital Cost:** The capital cost for the current sludge incineration system for the town of Rio Dell, CA with a population of about 40% that of Bath was around $1 million (Facility Superintendent, personal communication, 2019). The assumption of linearity between population and capital cost indicates that the City of Bath would need to invest $1.4 million for a heat dryer that could process all of their sludge. This is greater than the maximum of $1.1 million.
- **Operation and Maintenance Cost:** Annual O&M costs were around $180 - $300 per ton of dry solids (DTS) in the year 2005 (EPA 2019b), and anywhere between 22-55% of those costs are due to electricity demands. Some facilities could use the waste gas from the process and decrease their energy costs, when economically feasible, and reduce their O&M costs (EPA 2019b; Water Environment Federation 2014). Due to energy requirements, facilities that can make this economically feasible are larger and produce at least 10 DTS each day (EPA 2019b). It is assumed that the facility in Bath is not large enough for a cogeneration system to be feasible. A mid-range O&M estimate of $240 per ton suggests that the annual operation and maintenance for this system would be around $650,000. This is greater than the maximum of $500,000.
- **Moisture Content:** Heat drying systems can dewater sludge up to 90% solids (EPA 2019b; Water Environment Federation 2014).

5.2.2 Solid Bowl Centrifuge

Centrifuges utilize centrifugal acceleration through vessel rotation to separate solids from liquids in a sedimentary process that can be described by Stokes equation (deLara et al. 2007). To determine the settling rate within a centrifuge, the gravitational constant from Stokes equation is replaced by an acceleration constant that is dependent on the angular acceleration and radius of the vessel (deLara et al. 2007). The first dewatering stage involves the removal of free water, and the second stage removes capillary water through compression and compaction (deLara et al. 2007). Vertical and horizontal shaft centrifuges can both be used for sludge dewatering (deLara et al. 2007), and horizontal solid-bowl centrifuges are the most common for municipal wastewater sludge (Figure 5) (EPA 2019a). This technology is best suited for facilities with flows higher than 100-L/s due to the fairly high electricity costs, or for facilities that have space limitations since they have a small footprint-to-capacity ratio (deLara et al. 2007).

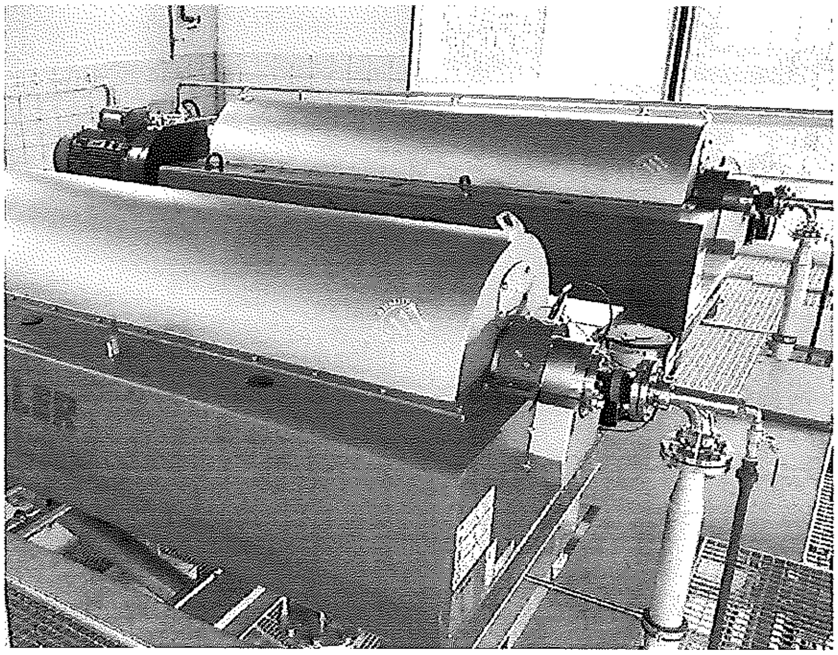


Figure 5: Image of two solid bowl centrifuges in parallel (Environmental Water Solutions 2019).

Constraint Analysis

The centrifuge alternative meets all project constraints. The capital cost and annual O&M are projected to be less than the respective maximum amounts, and the solids content of the sludge cake is high enough for assumed compliance with federal landfill disposal regulations.

- **Capital Cost:** A memorandum compiled for the City of Sunnyvale, CA wastewater treatment plant upgrade in 2009 reported that the capital cost of a centrifuge system designed to process 14,650-lb/day would be $3,429,000 in total, including the cost of construction for the dewatering building (Slezak 2009). The BWWTP design loading rate is 432-lb/hr, or 3,456-lb/day (Table 4). Assuming linearity and subtracting the construction cost for the building, the capital cost for a new centrifuge at the BWWTP would be $689,600. This is less than the maximum of $1.1 million.

- **Operation and Maintenance Cost:** The Sunnyvale wastewater treatment plant upgrade reported that the annual O&M for a centrifuge would be $1,241,000 in total, which scales to $389,700 for the BWWTP. This is less than the maximum of $500,000.

  In the year 1997, a wastewater treatment facility in Oshkosh, WI reported a total O&M cost of $40 per DTS using a centrifuge (Foltz and Kruzick 1997). This total was comprised of $23 per DTS for polymer, $12 per DTS for labor, and $5 per DTS for electricity. From this information, it was estimated that the annual O&M cost for a centrifuge at the BWWTP would be $145,600. This value is almost three times less than the annual cost estimated from the Sunnyvale report, which demonstrates the necessity of estimating costs based on consistent sources and assumptions (such as unit costs for polymer and electricity). The value determined from the Sunnyvale report was used for the analysis.

- **Moisture Content:** Solid bowl centrifuges that are loaded with a mixture of primary sludge and undigested WAS typically produce sludge cake with 25% - 35% solids (EPA 2019a).

5.2.3 Screw Press

A screw press includes a stainless steel screw conveyor inside a wire screen basket with 200-μm pores that is inclined about 20° from the horizontal (Figure 6) (EPA 2016; Davis 2010). Sludge is passed into the inclined screw vessel, which rotates slowly (generally 2-4-rpm) as it conveys material through the system (Perinpanayagam 2013; Mumbi et al. 2017; Davis 2010). The lower portion of the system is wider and provides space for the sludge to dewater by gravity (EPA 2016; Davis 2010). The diameter of the vessel decreases with elevation, and the sludge dewaters due to compression in the upper portion of the press. This technology is best suited for facilities that are interested in automating their dewatering process to reduce necessary operator attention.

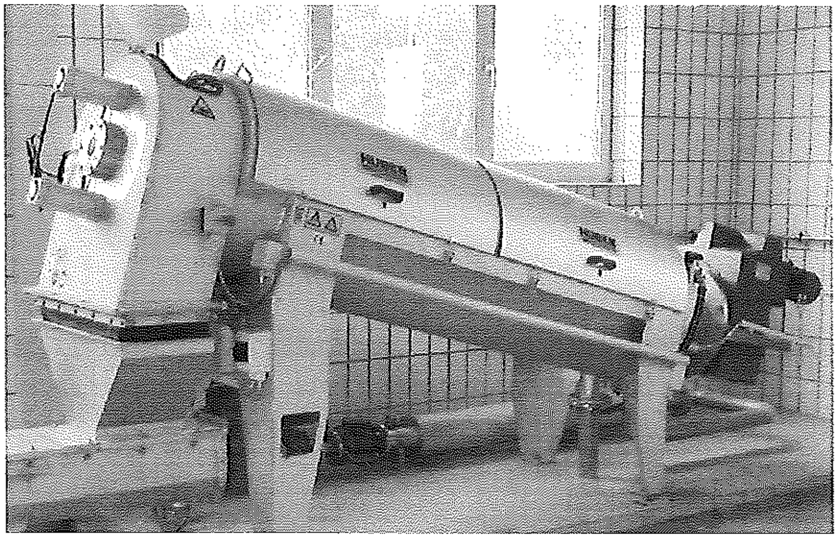


Figure 6: Image of an inclined screw press (Environmental Water Solutions 2019).

Constraint Analysis

The screw press alternative meets all project constraints. The capital cost and annual O&M are projected to be less than the respective maximum amounts, and the solids content of the sludge cake is high enough for assumed compliance with federal landfill disposal regulations.

- **Capital Cost:** The capital cost for a screw press sized for the BWWTP ranges between $650,000 and $1.1 million (Bryan Levitt, personal communication, 2019). Data obtained from the 2009 Sunnyvale, CA wastewater treatment plant upgrade was manipulated appropriately and resulted in an estimated capital cost of $709,700. This meets the maximum cost constraint.
- **Operation and Maintenance Cost:** Annual O&M for a screw press that meets sized for the BWWTP upgrade was determined from the City of Sunnyvale data to be $318,500. This is less than the maximum annual operation and maintenance cost constraint.
- **Moisture Content:** Screw presses typically produce sludge cake with 20-25% solids (EPA 2016).

5.2.4 Belt Filter Press

Belt filter presses utilize gravity and pressure to dewater sludge. At the entrance of the machine, material is fed onto a flat or slightly inclined porous belt that allows for gravity drainage (deLara et al. 2007, EPA 2000b). The material is then and then fed into the "wedge zone", which is a low-pressure area at the front-end of the machine where sludge is compressed between two porous belts (Figure 7) (deLara et al. 2007). The belts are then passed in a serpentine pattern through rollers that decrease in diameter through the system to increase pressure to remove additional water (EPA 2000b). This technology is attractive to facilities that desire low capital cost and relatively low O&M.

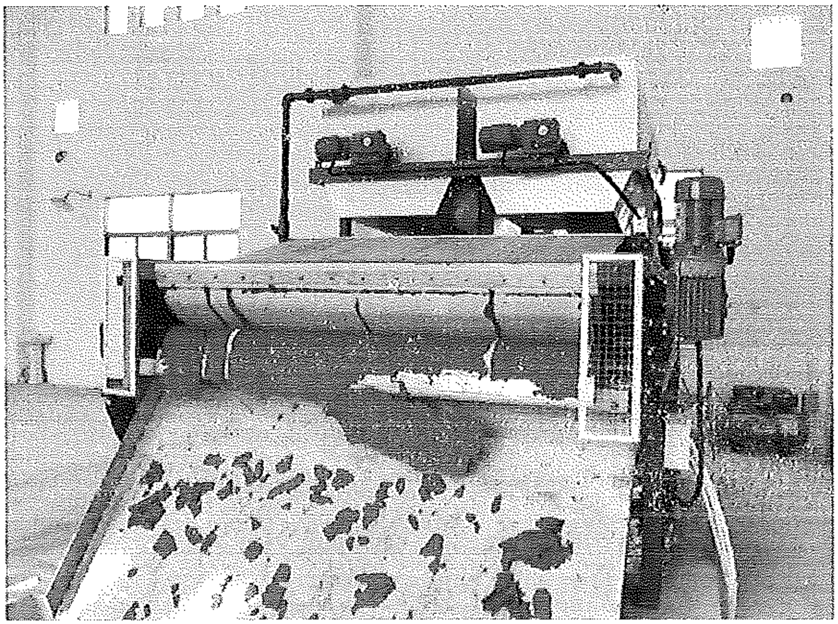


Figure 7: Image of a belt filter press (Environmental Water Solutions 2019).

Constraint Analysis

The belt filter press alternative meets all project constraints. The capital cost and annual O&M are projected to be less than the respective maximum amounts. The range of achievable solids content in the processed sludge bounds the minimum acceptable percentage.

- **Capital Cost:** The capital cost of a belt filter press designed for the City of Sunnyvale, CA would be \$8,614,000 in total (Slezak 2009). Using aforementioned assumptions, the capital cost for a new belt filter press at the BWWTP would be \$589,300. This is less than the maximum of \$1.1 million.
- **Operation and Maintenance Cost:** Annual O&M for a belt filter press designed for the City of Sunnyvale would be \$1,230,000 in total. The scaling procedure suggests that annual O&M for a new belt filter press at the BWWTP would be \$376,000. This is less than the maximum of \$500,000.
- **Moisture Content:** Belt presses that process mixtures of primary sludge and WAS can achieve cakes with 18% - 28% solids, depending on the mixture (Slezak 2009; Davis 2010). This range bounds the minimum of 20%. Since the BWWTP uses a belt press currently that produces solids within compliance for landfill disposal, it is assumed that the operators could determine the proper polymer dose and primary sludge-to-WAS ratio for a new belt press such that the resulting sludge cake would

be compliant with landfill disposal regulations.

5.3 Results of Preliminary Screening

Heat drying is the only technology that is infeasible for the BWWTP upgrade. This is due to its high capital and annual O&M costs. If the facility were interested in selling their biosolids for beneficial uses, the operation and maintenance cost may be offset by profits from the sale of biosolids and the resulting annual costs could decrease to an acceptable range. If the facility would benefit monetarily on an annual basis it may consider relaxing its capital cost ceiling as well. Since the facility is clear in their intention to continue to landfill the biosolids, heat drying is infeasible. The technologies selected for further analysis are the solid bowl centrifuge, the screw press, and the belt press.

6 Description of Selected Initial Alternatives

Process descriptions for each of the three selected dewatering technologies in addition to their advantages and disadvantages are presented in this section.

6.1 Solid Bowl Centrifuge

Centrifuges accept a continuous feed of material through a scroll conveyor that lifts solids out of water and scrapes them through to the discharge port (Davis 2010). Centrifuges can operate with concurrent or countercurrent flow. Concurrent flow centrifuges have reduced turbulence compared with counter-current flow, which supports reduced floc shear (Slezak 2009). Centrifuge systems include direct polymer injections to aid in sludge conditioning (Figure 8). Direct injections (as opposed to external polymer mixing tanks) prevents floc shear which improves solids capture and centrate quality (Slezak 2009).

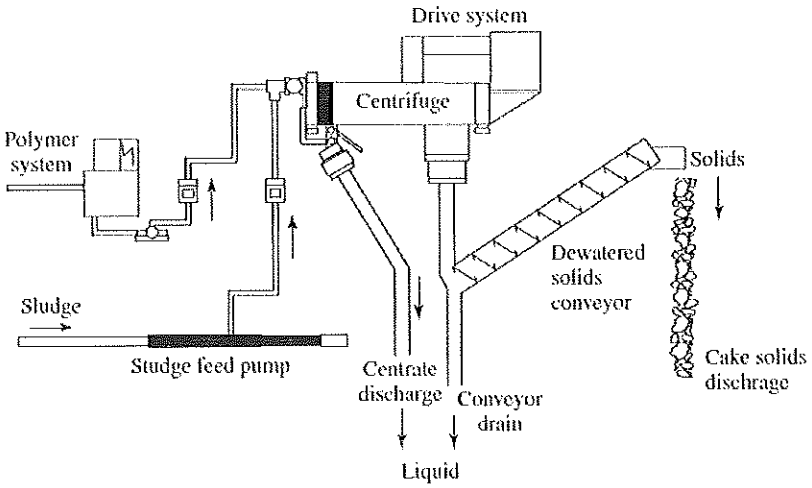


Figure 8: Process layout of a solid-bowl centrifuge (Davis 2010).

The main factors that affect centrifuge performance are influent solids concentration, sludge conditioning, feed flow rate, and temperature. This technology is very sensitive to changes in sludge composition (EPA 2019a; Davis 2010). It is important for an experienced operator to be able to anticipate seasonal variations in sewer discharges and sludge quality (EPA 2019a). A centrifuge is appropriate for sludge with a solids content between 3-6% (EPA 2019a), and optimal performance is achieved when the feed contains less than 4% solids (Davis 2010). These machines typically capture 95% of the influent solids and produce high quality centrate (deLara et al. 2007; Davis 2010).

Advantages

- Low operation and maintenance costs and operator attention when the system is stable (EPA 2019a)
- Automation of the system allows for one shift each day with 24 hours of operation (EPA 2019a)
- Easy to clean (EPA 2019a)
- Odors are easy to maintain since the centrifuge is a closed system and the odors originate from point sources (Slezak 2009)
- Small footprint relative to capacity (EPA 2019a, Slezak 2009)

Disadvantages

- High power consumption (EPA 2019a, Slezak 2009, Woodard & Curran 2016)

- Very sensitive to changes in sludge composition, so polymer doses may require frequent adjustment (Davis 2010; Woodard & Curran 2016)
- Odor control is required (Slezak 2009)
- Noisy during operation (EPA 2019a)
- Performance must be optimized by an experienced centrifuge operator (EPA 2019a)
- Slow start-up and shutdown times (EPA 2019a)
- Internal parts are subject to abrasion and replacement parts are expensive (EPA 2019a)

THIS WHAT I HEAR OVER
AND OVER AGAIN.

6.2 Screw Press

Screw presses are continuous-feed devices that can be fully automated (Figure 9) (EPA 2016). This technology requires sludge thickening prior to loading, which can be optimized to allow for a wide range of influent solids concentrations (Mumbi et al. 2017).

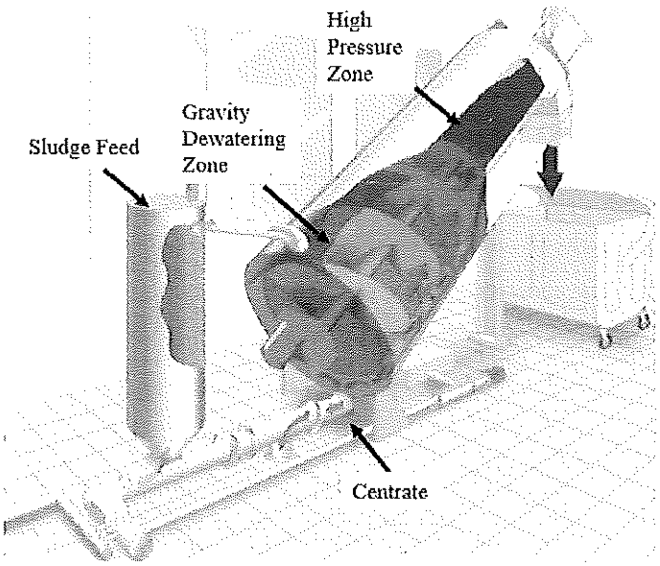


Figure 9: Diagram of an inclined screw press (Modified EPA 2016).

The typical hydraulic loading rate for a screw press is 45-gpm to 90-gpm (Davis 2010). Typical solids capture is less than 95% (Woodard & Curran 2016). Due to the low pressure required for dewatering, screw presses use about 1/8 of the power required for belt presses, and 1/20 of the required power for centrifuges (Mumbi et al. 2017). Performance is influenced primarily by sludge quantity and quality. Systems are sized based on residuals capacity and solids throughput rates, with the consideration that each screw press requires about four hours of sludge retention time (Perinpanayagam 2013).

Advantages

- Full automation reduces operation costs (EPA 2016; Perinpanayagam 2013)
- Slow rotational speed reduces vibration and maintenance costs (EPA 2016; Perinpanayagam 2013)
- Low power consumption (Woodard & Curran 2016; Mumbi et al. 2017)
- Limited odors due to the enclosed design (EPA 2016; Perinpanayagam 2013)
- Low noise associated with operation (Woodard & Curran 2016)

Disadvantages

- Moderately high solids concentration remains in the centrate (Woodard & Curran 2016; Slezak 2009)
- The sludge cake retains a higher moisture content than centrifuge (Perinpanayagam 2013)
- Larger footprint than the centrifuge (Woodard & Curran 2016)

6.3 Belt Filter Press

NO ! YES !

Belt filter presses require batch feeding and operator attention during the dewatering process (deLara et al. 2007). When the sludge feed has a low solids content, the gravity drainage zone (Figure 10) is limiting since the belt speed needs to be reduced enough to provide adequate drainage time (Davis 2010). When the feed has a higher solids content the compression process is limiting. In this situation the loading rate needs to be reduced so solids do not get squeezed out of the sides of the belt (Davis 2010).

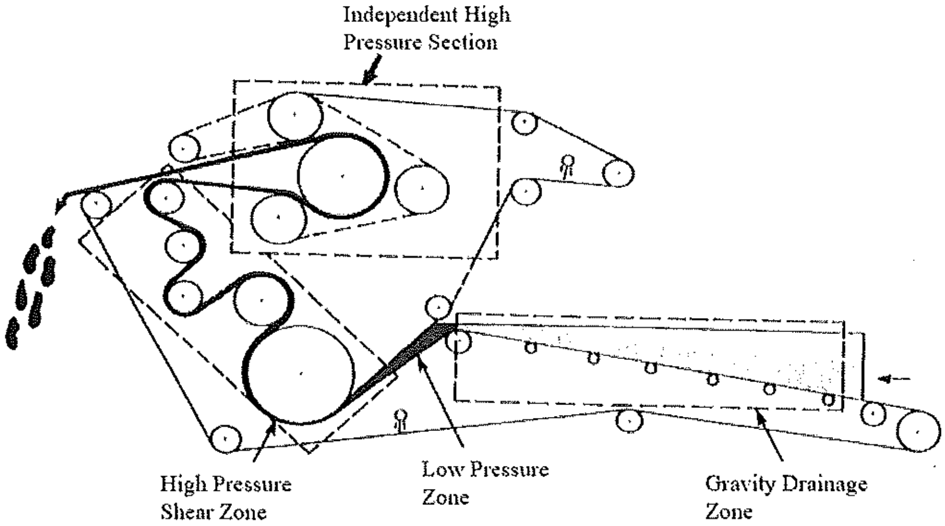


Figure 10: Schematic of a belt filter press (Modified EPA 2000b).

Belt filter presses with mixed sludge feed typically capture more than 95% solids (deLara et al. 2007; Slezak 2009). The belts are washed with high-pressure water jets between sludge loads (deLara et al. 2007). Since this machinery requires operator attention, it is important to design for excess capacity so larger-than-anticipated amounts of solids can be dewatered during normal shift hours (EPA 2000b). Self-enclosed belt filter presses can be used to minimize odor, and their capital cost is estimated to be 10% higher than traditional belt filter presses (EPA 2000b). The main factors that affect belt filter press performance include the range of solids concentrations in the feed, the volume of thickened sludge to be dewatered each day, the belt speed and tension, the type, dosage, and point of application of the polymer flocculant, and the hydraulic loading rate (deLara et al. 2007).

Advantages

- Low capital cost (Slezak 2009)
- Low operating cost (Slezak 2009)
- Low power consumption (deLara et al. 2007; Woodard & Curran 2016)

Disadvantages

- High operator attention required (automation not suggested) (Woodard & Curran 2016)
- High water consumption (for washing) (deLara et al. 2007, Woodard & Curran 2016)
- Very sensitive to variable sludge feed characteristics (Woodard & Curran 2016)

- Odor control is required (deLara et al. 2007, Woodard & Curran 2016)
- Noisy during operation (deLara et al. 2007)
- Includes multiple bearings, thus multiple opportunities for mechanical failure (deLara et al. 2007)
- Large footprint (Slezak 2009)

7 Detailed Analysis of Initial Alternatives

Each of the three selected initial alternatives were analyzed with regard to their ability to satisfy the system criteria. Each criterion was analyzed for all three design alternatives, and the possibility of associated required permits was considered. All costs associated with capital investment and annual O&M were adapted from the Sunnyvale wastewater treatment facility upgrade. This was to ensure consistency between assumptions (such as the unit cost of polymer and power) so accurate comparisons could be made between technologies.

7.1 Construction Costs

Any of the dewatering systems could be placed in the location of the old belt press, so building construction is unnecessary and was not included in the capital cost estimates. Necessary components of the capital cost include the dewatering equipment and feed pumps, polymer feed systems and mixing tanks, and the sludge cake handling system, which for Bath would be a conveyance system to deliver the cake from the dewatering equipment on the second floor of the building to the dumpsters on the first floor. A 20% contingency was added to each estimate to account for unforeseen costs, and because the assumption of linearity used to scale Sunnyvale WWTP costs to apply to the Bath WWTP is probably inaccurate. In the interest of conservancy, it is assumed that actual capital costs would be greater than the linearly scaled estimates.

The capital cost of the belt filter press was the least expensive. This can be attributed to the cost of the dewatering equipment itself. The total cost to implement the screw press was about 2% higher than the centrifuge, which can be attributed to its external polymer mixing system and feed pump (Table 7).

&

BUT BELT PRESS
ALSO NEEDS THIS

Table 7: Capital cost breakdown for each dewatering system, scaled from data obtained from the Sunnyvale WWTP upgrade (Slezak 2009).

	Centrifuge	**Screw Press**	**Belt Filter Press**
Dewatering Equipment ($)	473,033	449,792	355,936
Polymer Mixers/Flocculation Tanks ($)	N/A	11,957	5,479
Polymer Mix Feed Units ($)	13,809	20,639	20,639
Dewatering System Feed Pump ($)	27,409	41,113	41,113
Cake Handling System ($)	67,942	67,948	67,942
20% Contingency ($)	116,438	118,290	98,222
Total ($)	**698,631**	**709,738**	**589,331**

7.1.1 Operation and Maintenance Costs

Annual O&M consists of the prices for maintenance, power, polymer, and biosolids disposal. A contingency of 15% was added to account for unforeseen costs that may be associated increased electricity rates, polymer dosage alterations, or unanticipated maintenance. Costs were based on estimates of $0.20/kWh for power, $2.25/ton for polymer, and a landfill disposal fee of $44.69/wet ton (Slezak 2009).

Annual O&M is projected to be the lowest for the screw press and the highest for the centrifuge. The difference can be attributed to the high power consumption required for the centrifuge and the higher required polymer dose (Table 8).

Table 8: O&M cost breakdown for each dewatering system, scaled from data obtained from the Sunnyvale WWTP upgrade (Slezak 2009).

	Centrifuge	**Screw Press**	**Belt Filter Press**
Maintenance ($/yr)	23,818	11,909	23,818
Power ($/yr)	18,479	406	9,702
Polymer ($/yr)	93,026	10,220	31,009
Biosolids Handling/Disposal ($)	234,043	292,554	301,793
15% Contingency ($)	20,299	3,380	9,679
Total ($)	**389,666**	**318,469**	**376,001**

Annual maintenance is expected to be the lowest for the screw press and equal for both the belt filter press and the centrifuge. The belt filter press requires frequent cleaning, and belts in the high-pressure zone typically need replacement after 2,000 - 3,000 hours of use (Perinpanayagam 2013). In addition, the expected annual solids disposal cost is greater for the belt filter press than for the other two technologies due to the higher cake moisture content. Components of the centrifuge are subject to abrasion and wear due to the high rotational speed and associated vibrations, and replacing parts can be expensive and necessitate manufacturer attention (EPA 2019a). The screw press requires periodic cleaning of its outer casing (Slezak 2009).

7.1.2 Permitability

Each of the sludge dewatering alternatives are common technologies that are used in municipal wastewater treatment facilities around the country. The selected dewatering equipment would be purchased from a reputable company. The installation and use of the technology would be compliant with industry standards. It is assumed that ~~nay~~ any of the three dewatering technologies would be compliant with current and future BWWTP operating permits, and that permits regarding the implementation and use of any of the three alternative technologies would not be required.

7.1.3 Other Criteria Established by the Community

Community criteria include moisture content, odor and ease of operation. Minimal odor is preferred due to the proximity of the facility to a residential area, and less operator attention is preferred in the interest of conserving monetary and time resources.

Moisture Content: Moisture content is expected to be the lowest for the centrifuge, which produces cake with 25% to 35% solids. Belt filter presses produce cake with 18% and 28% solids, which bounds the range expected for a screw press (these produce 20% to 25% solids). To be conservative, it is assumed that the belt filter press would produce cake with a higher moisture content than the screw press since that is a possibility.

Odor: Sludge at the BWWTP is an aerobically digested blend of raw sludge and WAS. Associated odors result from mercaptan and dimethyl sulfide (EPA 2000a). The centrifuge and the screw press are enclosed systems and odors are emitted as point sources (Slezak 2009; Perinpanayagam 2013). The belt filter press is open to the surrounding environment and odors are emitted as a nonpoint source (Slezak 2009; Woodard & Curran 2016). Odor control is required over the entire belt press, and system enclosure may also be required to eliminate odor from the ambient air (Slezak 2009; Perinpanayagam 2013). Odor containment is easier for the centrifuge and the screw press than for the belt press since smaller volumes of foul air require treatment. Centrifuges produce more odorous sludge cakes than screw presses, and odor control may be required at the cake and centrate outlets of the centrifuge.

Ease of Operation: Belt filter presses require more operator attention than the other two alternatives. This technology that is not automated, so dewatering can only be performed during normal shift hours, and the belts require washing between each use (deLara et al. 2007). Belt filter presses are also very sensitive to variations in sludge characteristics and polymer doses may require frequent adjusting (Woodard & Curran 2016). The belt speed may also require frequent adjusting based on the solids content of the feed sludge, since that parameter dictates whether the gravity drainage zone or the compression zone is the limiting process. Centrifuges are also very sensitive to changes in sludge composition (Davis 2010; Woodard & Curran 2016). This is likely because centrifuge dewatering is achieved through a sedimentation process that depends on the density of the sludge and the rotational acceleration of the centrifuge. Although a definitive statement was not found in literature, screw presses appear to be less sensitive to sludge composition than the other two technologies. This may be due to the slow compaction process that is used to separate the liquids from the solids. Automated operation is an option for both centrifuges and screw presses, which presents a significant advantage over the belt press (Perinpanayagam 2013).

7.2 Selected Alternative

The Pugh method identified the screw press as the preferred design alternative (Appendix B). The centrifuge was preferred over the belt filter press. The capital cost for the screw press is higher than the centrifuge but the annual cost of O&M is lower, so the screw press is a lower-cost investment over the lifetime of the technology. Odor control is less of a concern for the screw press than for the centrifuge. Both technologies can be automated, and the screw press appears to require less frequent polymer adjustment.

8 Recommendations and Conclusions

The BWWTP is advised to replace the belt filter press with a screw press system. This technology satisfies the constraints by requiring less than the maximum allowable capital cost and annual O&M budget, and by producing sludge cake with an expected solids content of 20% to 25%. The system offers minimal odor nuisances, and the dewatering schedule can be automated for ease of operation.

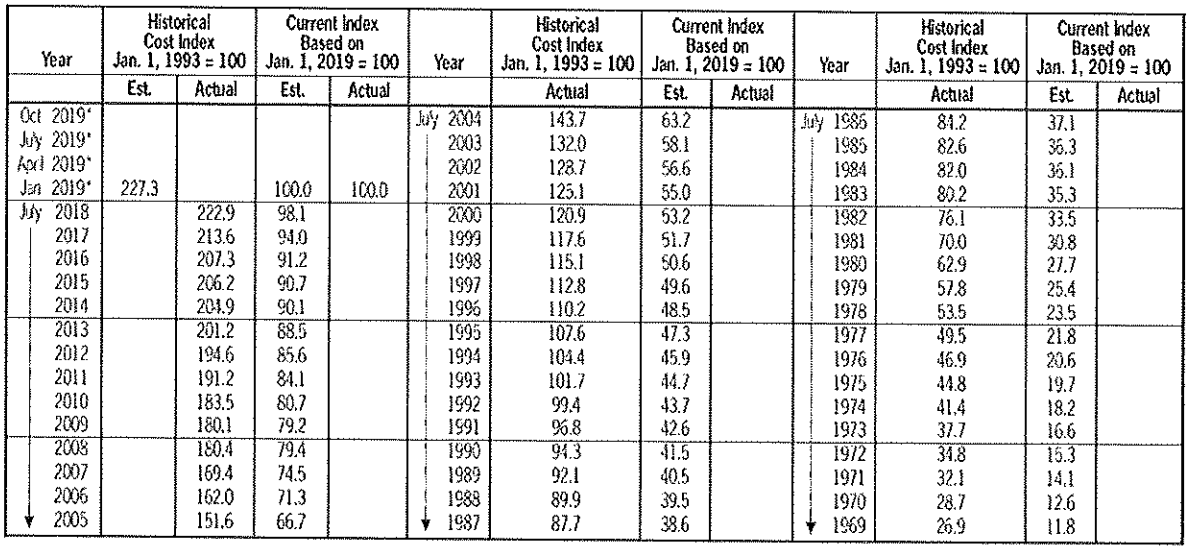
The maximum required hydraulic loading rate for the BWWTP upgrade is 245-gpm, which amounts to an average weekly volume of 386,400-gal and maximum weekly volume of 588,000 gallons assuming 40 hours of operation. The new dewatering system must be sized to manage the maximum loading rate. Screw presses typically offer between 45-gpm and 90-gpm (Davis 2010). Two, 90-gpm screw presses are recommended. These could be automated to operate for 36 hours each week under average conditions, or 55 hours each week to meet the peak demand. The installation of two screw presses will offer the benefit of system redundancy. If one press needs to be taken off-line, the schedule of the other could be adjusted to satisfy the entire system demand.

Sludge conditioning should be achieved with dry polymer. Liquid polymer does not perform well in cold climates because low temperatures can affect the the density and render pumping impracticable (deLara et al. 2007). Typical polymer addition prior to screw press dewatering ranges between 20 and 40 pounds per DTS, and operators are advised to perform batch tests to determine the proper polymer dose (Perinpanayagam 2013). Polymer should be mixed in a laminar fashion to prevent floc shearing and to maximize polymer efficiency (EPA 2019a; EPA 2000b). An adjustable speed progressive cavity pump or a rotary lobe pump is suggested for delivery from the polymer mixing tank to the press because they will not destroy the polymer (EPA 2019a).

Appendix A: Economics

Many capital and O&M costs associated with the design alternatives were reported in literature in units of dollars per dry ton of solids (DTS) produced. To convert the average weekly sludge production of 30-yd^3 reported by the BWWTP, it was assumed that the density of dewatered sludge is 1050-kg/m^3 (deLara et al. 2007). The BWWTP was found to produce an annual average of 1,638,000-kg (1806-ton) of dry sludge. In addition, all costs were brought to their present value using the RSMeans historical construction cost index (Table A1).

Table A1: RSMeans construction cost indices used to bring literature values to their present-worth (RSMeans 2019).



Year	Historical Cost Index Jan. 1, 1993 = 100		Current Index Based on Jan. 1, 2019 = 100		Year	Historical Cost Index Jan. 1, 1993 = 100	Current Index Based on Jan. 1, 2019 = 100		Year	Historical Cost Index Jan. 1, 1993 = 100	Current Index Based on Jan. 1, 2019 = 100	
	Est.	Actual	Est.	Actual		Actual	Est.	Actual		Actual	Est.	Actual
Oct 2019*					July 2004	143.7	63.2		July 1986	84.2	37.1	
July 2019*					2003	132.0	58.1		1985	82.6	36.3	
April 2019*					2002	128.7	56.6		1984	82.0	36.1	
Jan 2019*	227.3		100.0	100.0	2001	125.1	55.0		1983	80.2	35.3	
July 2018		222.9	98.1		2000	120.9	53.2		1982	76.1	33.5	
2017		213.6	94.0		1999	117.6	51.7		1981	70.0	30.8	
2016		207.3	91.2		1998	115.1	50.6		1980	62.9	27.7	
2015		206.2	90.7		1997	112.8	49.6		1979	57.8	25.4	
2014		204.9	90.1		1996	110.2	48.5		1978	53.5	23.5	
2013		201.2	88.5		1995	107.6	47.3		1977	49.5	21.8	
2012		194.6	85.6		1994	104.4	45.9		1976	46.9	20.6	
2011		191.2	84.1		1993	101.7	44.7		1975	44.8	19.7	
2010		183.5	80.7		1992	99.4	43.7		1974	41.4	18.2	
2009		180.1	79.2		1991	96.8	42.6		1973	37.7	16.6	
2008		180.4	79.4		1990	94.3	41.5		1972	34.8	15.3	
2007		169.4	74.5		1989	92.1	40.5		1971	32.1	14.1	
2006		162.0	71.3		1988	89.9	39.5		1970	28.7	12.6	
2005		151.6	66.7		1987	87.7	38.6		1969	26.9	11.8	

An electronic appendix containing the calculations used to estimate costs for the BWWTP is available upon request.

Appendix B: Pugh Method

The Pugh method was appropriate because the client did not provide weights or rankings for the criteria. This method involves arbitrarily selecting an alternative as the datum by which the other alternatives are judged, and then selecting the winning alternative as the new datum. The ability of each alternative to satisfy the project criteria is judged as the same (S), better than (+) or worse than (-) the datum. The pluses and minuses are summed for each alternative, and the design with the most pluses becomes the new datum. The minuses can be used to inform engineering judgment. The method is complete when a clear winning alternative is identified.

The first datum was arbitrarily selected as the centrifuge. The screw press was selected as the second datum based on the results of the first iteration (Table B1). The second iteration identified the centrifuge as the new datum (Table B2), which indicated a cyclic pattern and concluded the Pugh Method.

Table B1: The first Pugh iteration identified the screw press as the second datum.

Criteria	DATUM: Centrifuge	Screw Press	Belt Filter Press
Capital Cost	S	-	+
O&M cost	S	+	+
Moisture Content	S	-	-
Odor	S	+	-
Ease of Operation	S	+	-
Total	(+)	3	2
	(-)	2	3

Table B2: The second Pugh iteration identified the centrifuge as the new datum, which indicated a cyclic iterative pattern.

Criteria	DATUM: Screw Press	Centrifuge	Belt Filter Press
Capital Cost	S	+	+
O&M cost	S	-	-
Moisture Content	S	+	-
Odor	S	-	-
Ease of Operation	S	-	-
Total	(+)	2	1
	(-)	3	4

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