BROCKVILLE
CITY OF THE 1000 ISLANDS

BROCKVILLE WATER POLLUTION CONTROL CENTRE UPGRADE

CLASS ENVIRONMENTAL ASSESSMENT REPORT

Technical Memorandum No. 5
Evaluation of Sludge Treatment Needs and Options

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1. Introduction

The City of Brockville is proceeding to complete a Class Environmental Assessment to assess alternative solutions for a proposed Brockville Water Pollution Control Plant (WPCC) Upgrade.

The upgrade works, as a minimum, are to provide the current “normal” level of treatment prescribed by the Ministry of Environment (MOE), which is considered as being secondary treatment or equal and consistent with the Provincial Guideline F-5.

This Technical Memorandum (TM#5) has been prepared to evaluate the sludge handling needs, capacity of existing sludge handling units and options for optimization and/or capacity increases.

2. Background

Technical Memorandum No. 3 provided a review and screening of secondary treatment process options. Secondary treatment processes will increase the sludge generated at the plant and the treatment needs to handle this sludge. Currently, the plant has anaerobic digestion and dewatering using centrifuges. Sludge handling requirements will need to consider:

- Amount of additional sludge generation with full secondary treatment both at current and design flows
- Capacity of existing sludge handling processes
- Options for optimizing sludge handing or increasing capacity

3. Sludge Treatment Needs

3.1 Current Sludge Needs and Processes

Current sludge production for the Brockville WPCC is from the primary clarifiers. **Table 1** provides the current sludge concentration, volume and mass. Current production is based on current flows that are 81% of design flows (i.e. current average flow of 17,753 m^3/d versus a design capacity of 21,800 m^3/d). **Table 1** also provides the estimated sludge generation at design flows, assuming a linear relationship between flow treated and sludge generated at the plant.

TABLE 1:
Current and Predicted Design Primary Sludge Generation

Parameter	Current	Design
Plant Flow (ML/d)	17,753	21,800
Raw Sludge (m^3/d)	50.6 (average) 63.6 (max month)	62.1 (average) 78.1 (max month)
Raw Sludge Concentration (%)		
• Total Solids	3.9	3.9
• Volatile Solids	2.6	2.6
Raw Sludge Mass (kg/d)		
• Total Solids	1,973	2,422
• Volatile Solids	1,316	1,615

The Brockville WPCC has two anaerobic digestion tanks (i.e. both primaries). Each tank is flat bottomed with fixed covers. The dimensions, loading data, and performance measures for the digesters are provided in **Table 2**. The loadings and performance measures are well within typical operating ranges. Operating temperature and pH are within typical ranges. Digester alkalinity and volatile acids concentrations are within optimal ranges, as is the volatile acids to alkalinity ratio. Overall stabilization is expected to be good, with an average VS destruction of 48.7 %. Optimal VS destruction might be higher, and with all operating parameters at expected levels, the only potential limiting condition might be digester dead space and/or inadequate mixing.

The Brockville WPCC has two high-speed centrifuges. Polymer is added to the centrifuges to improve solids capture and centrate quality. The performance of the centrifuges is summarized in **Table 3**. The current values are based on 2003 to 2004 averages, it has been assumed that all raw sludge is treated in the centrifuges and no supernatant is produced (two primary digesters, no secondaries). An average cake concentration of 36% is provided in the 2003 annual operations report. Centrate quality averaged 1,160 mg/L, which is good.

TABLE 2:
Anaerobic Digesters Sizing and Current Loadings

Parameter	Current Value	Est. Design (primary only)	Typical Value or Range
Dimensions (m)			
Number	2		NA
Diameter	14		NA
Depth	7		NA
Volume of each digester (m^3)	1,060		NA
Raw Sludge Volume (m^3/d)			
Average	50.6	62.1	NA
Maximum – monthly (30 d moving average)	63.6	78.1	NA
Raw Sludge Total Solids (%)	3.9	3.9 (assumed)	3.5 – 7
Raw Sludge VS (%)	67.8	67.8 (assumed)	65
Hydraulic Retention Time (d)			
Average	42	34	NA
Maximum – monthly	33	27	15 (minimum)
Volatile Solids Loading ($g/m^3 \cdot d$)	631	774	650 – 1,600
Volatile Solids Destruction (%)	48.7	NA	45 – 60
Alkalinity (mg/L)	2057	NA	2,000-2,500
Volatile Acids (mg/L)	74	NA	50-300
Volatile Acids/Alkalinity Ratio	0.036	NA	< 0.2 optimal
Gas Production per kg of VS Destroyed (m^3/kg)	0.98 (926 m^3/d, assumed effluent TS of 1.5%)	NA	0.75 – 1.0 (WEF, 1991)
Temperature (°C)	37	NA	35
pH	6.8-6.9	NA	6.8 – 7.2 (WEF, 1991)

Notes:
1. Typical values taken from MOE (1984) unless otherwise noted
2. Current Values are 2001 averages (or peak values where noted)

TABLE 3:
Centrifuge Loadings and Performance

Parameter	Current Value	Typical Value or Range
Flow to Centrifuges (m^3/d)		
Average	50.6	NA
Maximum day	63.6	NA
Solids Content of Digested Sludge (%)	2.7 (assumed)	5 – 13 (MOE range)
Volatile Solids Content of Digested Sludge (%)	51.9	50
Hours of Operation (h/week day) Average	7h/day, 5day/week	Assumed (operational manual)
Hydraulic Loading to Centrifuges (m^3/h of operation)	10.1	NA
Solids Loading to Centrifuges (kg/h of operation)		
Average	273	213 (each)
Maximum day	1,271	NA
Cake Solids (%)	36	15 – 25 (MOE range)
Solids Capture (%)	96	95 – 99
Centrate Concentration (mg/L)	1,160	Na

Notes:
1. Typical values taken from MOE (1984) unless otherwise noted
2. Current Values are 2003 to 2004 averages (or maximum values where noted)

3.2 Secondary Treatment Sludge Generations

Each secondary treatment process reviewed in Technical Memorandum No. 3 (TM3) will produce solids in addition to those generated in the primary clarifiers. A comparison of the expected solids generation and characteristics for three of the secondary processes are provided in **Table 4**. The BAF is included as this process produces a unique solids stream. The MBBR will produce one sludge stream (as there is no primary clarification), with similar concentration and sludge characteristics to the RBC process.

TABLE 4:
Estimated Secondary Sludge From Short-Listed Options at Design Flows

Parameter	Process		
	ASP	**RBC**	**BAF**
Mass Sludge Produced (kg/d)	2,700	2,250	2,130
Concentration (mg/L)[1]	5,000	5,000 – 10,000	<500
Flow (m^3/d)	540	225	4,260

Note:
1. Estimated based on literature values and consultant knowledge. BAF concentration refers to washwater stream.

There are a number of options for handling the biological sludge generated. The main options are:

- Co-thickening in the primary clarifiers
- Separate gravity or mechanical thickening of the biological sludge and blending it with the raw sludge

The main disadvantage of co-thickening secondary sludge with the raw sludge is that it reduces the primary clarifiers capacity and can reduce the concentration of the raw sludge. Separate thickening (either mechanical or gravity) adds an additional process to the plant with associated operational, mechanical and labour requirements. The BAF process has more limited options as the stream is too dilute for most mechanical thickening devices (e.g. Gravity Belt Thickener) and would have to be either co-thickened or thickened with separate gravity thickening. Dissolved air flotation may also be an option for BAF solids.

3.3 Current and Future Sludge Treatment Needs

To establish preliminary sludge handling requirements, it is assumed that the secondary sludge will be co-thickened with the primary sludge. Since the ASP process has the largest estimated sludge generation it is used for this evaluation. **Table 5** provides the estimated sludge generation at design flows and the loading to the existing digesters. Combined raw and co-thickened secondary sludge concentration is estimated at 3.5%, lower than the current 3.9% to account for co-thickening the secondary sludge. The values for HRT and VS loading are just above MOE design guidelines, limits that are often considered to be conservative. Therefore, since both loadings are within 10% of the guideline value, it is assumed that the digester capacity is adequate.

TABLE 5:
Sludge Generation and Digester Loading at Design

Parameter	Estimated Design Condition with ASP	Typical Value or Range
Volume of each digester (m^3)	1,060	NA
Assumed Combined Sludge Total Solids (%)	3.5	3.5 – 7
Combined Raw and Secondary Sludge VS (%)	70	65
Combined Sludge Flow (m^3/d)	146	NA
Average Hydraulic Retention Time (d)	14.5	15 (minimum)
Volatile Solids Loading ($g/m^3 \cdot d$)	1,690	650 – 1,600

Notes:
1. Typical values taken from MOE (1984) unless otherwise noted
2. Estimated Design condition with ASP and design conditions

4. Sludge Handling Options

4.1 Separate Biological Sludge Handling

Thickening processes are applied at municipal WWTPs to reduce the volume of waste sludge (i.e., primary, secondary, or mixed sludge) by the removal of free water. This can reduce the size and improve the efficiency and operational performance of downstream sludge treatment processes (e.g., digestion, dewatering, and drying) and decrease associated storage volume requirements. Sludge volume reduction is desirable for decreasing the cost of liquid biosolids transport by tanker trucks for direct application to land or for dewatering (both practices currently used at Brockville). Sludge thickening is carried out by either co-thickening in the primary clarification stage, supernating from secondary digesters, or through the application of separate mechanical thickening of waste secondary sludge and/or raw sludge (Metcalf & Eddy, 1991). Application of separate mechanical thickening is most prevalent and economically feasible at medium to large-sized WWTPs.

The most common application of thickening typically involves the processing of secondary sludge with a solids concentration of less than 1% (weight/weight). Thickened sludge concentrations of up to 6 to 8% are possible. Sludge thickening is generally accomplished using physical process such as gravity thickeners, flotation thickeners, centrifuges, gravity belt thickeners or perforated rotary drum screens to decrease the water content of the liquid sludge. These methods differ with respect to process configuration, degree of achievable solids concentration, and the requirement of chemicals, energy, and labour (WEF & ASCE, 1992).

Owing to the potential for anaerobic conditions in the primary clarifiers, separate mechanical thickening of secondary process sludge rather than co-thickening is beneficial at biological nutrient removal (BNR) facilities to minimize the potential for phosphorus release from biological sludge. In addition anaerobic conditions have been noted in the primary clarifiers, and removal of the secondary sludge loading from the primary process can only enhance this treatment component.

The following are commercially available and established process options for waste biological sludge thickening:

- Gravity Thickening
- Dissolved-Air Flotation (DAF)
- Centrifugation
- Gravity Belt Thickening (GBT)
- Rotary Drum Screening (RDS)

Of these five alternatives, the GBT, RDS, DAF, and centrifuge mechanical thickening processes are considered to be the most technically effective and feasible for possible application. Gravity thickening would require the use of a new settler or a reused primary and has the potential for odours and will not obtain the same thickened secondary process sludge concentration as the other methods.

The GBT, RDS, and centrifugation processes can generate the highest solids concentrations of up to 8%, with the use of polymer. DAFs generally can generated about 5% TS, with the use of polymer. Centrifugation and DAF offer the flexibility of being able to operate without polymer, albeit at somewhat reduced maximum achievable solids concentrations and solids capture efficiencies. These two processes permit a more continuous mode of operation. However, both processes are considered relatively complex and energy intensive and have greater life-cycle costs than the GBT and RDS processes.

The GBT and RDS are considered relatively simple processes, requiring periodic operator attention to start up the process on a daily basis, adjust for appropriate operating conditions during batch-wise processing of secondary process sludge, and occasional monitoring and cleanup. Centrifugation is also operated in this manner, but possesses a higher degree of process automation permitting a somewhat lower degree of operator attention. Both the centrifuge and DAF processes are considered complex and energy intensive.

Therefore, since the expected thickened solids from the DAF process is less than the other three units, it has not been short listed for the Brockville site. However, depending on the treatment process selected DAF thickening may be reconsidered at that time.

The RDS and centrifuge processes are enclosed units that minimize the potential for off-gas and process liquid releases. The GBT process has an exposed moving fabric belt with associated potential for the release of off-gases, vapours, and splashes. Cleaning requirements are therefore greater with the GBT than for the RDS and centrifuge processes.
While the enclosed RDS process design permits a more favourable operating environment than GBT technology, polymer requirements are higher and there are fewer full-scale experiences with the RDS technology in secondary process sludge thickening applications compared with the GBT or centrifuge technologies although a RDS process has been operating successfully at the Barrie WWTP for eight years. It is therefore recommended that pilot plant testing of the RDS process be conducted to confirm the high anticipated performance capabilities. This would generate useful information for consideration in the design of the full-scale separate secondary process sludge thickening system.

The following is a description of the mechanical thickening processes that are most suitable for municipal WWTP biological sludge processing applications.

Centrifugation

Centrifuge thickening systems use a centrifugal force of up to 3000 G to increase the driving force for solids and liquid separation. Decanter centrifuges are compact devices that utilize a rotating cylindrical bowl with a truncated cone-shaped end for solids/liquid separation, with separated solids being conveyed to the discharge end of the device by an internal auger. Centrifuges can thicken biological sludge with or without polymer. The use of polymer increases the solids capture efficiency and thickened sludge solids concentrations. Automatic adjustment of the differential speed between the bowl and conveyor is possible, which is based on dry material loading (i.e., torque dependent), for the control of discharge solids concentration. Maintenance and electrical power costs for centrifugation systems can be substantial, therefore, these processes are mainly applicable at larger WWTP (i.e., 20 MLD or greater) where space may be limited and skilled operators are available (Metcalf & Eddy, 1991).

Gravity Belt Thickening

Gravity belt thickening uses a slow moving fabric belt to separate sludge solids and free water by gravity drainage and capillary suction forces imparted by the fabric's interstitial voids. Polymer is required to precondition the sludge, and is prepared and aged in a small tank upstream of the thickening process. The conditioned sludge enters a feed/distribution box from where it is evenly distributed across the width of the moving belt. Sludge thickening on the device is aided by multiple rows of plows and drainage elements which slow the flow of sludge and provide additional retention time over the horizontal gravity belt. After the thickened sludge is removed, the belt travels through a wash cycle.

Rotary Drum Screening

Rotary drum screen thickeners are internally fed with dilute sludge from a headbox after conditioning with polymer. The suspension is distributed onto the internal surface of the rotating screening cylinder and physically strained for the separation of free water. The cylinder can be fitted with interchangeable screening panels and is slowly rotated (e.g., 2-10 rpm) with a variable speed drive electric gear motor. Separated solids are retained on the surface of the screen and are conveyed to the discharge end of the unit where they drop out through a chute. The RDS process has a built-in spray backwashing system controlled with programmable timers that can be optimized for each application. The rotational speed of the drum can be adjusted and optimized based on site-specific operating requirements to achieve the desired levels of thickened sludge concentration, solids capture efficiency and polymer consumption. The system can be supplied as an enclosed unit with a vent stack for containment and minimization of odour and vapour releases.

4.2 Digestion Options

The Brockville WPCC already utilizes anaerobic digesters to stabilize the sludge and reduce its mass (i.e. volatile solids reduction). The plant's mesophlic anaerobic digesters are operating well and should be adequate for future design loadings with secondary sludge.

A number of potential optimization measures and retrofit options have been identified for possible application at the Brockville WPCC for improved biosolids processing. These will address the potential areas of concern which include primary digester capacity limitations (although marginal) at future loading conditions with regard to hydraulic retention time, and volatile solids (VS) loading rate with secondary sludge. The alternatives for consideration are:

- No process upgrading; improvements limited to clean-out and inspection of primary digester,
- Improve heating system and possibly the mixing system,
- Improve primary clarification process,
- Separate mechanical thickening of secondary process sludge,
- Install a new mesophilic anaerobic primary digester,
- Install provision for digested sludge separation and recirculation at primary digester,
- Convert primary digester to thermophilic anaerobic mode,
- Upgrade to dual digestion, including pre-treatment with autothermal aerobic digestion.

Digestion processes that are operated at thermophilic temperature conditions, such as theromophlic anaerobic or autothermal aerobic, can achieve enhanced stabilization and disinfection and, depending on the treatment time and process configuration, can potentially produce Class A quality biosolids based on U.S. EPA regulatory criteria. The U.S. EPA regulations designate biosolids as "Class A" or "Class B" in regard to the level of pathogens. If pathogens are reduced to below detectable levels, the biosolids meet Class A designation allowing for unrestricted use on lands. There are detectable quantities of pathogens in Class B biosolids, but these have been reduced to levels that do not pose a threat to public health and the environment. Class B biosolids may be used in a land application programs with some restrictions to allow natural processes to further reduce pathogens in the biosolids. The last two options noted above operate at higher temperatures and could potentially produce a Class A biosolids that may be a benefit to the City for future regulatory and/or land use issues.

<u>No Additional Process Upgrading</u>

This option would involve the continued use of the two primary anaerobic digestion process for sludge stabilization. The average retention time currently provided by the primary digester is about 42 days and the process is operating well. The measured VS reduction efficiency of about 49% (raw primary sludge only) in the primary digester, which is within the typical levels of 40-50% expected for mesophilic anaerobic digesters.

However a constraint with current operations is the impact of no secondary digester or on-site storage for dewatering system downtimes and liquid biosolids storage for a partial land application program. A new third digester (secondary) or storage tank would assist with optimizing operations at the facility.

Improved Heating & Mixing Systems

Under this option, the existing primary digester would be evaluated and enhanced if needed by the installation of additional heat exchanger capacity to enhance performance. The installation of a new boiler with improved automated control features would also be considered in order to provide additional heating energy for the digestion process. These measures may not be necessary as the current digester temperatures are good.

The existing gas mixing system (i.e., by compression, recirculation and injection of biogas) may require upgrading. This could be further determined by undertaking a tracer test to confirm digester mixing adequacy. The possible augmentation of mixing could involve sludge recirculation pumping, expansion of the existing gas mixing system, and/or confined draft tube mixers.

Chopper pumps should be considered for sludge recirculation to reduce the potential for line plugging which has recently plagued system operations.

Improvement of Primary Clarification/Thickening Process

Generally, if the primary clarification process is improved to increase the concentration of settled sludge to be pumped to the primary digester, this would achieve a corresponding increase in the hydraulic and solids retention times within the primary digester, at a given solids loading rate, for a potentially enhanced degree of stabilization. There may not be much of an opportunity to improve the primary clarification process at the Brockville WPCC as it has been subject to previous optimization and other review efforts.

Separate Thickening of Secondary Process Sludge

One method to increase the raw sludge concentration and capacity of the existing sludge digestion system would be to separately thicken the secondary process sludge stream rather than co-thickening in the primary clarifiers. Solids concentrations of both the secondary process sludge stream and the raw primary sludge stream can be substantially increased by utilizing this enhanced sludge pre-thickening method, with resultant significant increases in primary digester HRT. Control of primary sludge pumping from the primary clarification stage to the digestion stage could offer further potential for maximizing the overall concentration of raw combined sludge.

As summarized in Section 3.1, there are numerous other potential advantages associated with separate mechanical thickening of secondary process sludge at the Brockville WPCC. This includes reduced heating requirements, a reduction or elimination in supernatant return from the anaerobic digester to the liquid train and reduced haulage.

Installation of New Anaerobic Primary Digester

Rather than risk operating the existing digesters at elevated loadings, a new primary digester could be installed in parallel with the existing digester. A new feeding and gas collection system would have to be installed and overall capital cost for construction would be relatively high.

Provision for Digested Sludge Separation & Recirculation at Primary Digester

Installation of a solid/liquid separation stage following the primary digester would allow for recirculation of settled digested sludge back to the reactor. Hydraulic and solids retention times would be decoupled in this anaerobic contact process configuration. This would result in reduced digester HRT requirements and potentially increased process stability. The solid/liquid separation stage could incorporate either sedimentation or flotation of digested sludge solids. Digester sludge concentrations would be increased, potentially requiring increased digester mixing.

Conversion of Anaerobic Primary Digester to Thermophilic Mode

An innovative upgrade option would involve the conversion of the existing mesophilic anaerobic primary digester for operation in thermophilic mode. This would result in increased digestion capacity through markedly higher biological reaction rates, permitting lower HRTs for sludge stabilization. Destruction of volatile solids and pathogens would be superior, with the potential for achieving a Class A sludge biosolids if a temperature of at least $53^{o}C$ is consistently maintained.

Installation of a new roof, insulation and increased heating and improved temperature and feed control would be required. This would require a detailed engineering review to determine if the concept were structurally and technically feasible with the existing digesters. Enhanced pre-thickening of raw sludge would not be necessary. Odour potential would also increase with this option.

Upgrading to a Dual Digestion Process

This upgrade option would involve the addition of a small autothermal aerobic digester (ATAD) upstream of the existing mesophilic two-stage anaerobic digestion system. This compact first stage autothermic reactor would be designed for a short one-day HRT and would rely on either air or pure oxygen for partial oxidation of the raw combined sludge. Process temperatures of 50-65^{o}C could be achieved through the exothermic reactions, providing that influent sludge solids concentrations are at least 3%. The dual digestion system would not require heating so increased amounts of surplus anaerobic digester biogas would result for use elsewhere (e.g., co-generation of energy). HRT requirements in the anaerobic primary digestion stage can be reduced to 8-10 days for effective overall sludge stabilization and anaerobic process stability would be improved. Improved overall VS destruction and reduced stabilized sludge odour are claimed. Another benefit of the dual digestion process is the pasteurizing effect of the first stage which would result in a higher quality digested sludge, and potentially a Class A biosolids .

4.3 Dewatering Options

The Brockville WPCC could continue with its centrifuge dewatering and expand as necessary or consider a liquid biosolids program or alternative dewatering options (e.g. belt presses).

Dewatering is the physical process by which water is separated and removed from undigested sludge or biosolids (i.e., stabilized sludge). As a result, a relatively low-volume cake is produced to facilitate hauling or further processing. The dewatered cake behaves more as a solid which reduces the cost of subsequent treatment, handling, and disposal.

In certain cases, dewatering is a prerequisite for further sludge/biosolids processing. Composting, drying, incineration, certain alkaline stabilization processes, and monofill disposal, for example, require a dewatered influent cake.

Dewatered biosolids require significantly less storage volume, reducing the strategic storage requirements during wet weather conditions in the City.

For any dewatering application, the following considerations will determine the selection and sizing of the most appropriate process:

- Type of sludge (i.e., primary and/or secondary solids, type of secondary treatment process solids, degree of stabilization, if any).
- Characteristics of the influent sludge/biosolids (i.e., solids concentration and flow rate),
- Amount of required conditioning chemical (i.e., primarily polymer),
- Required solids concentration of the dewatered cake.

- Space availability for the dewatering system.
- Final utilization/disposal processes and routes.

For a dewatering method to be cost effective, its compatibility with the plant size, sludge treatment process and utilization or disposal routes available must be investigated. Consideration should be given to sludge/biosolids type and other site-specific variables including wastewater and sludge treatment processes. The effects of sidestreams (e.g., filtrate or centrate) on the wastewater treatment system should be considered. Suspended solids recovery efficiency of greater than 95% is an important design objective to prevent excessive recycle loads to the WPCC liquid train.

There are a number of benefits associated with dewatering, especially in the case of stabilized biosolids. The dewatered cake solids concentration achievable will influence the cost of downstream biosolids management operations. The costs of hauling dewatered biosolids to a final utilization or disposal site are substantially reduced and the handling of a dewatered product is generally easier. Following dewatering, the cake can have the properties of a solid. Manure spreaders can be used for land application.

The processes used to dewater sludge can be divided into two categories, mechanical and air-drying. Mechanical dewatering is more capital intensive and applied mainly at medium to large sized WWTPs, while air drying is used at smaller plants that have available land. Benefits associated with mechanical dewatering include compactness, aesthetics, insensitivity to climate, and reduced hauling costs.

Mechanical methods include:

- Vacuum filtration
- Centrifugation
- Belt press filtration
- Filter presses

Air-drying processes include:

- Drying beds
- Sludge lagoons

The following paragraphs give a description of the mechanical and air-drying processes used to dewater municipal wastewater treatment sludge. Although most mechanical dewatering processes are straightforward, variability in influent sludge/biosolids properties and incomplete understanding of their composition and behaviour makes it difficult to predict dewatering equipment performance (Spinosa and Vesilind, 2001).

Mechanical dewatering processes rely on the conditioning of the sludge/biosolids influent stream with chemicals (e.g., suitable polymer) to enhance cake solids concentrations, solids capture, and filtrate or centrate quality. The performance of some air drying processes can be improved by the use of polymers.

Additional information on dewatering process alternatives and design aspects can be found in USEPA (1987), Metcalf & Eddy (1991), and WEF & ASCE (1992 and 1998).

Vacuum filtration

In vacuum filtration a horizontal cylindrical drum rotates partially submerged in a vat of sludge. The drum is covered by a filter and is divided into compartments. Each compartment is sealed from its adjacent section and as a result three distinct process zones are formed: a cake formation zone, a cake *dewatering* zone and a cake discharge zone. A rotary valve connected to the different compartments controls the various phases of the cycle. Vacuum is applied on the downstream side of the filter media. Atmospheric pressure exerted on the upstream side of the filter forces the liquid to move through the pores. To enhance solids capture, the sludge/biosolids influent is conditioned with lime, ferric chloride or polymers.

Although vacuum filtration has been very popular for the past 60 years its use for sludge dewatering has declined. The main reasons have been the development of alternative mechanical dewatering processes and the high operating costs and maintenance problems associated with vacuum filtration.

Yield is the most common measure of vacuum filter performance. It is expressed as the cake dry solids mass discharge rate per unit filter surface area. Design values between 17 to 29 $kg/m^{2}\cdot h$ (Metcalf & Eddy, 1991; McFarland, 2000) are typical for anaerobically digested sludge.

Performance is easily affected by the characteristics of the sludge/biosolids stream being filtered, especially its solids content. The optimum feed solids content is between 6 and 8% dry solids (ds).

Vacuum filters typically produce cake with 15 to 20% dry solids content (McFarland, 2000) although higher values have been reported in the literature (Metcalf & Eddy, 1991).

Centrifugation

In centrifugal dewatering of sludge/biosolids the separation of solids and liquid is achieved by the G-force developed by a rotating cylindrical drum or bowl.

Two types of centrifuges exist for dewatering of sludge/biosolids: the imperforate basket centrifuge and the solid-bowl centrifuge. The most commonly used type for sludge/biosolids applications is the high-speed countercurrent solid-bowl centrifuge. The following paragraphs will focus on this particular type of centrifuge.

In a solid bowl centrifuge, influent sludge is continually fed into a rotating bowl, which contains a screw-type conveyor or scroll. In countercurrent centrifuges the bowl and scroll rotate in opposite directions and at different speeds. Sludge enters the centrifuge via a stationary pipe, which extends to the center of the centrifuge. Under the influence of centrifugal forces (i.e., up to 3000Gs) the solids are pushed against the outer walls of the centrifuge and are then transported by the scroll towards the cake discharge end. The reject water, or centrate, flows to the opposite end of the unit.

Centrifuges are compact machines that have to perform three functions: produce a clarified effluent (centrate), produce a dry cake and convey the cake along the bowl to the discharge port.

The dimensions of a centrifuge affects its performance. Increasing the diameter increases capacity and clarification, while increasing its length increases clarification (i.e., solids capture efficiency).

- The beach angle and the pool volume, which control the amount of sludge held inside the unit affect cake moisture, centrate quality and conveyor capacity for the solids.
- The differential speed between the scroll and the bowl, which is normally controlled by varying the scroll speed, determines the rate of solids removal by the scroll. It affects cake dryness, solids recovery and centrifuge throughput.
- The G force exerted on the sludge/biosolids particles is controlled by the bowl speed. Low and high G-force centrifuges can be used.

Pilot scale testing with the intended sludge/biosolids stream can be used to develop design parameters.

Centrifuge performance is measured by the cake dry solids content produced and the centrate quality. Depending on the type of sludge processed a centrifuge can produce cake of up to 30 to 35% dry solids (Metcalf & Eddy, 1991; WEF & ASCE, 1992). The type and origin of sludge (e.g., type of secondary treatment process and/or stabilization process) has a direct effect on capacity, cake solids concentration, and polymer requirements.

In the past, solids recovery rates have been quoted as being problematic; however, the use of polymers and automatic control systems has allowed centrifuges to achieve greater than 95% solids capture efficiency.

Belt press filtration

In belt press filtration, sludge is compressed between two tensioned porous belts passed over various diameter rollers. Although many different designs of belt presses exist, all include the following components: polymer conditioning zone, gravity drainage zone, low-pressure zone and high-pressure zone.

The conditioned sludge/biosolids stream is introduced to the gravity drainage zone where it is thickened by the gravity drainage of free water. Following this, the sludge is squeezed between porous cloth belts in the low-pressure zone and subsequent high-pressure zones, where additional water is removed.

A typical belt filter press systems consist of:

- Sludge/biosolids feed and conditioning system (feed pumps, polymer feed equipment, conditioning tank)
- Belt filter press with dewatering belt(s)
- Cake conveyor and hopper
- Support systems and equipment (automated control system, wash water system)

Belt filter presses are sized based on belt width. These vary from 0.5 to 3.5 m, with 1 to 2 m belts most typical for municipal WWTP applications. Influent loading rates vary from 90 to 680 kg/m·h dry solids and hydraulic throughput ranges from 1.6 to 6.3 L/m·s (Metcalf & Eddy, 1991). Typical feed solids range from 1 to 8% ds, depending on sludge origin. Depending on the feed solids concentration, belt press capacity is either hydraulically or solids loading limited. Expected cake solids may vary between 12 to 40 % ds (USEPA, 1987; Metcalf & Eddy, 1991) and are typically between 15 to 30% ds with 80 to 95% solids capture for dewatering of digested biosolids (WEF & ACSE, 1992).

In belt filter presses a control system is incorporated for automatic start-up and shut-down under normal operating conditions and in emergencies. A high-pressure wash system is required for belt washing to ensure good performance. The flow rate required for belt washing is normally 50 to 100 percent of the influent sludge flow rate, and the combined filtrate and belt wash water is normally 1 to 1.5 times the incoming sludge flow quantity.

Cationic polymers are used in most cases to condition the sludge prior to its introduction to the belt filter press. Several polymer feed points are typically provided. This allows different polymer-sludge contact times in case sludge characteristics change.

Performance of belt filter presses are greatly affected by feed characteristics. The most important operational parameters affecting performance are:

- Polymer type and dosage; proper sludge/biosolids conditioning with polymer is crucial
- Belt speed which affects cake solids content; lower speeds result in higher solids content and higher solids capture for a given polymer dosage
- Belt tension; higher belt tension produces a drier cake but reduces solids capture
- Effective belt washing.

The following problems have been encountered in full-scale applications:

- Sludge escaping from between belts
- Clogging of belts
- Odours.

Optimal belt tension and speed will prevent the problem of sludge squeezing out from between the belts. Odour control can be achieved with high rate ventilation, scrubber systems or chemical dosing. If chemical dosing is implemented for odour control it is advisable to introduce the chemical upstream of the influent pumps which can act as mixers.

Filter press

Pressure filter presses consist of a series of plates each with a recess. Sludge/biosolids are pumped under high pressure into the plate recess. The plates are covered with filter media, which allows filtrate to pass through under driving pressure. The process is operated in a batch-wise manner and produces a relatively dry cake of greater than 35% dry solids. Two types of filter presses are most commonly used in the wastewater industry: the fixed-volume recessed plate filter press and the variable-volume recessed plate (i.e., diaphragm) filter press.

The Elmira WWTP (Region of Waterloo) uses a filter press for dewatering of chemically stabilized (lime) biosolids for dedicated landfill disposal.

The most important design parameters for filter presses are the required solids concentration in the cake, the feed sludge throughput rate and the solids capture efficiency. Their performance is affected by:

- Solids content in the feed sludge/biosolids
- Conditioning chemical dosage
- Cake solids content
- Total cycle time
- Solid capture efficiency

With filter presses, increased cycle time results in higher cake solids content. Solids recovery to levels above 95% should be a design objective. Lower solids capture may be the result of a torn filter cloth or sludge adhering to the filter and being washed off and recycled in the wash water. If increased washing is used to increase filter performance, re-circulation of fines back to the wastewater treatment works can occur which can result in process problems.

Control levels vary from manual to fully automatic. However, operator attention is required during the sludge discharge phase to make sure that the cake is separating from the filter medium.

Air Drying Processes

Drying beds belong to the air-drying method of sludge/biosolids dewatering. Water removal is achieved through natural evaporation and gravity or induced drainage (USEPA, 1987). Energy costs are lower than for mechanical dewatering processes. Increased odour difficulties result from applications of undigested sludge.

There are several types of drying beds such as conventional sand drying beds, paved drying beds, vacuum assisted drying beds and artificial media beds. These systems are most appropriate for arid climates although they can be covered. Space requirements for air-drying processes are significant and sufficient land is not available at the Brockville WPCC for this process.

Sludge lagoons can be used for dewatering stabilized biosolids if adequate land is available. Water removal is achieved primarily through evaporation. If substantial amounts of supernatant are generated by thickening, decanting may be practiced. A distinction must be made between sludge drying lagoons and sludge storage lagoons (USEPA, 1987). There are certain limitations in the application of dewatering lagoons. Untreated sludge is not suitable for lagoon application. Proximity to a groundwater aquifer may impose application restrictions and the requirement for lagoon lining.

Biosolids are applied in a manner that ensures even distribution across the lagoon. Sludge depths are typically 0.75 to 1.25 m (Metcalf & Eddy, 1991). Supernatant decanting lines are often incorporated in the design. Dewatered solids are removed mechanically by front-end loaders, bulldozers or draglines. Typical solids content of the dewatered biosolids is 25 to 30%. Solids loading rates range from 36 to 39 $kg/m^{3}\cdot yr$ and the cycle times may be several months to years.

Maintaining the retaining dykes and controlling dyke vegetation are the main maintenance requirements. Again, space requirements for lagoon drying processes are significant and sufficient land is not available at the Brockville WPCC for this process

5. Review of Sludge Handling Options

This section provides a review of the sludge handling options to address the additional sludge generated by the secondary treatment processes to be added to the facility. The status quo for the secondary treatment addition would be to maintain the existing solids handling and existing equipment and would include:

- Primary clarifier co-thickening of biological sludge prior to digestion. For all secondary processes except for the BAF and the MBBR concepts this would be possible and loadings would be within typical MOE guideline limits. The BAF produces a low strength backwash or waste stream that would require additional primary clarifier capacity and a cost for this clarifier has already been added to the secondary treatment process review (i.e. TM3). The MBBR concept does not include primary clarifiers; the process sludge is handled once with some form of separate gravity settling (secondary clarifiers) or mechanical thickening following the MBBR reactors.

- The existing digester capacity is adequate for current flows and may be adequate at future flows with secondary sludge added, but some optimization to ensure enhanced mixing and heating may need to be considered. Loading at design with secondary sludge would slightly exceed MOE typical design guidelines.

- Dewatering can be accomplished either solely or in conjunction with a liquid sludge land application program. The existing centrifuges may not be appropriate for combined raw and biological sludge and have a historical record of high maintenance and rebuild costs. A review of other dewatering technologies recommended either centrifuges or belt presses for the plant – these two processes are further evaluated below.

5.1 Biological Sludge Handling Options

The cost of co-thickening the biological sludge generated by the new secondary processes is expected to be minor, in terms of the cost of operating the primary clarifiers only, compared to continued use of these primary clarifiers for raw sludge only. This would not be the case for the BAF or MBBR processes as indicated above. The main advantages of separate mechanical biological sludge handling are:

- Increased primary clarifier capacity for handling wet weather or CSO flows at the WPCC

- Increased sludge concentration in the anaerobic digesters both by maintaining the current primary sludge concentration and increasing the biological sludge concentration, this will potentially increase the capacity of the digesters by increasing the HRT

- Increased digested sludge concentration thus reducing haulage costs for land application and/or increasing the feed concentration to dewatering.

The benefit to the City for these advantages depends on their importance to the City.

In terms of mechanical thickening, three processes have been short listed, including centrifuge, gravity belt thickening (GBT), and rotating drum screen (RDS). A summary of expected performance levels, operational characteristics, and preliminary capital cost estimates (equipment cost only) for the different mechanical thickening processes is shown in **Table 6**. In sizing the GBT, RDS, and centrifugation processes, a WAS processing period of 7 hours per day and 5 days per week, corresponding to a required hydraulic throughput rate of 80 m^3/h, is assumed. The WAS generation rate of 540 m^3/d with 0.50% total solids content is considered typical of a WWTP with a design average wastewater loading rate of 21,800 m^3/d.

The information in **Table 6** can be used as a basis for a preliminary comparison of the process. Performance data should be confirmed with on-site pilot-scale.

TABLE 6:
Performance and Capital Cost Information for Alternative Waste Activated Sludge Thickening Processes

Parameter	GBT	RDS	Centrifuge
Capture rate (%)	95 – 98	96 – 98	95 – 98
Expected dryness (%)	4 – 8	4 – 8	6 – 8
Polymer consumption (g/kg)	2 – 5	3 – 7	2 – 6
Maximum firm capacity (m^3/hr)[1]	80	80	80
Cost ($) Equipment Unit Only[1]	$360,000	$360,000	$1,450,000

Notes:
1. Capacity and pricing are based on systems with redundancy to allow for maintenance or failure of a single unit,

The RDS process has a lower capital cost and offers a somewhat better operator environment than the GBT process since the former can be installed as a fully enclosed unit with provision for off-gas venting. This advantage is similar to that of the contained centrifugation process. However, objectionable odours would not be expected in the processing of waste activated sludge on the exposed moving belt of the GBT process, although this observation may be site specific. Odours with fixed film processes (i.e. RBC) have been noted elsewhere. The GBT process has a greater number of proven full scale applications than does RDS and requires lower amounts of polymer. The increased polymer consumption by the RDS process is due to a greater tendency of the flocculated sludge particles to break apart by the shearing action of the rotating drum.

The cost of the building to house the thickeners is considered to be equal for all choices. Although there is a slight difference in the size and number of units required for each process, it is negligible when considering the entire building, which would house both thickening and dewatering processes as well as polymer storage, electrical equipment, conveyors and a loading bay. HVAC design for each option will also not differ in terms of pricing. Although centrifuge and RDSs are more contained and produce less odours than GBTs, the HVAC unit size is generally chosen to allow ten air exchanges per hour, which will allow sufficient air exchanges for all thickening options.

Based on an assessment of the various identified cost, performance and operational factors, the RDS processes has been identified as the preferred option for possible application at the Brockville WPCC. This is reflected by the life cycle costing shown in **Table 7**, where the RDS had the lowest life cycle cost. Life-cycle costs were based on capital costs and main O&M costs. Main O&M costs were assumed to be polymer usage and electrical costs.

Life cycle costing of items that differentiate each process favours the GBT and RDS processes. These two processes have a life-cycle cost under 1 million dollars, whereas the centrifuge process is above 2 million. The GBT and RDS life cycle costs are within 15% of each other, and this difference will be reduced when building costs are added in. The RDS has advantages in terms of a better operator environment, since this process is enclosed, whereas the GBT is not. Therefore, based on the assessment of various identified cost, performance and operational factors, the rotating drum screen (RDS) process is recommended as the preferred alternative for mechanical thickening of the WAS at the Brockville WPCC.

TABLE 7:
Life Cycle Costs for Waste Activated Sludge Thickening Technologies

Parameter	GBT	RDS	Centrifuge
Equipment cost ($)	$360,000	$360,000	$1,450,000
O&M cost ($/year)	$32,050	$40,660	$46,290
Present Value of O&M ($)	$471,050	$598,030	$680,840
Net Present Value ($)	$831,050	$958,030	$2,130,840

5.2 Digestion Options

The existing two primary digesters should be sufficient to maintain adequate solids stabilization to meet current and future requirements. Optimization of the digesters should be undertaken to enhance their performance and ensure adequate stabilization at increased loadings. Optimization could include a tracer test to evaluate short-circuiting and dead-spots in the digesters. Digester cleanouts, enhanced mixing and inlet modifications may all be recommended to enhance these digesters and ensure adequate stabilization for future loadings, with secondary sludge.

Other options reviewed in Section 3.2 may be considered as part of an overall solids handling strategy for the City, in particular to meet more stringent biosolids needs. For example, although not required, a EPA Class A sludge could be produced by providing additional digester capacity, converting to thermophilic or upgrading to a dual stage digestion process.

Since none of enhanced digester upgrade options are necessary at the current time to handle the future secondary treatment process sludge, except perhaps optimization, no costing of alternatives has been undertaken. However the flexibility of having a third digester to act as a liquid storage tank or dewatering feed tank was deemed to be beneficial for the operation of the solids handling process. The budget cost for a third digester with a volume of 1,500 m^3 is estimated at approximately $2.5 million.

5.3 Dewatering Options

The Brockville WPCC can currently either dewater using centrifuges or haul liquid digested biosolids for land application. Future needs to handle both primary and biological sludge will increase the dewatering and type of dewatering equipment required. This comparison is based on an evaluation of the two short-listed dewatering processes for Brockville: centrifuge and belt press. A cost comparison was created for these two options and can be seen in **Table 7**.

TABLE 7:
Summary of Performance and Polymer Costs

Parameter	Belt filter press	Centrifuge
Dewatered solids concentration (% ds)	25	30
Polymer dosage (kg/dry tonne)	6	7
Maximum capacity (m^3/hr)	20	20
Cost ($) equipment cost only[1]	$550,000	$1,000,000

Notes:
1. Capacity and pricing are based on systems with redundancy to allow for maintenance or failure of a single unit.

Life-cycle costs were based on capital costs and main O&M costs. Main O&M costs were assumed to be polymer usage and electrical costs. Results are shown in **Table 8**. The belt press has a lower life-cycle cost based O&M costs reviewed and capital cost of equipment. Similar to the thickening evaluation the cost for the building modifications and feed equipment is expected to be the same for both processes.

The WPCC currently has a centrifuge dewatering building and this building may be difficult to retrofit for filter presses, making the centrifuge option more attractive. However there are two outstanding issues:

- Odour issues have been observed with high-speed centrifuges dewatering combined raw and biological sludges. This observation has been noted at some sites and has resulted in an odourous cake that becomes an issue requiring onsite handling and problems if land applied.

- Cake haulage costs will be greater for the belt press based on the expected cake concentrations. At a 25% cake concentration it is estimated that 13,300 Wet kg/d will be produced. At a cost of $85 per tonne for disposal (transport and disposal) a yearly cost of $293,500 is determined. Assuming a linear relationship the cost for a 30% cake would be $244,600 per year. This yearly savings of $48,900 or ammortized saving of $719,500 over the 20 year period would be credited to the centrifuge process.

TABLE 8:
Life Cycle Costs for Sludge Dewatering Technologies

Parameter	Belt Press	Centrifuge
Equipment cost ($)	$550,000	$1,000,000
O&M cost ($/year)	$89,220	$114,200
Present Value of O&M ($)	$1,312,260	$1,683,420
Net Present Value ($)	$1,862,260	$2,683,420

Therefore, either process could be utilized for dewatering at the facility. The belt press unit appears to have a lower capital and life cycle cost, but will potentially require additional haulage costs that will make the life cycle costs closer. The plant also has an existing centrifuge building that can be retrofitted more easily for new centrifuges than for filter presses. A review of the ability of the existing centrifuges to handle a combined sludge as oppose to the raw sludge they are currently handling and upgrading accordingly may also be a cost effective means to dewater at the site, especially if the land application of liquid sludge can be continued.

6. Conclusions

The solids handling requirements at the Brockville WPCC are an important consideration due to various impacts, including a direct future loading increase due to the secondary sludge produced from any of the options recommended. A secondary treatment process and its secondary sludge will potentially double the sludge production at the plant.

The secondary sludge can be either co-thickened in the primary clarifiers or thickened separately with mechanical thickening devices. The BAF would require an additional primary clarifier to handle the low strength waste stream and this has been accounted for in the secondary process review. The MBBR process would not have primary clarifiers and separate gravity or mechanical thickening would be required, the rotating drum screen (RDS) process is recommended for this. All other processes could be provided with separate mechanical thickening, and the benefits for this have been outlined above. If separate mechanical thickening is considered for any of the secondary processes, except the BAF, the RDS system is recommended, as it provides similar life cycle costing to the GBT and an enclosed environment.

The anaerobic digester capacity should be adequate with the addition of secondary sludge, although loadings will slightly exceed current MOE design guidelines. Optimization in terms of mixing and heating should ensure the process continues to provide adequate stabilization. The provision of a third digester to optimize operations and flexibility in terms of dewatering and liquid biosolids storage is recommended.

Either centrifuge or filter press dewatering can be used for dewatering solely or in connection with a liquid biosolids application program. The filter press process was deemed to be more cost effective, but will produce a less concentrated cake that will increase haulage and disposal costs. If a combined dewatering and liquid sludge application strategy is to be continued in the future, refurbishing and expanding the existing centrifuge process at the plant would potentially be the most cost effective option – especially if the utilization of a liquid biosolids application program is optimized. This is the case as a liquid biosolids application program is generally the most cost-effective method for handling biosolids. Lastly, although building modifications were not reviewed, the existing centrifuge dewatering building is expected to be more economically retrofitted for either an expanded or replaced centrifuge operation as opposed to installing filter presses. As such centrifuge dewatering with continued liquid biosolids application as much as possible is recommended. This dual-solids handling program has the advantage of being economical and reliable since it provides two means of handling the biosolids from the plant.