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REPORT ON THE DEVELOPMENT OF ENERGY CONSUMPTION GUIDELINES FOR WATER/WASTEWATER

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EXECUTIVE SUMMARY

In 2002, “Wisconsin Focus on Energy,” (***Focus***) invited proposals to “benchmark” energy consumption at water and wastewater utilities in Wisconsin. The desire was to establish a baseline of how our utilities - both public and private - have been consuming energy as compared to the rest of the world. Upon completion of a search of USA literature/documentation it was clear that existing guidelines were not well defined nor documented therefore, ***Focus*** developed a proposal to develop guidelines as well as benchmark. Both tools will provide designers and reviewers the necessary tools to evaluate long term operating costs.

Awareness of energy consumption has been increasing in the US and world markets have certainly tightened in supplies. Competition for world reserves of energy have continued to escalate as energy rich nations continue to attempt to restrict supplies, driving prices ever higher.

The world has become sensitive to “consumption” to the point where conservation of resources becomes not only economically viable, politically correct but the right thing to do.

Energenecs - historically an interface amongst designers, builders, and users of equipment proposed to engage our field service experience in determining actual field values for energy consumption at water and wastewater utilities. We teamed with two leading forces in our field of endeavor McMahon as a consulting engineer with broad design/integration experience; and, WRc a water research center with world experience in benchmarking studies.

The outgrowth of this study is embodied in the attached detailed report. It represents considerable personal commitments beyond the scope of this contract. In this regard, I believe we owe a great debt of gratitude to our partners in this study - those who have spent extended hours in making this work a reality:

> **Chad Olsen, P.E.** of McMahon Associates for his consistent and persistent review of the data and for his insight into the process nuances which only a true environmental engineer could garner.
>
> For **Jared Feider, E.I.T.,** for his persistent work in both field measurements and in coordination of the data transfer - a monumental task in light of the intercontinental bridge required to bring this report to reality.
>
> And **David Landon** of WRc for his understanding in repetitive requests for multiple copies of data which seemed to disappear in transmittals between continents.
>
> We wish to extend our deep appreciation to **Joe Cantwell, P.E.,** for his unending patience and continued input in review and completion of this contractual report.
>
> Finally we extend our appreciation to **Focus on Energy** for their recognition of the need and value for this study to establish the awareness of the baseline water/wastewater energy consumption in the State of Wisconsin and also the unprecedented development of energy guidelines for designers to use in designing new facilities and to operators to compare their energy consumption.

We hope that the comprehensive body of knowledge offered herein is of value to all parties - from designers to regulators to owners/operators to rate payers of wastewater and water utilities.

Don Voigt, P.E.
President, Energenecs

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SUMMARY

I OBJECTIVES

The objectives of the study are:

- To develop design guidelines for energy efficient design practices in:

  Water treatment facilities, storage and distribution systems;
  Wastewater treatment facilities, conveyancing and collection systems.

- To develop recommendations for inclusion of energy efficiency components into design practices review in the state if Wisconsin.

II REASONS

Wisconsin Focus on Energy wishes to establish a set of design practice guidelines that exemplify energy-efficient options in the design of water and wastewater facilities. It is intended that these guidelines can be used in the design and design review of water and wastewater facilities to encourage the inclusion of energy-efficient practices in associated projects.

IV RECOMMENDATIONS

Recommendations specific to individual plants have been made within the report. This summary contains only Wisconsin-wide recommendations.

- When motors have reached the end of useful life, in most applications they should be replaced with premium efficiency motors.
- Pump scheduling should be optimized to ensure that the most efficient combination of pumps is selected for the particular flow/ head conditions.
- When selecting a pump, the correct pump size for existing flows should be specified. Future flows should be handled by increasing the impeller size of existing pumps, and/or installing additional pumps as necessary.
- In situations where it is operationally possible, machines should be selected to run during periods of off-peak electricity tariffs.
- Where on-site power generation is available, the economics should be explored of using this during periods of peak electricity tariff.
- Install electronic variable speed drives on the motors of pumps and blowers where reduced-flow operations are frequently required.
- Install dissolved oxygen monitoring and control to increase the aeration efficiency of activated sludge wastewater plants.

- Consider improving the aeration efficiency of activated sludge wastewater plants by upgrading the means of aeration, for instance by using fine bubble aeration.

- Where anaerobic sludge digestion takes place at a site, utilize the biogas to produce combined heat and power, or as a fuel for the heating boiler. At the very least, methane in the biogas should be destroyed by burning in a flare stack before discharge of the wastegas to the atmosphere.

V RESUMÉ OF CONTENTS

Energy and process studies have been undertaken at a range of water and wastewater facilities in Wisconsin. The performance of the plants has been benchmarked against each other and against performance of similar plants in Europe. Guidelines have been developed for energy-efficient utilization, design and specification for treatment unit processes.

1. INTRODUCTION

1.1 Background

Wisconsin Focus on Energy wishes to establish a set of design practice guidelines that exemplify energy-efficient options in the design of water and wastewater facilities. It is intended that these guidelines can be used in the design and design review of water and wastewater facilities to encourage the inclusion of energy-efficient practices in associated projects.

In order to minimize its costs, a utility must look to improve the efficiency of its operations. Energy is responsible for a major portion of a water utility's cost. The first step in achieving an improvement in efficiency is to evaluate the actual recent and current energy costs. The second step is to realize the costs that might be achieved if the operations were running efficiently, and the third step is to understand reasons for any shortfall and to take steps to correct the situation. This project will compare actual with achievable energy costs and produce guidelines for the energy efficient design of new and refurbished works that will be used to reduce operating costs in the long term.

By bringing together the complementary skills of international benchmarking and technical benchmarking within the international water industry, the project plans to identify real efficiency savings.

1.2 Objectives

The objectives of the study are:

- To develop design guidelines for energy efficient design practices in:

    Water treatment facilities, storage and distribution systems;

    Wastewater treatment facilities, conveyancing and collection systems.

- To develop recommendations for inclusion of energy efficiency components into design practices review in the state if Wisconsin.

In essence, these objectives will be met by analyzing current energy usage and current process efficiency; establishing key performance indicators for comparison within Wisconsin and with European sites; and creating guidelines/benchmarks for energy usage on Wastewater and Water treatment plants.

1.3 Scope of Work

- Design and provide plant performance data sheets to be completed by the utility's staff with help from process experts.
- Energy usage of individual items of plant has been measured during technical visits by energy consultants.
- Analyze data for selected facilities to create a steady state computer model using WRc's Plan-It STOAT software and an energy balance.
- Analyze data to produce Key Performance Indicators (KPI). The values of KPIs for energy consumption of European utilities have been established in previous projects.
- Benchmark KPIs within Wisconsin sites and with European utilities.
- Provide guidelines for improvements in efficiency and performance.
- Provide guidelines for energy usage.
- Provide a copy of Plan-It STOAT software.

1.4 Structure of Report

The bulk of the detailed process and energy analyses undertaken within this project are provided within appendices to this report.

The findings of the study are recorded in the body of the report.

Brief details of the process and energy studies carried out are provided in Section 2 – Outline of Studies Undertaken.

The outcome of the process and energy studies is contained in Section 3 – Study Findings.

In Section 4 - Benchmarking, the findings for individual plants are compared with each other and with plants of similar size in Europe.

Section 5 – Guidelines, deals with those practices exercised in Wisconsin where there is room for improvement compared with practices outside America.

In Section 6 – Energy Usage Guidelines, guidance is provided on the installed power for commonly used machines in wastewater treatment processes.

This report contains six appendices that provide support information for the report's findings. The report may be read without reference to the appendices, but it is likely that any detailed investigation into the findings of the report will involve a visit to one or more of the appendices for support information. The appendices are:

Appendix A – Technical description of plan-It Stoat;

Appendix B – Energy related studies for each plant;

Appendix C – Process related studies for each plant;

Appendix D – Plant descriptions;

Appendix E – Benchmarking;

Appendix F – Glossary of terms.

2. OUTLINE OF STUDIES UNDERTAKEN

2.1 Energy Study

Details of performance of individual items of plant have been obtained during site visits. The following are of particular interest to the energy study:

- measured values of voltage and current;
- means of machine control;
- running times;
- duty (e.g. pump head, flow, speed);
- plant power factor
- energy bills
- energy tariffs

An energy model has been developed for each plant, the output of which indicates the expected energy usage of the whole plant and the percentage of the total consumed by each piece of equipment. This data can be used to assess the calculated energy used compared to billed energy and the performance of individual items of plant.

Large amounts of electrical energy are required by wastewater treatment operations, and 90% of electrical energy used within the water industry is used to drive electric motors. Aeration in activated sludge systems is particularly energy intensive and, to a lesser extent, so are sludge dewatering processes. Preliminary and primary treatment processes use less energy in comparison and detailed analysis of the power costs involved in such processes is usually considered to be not worthwhile.

2.2 Process Study

Where possible a computer model has been created for each of the plants under review.

Plan-it Stoat is a computer program that facilitates the conceptual design and planning for the construction, expansion, and modification of wastewater treatment facilities. This tool is not an expert system, but rather an interconnected collection of unit processes and tools that perform calculations or specific tasks that are essential to selecting, sizing, and siting wastewater treatment plants.

A functional description of the Plan-It Stoat software is provided at Appendix A.

For the purposes of this project, the software has been used to create a process model of each of the following plants:

- City of Ashland Wastewater Treatment Facility
- City of Burlington Wastewater Treatment Facility
- Grassland Dairy Products Wastewater Treatment Facility
- Green Bay Metropolitan Sewerage District Wastewater Treatment Facility
- City of La Crosse Wastewater Treatment Facility
- Papermill A Wastewater Treatment Facility
- City of Rhinelander Wastewater Treatment Facility

Plan-It Stoat cannot model the performance of the City of Portage Wastewater Treatment Facility (an RBC does not exist in Plan-It Stoat's suite of models) nor the Cities of Eau Claire and Kenosha Water Treatment Facilities (because they are water treatment plants). For each of these its process has been reviewed by an experienced process engineer using standard methods.

3. STUDY FINDINGS

This section contains the outcome of the study and analysis of the data collected for each of the plants. The findings for each plant are divided between energy-related issues and process-related issues. Where possible a Plan-It Stoat model has been created for a plant, and this has formed the basis for study of the process-related issues. Where it was not possible to create a Plan-It Stoat model, other means of assessing process requirements have been adopted.

Energy-related studies are attached at Appendix B.

Process related studies are attached at Appendix C

A description of each plant is attached at Appendix D

In the following process-related study, it was found that the aeration efficiency was less than expected for wastewater treatment facilities that utilize an activated sludge treatment process. Possible reasons for this are:

- The size of the aeration tank or ditch is inappropriate for the hydraulic loading;
- The aeration system is oversized for the duty;
- Over-aeration due to ineffective D.O. control;
- The tank or ditch geometry is not optimal;
- The biological process is ineffective;
- A chemical in the incoming sewage is causing a low alpha factor, leading to inefficient oxygen uptake;
- A faulty aerator, e.g. worn brushes or incorrect level of immersion;
- Inadequate mixing, leading to settlement of the mixed liquor at points within the tank;
- Incorrect metering of power or applied flow and load. (i.e. the aeration efficiency is actually higher than the information indicates).

In some cases it has been possible to identify some reasons why this should be the case for a particular plant, and this has been reported on a plant-by-plant basis below. Without a more detailed study it is not possible to identify all the reasons for any particular plant.

3.1 City of Ashland Wastewater Treatment Facility

3.1.1 Energy

The estimated total energy use is a very good fit to the measured total energy use, taken from an averaged value from electricity bills.

The following analysis relates to the notable uses of energy.

Aeration, both oxidation ditch and sludge, amounts to 79.4% of the total on-site energy. This is at the top-end of the expected range for this duty.

The jet pump for the sludge storage tank is responsible for 2.2% of on-site energy. There is associated energy from the aeration blower for the duty of mixing and aerating the sludge tank, but the proportion of air used for this compared with oxidation ditch duty is not advised and cannot be evaluated. The sludge tank is mixed and aerated with the purposes of preventing septicity and making the tank contents homogeneous for consistency of dewatering performance.

The belt press appears to be greatly oversized – requiring operation of only 10.5 hours per week to dewater the sludge. It might be considered better practice to dewater the sludge as it is produced, avoiding the need to store it for more than one day, thus saving energy by dispensing with the need for extensive mixing of the sludge storage tank.

3.1.2 Process Assessment

The Plan-It STOAT modeling indicates the following:

? The DO system implemented in June 2002 has the potential to approximately halve the energy consumption in the oxidation ditch.

? Without knowledge of the influent phosphorus concentration no estimate of the efficiency of usage of the aluminium dosing system can be made. Since no records of the aluminium dose have been supplied such a calculation could not, in any case, have been made. But monitoring these two – the dose and the influent phosphorus concentration – would allow an estimate of the necessary consumption to be made.

? The site should not nitrify during winter, given the data about wastage rates and sewage temperature. There is no data on the influent ammonia and it may be that during winter the high BOD is caused by de-icing chemicals, low in nitrogen; otherwise, we would expect the nitrogen load to also increase, so that the site records on ammonia removal would be suspect.

? There is scope, as indicated by EDI, to operate with only one oxidation ditch. However, there would be no real reduction in the energy requirements, other than through a reduction in the mixing energy.

? We calculated the aeration efficiency to be 0.89kg O_2/kWh, this is lower than would be expected for a jet air system and shows the plant is running inefficiently.

3.2 City of Burlington Wastewater Treatment Facility

3.2.1 Energy

The estimated energy use is a fairly good fit to the measured use, being within 3.16%.

The energy use is low compared to other Wisconsin plants.

The blowers that provide aeration to the activated sludge tanks are the principle users of on-site energy, utilizing 76.2% of the total on-site energy. This is at the top-end of the expected range for this duty, but there is no sludge dewatering following digestion so the other energy uses on site are low.

The digester-mixing compressor uses 3.8% of on site energy.

The sludge storage tank mixers use a total of 3.2% of the on site energy. These mixers are only run when the tank is being loaded out during the spring and summer.

This site has a combine heat and power plant installed, the plant has not been used since the acceptance of high strength industrial waste began. Facilities are provided to use the energy from the biogas for heating the digesters. If the biogas contains high levels of hydrogen sulfide or other problem gases then investigations should be carried out into the possibility and cost of installing a gas scrubber.

3.2.2 Process Assessment

The Plan-It STOAT modeling indicates the following:

? If the aeration tanks were run with DO system control set at 2mg/l there is the potential to save approximately half the energy consumption of the aeration plant, providing adequate mixing can be maintained. Effluent quality is maintained and there is a reduction in energy use.

? No record of the ferric dose has been supplied, monitoring the dose would allow an estimate to be made of the necessary consumption. It is possible that a reduction in chemical may be made.

? The aeration efficiency was calculated to be 0.48kg O_2/kWh, which is much lower than would be expected for a diffused air system. This is because the biofilters installed upstream of the activated sludge plant remove much of the organic load. The aeration tanks are therefore lightly biologically loaded, but still require the aeration for mixing purposes.

3.3 City of Eau Claire Water Utility

3.3.1 Energy

The estimated energy use is a fairly good fit to the measured use, being within 3.8%.

The power costs can be broken into key stages as follows:

Abstraction energy costs	70,493 $ p.a.
Water treatment energy costs	130,482 $ p.a.
Sludge treatment energy costs	10 $ p.a.
Total per works	200,985 $ p.a.

The most notable users of on site energy are the high service lifting pumps. The five pumps between them use 58% of on-site energy.

The well pumps use a total of 35.2% of the on site energy. This leaves a total of 7% of on site energy actually used in the treatment processes.

Some of the well pumps operate very little, with average usage as little as eight minutes per day. The reason for the utilization level of each well has not been investigated within this study.

The two largest (500hp) high lift pumps operate very little - with average usage as little as twenty minutes per day. The three smaller pumps, each of which has recently been equipped with a high-efficiency motor, are apparently used to accommodate the base load. Control of pumped flow is by manually stopping and starting the pumps. The average utilization of pump capacity appears low at 22%, but a high level of spare capacity is necessary to provide the flexibility to service the diurnal range of plant outlet flow.

The recent addition of soft-start control to motors of the three most-used high lift pumps will save energy, as the pumps are stopped and started frequently.

3.3.2 Process assessment

The analysis of the plant performance data indicates the following:

? The VOC stripping filters appear to be working efficiently with power usage comparable to the calculated value.

? There appears to be potential for reducing the energy used to pump water to the backwash feed tank.

- In common with most water treatment plants the majority of on-site energy is used in the influent and high-lift pumping of the water. At Eau Claire the treatment processes use only a small percentage of the total on-site energy. In seeking energy savings, It would make sense to concentrate on maximizing the efficiency of the pumping systems in preference to investigating ways to save energy in the treatment processes.

3.4 Grassland Dairy Products Wastewater Treatment Facility

3.4.1 Energy

The estimated energy use is a fairly good fit to the measured use.

Although the energy use is high for an activated sludge plant, this is largely because of the particular treatment needs of this industrial treatment plant. The equalization basin mixers utilize 9.2% of the plant energy, a use not normally encountered in a municipal treatment plant.

Oxidation ditch aeration amounts to 61.0% of the total on-site energy. This is at the top-end of the expected range for this duty, the aeration efficiency being lower than might be expected.

The other large user of on site energy is the DAF plant with 7.8% of the on-site energy. The DAF unit was originally installed to thicken the waste activated sludge (WAS) only, whereas it is being used to clarify a combination of WAS and effluent from the secondary clarifiers. This is due to the poor settling characteristics of the mixed liquor suspended solids. If it was possible to adjust the overall process to improve the MLSS settling characteristics then the cost of DAF treatment would be reduced significantly.

3.4.2 Process Assessment

The Plan-It STOAT modeling indicates the following:

- The aeration efficiency is estimated to be 0.56kg O_2/kWh, which is lower than would be expected for an oxidation ditch.

- Facilities are provided to run only one of the anaerobic tanks and one of the oxidation ditches. Further investigation would be required, but if this were possible then energy savings would be realized by shutting down one stream.

- The mixing of clarified secondary effluent and waste activated sludge for treatment in the DAF plant is not ideal. A process investigation into the cause of the poor settleability of the MLSS could lead to a more energy-efficient solution.

3.5 Green Bay Metropolitan Sewerage District Wastewater Treatment Facility

3.5.1 Energy

The estimated energy use is a good fit to the measured use.

Green Bay is the largest of the Wisconsin sites, yet the energy usage KPI (84 kWh per pe per annum) is the highest of the sites. This can be explained in part by:

- the high energy use for influent pumping of both industrial and domestic sewage, amounting to 19.7% of the total onsite energy, and:

- the use of energy for sludge incineration accounting for 10% of the on-site electrical energy.

Without these two users the energy usage KPI would be 59 kWh per pe per annum, which is still high among Wisconsin sites.

Aeration amounts to 33.4% of the total on-site energy. This is a lower than average percentage than for most sites, but must be considered in conjunction with other high energy users on site including influent pumping, sludge thickening and incineration.

The service water pumps use 6.0% of the on site energy. These pumps are mostly used to supply spray water to the scrubbers of the sludge incinerators.

The interim pump, which pumps effluent from the South plant to chlorination uses 1.3% of onsite energy. This could be reduced if less flow was treated in the South plant.

In addition to the use of electrical energy, natural gas is used to fuel the incinerator.

3.5.2 Process Assessment

The Plan-It STOAT modeling indicates the following:

- There is scope to run all four lanes on the North plant and shut down the South plant without losing effluent quality. This would save on the cost pumping effluent from the South plant to the outlet.

- The aeration efficiency was calculated to be 1.14kg O_2/kWh, this is lower than would be expected for a fine bubble aeration system.

- The provision of aeration blowers is oversized, with typically one of the four blowers in operation at any time.

In both the modeled winter and summer cases it was not possible to achieve the same phosphorus concentration as the measured value. There are several possible explanations as to why the site is behaving in this way and the why the model cannot mirror the same behavior.

The presence of volatile fatty acids or iron or aluminium salts in the incoming wastewater. Volatile fatty acids are used by Phosphorus-accumulating organisms and are a key component in the cycle of biological phosphorus removal. No chemicals are deliberately added at the site, but it is possible that chemicals added at the paper mills are present in the incoming wastewater. These metal salts would chemically aid the removal of phosphorus. Inadequate mixing, leading to larger anaerobic zones increasing the biological removal of phosphorus. Phosphorus-accumulating organisms (PAOs) with a higher growth rate than is normally observed. The site is removing phosphorus, and could be worth further investigation. If there is a strain of PAO that grows faster than normal then its cultivation and use elsewhere could be beneficial. More likely is that the behavior is a consequence of unknown anaerobic zones, but even here better identifying these zones may lead to their deliberate creation at other sites.

3.6 City of Kenosha Water Utility

3.6.1 Energy

The estimated energy use is an extremely good fit to the measured use, being within 1.71%.

The power costs can be broken into key stages as follows:

Abstraction energy costs	96,630 $ p.a.
Conventional plant treatment costs	16,911 $ p.a.
Membrane plant treatment costs	62,633 $ p.a.
Booster pumping costs	176,084 $ p.a.
Total works	352,297 $ p.a.

The most notable users of on site energy are the high lift pumps, which use 50% of on-site energy. Current practice of running the high lift pumps is to use one pump 24 hours a day and use a second pump 11.7 hours a day. The second pump is used during the night to fill up service reservoirs and takes advantage of lower electricity costs.

The low lift pumps use a total of 27.4% of the on site energy. This leaves a total of 22.6% of on site energy actually used in the treatment processes.

The majority of water is treated by the membrane plant under current operating practice. The membrane plant uses 17.8% of total onsite energy and the conventional filter plant uses 4.8% of total onsite energy. The conventional plant uses a much smaller amount of power, but does have higher chemical costs and the quality of the treated water is not as good.

3.6.2 Process Assessment

Solely in economic terms it would appear, from available information, to be beneficial to minimize the use of the membrane plant. The approximate savings that could be made by reducing the proportion treated by the membrane stream, assuming the same average throughput as at present and excluding the other factors shown above, would be:

75% conventional, 25% membrane	annual saving = $62375
90% conventional, 10% membrane	annual saving = $102295

However, use of the membrane plant will give benefits in relation to security of treatment, particularly for Cryptosporidium removal, and such benefits are difficult to quantify in economic terms. Well operated conventional treatment is also capable of providing a high degree of security against Cryptosporidium, and it would be valuable to carry out an evaluation of the design, operation and performance against accepted practices for minimizing Cryptosporidium risk. This could help to justify any reduction in membrane plant throughput and increased use of the conventional stream.

3.7 City of La Crosse Wastewater Treatment Facility

3.7.1 Energy

The estimated energy use is a reasonably good fit to the measured energy use.

Aeration amounts to 39.0% of the total on-site energy. This is lower than the average percentage for most sites, but this is due to the large use of energy for other purposes.

The mixers in the activated sludge plant use a total of 16% of onsite energy. This is a large percentage of the total energy and is a possible area for improvement.

Influent pumping amounts to 8.6% of the total onsite energy.

Settled sewage pumping amounts to 7.7% of the total onsite energy.

Sludge dewatering uses a total of 7.3% of the total onsite energy, this is lower than expected and can be explained by the disposal of 35% of sludge in a liquid state.

The aeration efficiency of this site has been calculated to be 1.02 kgO_2/kWh, this is lower than might be expected for fine bubble aeration.

The biogas from the digesters is used for sludge heating or is sent to flare. There may be scope to utilize all of the energy from the biogas with the installation of a combined heat and power system. Further investigation into this possibility would be required.

3.7.2 Process Assessment

The Plan-It STOAT modeling indicates the following:

- If the aeration lanes are run with DO control the plant should achieve all effluent limits, assuming that the limits allow for a higher level on Ammonia in the effluent in the colder winter months.

- The current wastage rates are much lower than Plan-It Stoat predicts for MLSS concentrations provided.

- The model indicates that there is scope to operate with only one train. However this would result in no real reduction in the energy requirements since significant energy would still be required to sustain the necessary recycle rate within the train.

- Aeration efficiency was estimated to be 1.04 kgO_2/kWh. This is lower than would be expected for fine bubble aeration.

3.8 Papermill A Wastewater Treatment Facility

3.8.1 Energy

The estimated energy use is a good fit to the measured use, being within 3%.

Aeration amounts to 71.3% of total onsite energy use. This is very high compared with other sites, but it must be noted that this plant treats high strength industrial waste and there is no primary treatment to remove solids prior to activated sludge treatment.

Influent pumping amounts to 9.6% of total onsite energy.

The Zimpro sludge treatment process amounts to 8.6% of total onsite energy. This is not a large proportion of total energy but may be reduced by the use of anaerobic digestion.

3.8.2 Process Assessment

- If the aeration lanes are run with a lower DO setpoint the plant should still achieve all effluent limits.
- The current MLSS have higher suspended solids concentration than Plant-It STOAT predicts. This is possibly due to the composition of the trade effluent being vastly different to domestic sewage.
- The model indicates that there is no scope for diverting all of the flow to either of the plants, these scenarios caused failure of effluent quality.
- Aeration efficiency was estimated to be 0.96 kgO_2/kWh. This is lower than would be expected for a jet aeration system.

3.9 City of Portage Wastewater Treatment Facility

3.9.1 Energy

The estimated energy usage is a good fit to the measured use.

The raw wastewater pumps use a total of 26.5% of the on site energy. This is the largest user of energy on site. In this case the site requires the influent to be pumped up to the head of the works so this energy consumption can not be avoided.

The RBC supplementary aeration amounts to 13.0% of the total on-site energy. When it is considered that this air is supplied to sixteen RBCs then the total energy use per unit is less than 1%.

The AHU exhaust fan uses 9.6% of the on site energy. This fan is for ventilation of the RBC building to allow safe entry to site staff. This energy could be reduced if the RBCs were covered individually.

The RBC drives are each using approximately 2% of the on site energy.

Although it reliably produces a high quality of effluent, this plant is not a high-energy consumer. It would be much higher if the plant was an activated sludge plant.

There is no mention in the literature provided as to whether the biogas from the digesters is used to heat the digested sludge. There is possible scope for using the biogas energy to heat the incoming digester sludge, further investigations in to this possibility are recommended.

3.9.2 Process assessment

The analysis of the plant performance data indicates the following:

- The RBC units produce a satisfactory effluent quality.
- The downstream RBC units in each row do not need to be aerated.
- Maximizing the use of iron salt required for P removal at the inlet of the primary sedimentation would be beneficial in reducing the load applied to the RBC minimizing the need to run the air blower.
- The recirculation pump is beneficial in distributing the organic load through all the RBC units in each row and is cost-effective.
- The DS of the cake produced by the belt press is low (18%). Consideration should be given to a short trial to test the effect on the cake solids concentration of reducing the sludge feed rate. This will have the effect of reducing the cost of cake transport and disposal from site.

3.10 City of Rhinelander Wastewater Treatment Facility

3.10.1 Energy

The estimated energy usage is a fairly good fit to the measured use.

The biotower recirculation pumps use a total of 30.4% of the on-site energy. This is the largest user of energy on site. There may be scope for reducing the recycle flow, if the performance of the filters was not affected and therefore reducing the energy used by the pumps.

The raw sewage pumps use a total of 22.1% of the on-site energy In this case the site requires the influent to be pumped up to the head of the works so this energy consumption cannot be avoided.

The liquid storage loadout pumps that mix and pump liquid sludge uses 9.6% of the on-site energy.

The air supply compressor that supplies air to the air diaphragm sludge pumps of the secondary clarifiers uses 11% of the on-site energy. Replacing the diaphragm pumps with units that are more energy efficient could reduce this high use of energy.

This plant is not a high-energy consumer; it would be much higher if the plant was an activated sludge plant.

This plant is using natural gas to heat the digester sludge; there is scope for utilizing the biogas produced in the digesters instead of venting the gases to the atmosphere. Further investigation into the use of biogas is required, but could prove to save on the cost of natural gas.

3.10.2 Process Assessment

- There appears to be no difference in the effluent quality when the trickling filters are not supplied with forced ventilation in the two months of the year when the fans are not running. The saving from not using the forced air ventilation and presuming that natural ventilation was sufficient would be $2600 per annum assuming a cost of 0.05$/kWh.
- No information was available on diurnal variations that could result in extreme loadings on the filters that might require enhanced levels of ventilation.
- The efficiency of the forced air ventilation fans was estimated to be 3.2 kg BOD removed/kWh. This figure is double the efficiency of a good aeration basin. This is based on the filters removing an average of 468 kgBOD/day.
- The forced air ventilation fans provide the filters with 852 kgO_2/day.
- The trickling filter process is more energy efficient than the activated sludge process. However filters are more sensitive to loading variation and may take longer to become operational. The filters at this works require less long-term maintenance than low-rate stone-filled filters and require less plan area.
- If it was thought to be beneficial, there is scope for reducing the recycle rate of the trickling filters and therefore the pumping energy required.

- The desludging pumps for the secondary clarifiers are driven by air motors that are fed from a compressor. A saving in energy may be realized by replacing this arrangement with modern electric-motor driven pumps.

4. BENCHMARKING

4.1 Purpose of Section

In this section, the findings for individual plants are compared with each other and with plants of similar size in Europe.

Eau Claire and Kenosha are water treatment plants and thus it is not possible to compare them with other Wisconsin wastewater treatment plant. However, Eau Claire and Kenosha are compared with good operating practice.

This section summarizes the KPI analysis undertaken at the individual works level. A detailed account of the analysis in contained in Appendix E.

Power costs can be expected to increase with works complexity (number of wastewater and sludge treatment processes) and works size (higher flows and loads). The basis of comparison adopted has been to derive a KPI for power costs by dividing the annual cost by a suitable multiple of the works population equivalent.

4.2 Method

The KPIs used are these:

? Energy costs ($ per annum);
? Energy costs, normalized using the population equivalent served ($ per pe per annum);
? Energy used (kWh per annum);
? Energy used, normalized using the population equivalent served (kWh per pe per annum);
? Aeration efficiency, expressed as kg oxygen demand removed per kWh used;
? Aeration energy costs and aeration energy used ($ per annum and kWh per annum)
? Energy used for each process kWh per day and kWh per pe per day);
? Average sewage flow, m^3 per pe per day and as a proportion of the flow to full treatment;

4.3 Exchange rate

£ Sterling have been converted to the $ at the rate of £0.646 = $1.00.

4.4 Power cost per population equivalent

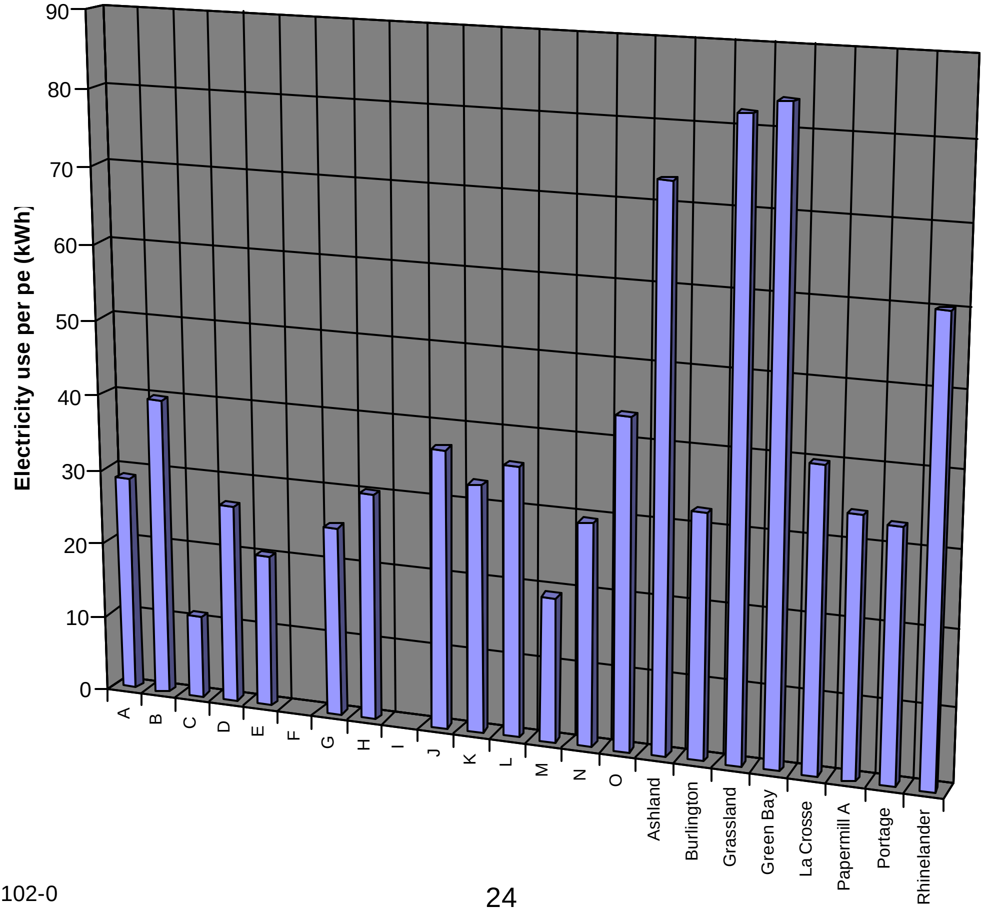
Table 4.1 lists the Wisconsin and European plants and the population equivalent of each. It also indicates the actual annual energy use (000kWh/yr) and cost ($000/yr), together with the KPIs of energy use (kWh/pe) and energy cost ($/pe). Figure 4.1 compares the KPI for energy use for each plant.

Table 1.1 Comparison of energy use and cost

Works code	**Population equivalent**	**Total energy use**		**Total energy cost**	
	000s	**000kWh/yr**	**kWh/pe**	**$000/yr**	**$/pe**
Wisconsin					
Ashland	26.1	1911	73	82	3.14
Burlington	82.0	2654	32	118	1.44
Grassland	9.8	803	82	35	3.56
Green Bay	421.1	35241	84	1171	2.78
La Crosse	138.5	5535	40	242	1.75
Papermill A	506.0	17253	34	518	1.02
Portage	36.9	1223	33	61	1.66
Rhinelander	12.6	757	60	32	2.53
European					
A	56.0	1613	29	81	1.45
B	77.0	3059	40	164	2.13
C	42.8	468	11	28	0.65
D	61.6	1628	26	81	1.33
E	64.3	1306	20	77	1.19
F	13.8	-	-	41	2.94
G	82.0	2067	25	103	1.26

Works code	**Population equivalent**	**Total energy use**		**Total energy cost**	
	000s	**000kWh/yr**	**kWh/pe**	**$000/yr**	**$/pe**
H	733.3	22132	30	1096	1.50
I	17.3	-	-	189	10.9
J	406.4	15030	37	1024	2.52
K	61.0	2003	33	136	2.24
L	9.0	322	36	22	2.43
M	33.0	633	19	59	1.78
N	68.0	2000	29	155	2.28
O	275.0	12000	44	743	2.70

Figure 1.1 Annual use of electricity and population equivalent



4.5 Aeration power cost per population equivalent

Table 4.2 lists the Wisconsin and European plants and the population equivalent of each. It also indicates the aeration energy use (kWh/day) and the aeration efficiency, together with the KPIs of aeration energy cost ($000/yr) and ($/pe).

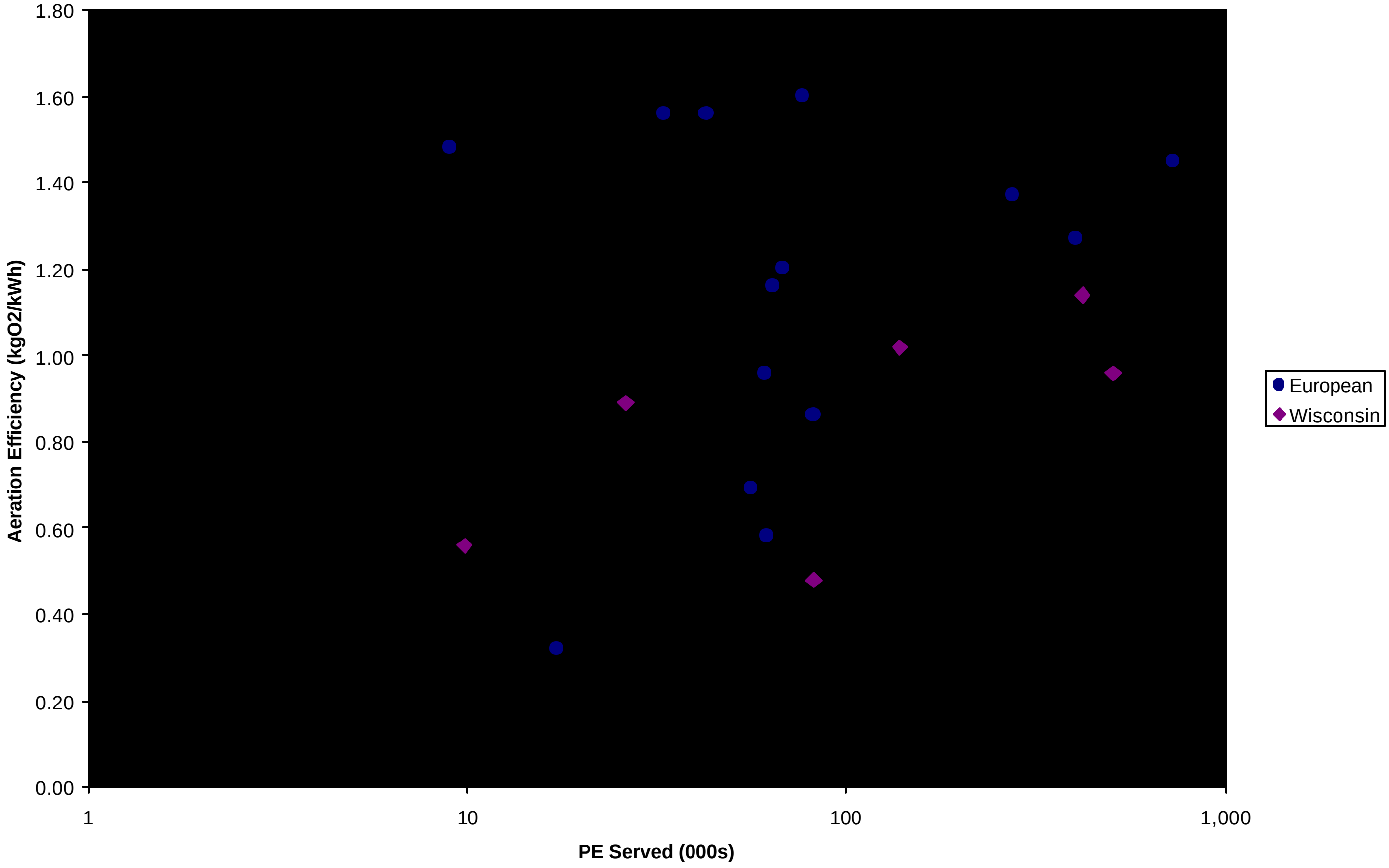
Figure 4.2 compares the KPI for aeration efficiency against the population equivalents.

Table 1.2 Comparison of Aeration Efficiencies and Aeration Energy Costs

Works code	**Oxygen demand**	**Energy used by blowers & aerators**	**Aeration efficiency**	**Aeration energy cost**	
	kg/day	**KWh/day**	**KgO$_2$/kWh**	**$000/yr**	**$/pe**
Ashland	3626	4059	0.89	64	2.44
Burlington	2603	5369	0.48	87	1.06
Grassland	801	1432	0.56	23	2.32
Green Bay	36445	31991	1.14	388	0.92
La Crosse	6650	6540	1.02	105	0.75
Papermill A	31509	32867	0.96	360	0.71
A	2287	3315	0.69	-	-
B	8035	5028	1.60	-	-
C	1504	962	1.56	-	-
D	1931	3344	0.58	-	-
E	2783	2398	1.16	-	-
G	3639	4247	0.86	-	-
H	58763	40626	1.45	-	-
I	2211	6998	0.32	-	-
J	28831	22771	1.27	522	1.28
K	3337	3485	0.96	85	1.38

Works code	**Oxygen demand**	**Energy used by blowers & aerators**	**Aeration efficiency**	**Aeration energy cost**	
	kg/day	**KWh/day**	**KgO$_2$/kWh**	**$000/yr**	**$/pe**
L	733	494	1.48	12	1.3
M	2052	1317	1.56	-	-
N	4930	4112	1.20	-	-
O	26563	19411	1.37	-	-

Figure 1.2 Aeration efficiency and population equivalent



4.6 Energy used for each process

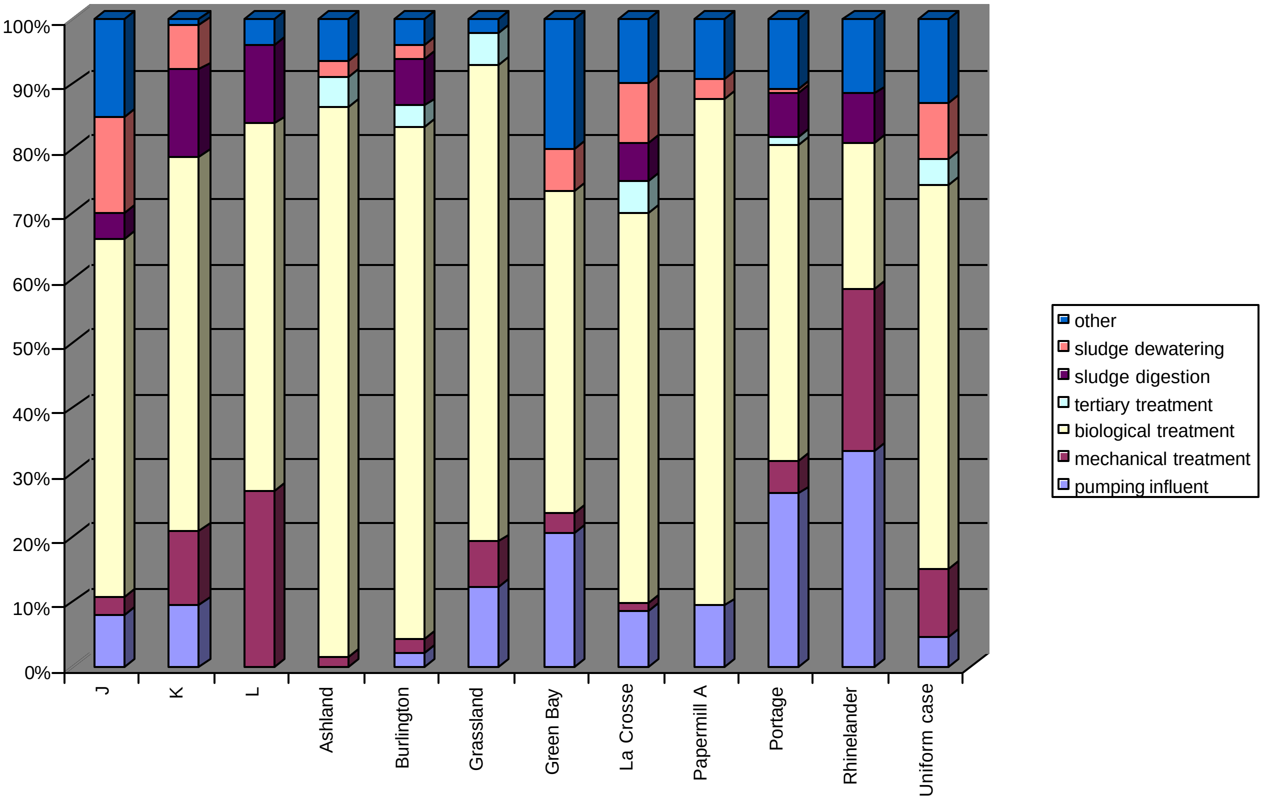
Table 4.3 lists the Wisconsin and European plants and the population equivalent of each. It also indicates a detailed breakdown of power usage for each process (kWh/000pe/day).

Figure 4.3 compares the KPI for energy use distribution for each process. Figure 4.4 compares the KPI energy usage of each process per thousand-population equivalent.

Table 1.3 Detailed energy breakdown

		Sewage treatment processes				Sludge treatment processes		All site
Works code	Population equivalent	Influent pumping	Mechanical treatment	Biological treatment	Tertiary treatment	Sludge digestion	Sludge dewatering	Other
	000s	KWh/000 pe/day	KWh/000 pe/day	kWh/000 pe/day	KWh/000 pe/day	KWh/000 Pe/day	kWh/000 pe/day	KWh/000 pe/day
Ashland	26	0	3	170	9	0	5	13
Burlington	82	2	2	68	3	6	2	3
Grassland	10	28	16	168	11	0	0	5
Green Bay	421	45	7	107	0	0	14	43
La Crosse	139	10	2	73	6	7	12	12
Papermill A	506	31	0	258	0	0	10	31
Portage	37	26	5	48	1	7	1	10
Rhinelander	13	52	39	35	0		0	18
J	406	8	3	56	0	4	15	15
K	61	9	12	57	0	13	7	1
L	9	0	26	55	0	12	0	4
Uniform case	110	5	13	70	5	0	10	15

Figure 1.3 Process energy use distribution



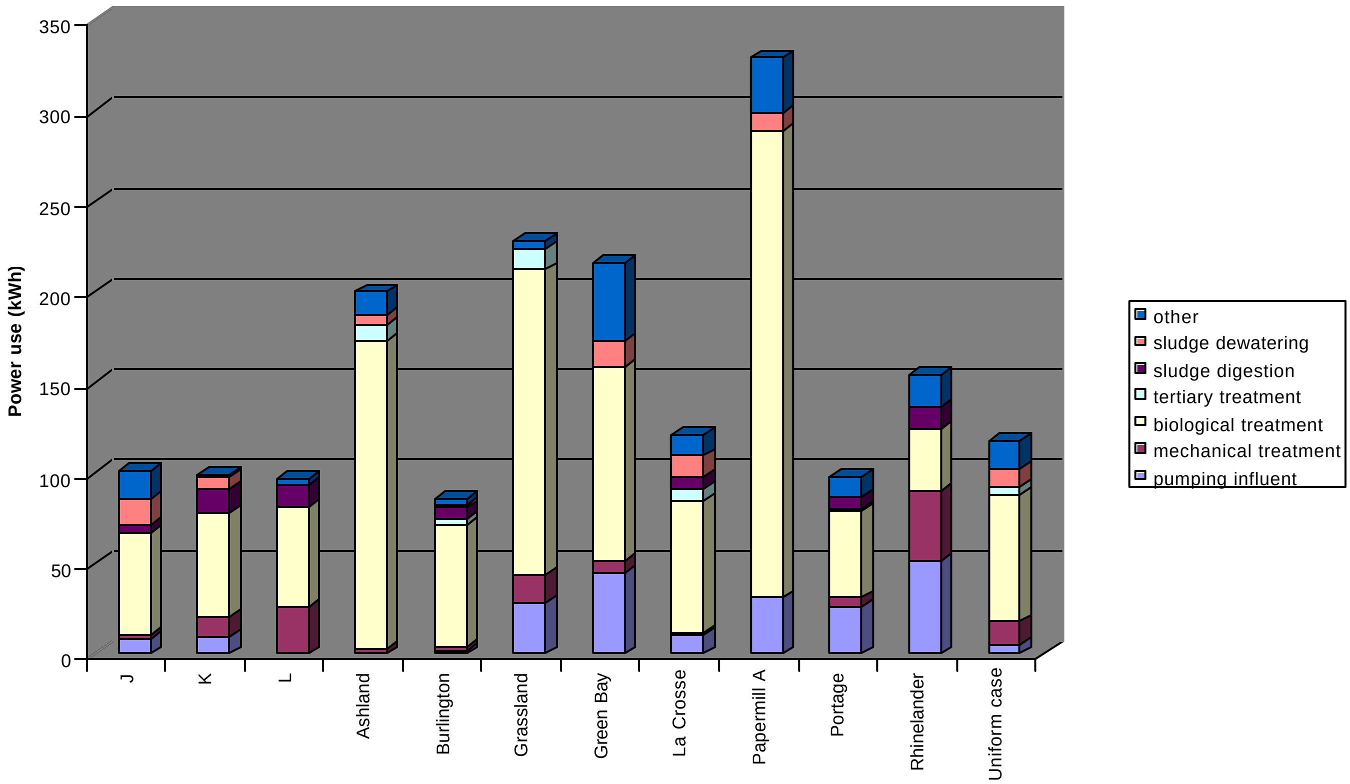


Figure 1.4 **Process energy use per 1000-population equivalent**

The process energy use distribution chart, Figure 4.3 shows that the majority of Wisconsin sites use a higher percentage of energy for biological treatment than the European sites.

The Wisconsin sites use a higher percentage of energy for influent pumping than both the European sites and the uniform case.

The digestion energy percentage used by the Wisconsin sites is lower on average compared to the European sites.

The process energy use per 1000 population equivalent chart, Figure 4.4 shows that there is a lot of variation in the energy use for individual processes across the Wisconsin sites.

4.7 Average sewage flow

Table 4.4 lists the Wisconsin and European plants and the population equivalent of each. It also indicates the dry weather flow (DWF), the average flow and the consented flow to full treatment.

Table 1.4 Comparison of sewage flows

Works	Total pe	DWF		Average flow		Consented flow to full treatment (3DWF)	
	000s	m^3/day	l/pe/day	m^3/day	l/pe/day	m^3/day	Multiple of average flow
Ashland	26.1	4550	174	6587	252	13661	2.1
Burlington	82.0	10850	132	12113	148	32513	2.7
Grassland	9.8	255	26	265	27	764	2.9
Green Bay	421.1	98100	233	114020	271	294273	2.6
La Crosse	138.5	31200	225	40540	293	93600	2.3
Papermill	506	22993	45	24529	49	68979	2.8
Portage	36.9	5150	139	6057	164	15422	2.5
Rhinelander	12.6	3600	287	4202	333	10834	2.6
A	56.0	10500	188	15625	279	29290	1.9
B	77.0	15000	195	12900	168	40000	3.1
C	42.8	12200	285	15250	356	32400	2.1
D	61.6	15874	258	15800	256	47621	3.0
E	64.3	8000	124	8746	136	32832	3.8
F	13.8	7430	540	4406	320	14860	3.4
G	82.0	20000	244	25736	314	75000	2.9
H	733.3	273024	372	400000	545	655766	1.6
I	17.3	9000	519	11000	634	15500	1.4
J	406.4	-	-	165888	408	259200	1.6
K	61.0	7670	126	11315	185	-	-
L	9.0	2645	294	4045	449	15600	3.9
M	33.0	8653	262	10400	315	26000	2.5

N	68.0	12500	184	17000	250	34560	2.0
O	275.0	129600	471	159155	579	316244	2.0

The Wisconsin sites are all designed in such a way that they can treat storm flows without effecting the effluent quality. This is to be expected as the Wisconsin sites are designed with a larger capacity than is required.

5. GUIDELINES

This section of the report deals with those practices exercised in Wisconsin in which there is room for improvement compared with practices outside the USA. It builds on the findings for individual plants (Section 3) and the comparison of plants with each other and with other plants in Europe (Section 4). The section is divided under the following headings:

? Motor efficiency;

? Optimal pump scheduling;

? Optimal pump sizing;

? Aeration efficiency;

? Other process optimization;

? Heat & power from digester gas and

? Optimal use of tariffs.

5.1 Motor efficiency

A study has been made of the value to be realized by replacing a motor at the end of its life with a premium efficiency motor. This study is detailed in Appendix E.

The findings summarized in the following table can be used to determine whether a premium efficiency motor or a general purpose motor should be selected. For example if a 100hp motor which was used 12 hours a day needed replacement it would be cost effective to replace with a premium efficiency motor. Another example would be if a 200hp motor which was used 6 hours a day needed replacement it would not be cost effective to replace with a premium efficiency motor.

The study concludes that, for motors operation for long periods of time each day, replacement of a motor (when replacement is necessary) by a premium efficiency motor results in a payback period within five years. The exception to this is largest motor in the study, the premium efficiency 500hp motor having a capital cost 64% higher than the equivalent size of general purpose motor.

An interesting conclusion is that, even for low daily usage of 6 hours per day, it is still economical to adopt a premium efficiency motor as a replacement within the range of motor size 15 to 100hp. The data and analysis to support these conclusions can be found in Appendix E.

The study has not considered the cost of repairing a motor rather than replacing it. This possibility must be assessed on a case-by-case basis and cannot be evaluated empirically.

Table 5.1 Guide to selecting efficiency of replacement motor

Hours run time	**Premium efficiency motor**	**General purpose motor**
6	?15hp up to 100hp	<15hp, >100hp
12	?5hp up to 200hp	<5hp, >200hp
18	1hp up to 200hp	500hp
24	1hp up to 200hp	500hp

Assumptions made in the above table:

? Electricity set at a constant price of $0.03 per kWh

? Discounting factor for Net Present Cost set at 5%

? The period of economical payback is set at five years

? Only motors within the size range 1 hp to 500 hp were considered

? Only induction motors were included in the study

5.2 Optimal pump scheduling

Optimal pump scheduling is possible on existing sites and should also be given serious consideration on the design of new sites or upgrades to existing sites.

The main aim of optimal pump scheduling is to control the use of several different size pumps, for the same purpose, to meet the incoming flow or the flow demand. Depending on the required flow the pumps should be used in different combinations to meet the demand using the smallest pump or pumps possible.

An example would be to have three different sized pumps 3000gpm of 200hp, 4000gpm of 300hp and 6000gpm of 500hp. These pumps could be used in combination to meet a flow that varies from 3000gpm to 12000gpm and all of the flows in between. If the required flow were 9000gpm then the optimum pumps to use at that time would be a 4000gpm and a 6000gpm pump. This combination would use the minimum amount of energy and meet that flow demand.

This type of pump scheduling can be achieved in the most efficient way by the use of automatic control. Key inputs to the control algorithm are:

? The typical diurnal pattern for the pumping system, perhaps with a different model for each season;

? The actual flow at any time;

? The rate of increase or decrease of actual flow at any time;

? The power, flow and efficiency of each possible pump;

? Identification of those pumps that are available at that time;

5.3 Optimal pump sizing

A saving in capital cost can be realized by purchasing a pump or group of pumps that is no larger than is required for the duty. Since the pumps will be operating at their selected duty point, the most efficient point of operation, then operational cost savings can also be made. If in the future a greater capacity is required, then fitting of larger impellers, replacement by larger machines or additional pumping should be considered.

5.4 Aeration efficiency

For wastewater treatment plants aeration efficiency has a large effect on the efficiency of an entire plant. This is because aeration is normally the largest use of energy of any process. Aeration efficiency can be improved on existing plants and can also be maximized when designing a new plant.

On an existing site there are limited options to improving aeration efficiency. This is because the design of the tanks has a large effect on the aeration efficiency. There are two possible options for improving the aeration efficiency.

- Dissolved oxygen control can be applied to any site with any type of aeration plant, be it diffused air or surface aeration. With dissolved oxygen control fitted to the system only the required amount of oxygen by the micro-organisms and air for mixing purposes is supplied. This removes the problem of wasted energy where blowers or surface aerators are running flat out when the process does not require it.

- Where sites are fitted with course bubble diffused aeration the efficiency can be vastly improved by replacement with fine bubble diffusers.

When designing a new activated sludge plant there are more ways of ensuring good aeration efficiency. It is obvious that fitting dissolved oxygen control and having fine bubble diffusion if using diffused aeration will improve the aeration efficiency, but other design factors should also be given consideration, including not oversizing the aeration system.

- When designing for diffused aeration the depth of the tank should be between 15 and 25ft to maximize the efficiency of the diffuser system.

- When designing for diffused aeration the width of the tank should be restricted so that zones of inadequate mixing are avoided.

- When designing for surface aeration the tank depth should be dependent on the power rating of the aerator.

- When designing for surface aeration the width should be dependant on the power rating of the aerator.

- When designing for surface aeration the aerators should be variable speed to allow for different dissolved oxygen demands.

5.5 Other process optimization

5.5.1 Enhanced RBCs

If an existing RBC plant requires upgrading to meet higher flows and/or increased influent strength then combined fixed film and suspended growth process should be considered. This option is cheaper than installing a whole new plant and can run on less power than an activated sludge plant.

If the plant is required to meet more stringent effluent limits for nutrient removal, then the combined fixed film and suspended growth processes can be used to greatly reduce chemical dosing costs by removing a large amount of nutrients biologically. This means that reduced amounts of chemicals are used to remove the remaining nutrients.

5.5.2 Sludge dewatering equipment

When designing sludge dewatering equipment is it more efficient to fit the minimum size equipment for the dewatering requirements and have the plant running continuously, than install oversized equipment which runs for just a few hours per day.

This can save energy in a few different ways. The first being that any sludge that is held in liquid form before dewatering will need to be agitated or aerated, both of these processes require unnecessary power. The second being that smaller dewatering equipment would require smaller motors.

5.5.3 Roughing biofilters

When designing plants which treat high strength waste, such as industrial or a mixture of industrial and municipal waste, energy savings can be realized through the installation of roughing filters. These filters remove a large amount of the organic content of the influent and therefore reduce the size of the aeration plant and the power requirements.

5.6 Manipulation of power factor

Power factors can be manipulated with the use of synchronous motors. Synchronous motors have increased efficiency and provide the opportunity to increase the power factor of the motor. Another benefit of synchronous motors is that in large horsepower motors or motors with low rpm they can be cheaper to install. While the induction motor might be less costly, the other selection criteria in this range of size often favors the synchronous motor.

A synchronous motor is almost identical to a generator of the same rating. The provisions for starting a synchronous motor are the major difference from induction motors, although there may also be some difference in the length to diameter proportions as well. The induction motor has a large number of un-insulated conductors short-circuited upon themselves while the synchronous motor has a number of electromagnets built into its rotor. These electromagnets are energized by direct current that can be adjusted by external controls. Changing this excitation can change the power factor, either lowering the line current to the motor, and/or supplying magnetizing VAR's to the rest of the system and thereby raising the overall power factor for the plant.

The synchronous motor cannot be started in the same way as an induction motor therefore another means of starting has to be built into the motor. This is why synchronous motors are only selected for applications with relatively infrequent starts. Most synchronous motors are started as induction motors, using a set of squirrel-cage rotor bars built into the faces of the iron cores of the rotor electromagnets. These bars also provide a stabilizing influence during normal operation. The motor should be unloaded when started because the starting torque provided by the rotor bars is usually much less than full rated power.

Another reason for starting the synchronous motor this way is to protect the DC coils wound around the rotor electromagnets. Otherwise, these coils would experience very large voltages (perhaps tens of thousands of volts) during starting. Frequently, this protection consists of short-circuiting the field windings either directly or through a field discharge resistor. When short-circuited, the large inductive reactance of these coils dissipates the intensity of the voltage without excessive current. As the rotor speed approaches synchronism, the over-voltage hazard drops to acceptable levels, the field shorting can be eliminated, and direct current supplied to the field coils. When this happens, the motor locks into step with the supply frequency and the motor operates in synchronism.

A specially designed motor controller performs these operations in the proper sequence and at the proper times during the starting process.

5.7 Heat and power from digester gas

The most important use of biogas from digesters is as a fuel to maintain the correct process temperature in the digesters. A well operated site should generate a sufficient amount of gas to meet heating requirements for the digesters. Using this biogas to should eliminate the need to purchase natural gas to fuel boilers. Depending on the quantity of gas produced there may be scope to utilize any surplus gas to generate electricity in a combined heat and power (CHP) system.

The quantity of gas required to sustain digester temperature at 35?C can be estimated from the following equation.

Total heat required = Heat required to raise temperature of feed gas

+ Heat lost from the digester by radiation

$$= mc\ (35 - T_I) + UA\ (35 - T_o)$$

where:

m = mass flow rate of sludge (kg/s)

c = specificy heat capacity (4.2 kJ/kg.?C

T_I = sludge inlet temperature (?C)

U = overall heat transfer coefficient (W/m^2.?C)

= 3.5 for un-insulated concrete digesters

= 4.8 for un-insulated steel digesters

= 2.5 for insulated or underground digesters

A = total area of digester (assumed as a cylinder with flat ends) (m^2)

T_o = air temperature

The required amount of gas for heating requirements can be calculated by estimating its calorific value knowing the amount of sludge to be fed and estimating the radiation loss for the digester. A typical low-pressure hot water boiler and heat exchanger typically have a combine efficiency of 70%. Hence the amount of gas required can be calculated from the heat duty according to the equation:

Amount of gas required = Heating duty/ (0.7 x Calorific value of gas)

The average calorific value of the gas can be calculated from the percent methane in the digester gas. The predicted gas required for heating digester sludge should be calculated for summer, winter and average temperatures to predict if there will be a sufficient supply all year round. If there is sufficient supply then the need for natural gas for digestion could be removed.

Where a site has more than sufficient gas to maintain heating in the digester there may be scope to use a combined heat and power system. The CHP system may be considered as two separate items, a gas engine and a generator. The gas engine burns the gas and subsequently transfers the heat generated into mechanical energy which drives the generator. The generator is used to provide electricity. The cooling water from the gas engine, necessary to protect the engine from high temperatures, is used for heating the digester. In addition further heat is usually recovered from the hot exhaust gases. In the UK CHP units commonly achieve a conversion rate of biogas to electricity at a rate of $1m^3$ biogas generates 3 kWh of power.

When CHP units are used only 50% of the gas energy is available for heating the digester, as opposed to a minimum of 70% for a normal boiler. As with the boiler the amount of gas available and the amount of heat required for digestion must be calculated for summer, winter and average temperatures. If a site is producing enough gas for summer and average temperatures then it may still be worth installing CHP, the cost of supplementary fuel in the shortfall winter months is likely to be offset by the extra electricity production.

The level of hydrogen sulfide in digester gas and the moisture content will influence both the economic and technical decision to install a CHP system. High H_2S levels in the gas will cause corrosion in the engines; it may therefore be necessary to install gas scrubbers to lower the H_2S level. Most CHP suppliers claim that only levels higher than 1000ppm would justify the installation of gas scrubbers.

5.8 Optimal use of tariffs

Most electricity suppliers who provide waste water and water utilities sell their electricity at two or sometime three different tariffs. Peak tariffs occur when there is high demand for electricity from all customers, both domestic and industrial. Off peak tariffs occur when demand is low, for example during the night.

Any non-essential uses of energy such as pumping or dewatering which can be carried out during off peak tariffs should be scheduled for off peak times. This could include the filling of washwater header tanks/service reservoirs or the dewatering of sludge that is only carried out periodically.

Where back up generation is available on site it may be beneficial to utilize the generators when electricity tariffs are at a premium rate. Many sites have an agreement to use back-up generation when the electricity utility requests it, however there is scope to save money if back-up generation is used at times when peak tariff is in place.

When considering the use of back-up generation the following costs should also be considered to ensure a saving; generator fuel, operation and maintenance labor, parts and general wear and tear to the generator. If the whole life cost of using the generators is still lower than paying peak electricity prices then this option should be used.

6. ENERGY USAGE GUIDELINES

Energy use guidelines have been provided for the major processes associated with wastewater treatment plants. These have been calculated as the installed power expected on a European plant. All assumptions are based on installed power for motors allowing a contingency based on the fact that equipment does not run at maximum efficiency. Expected power consumptions are shown in table 6.1.

The guidelines have been provided for a range of population equivalents for the plants. Four different size plants have been considered for this table, with population equivalents of 1,000, 2000, 20,000 and 100,000. The principle of using the population equivalent as a measure of plant size is widely adopted in the water industry across Europe, as it offers a better representation of the plant requirement compared to the value of flow, which does not account for strength of waste.

Table 6.2 contains the calculated process values for the four different size plants used to calculate the power guidelines. Table 6.3 advises the power guidelines for all four sizes of plant. It may be seen from Table 6.3 that, in only a small number of processes applications like aeration and sludge dewatering is the installed power of any significance compared to the total for the plant.

Assumed "Units" For Energy Calculations

Assumptions	Metric Units	Metric Values	U.S. Units	U.S. Values
1 horsepower	(kW)	0.7457	N/C	
Per Capita dry weather flow rate	(liters/head/day)	250	gals/person/day	66.7700
Flow to full treatment/dry weather flow		3		
Per capita flow to full treatment folow rate	(liters/head/day)	750	gals/person/day	200.3200
Per capita 6 times dry weather flow rate	(liters/head/day)	1500	gals/person/day	400.6400
Per capita crude sewage laod	(gBOD/head/day)	60	lbsBOD/person/day	0.1322
BOD removal across primary tanks	(%)	20	N/C	
Per capita settled sewage load	(gBOD/head/day)	48	lbsBOD/person/day	0.1100
Per capita settled sewage load	(gBOD/head/day)	7.5	lbsBOD/person/day	0.0150
Primary/activated co-settled sludge production	(g/head/day)	80	lbs/person/day	0.1760
Primary/activated sludge sodids concentration	(Kg/m^3)	30	lbs/ft^3	20.1220
Sludge/pump daily run time	(h/d)	8	N/C	
Aerated grit chambers minimum retertion time at peak flow	(minutes)	5	N/C	
Aerated grit chambrs depth	(m)	2	ft	6.5000
Aerated grit chambers width:depth ratio		2		
Aerated grit chambers air supply	(m^3/min/m)	2.45	ft^3/min/ft	26.3785
Atmosheric pressure	(N/m^2)	101325	lbs/in^2	14.6959
Discharge pressure for 2 m depth	(N/m^2)	130000	lbs/in^2	18.8514
Density of air	(0 C and 1 atm)	1.2928	32degrees and 1atm	34.3740
Velocity gradient for flocculator	(G) (1/seconds)	100	N/C	
Retention time in flocculator at dry weather flow	(hr)	0.17	N/C	
Maximum upflow velocity in primary sedimentation tank	(m/h)	1.5	ft/hr	4.9200
Power installed/tank	(16 m diameter (kW)	0.5	(xft dia.)(kW)	26.2500
Power installed/tank	(25 m diameter) (kW)	1	(xft dia.)(kW)	82.0208
ASP Oxygen usage fro BOD oxidation	(gO/gBOD)	1.2	lbs of O/lbs of BOD	0.0026
ASP Oxygen usage fro AMO oxidation	gO/gAmN)	4.6	lbs of O/lbs of AmN	0.0101
ASP Aerator efficiency of installed blowers/ aerators at average load	(kgO/KWh)	0.5	lbsO/KWh	1.1000
ASP Power of WAS pumps? Pwer of RAS Pumps		0.1		

Trickling filters loading rate	(kg of BOD/m^3/day)	0.1	lbs of BOD/ft^3/day	0.0671
Trickling filter depth	(m)	1.83	ft	6.0039
Power installed for trickling filter drive	(kW)	0.2	N/C	
Recirculation pump head	(m)	10	ft	32.8083
Recirculation pump flow rate	(# of dry weather flow)	1	N/C	
Low Pressure UV lamp/ maximum flow per lamp (liters per lamp)	(163 cm):(liters/lamp)	1.1	(Xin):(gallons/lamp)	64.1731
Low Pressure UV lamp/ power output at 254nm per lamp (W/lamp)	(163 cm):(W/lamp)	26.7	(Xin):(W/lamp)	64.1731
Low Pressure UV lamp conversion efficiency of input power into radiation	(%)	35	N/C	
Low pressure UV lamp proportion of UV radiation energy at 254 nm	(%)	85	N/C	
Low Pressure UV lamp theoretical UV efficiency	(%)	29.75	N/C	
Low Pressure UV lamp adopted efficiency		26.7		
Low Pressure UV lamp/power input	(163 cm):(W/lamp)	75	(Xin):(W/lamp)	64.1731
Low Pressure UV lamp power output at 254 nm per lamp	(W/lamp)	125	N/C	
Low Pressure high intensity UV lamp conversion efficiency of input power into radiation	(%)	41	N/C	
Low Pressure high intensity UV lamp proportion of UV radiation energy at 254 nm	(%)	95	N/C	
Low Pressure high intensity UV lamp/ power input	(147cm):(W/lamp)	300	(Win):(W/lamp	57.8739
Medium pressure UV lamp installed power/low presure installed power		3x		
Velocity gradient for chlorinator mixer	(G) (1/sec)	3000	N/C	
Minimum mixing time for chlorination	(sec)	1	N/C	
Viscosity of water (Ns/m^2)	(Ns/m^2)	0.001139	Voscosity/ft^2	0.0114
Machine efficiency	(%)	50	N/C	

Table 6.1 Calculated process values used to establish guideline installed power

Population equivalent	**1000**	**2000**	**20,000**	**100,000**
Dry weather flow rate (m3/d)	250	500	5000	25000
Dry weather flow (gpd)	66,045	132,090	1,320,897	6,604,485
Maximum flow rate (m3/d)	750	1500	15000	75000
WWF (gpd)	198,135	396,269	3,962,691	19,813,454
Flow per Capita (gallons/day)	198	198	198	198
Ammonia load (kg AmN/d)	7.5	15	150	750
Ammonia (lb/d)	16.5	33.1	330.7	1653.5
Ammonia (mg/l)	30	30	30	30
Settled sewage BOD load (kg BOD/d)	48	96	960	4800
BOD (lb/d)	106	212	2116	10582
BOD (mg/l)	192	192	192	192

Population equivalent	**1000**	**2000**	**20,000**	**100,000**
Forced vortex circular grit chamber volume (m3)	1.2	1.2	3.6	30.4
Forced vortex circular grit chamber diameter (m)	3.5	3.5	6.7	11.1
Aerated grit chamber volume (m3)	N/A	N/A	52	260
Aerated grit chamber length (m)	N/A	N/A	13	65
Aerated grit chamber aeration (m3/h)	N/A	N/A	352	1758
Aerated grit chamber air rate (kg/s)	N/A	N/A	0.126	0.631
Flocculator volume (m3)	1.8	3.5	35	177
Primary tank sedimentation area (m2)	21	42	417	2083
Number of sedimentation tanks	2	2	2	4
Sedimentation tank diameter (m)	3.6	5.1	16.3	25.7
Non-nitrifying AOR oxygen requirement (kg O/d)	57.6	115.2	1152	5760
AOR, non-nitrify (lb/d)	127.0	254.0	2539.7	12698.5
Nitrifying AOR oxygen requirement (kg O/d)	92.1	184.2	1842	9210
AOR, nitrify (lb/d)	203.0	406.1	4060.9	20304.4
Volume of trickling filter medium (m3)	480	960	9600	48000
Area of trickling filter beds (m2)	262	525	5246	26230
No of trickling filter beds	2	2	8	32
Trickling filter bed diameter (m)	12.9	18.3	28.9	32.3
No of low pressure UV lamps	7.9	15.8	157.8	789.1
No of low pressure high intensity lamps	2	4	36	176
No of medium pressure lamps	NA	NA	14	66
Nominal volume required for intensive mixing of sodium hypochlorite (m^3)	0.0087	0.0174	0.1736	0.8681
Co-settled sludge weight production (kg/d)	80	160	1600	8000
Co-settled sludge volume production (m^3/d)	2.7	5.3	53.3	266.7

Population equivalent	**1000**	**2000**	**20,000**	**100,000**
Hourly sludge volume rate (m^3/h)	0.33	0.67	6.67	33.33

Terms:

AE	Aeration efficiency
AOR	Actual oxygen requirements
CB	Coarse bubble
CMD	Cubic meters per day
DWF	Dry weather flow
FB	Fine bubble
GPD	Gallons per day
HP	Horsepower
MGD	Million gallons per day
SAE	Standard aeration efficiency
SOR	Standard Oxygen requirements
WWF	Wet weather flow

Table 6.2 Guideline installed power (horsepower) for a range of plant sizes

Equipment	**Small 1,000 pe**	**Medium 2,000 pe**	**Medium 20,000 pe**	**Large 100,000 pe**
Preliminary treatment				
Fine screens	0.7	0.7	1.5	6.0
Screenings compactor/dewatering equipment	0.7	0.7	1.5	6.0
Dewatering screenings macerator and compactor	1.5	1.5	4.5	22.4
Aerated grit chambers	N/A	N/A	4.7	23.6
Forced vortex circular grit chamber	0.75	0.75	1.0	1.5
Grit collectors	N/A	N/A	0.7	3.0
Grit transfer pump	N/A	N/A	3.0	6.0
Primary treatment				
Flocculators	0.3	0.6	6.0	30.1
Sedimentation drives	N/A	N/A	0.7	3.0
Sludge pumps	1.5	1.5	3.7	8.2
Scum pumps	1.5	1.5	3.7	8.2
Secondary treatment				
Assumptions – Fine Bubble (FB) Aeration, Standard Aeration Eff. (SAE) = 6.0 lbs of O2/hp hr and, Actual Oxygen Requirement/Standard Oxygen Requirement (AOR/SOR) = 0.4				

Equipment	**Small 1,000 pe**	**Medium 2,000 pe**	**Medium 20,000 pe**	**Large 100,000 pe**
HP, non-nitrify, FB (Theoretical Calculated Demand)	2.2	3.9	39.2	196.0
HP, nitrify, FB (Theoretical Calculated Demand)	3.5	6.3	62.7	313.3
Assumptions – Coarse Bubble (CB) Aeration, Standard Aeration Eff. (SAE) = 2.5 lbs of O2/hp hr and AOR/SOR = 0.55				
HP, non-nitrify, CB (Theoretical Calculated Demand)	3.8	7.7	77.0	384.8
HP, nitrify, CB (Theoretical Calculated Demand)	6.2	12.3	123.1	615.3
Trickling filter distributors	0.3	0.3	1.2	4.8
Trickling filter recirculation pumps	0.4	0.8	8.5	42.3
Clarifier drives	N/A	N/A	0.7	3.0
Return activated sludge pumps	3.7	3.7	14.9	37.3
Waste activated sludge pumps	0.4	0.4	1.5	3.7
Trickling filter sludge pumps	0.4	0.4	1.5	3.7
Scum pumps	0.4	0.4	1.5	3.7
Disinfection				
UV lamps – Low pressure	0.6	1.2	11.8	58.8
UV lamps – Low pressure high intensity	0.6	1.2	10.8	52.8
UV lamps – Medium pressure	1.8	3.5	35.3	176.5
Chlorinator mixer	0.1	0.3	2.7	13.3
Solids processing				
Gravity belt thickeners	0.2	0.2	0.2	0.4
Belt thickeners	7.5	7.5	7.5	14.9
Thickened sludge pumps	4.1	4.1	4.1	8.2
Dewatering centrifuges including chemical dosing, feed pumps and conveyors	14.9	14.9	14.9	44.7
Belt presses including chemical dosing, feed pumps and conveyors	11.2	11.2	14.9	37.3
Anaerobic digestion incl. mixing compressor, recirc pumps and HEs	N/A	N/A	12.0	46.8

7. RECOMMENDATIONS

This study has highlighted a number of areas where improvements may be made in energy-efficient practice for both wastewater and water treatment plants in the State of Wisconsin.

Recommendations have been made on a Wisconsin-wide basis and on a site-specific basis.

Wisconsin-wide

- When motors have reached the end of useful life, in most applications they should be replaced with premium efficiency motors.
- Pump scheduling should be optimized to ensure that the most efficient combination of pumps is selected for the particular flow/ head conditions.
- When selecting a pump, the correct pump size for existing flows should be specified. Future flows should be handled by increasing the impeller size of existing pumps, and/or installing additional pumps as necessary.
- In situations where it is operationally possible, machines should be selected to run during periods of off-peak electricity tariffs.
- Where on-site power generation is available, the economics should be explored of using this during periods of peak electricity tariff.
- Install electronic variable speed drives on the motors of pumps and blowers where reduced-flow operations are frequently required.
- Consider friction losses (“K” values) in the selection of isolation, control, check valves and associated piping.
- Install dissolved oxygen monitoring and control to increase the aeration efficiency of activated sludge wastewater plants.
- Consider improving the aeration efficiency of activated sludge wastewater plants by upgrading the means of aeration, for instance by using fine bubble aeration.
- Where anaerobic sludge digestion takes place at a site, utilize the biogas to produce combined heat and power, or as a fuel for the heating boiler. At the very least, methane in the biogas should be destroyed by burning in a flare stack before discharge of the wastegas to the atmosphere.
- Consider overall energy consumptions in the mixing of biosolids stabilization and mixing basins – including the use of intermittent mixing versus constant/continuous mixing.

City of Ashland Wastewater Treatment Facility

- Operate only one of the oxidation ditches to save mixing energy.

- Dewatering the sludge on the belt press as is produced to save energy that is currently used in mixing the sludge storage tank.

- Utilize the DO control system to improve the aeration efficiency

City of Burlington Wastewater Treatment Facility

- Install a DO control system to save energy on the aeration plant and improve the aeration efficiency.

- Utilize the combined heat and power plant, investigations should be made into installing a gas scrubber if the levels of hydrogen sulfide are a problem.

City of Eau Claire Water Utility

- Optimize the scheduling of the high lift pumps in order to use the optimum efficiency of pumps for each capacity.

Grassland Dairy Products Wastewater Treatment Facility

- Conduct process investigations into poor settleability of sludge so that present use of the DAF plant for all effluent and WAS can be halted.

- Operate only one of the anaerobic tanks and oxidation ditches to save energy on mixing and increase aeration efficiency.

Green Bay Metropolitan Sewerage District Wastewater Treatment Facility

- Utilize the entire North aeration plant and minimize use of the South aeration plant, this will save energy pumping the South aeration plants effluent to the outlet.

City of Kenosha Water Utility

- Maximize use of the conventional treatment plant to save energy on the membrane plant. Determine the maximum use of the conventional plant conducive with keeping a sufficiently high quality of treated water.

- Continue current practice of running high lift pumps at night to fill up service reservoirs

City of La Crosse Water Treatment Facility

- Install DO control system to save energy on the aeration plant and improve the aeration efficiency

- Investigate the installation of a combined heat and power plant to utilize all of the biogas from the digesters

Papermill A Wastewater Treatment Facility

- Install DO control system to save energy on the aeration plant and improve the aeration efficiency.

City of Portage Wastewater Treatment Facility

- Aeration of the downstream RBC units is not required and stopping this practice would result in a significant energy saving.

- Optimize the use of chemical phosphorus removal in the primary tanks to reduce load applied to the RBCs.

- Investigate the installation of a combined heat and power plant to utilize all of the biogas from the digesters.

City of Rhinelander Wastewater Treatment Facility

- Minimize the use of forced air ventilation if effluent quality is not effected to save energy.

- Investigate the possible reduction of recycling effluent from the biotower to save pumping energy.

- Investigate the installation of a combined heat and power plant to utilize all of the biogas from the digesters

APPENDIX A – TECHNICAL DESCRIPTION OF PLAN-IT STOAT

Plan-it STOAT is a wastewater treatment facility planning tool - a computer program that facilitates the conceptual and preliminary design and planning for the construction, expansion, and modification of wastewater treatment facilities. This tool is not an expert system, but rather an interconnected collection of unit processes and tools that perform calculations or specific tasks that are essential to selecting, sizing, and siting wastewater treatment plants. The intent is to allow a practitioner to easily define and evaluate the approximate size and capital and operating costs for a variety of alternative sequences of unit processes and unit operations for the treatment of wastewater. The user of the tool will define the exact sequence of unit operations in each alternative and the method and criteria by which they will be compared.

The underlying concept to Plan-it STOAT is that the user provides the skill and expertise to select a wastewater treatment technology for a particular application. The Plan-it STOAT software is a tool to assist an experienced designer and to make the analysis quicker. An experienced wastewater design professional will be able to use Plan-it STOAT to quickly evaluate preliminary treatment plant designs, including sizing the unit processes, evaluating performance, major design constraints, the footprint for the facilities, and preparing a preliminary hydraulic profile through the treatment process. The primary design constraints are assumed to be effluent quality, cost, land area consumed, and hydraulic head requirements.

The Plan-it STOAT model will assist the user in performing the following specific tasks:

? Preliminary sizing of unit processes
? Calculation of mass and flow balances
? Prediction of effluent quality
? Preliminary hydraulic calculations
? Capital and operating cost comparisons of alternatives
? Performance evaluations
? Site planning
? Diagnostics

Plan-it STOAT contains algorithms based on traditional design methods and criteria as well as complex mechanistic algorithms such as the International Association on Water Quality (IAWQ) and WRc mechanistic models. This will allow engineers to compare results using conventional criteria and numerical methods. This will also facilitate the development of expertise and comfort with advanced design methods. All models are steady state to simplify use and increase computational speed.

Plan-it STOAT has three separate, but closely interrelated, functional areas or modes:

1. A process mode – to either size tanks based upon flow and quality, or to calculate effluent quality based upon tank size and operating conditions. This mode will perform basic process calculations and calculate flow and mass balances on the treatment configuration.

2. A hydraulic mode - to define the sequence of hydraulic elements in the liquid treatment train and to prepare a preliminary hydraulic profile.

3. A site layout mode - presents the user with an interactive site plan worksheet. The user will have the option of inputting an existing site plan or aerial photograph for use as a base. The model will output basic geometric shapes onto the base. The user will have the ability to move the shape locations on the site plan, and to interactively adjust unit process plan area. After resizing modules, the user may return to the process mode to estimate the effects on effluent quality.

Plan-It STOAT also contains detailed diagnostics which check for fundamental problems with a design, such as whether a channel will overflow or a hydraulic loading rate exceeds a company's design standards.

The software will accept input parameters such as influent wastewater quality; desired treated water quality; volumes, footprints, and grades of existing facilities; and other parameters and criteria of relative importance when comparing alternatives.

The output from the software includes:

- estimates of unit process facility volumes and land area requirements,
- a hydraulic profile,
- a mass balance,
- facility energy requirements,
- facility chemical requirements,
- estimated capital and operating costs.

Version 1.0 estimates capital costs based on cost curves developed by WRc. Users must be reminded that the capital cost function is only valid for *planning level* cost estimates, and will only be accurate within a range of -30% to +50%.

PLAN-IT STOAT VERSION 1.0 - WASTEWATER TREATMENT TOOLBOX

Table A1 Unit Processes and Associated Mathematical Models

Influent Wastewater	Detailed BOD COD-CN COD-CNP
Preliminary Treatment	
? Grit removal	Hydraulic detention time Hydraulic overflow rate
? Screens	Curve relating bar spacing to screens quantity Kirshmir Envirex
Primary Treatment	

? Primary clarifiers	Input estimate of percent removal Lessard Assume effluent concentration
? Ballasted flocculation	
Suspended Growth Processes ? Activated Sludge	SRT Equation IAWQ#1 model IAWQ#2 model IAWQ#3 model WRc BOD WRc BOD - Simple P
? Denitrification	Stensel Input Denitrification rate Also can be modeled with all activated sludge models except SRT equation
? Selector	Hydraulic retention time F/M gradient
? Secondary settling tanks	Takacs model Surface overflow rate Solids loading rate Ideal solids separation
? Lagoon	EPA Gloyna
? Sequencing Batch Reactors	Stensal Barnard
Chemical Methods	
? Chemical P Removal	IAWQ#2 Chemical Equilibrium
Fixed Film Processes	
? Trickling Filter	Volumetric loading Germain/Schultze Nitrification Germain/Schultze IAWQ model
? Upflow biological filter (BAF)	Volumetric loading WRc model
? Downflow biological filter	Volumetric loading WRc model

Tertiary Treatment	
? Sand filtration	Area hydraulic loading rate
? Post aeration	Weir Forced Aeration Cascade
Equalization	Circular Rectangular
Disinfection	
? Chlorination	Hydraulic Retention time CT
? UV	EPA Tchobanoglous/Darby
Sludge Treatment	
? Aerobic digestion	Hydraulic retention time IAWQ Adams/Eckenfelder VSS destruction
? Mesophilic anaerobic digestion	SRT HRT VSS loading
? ATAD	WRc model
? Thickening	Solids loading rate Hydraulic loading rate WRc
? Sludge dewatering	
User Defined Models	
? Black box	
? User-defined	

Table A2 Hydraulic Elements

Bar screens	
Conduits	Trapezoidal channel, Rectangular channel, Full rectangular channel, Circular pipe, Full circular pipe.
Transitions and Junctions	Gradual expansion, Sudden expansion, Contraction, Reducer, Collector, 45 degree bend, 45 degree channel bend, 90 degree bend, 90 degree channel bend, 180 degree bend, 180 degree channel bend, Fixed loss, Minor loss, Inlet, Exit, Submerged orifice, Surface orifice.
Valves	Swing check valves, Butterfly valves, Gate valve, Sluice gate, Plug valve.
Hydraulic controls	Sharp edged weir, Single V-notch, Multiple V-notch, Parshall flume, Venturi, Fixed head.
Pumps	
Mixers and Splitters	Y-mixer, Y-splitter, T-mixer exit on run, T-mixer exit on branch, T-splitter exit on run, T-splitter exit on branch, Overflow.
Outlets	Liquid effluent, Sludge.
Continuity elements	2-way mixer, 3-way mixer, 2-way divider, 3-way divider, Overflow, Final effluent, Sludge.

APPENDIX B – ENERGY-RELATED STUDIES FOR EACH PLANT

B1 **CITY OF ASHLAND WASTEWATER TREATMENT FACILITY**

B2 **CITY OF BURLINGTON WASTEWATER TREATMENT FACILITY**

B3 **CITY OF EAU CLAIRE WATER UTILITY**

B4 **GRASSLAND DAIRY PRODUCTS**

B5 **GREEN BAY METROPOLITAN SEWERAGE DISTRICT WASTEWATER TREATMENT FACILITY**

B6 **CITY OF KENOSHA WATER TREATMENT FACILITY**

B7 **CITY OF LA CROSSE WASTEWATER TREATMENT FACILITY**

B8 **PAPERMILL A WASTEWATER TREATMENT FACILITY**

B9 **CITY OF PORTAGE WASTEWATER TREATMENT FACILITY**

B10 **CITY OF RHINELANDER WASTEWATER TREATMENT FACILITY**

GENERAL

Energy use

The average daily energy use for each plant has been taken from energy bills for one year.

An estimation of energy used by each plant, broken down into each item of equipment has been carried out. The inputs to this estimation are:

- Where available, details of voltage and current per phase of individual items of equipment, measured during a site visit by Energenecs engineers;
- Typical running hours per day per machine, advised by engineers from McMahon Associates, Inc. and Energenecs, Inc.;
- Where actual measured current and voltage is not available, the motor horsepower of each machine;
- Where none of the above is available, an estimation of the energy use based on WRc experience of similar treatment processes.

A table comparing measured and estimated energy use is provided for each plant. This table also indicates the percentage of energy consumed by each item of equipment.

Aeration efficiency

The greatest user of energy for an activated sludge wastewater treatment plant is likely to be the aeration system. Special attention is paid to the energy used for aeration, and also the aeration efficiency. Aeration efficiency is a ratio of the mass of oxygen required to treat the wastewater compared to the energy used by the aeration equipment. The units of aeration efficiency are kg O_2/kWh. If the ratio is less than 1.0 there is considerable scope for improvement, while a value of 1.5 indicates efficient aerators. A factor that reduces the efficiency of many aeration systems is uncontrolled operation, i.e. running at full output irrespective of the oxygen requirement.

The formula for oxygen demand are shown below:

No denitrification

Oxygen demand (kg/day) = $0.0864*q_s*(a + b + c)$

where:

$a = 0.75*(BOD_i – BOD_o)$

$b = 0.000525*C_{MLSS}*V/q_s$

$c = 4.3*(ammonia_i – ammonia_o)$

C_{MLSS} = mixed liquor suspended solids (mg/l)

q_s = average flow (litres/s)

V = volume of aeration tanks (m^3)

BOD and ammonia concentrations are in mg/liter

and the suffices ‘i’ and ‘o’ denote wastewater entering and leaving the aeration tanks, respectively.

With denitrification

Oxygen demand (kg/day) = $0.0864*q_s*(a + b + d + e)$

Where:

a & b are as above

$d = 1.64*(\text{ammonia}_i - \text{ammonia}_o)$

$e = 2.83*(\text{nitrate}_o)$.

B1 CITY OF ASHLAND WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for Ashland, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B1 Energy use for Ashland Wastewater Treatment Plant

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
		Hours/day	kWh/day	%
Retention storage lift station	Returns flow from storm retention basin to headworks	Used occasionally		
Grit pump	15hp Centrifugal pump	4	44.7	0.9%
Aeration Jet Pump #1	Jet pump	24	338.9	6.5%
Aeration Jet Pump #2	Jet pump	24	288.0	5.5%
Aeration Jet Pump #3	Jet pump	24	275.9	5.3%
Aeration Jet Pump #4	Jet pump	0	0.0	0.0%
Aeration Jet Pump #5	Jet pump	24	353.3	6.8%
Aeration Jet Pump #6	Jet pump	24	303.9	5.8%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
Aeration Jet Pump #7	Jet pump	24	310.4	5.9%
Aeration Jet Pump #8	Jet pump	24	302.5	5.8%
Lamson Aeration Blower	150hp One of three blowers	22	1886.0	36.1%
Blowers for low demand period	Used instead of Lamson blower for approx 1 month per year. 2 @ 40 hp	2	91.4	1.7%
RAS Pump #3	Centrifugal pump	24	152.6	2.9%
RAS Pump #5	Centrifugal pump	24	128.3	2.5%
Waste activated sludge pumps	3hp Centrifugal pump	1.5	3.4	0.1%
Final clarifier #1	Bridge drive	24	15.8	0.3%
Final clarifier #2	Bridge drive	24	16.5	0.3%
UV Disinfection	Trojan 3000 system	24	236.4	4.5%
Sludge storage tank pump	Jet pump	6	117.2	2.2%
Dewatering feed pumps	5hp progressive cavity	1.5	5.6	0.1%
Sludge dewatering	2.2hp* Belt press	1.5	4.5	0.1%
Belt press wash pump	5hp Centrifugal pump	1.5	5.6	0.1%
Power roof vent	Jet Aeration/Mix, ventilating main building	24	21.4	0.4%
Site drain pump	5hp Centrifugal pump	24	81.9	1.6%
Blower building effluent pump	Centrifugal pump	24	133.4	2.6%
Plant air compressor		12	89.5	1.7%
Scum pump	3hp Centrifugal pump	3	6.7	0.1%
Plant effluent re-use pump	5hp Centrifugal pump	3.5	13.0	0.2%
Estimated total for the plant			5226.8	100.0%
Measured total for the plant			5250.5	
%age difference			0.45 %	

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
Main station lift pumps	Off site. 150hp	24	2684.5	
Knight Road Lift Station	Off-site. Pumps raw sewage onto plant from 1/5 of the town	24	125.4	

Notes:
* Assumed energy

KPI Description	KPI Value	Comment
Energy use per population equivalent	73 kWh per pe per annum	Second highest in Wisconsin sites
Energy cost per population equivalent	$3.14 per pe per annum	Second highest in Wisconsin sites
Aeration efficiency	0.89kgO_2/kWh	Lower than expected

The estimated total energy use, derived as described above in the ‘General - Energy Use’ sub-section is a very good fit to the measured total energy use (within 1%), taken from an averaged value from electricity bills.

The following analysis relates to the notable uses of energy.

Aeration, both oxidation ditch and sludge, amounts to 79.4% of the total on-site energy. This is at the top-end of the expected range for this duty.

The jet pump for the sludge storage tank is responsible for 2.2% of on-site energy. There is associated energy from the aeration blower for the duty of mixing and aerating the sludge tank, but the proportion of air used for this compared with oxidation ditch duty is not advised and cannot be evaluated. The sludge tank is mixed and aerated with the purposes of preventing septicity and making the tank contents homogeneous for consistency of dewatering performance.

The belt press appears to be greatly oversized – requiring operation of only 10.5 hours per week of operation to cope with sludge production. It might be considered better practice to dewater the sludge as it is produced, avoiding the need to store it for more than one day, thus saving energy by dispensing with the need for extensive mixing of the sludge storage tank.

B2 CITY OF BURLINGTON WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for Burlington, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B2 Energy use for Burlington Wastewater Treatment Plant

Duty	**Function Description**	**Typical Running Time** Hours/day	**On-site energy use** kWh/day	**% of total On-site energy** %
Septage receiving pump	Centrifugal pump	0.79	2.9	0.04%
High strength waste receiving pump	Centrifugal pump	2.93	10.9	0.2%
Septage tank mixer # 1	Submersible mixer	24	71.2	1.0%
Septage tank mixer # 2	Submersible mixer	24	68.1	1.0%
Pista grit trap	Grit drive	24	10.6	0.2%
Grit removal pump	Centrifugal pump	24	91.7	1.3%
Primary clarifier # 1	Bridge drive	24	7.8	0.1%
Primary clarifier # 2	Bridge drive	24	7.3	0.1%
Primary sludge pumps	5 hp Plunger pumps	1.05	3.9	0.1%
Primary scum pumps	5 hp Plunger pumps	0.07	0.26	0.004%
Primary effluent sample pump	Centrifugal pump	0.5	0.4	0.01%
Biofilter feed pumps	Centrifugal pumps	24	82.2	1.2%
Intermediate clarifier # 1	Bridge drive	24	5.3	0.1%
Intermediate clarifier # 2	Bridge drive	24	4.7	0.1%
Intermediate sludge pumps	Plunger pumps	0.79	2.9	0.04%
Intermediate effluent sample pump	Centrifugal pump	0.5	0.5	0.01%
Ferric chloride feed pump	Centrifugal pump	1	0.2	0.003%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
Aeration blower # 1	Air supply blower	0	0	0%
Aeration blower # 2	Air supply blower	24	2684.5	38.1%
Aeration blower # 3	Air supply blower	24	2684.5	38.1%
Final clarifier # 1	Bridge drive	24	6.2	0.1%
Final clarifier # 2	Bridge drive	24	5.5	0.1%
RAS pump # 1	Centrifugal pump	0	0	0%
RAS pump # 2	Centrifugal pump	24	59.3	0.8%
RAS pump # 3	Centrifugal pump	24	59.6	0.8%
WAS pumps	Centrifugal pumps	0.53	4	0.1%
Final clarifier scum pumps	Submersible centrifugal pumps	0.0125	0.05	0.001%
UV unit		10	224	3.2%
Sludge wet well blower	Air supply blower	24	103.5	1.5%
Belt thickener feed pumps	10 hp Screw centrifugal pumps	1.852	14	0.2%
Belt thickener	Belt drive	1.71	5	0.1%
Filtrate pumps	10 hp centrifugal pumps	3.7	27.6	0.4%
Thickened sludge pumps	Progressive cavity pumps	5.98	12.5	0.2%
Digester sludge recirc pumps	Screw centrifugal pumps	2.85	4.6	0.1%
Hot water recirc pump # 1	Centrifugal pump	24	18.2	0.3%
Hot water recirc pump # 2	Centrifugal pump	24	35.6	0.5%
Digester mixing compressor	15 hp air supply compressor	24	268.5	3.8%
Digested sludge transfer pump	10 hp screw centrifugal pump	24	179	2.5%
Sludge storage tank mixer # 1	Submersible mixer	4.3	88.7	1.3%
Sludge storage tank mixer # 2	Submersible mixer	4.3	87.3	1.2%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
Sludge storage tank mixer # 3	Submersible mixer	4.3	48.8	0.7%
Sludge loadout pumps	Screw centrifugal pumps	7	52	0.7%
Calculated total for the plant			7042.7	100.0%
Measured total for the plant			7272.3	
%age difference			-3.16 %	

KPI Description	KPI Value	Comment
Energy use per population equivalent	32 kWh per pe per annum	Lowest in Wisconsin
Energy cost per population equivalent	$1.44 per pe per annum	Low
Aeration efficiency	0.48kgO_2/kWh	Much lower than expected

The estimated energy use is a fairly good fit to the measured use, being within 3.16%.

The energy use is low compared to other Wisconsin plants.

The blowers that provide aeration to the activated sludge lanes are the principle users of on-site energy, utilizing 76.2% of the total on-site energy. This is at the top-end of the expected range for this duty, but there is no sludge dewatering following digestion so the other energy uses on site are low.

The digester-mixing compressor uses 3.8% of on site energy.

The sludge storage tank mixers use a total of 3.2% of the on site energy. These mixers are only run when the tank is being emptied during the spring and summer.

This site has a combined heat and power plant installed, but it has not been used since the acceptance of high strength industrial waste began. Facilities are provided to use the energy from the biogas for heating the digesters. If the biogas contains high levels of hydrogen sulfide or other problem gases, then investigations should be carried out into the possibility and cost of installing a gas scrubber.

B3 CITY OF EAU CLAIRE WATER UTILITY

The following table compares the average daily energy use for Eau Claire, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B3 Energy use for Eau Claire Water Treatment Plant

Duty	**Function Description**	**Average Running Time** Hours/day	**On-site energy use** KWh/day	**% of total On-site energy** %
Well pump # 4	Vertical turbine pump	0.126	2.5	0.02%
Well pump # 6	Vertical turbine pump	2.25	41.9	0.4%
Well pump # 8	Vertical turbine pump	1.88	58.0	0.5%
Well pump # 9	Vertical turbine pump	2.93	107.4	0.9%
Well pump # 10	Vertical turbine pump	5.2	120.1	1.0%
Well pump # 11	Vertical turbine pump	12.3	342.7	2.9%
Well pump # 12	Vertical turbine pump	0.62	18.7	0.2%
Well pump # 13	Vertical turbine pump	18.26	490.5	4.1%
Well pump # 14	Vertical turbine pump	0.13	3.7	0.03%
Well pump # 15	Vertical turbine pump	22.2	668.8	5.7%
Well pump # 16	Vertical turbine pump	7.08	220.4	1.9%
Well pump # 17	Vertical turbine pump	22.3	655.0	5.5%
Well pump # 18	Vertical turbine pump	0.312	11.0	0.1%
Well pump # 19	Vertical turbine pump	22	745.6	6.3
Well pump # 21	Vertical turbine pump	13.39	584.9	4.9%
Well field booster pump	Centrifugal pump	1	77.6	0.7%
Packed tower fans	Air supply compressor	24	253.0	2.1%
Tower effluent pumps	Centrifugal pumps	24	289.2	2.4%
Lime feed pumps	Hose pumps	24	108.4	0.9%
Backwash tank fill pump # 1	Centrifugal pump	1.55	94.8	0.8%

Duty	**Function Description**	**Average Running Time**	**On-site energy use**	**% of total On-site energy**
Backwash tank fill pump # 2	Centrifugal pump	1.55	91.4	0.8%
Pipe gallery air compressor	Air supply compressor	1.2	11.6	0.1%
High service pump # 1	Centrifugal pump	2.53	434.4	3.7%
High service pump # 2	Centrifugal pump	14.4	5263.2	44.5%
High service pump # 3	Centrifugal pump	9	275.6	2.3%
High service pump # 4	Centrifugal pump	0.32	119.3	1.0%
High service pump # 5	Centrifugal pump	1.98	736.6	6.2%
Sedimentation tank sludge pump	Centrifugal pump	0.13	0.6	0.005%
Chemical pumps air compressor	Air supply compressor	0.2	1.9	0.02%
Calculated total for the plant			11829.0	100.0%
Measured total for the plant			12296.7	
% age difference			-3.80 %	

The estimated energy use is a fairly good fit to the measured use, being within 3.8%.

The power costs can be broken into key stages as follows:

Abstraction energy costs	70,493 $ p.a.
Water treatment energy costs	130,482 $ p.a.
Sludge treatment energy costs	10 $ p.a.
Total per works	200,985 $ p.a.

The most notable users of on site energy are the high service lifting pumps. The five pumps between them use 58% of on-site energy.

The well pumps use a total of 35.2% of the on site energy. This leaves a total of 7% of on site energy actually used in the treatment processes.

Some of the well pumps operate very little, with average usage as little as eight minutes per day. The reason for the utilization level of each well has not been investigated within this study.

The two largest (500hp) high lift pumps operate very little - with average usage as little as twenty minutes per day. The three smaller pumps, each of which has recently been equipped with a high-efficiency motor, are apparently used to accommodate the base load. Control of pumped flow is by manually stopping and starting the pumps. The average utilization of pump capacity appears low at 22%, but a high level of spare capacity is necessary to provide the flexibility to service the diurnal range of plant outlet flow.

The recent addition of soft-start control to motors of the three most-used high lift pumps will save energy, as the pumps are stopped and started frequently.

Case study

Three years ago the operator replaced the motor of a 200 hp high service pump. He used a high-efficiency motor instead of a general purpose motor.

The table below shows that, assuming electricity is charged a $0.03 per kWh and 24 hour operation, changing the motor has saved $983 in three years. The payback period for the more expensive efficient motor is about one year. However in practice the pump is only used for 2.5 hours per day, so the actual payback period is ten years.

There are savings to be made by adopting high efficiency electric motors, but not if the machine gets little use. $1,000 is saved within three years if the pump is operated for 24 hours per day, but no saving is made within three years if, as is the case, the pump is operated for only 2.5 hours per day

High Service Pump	General Purpose motor	Premium efficiency motor
Horsepower	200 hp	200 hp
Motor Efficiency	95.0 %	95.8 %
Purchase price	$ 8,592	$ 9,022
Operating cost, 3 years, 24 hours per day	$ 169,309	$ 167,896
Operating cost, 3 years, 2.5 hours per day	$ 17,636	$ 17,489
Total cost - 3 years, 24 hours per day	$ 177,901	$ 176,918
Total cost - 3 years, 2.5 hours per day	$ 26,228	$ 26,511

B4 GRASSLAND DAIRY PRODUCTS WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for Grassland, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B4 Energy use for Grassland Wastewater Treatment Plant

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
		Hours/day	kWh/day	%
West side equalization basin mixer	Submersible mixer	24	98.6	4.2%
East side equalization basin mixer	Submersible mixer	24	118.4	5.0%
West side basin plant feed pump	Submersible centrifugal pump	0	0	0%
East side basin plant feed pump	Submersible centrifugal pump	12	31.6	1.3%
Anaerobic mixer # 1	Submersible mixer	24	131.5	5.6%
Anaerobic mixer # 2	Submersible mixer	24	118.4	5.0%
Aeration basin # 1 aerator	Surface aerator	24	536.9	22.9%
Aeration basin # 2 aerator	Surface aerator	24	894.8	38.1%
Clarifier # 1	Bridge drive	24	19.7	0.8%
Clarifier # 2	Bridge drive	24	19.7	0.8%
Clarifier # 3	Bridge drive	24	19.7	0.8%
RAS pump # 1	Centrifugal pump	24	23.8	1.0%
RAS pump # 2	Centrifugal pump	24	21.8	0.9%
RAS pump # 3	Centrifugal pump	24	21.8	0.9%
WAS pump	Centrifugal pump	24	41.6	1.8%
DAF plant air compressor	Air supply compressor	3.25	16.9	0.7%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
DAF bottom collection	Scraper drive	1	0.8	0.04%
DAF top collection	Scraper drive	1	0.8	0.04%
DAF sludge auger		1	0.8	0.04%
DAF sludge auger		1	0.8	0.04%
DAF recycle pump	Centrifugal pump	24	157.8	6.7%
DAF thickened sludge pump	Rotary lobe pump	4	3.9	0.2%
UV unit		10	12.0	0.5%
Plant effluent pump # 1	Submersible centrifugal pump	2.4	19.7	0.8%
Plant effluent pump # 2	Submersible centrifugal pump	3.5	28.8	1.2%
Plant effluent reuse pump	Centrifugal pump	4	7.7	0.3%
Calculated total for the plant			**2348.5**	**100.0%**
Measured total for the plant			**2193.7**	
%age difference			**7.06 %**	

KPI Description	KPI Value	Comment
Energy use per population equivalent	82 kWh per pe per annum	High
Energy cost per population equivalent	$3.56 per pe per annum	Highest in Wisconsin sites
Aeration efficiency	0.56kgO_2/kWh	Lower than expected

The estimated energy use is a fairly good fit to the measured use.

Although the energy use is high for an activated sludge plant, this is largely because of the particular treatment needs of this industrial treatment plant. The equalization basin mixers take 9.2% of the plant energy, a use not normally encountered in a municipal treatment plant.

Oxidation ditch aeration amounts to 61.0% of the total on-site energy. This is at the top-end of the expected range for this duty, the aeration efficiency being lower than might be expected.

The other large user of on site energy is the DAF plant with 7.8% of the on-site energy. The DAF unit was originally installed to thicken the waste activated sludge (WAS) only, whereas it is being used to clarify a combination of WAS and effluent from the secondary clarifiers. This is due to the poor settling characteristics of the mixed liquor suspended solids. If it were possible to adjust the overall process to improve the MLSS settling characteristics then the cost of DAF treatment would be reduced significantly.

B5 GREEN BAY METROPOLITAN SEWERAGE DISTRICT WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for Green Bay MSD, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B5 Energy use for Green Bay Wastewater Treatment Plant

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
		Hours/day	kWh/day	%
Metro lift pump	Centrifugal pump	24	16946.4	17.7%
Mill raw lift pump	Centrifugal pump	24	1955.4	2.0%
Bar screens	Drive motors	2.4	8.9	0.01%
Headworks building	Screen drives, conveyor drives and washer press drive	4.8	50.0	0.1%
Primary tanks surface skimmers	Skimmer drives 3 hp each	24	214.8	0.2%
Primary sludge and grit pump SP-B1	Centrifugal pump	24	340.7	0.4%
Primary sludge and grit pump SP-B2	Centrifugal pump	24	362.9	0.4%
Primary sludge and grit pump SP-B3	Centrifugal pump	24	372.0	0.4%
Grit traps	Grit drive	24	89.5	0.1%
Grit classifiers	Classifier	4.8	2.9	0.003%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
Primary sludge a scum pump #1	Centrifugal pump	24	268.5	0.3%
Primary sludge a scum pump #2	Centrifugal pump	24	268.5	0.3%
Primary sludge a scum pump #3	Centrifugal pump	24	268.5	0.3%
Primary sludge a scum pump #4	Centrifugal pump	24	268.5	0.3%
North plant anoxic mixers	Submersible mixers	24	274.3	0.3%
South plant anoxic mixers	Submersible mixers	24	219.5	0.2%
Aeration compressor #1	Air blower	24	31990.7	33.4%
Blower cooling water recirc pump PP-C2	Centrifugal pump	24	74.5	0.1%
North plant RAS pump SP-B46	Centrifugal pump	24	1045.3	1.1%
North plant RAS pump SP-B51	Centrifugal pump	24	1073.8	1.1%
North plant RAS pump SP-B41	Centrifugal pump	24	1073.8	1.1%
North plant RAS pump SP-B49	Centrifugal pump	24	1073.8	1.1%
North plant RAS pump SP-B47	Centrifugal pump	24	997.0	1.0%
North plant RAS pump SP-B52	Centrifugal pump	24	997.0	1.0%
North plant RAS pump SP-B48	Centrifugal pump	24	997.0	1.0%
North plant RAS pump SP-B50	Centrifugal pump	24	997.0	1.0%
North plant RAS pump SP-	Centrifugal pump	24	997.0	1.0%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
B43				
North plant scum pump SP-B29	Centrifugal pump	24	243.4	0.3%
North plant scum pump SP-B35	Centrifugal pump	24	217.5	0.2%
North plant scum pump SP-B36	Centrifugal pump	24	217.5	0.2%
North plant scum pump SP-B25	Centrifugal pump	24	217.5	0.2%
North plant scum pump SP-B26	Centrifugal pump	24	217.5	0.2%
North plant scum pump SP-B33	Centrifugal pump	24	217.5	0.2%
North plant scum pump SP-B34	Centrifugal pump	24	217.5	0.2%
South plant clarifier	Bridge drive	24	25.3	0.03%
South plant RAS pump SP-N7	Centrifugal pump	24	1496.4	1.6%
South plant WAS pump SP-N13	Centrifugal pump	24	49.9	0.1%
South plant WAS pump SP-N14	Centrifugal pump	24	29.3	0.03%
South plant scum pump #1	Centrifugal pump	12	134.2	0.1%
South plant scum pump #2	Centrifugal pump	12	134.2	0.1%
South plant drain pump	Centrifugal pump	18	151.0	0.2%
Interim effluent pump LP-F13	Centrifugal pump	24	1270.3	1.3%
Gravity thickener #1	Collector drive	24	161.1	0.17%
Gravity thickener #2	Collector drive	24	161.1	0.17%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
Gravity thickener #3	Collector drive	24	161.1	0.17%
Gravity thickener #4	Collector drive	24	89.5	0.09%
Spray water pump WP-B5	Centrifugal pump	24	399.7	0.4%
Gravity thickener thickened sludge pump SP-G8	Progressive cavity pump	4.8	24.9	0.03%
Gravity thickener thickened sludge pump SP-G9	Progressive cavity pump	4.8	24.9	0.03%
Gravity thickener thickened sludge pump SP-G10	Progressive cavity pump	4.8	24.9	0.03%
North gravity thickener scum pump SP-G11	Progressive cavity pump	24	45.9	0.05%
South gravity thickener scum pump SP-G12	Progressive cavity pump	18	34.3	0.04%
South gravity thickener scum pump SP-G13	Progressive cavity pump	18	34.3	0.04%
Sludge holding tank compressor AC- 55	Air compressor	24	1374.7	1.4%
Gravity belt thickener	Belt drive	24	89.5	0.1%
Gravity belt thickener feed pump	Centrifugal pump	24	104.4	0.1%
Gravity belt thickener	Hydraulic drive unit	24	39.9	0.04%
Spray wash water pump LP-F17	Centrifugal pump	24	1077.4	1.1%
Polymer feed pump	Centrifugal pump	24	35.8	0.04%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
Thickener effluent return pump LP-F24	Centrifugal pump	24	1077.4	1.1%
Thickened WAS pump LP-F12	Progressive cavity pump	19.2	66.0	0.1%
Belt press grinder #1	Grinder drive	24	179.0	0.2%
Belt press grinder #2	Grinder drive	24	179.0	0.2%
Belt press # 1	Belt drives	24	214.8	0.2%
Belt press # 2	Belt drives	24	214.8	0.2%
Belt press	Hydraulic drive unit	24	33.3	0.03%
Belt press feed pump SP-S2	Progressive cavity pump	24	77.2	0.1%
East press cake conveyor SC-S2	Conveyor drive	24	63.2	0.1%
Horizontal conveyor	Conveyor drive	24	34.6	0.04%
East conveyor	Conveyor drive	24	60.5	0.1%
Cross conveyor SC-S27	Conveyor drive	24	59.9	0.1%
Storage bio screw conveyor	Conveyor drive	24	26.6	0.03%
Incinerator feed screw conveyor SC-S14	Conveyor drive	24	96.8	0.1%
Incinerator shaft drive	Shaft drive	24	360.9	0.4%
Ash screw conveyor SC-S22	Conveyor drive	24	20.8	0.02%
Ash bucket elevator SC-S25	Elevator drive	24	54.4	0.1%
ID fan IF-S11	Air blower	24	3579.4	3.7%
ID fan IF-S14	Air blower	18	1794.3	1.9%
Condensate transfer pump	Centrifugal pump	18	50.3	0.1%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
Condensate return pump	Centrifugal pump	18	30.2	0.03%
Combustion air fan IF-S8	Air blower	24	512.1	0.5%
Shell cooling fan IF-S18	Air blower	24	157.3	0.2%
Center shaft cooling fan	Air blower	24	522.2	0.5%
Scrubber water pump LP-S2	Centrifugal pump	24	517.4	0.5%
Waste heat recovery boiler feed water pump	Centrifugal pump	18	805.4	0.8%
Service air compressor	Air compressor	24	1217.8	1.3%
Service air compressor cooling water pump	Centrifugal pump	24	89.5	0.1%
Service water pump WP-B1	Centrifugal pump	24	1902.2	2.0%
Service water pump WP-B2	Centrifugal pump	24	1902.2	2.0%
Service water pump WP-B3	Centrifugal pump	24	1902.2	2.0%
Effluent recirculation pump LP-B10	Centrifugal pump	24	75.8	0.1%
Effluent recirculation pump LP-B12	Centrifugal pump	24	134.2	0.1%
Control compressor PP-B1	Air compressor	24	78.5	0.1%
Control air compressor	Air compressor	24	894.8	0.9%
Final basin collector FC-B1		24	16.6	0.02%
Final effluent strainer FS-B4		24	17.7	0.02%
Effluent cooling strainer FS-B8		24	22.6	0.02%
HVAC system	Entire site covered	24	4706.9	4.92
Calculated total for the plant			**95698.6**	**100.0%**

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
Measured total for the plant			**96549.6**	
%age difference			**-0.88 %**	

KPI Description	**KPI Value**	**Comment**
Energy use per population equivalent	84 kWh per pe per annum	Highest in Wisconsin sites
Energy cost per population equivalent	$2.78 per pe per annum	Average
Aeration efficiency	1.14kgO_2/kWh	Best in Wisconsin sites

The estimated energy use is a very good fit to the measured use, being within 1% of each other.

Green Bay is the largest of the Wisconsin sites, yet the energy usage KPI (84 kWh per pe per annum) is the highest of the sites. This can be explained in part by:

? the high energy use for influent pumping of both industrial and domestic sewage, amounting to 19.7% of the total onsite energy, and:

? the use of energy for sludge incineration accounting for 10% of the on-site electrical energy.

Without these two users the energy usage KPI would be 59 kWh per pe per annum, which is still high among Wisconsin sites.

Aeration amounts to 33.4% of the total on-site energy. This is a lower than average percentage than for most sites, but must be considered in conjunction with other high energy users on site including influent pumping, sludge thickening and incineration.

The service water pumps use 6.0% of the on site energy. These pumps are mostly used to supply spray water to the sludge incinerators.

The interim pump, which pumps effluent from the South plant to chlorination uses 1.3% of onsite energy. This could be reduced if less flow was treated in the South plant.

In addition to the use of electrical energy, natural gas is used to fuel the incinerator.

B6 CITY OF KENOSHA WATER TREATMENT FACILITY

The following table compares the average daily energy use for La Crosse, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B6 Energy use for Kenosha Water Treatment Plant

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
		Hours/day	kWh/day	%
Membrane plant low lift pump	Vertical turbine pump	24	5237.6	24.7%
Membrane backwash air compressor #1	Air compressor	9.4	407.0	1.9%
Membrane backwash air compressor #2	Air compressor	10.1	395.9	1.9%
Membrane backwash air compressor #3	Air compressor	13	233.6	1.1%
Membrane backwash air compressor #4	Air compressor	15.8	706.9	3.3%
Membrane backwash air compressor #5	Air compressor	17.2	1082.6	5.1%
Membrane backwash air compressor #6	Air compressor	14.1	630.9	3.0%
CIP sodium hydroxide mixing pumps	Centrifugal pump	1.25	48.8	0.1%
CIP pump	Centrifugal pump	1.25	32.6	0.2%
Conventional filter plant low lift pump #1	Vertical turbine pump	12	259.4	1.2%
Conventional filter plant low lift pump #2	Vertical turbine pump	12	314.3	1.5%
Alum mixing recirculation pump	Centrifugal pump	24	353.7	1.7%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
Alum feed pumps	Centrifugal pump	24	21.0	0.1%
Flocculator #1	Drive unit	24	86.0	0.4%
Flocculator #2	Drive unit	24	86.0	0.4%
Conventional filter backwash pumps	Vertical split case pump	0.017	1.7	0.01%
Polyphosphate feed pump	Centrifugal pump	24	11.5	0.1%
Fluoride feed pump	Centrifugal pump	24	12.2	0.1%
High lift pump #1	Vertical turbine pump	24	8046.5	38.0%
High lift pump #2	Vertical turbine pump	11.7	2519.3	11.9%
Parking lot pump #1	Submersible pump	24	468.5	2.2%
Parking lot pump #2	Submersible pump	11.7	228.4	1.1%
Calculated total for the plant			**21184.4**	**100.0%**
Measured total for the plant			**20828.2**	
%age difference			**1.71 %**	

The estimated energy use is an extremely good fit to the measured use, being within 1.71%.

The power costs can be broken into key stages as follows:

Abstraction energy costs	96,630 $ p.a.
Conventional plant treatment costs	16,911 $ p.a.
Membrane plant treatment costs	62,633 $ p.a.
Booster pumping costs	176,084 $ p.a.
Total works	352,297 $ p.a.

The most notable users of on site energy are the high lift pumps, which use 50% of on-site energy. Current practice of running the high lift pumps is to use one pump 24 hours a day and use a second pump 11.7 hours a day. The second pump is used during the night to fill up service reservoirs and takes advantage of lower electricity costs.

The low lift pumps use a total of 27.4% of the on site energy. This leaves a total of 22.6% of on site energy actually used in the treatment processes.

The majority of water is treated by the membrane plant under current operating practice. The membrane plant uses 17.8% of total onsite energy and the conventional filter plant uses 4.8% of total onsite energy. The conventional plant uses a much smaller amount of power, but does have higher chemical costs and the quality of the treated water is not as good.

B7 CITY OF LA CROSSE WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for La Crosse, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B7 Energy use for La Crosse Wastewater Treatment Plant

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
		Hours/day	kWh/day	%
Fine step screen	Screen drive unit	24	53.7	0.3%
Huber wash press	Wash press drive	1	3.3	0.02%
Grit trap # 1	Vortex drive	24	39.7	0.2%
Grit trap # 2	Vortex drive	24	39.7	0.2%
Grit pump #1	Centrifugal pump	1.17	4.8	0.03%
Grit pump #1	Centrifugal pump	1.17	4.8	0.03%
Grit washer # 1	Washer drive unit	1.5	2.5	0.01%
Grit washer # 2	Washer drive unit	1.5	2.5	0.01%
Raw sewage pump # 4	Centrifugal pump	24	1450.7	8.6%
Primary sludge pump (1,2,3)	Centrifugal pump	2.5	14.0	0.1%
Primary sludge pump (4,5)	Centrifugal pump	6	33.6	0.2%
Primary scum pump (1,2,3)	Piston pump	0.14	0.5	0.003%
Primary scum pump (4,5)	Piston pump	0.18	0.4	0.002%
Settled sewage effluent pump	Centrifugal pump	24	1291.8	7.7%
Aeration plant mixers	Submersible mixers	24	2682.9	16.0%
Aeration blower	Air blower	24	6539.7	39.0%
Final clarifiers	Bridge drives	24	19.9	0.1%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
RAS pumps	Two vertical turbine pumps	24	596.2	3.6%
WAS pump	Vertical turbine pump	18	278.2	1.7%
UV unit		10	838.3	5.0%
Gravity belt thickener # 1	Drive unit	24	69.6	0.4%
Gravity belt thickener # 2	Drive unit	24	69.6	0.4%
Digester feed pump # 1	Progressive cavity pump	24	179.0	1.1%
Digester feed pump # 2	Progressive cavity pump	24	179.0	1.1%
Digester building	Mixing pumps and heat exchangers	24	596.2	3.6%
Digested sludge gravity belt thickener	Drive unit and feed pump	6	119.2	0.7%
Thickened sludge feed pump	Progressive cavity pump	6	44.7	0.3%
Liquid storage tank mixing pumps	Centrifugal pumps	0.28	26.1	0.2%
Liquid storage tank loadout pump	Centrifugal pump	0.68	10.1	0.1%
Liquid storage tank transfer pump	Centrifugal pump	1.26	18.8	0.1%
Belt press feed pump	Progressive cavity pump	4.51	84.1	0.5%
Dewatering belt press	Belt press drives	5	504.5	3.0%
Centrifuge feed pumps	Progressive cavity pumps	2.83	42.2	0.3%
Sludge centrifuge # 1	Centrifuge drive	1.31	293.1	1.7%
Sludge centrifuge # 2	Centrifuge drive	1.31	293.1	1.7%
Cake transfer pumps	Progressive cavity pumps	2.83	21.1	0.1%
Flush water pump	Centrifugal pump	24	337.8	2.0%
Calculated total for the plant			**16786.8**	**100.0%**
Measured total for the plant			**15053.9**	

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
% age difference			**11.51%**	

KPI Description	**KPI Value**	**Comment**
Energy use per population equivalent	40 kWh per pe per annum	Low
Energy cost per population equivalent	$1.75 per pe per annum	Below average
Aeration efficiency	1.02kgO_2/kWh	Lower than expected

This estimated energy use is a reasonably good fit to the measured energy use, being within 12%.

Aeration amounts to 39.0% of the total on-site energy. This is lower than the average percentage for most sites, but this is due to the large use of energy for other purposes.

The mixers in the activated sludge plant use a total of 16% of onsite energy. This is a large percentage of the total energy and is a possible area for improvement.

Influent pumping amounts to 8.6% of the total onsite energy.

Settled sewage pumping amounts to 7.7% of the total onsite energy.

Sludge dewatering uses a total of 7.3% of the total onsite energy, this is lower than expected and can be explained by the disposal of 35% of sludge in a liquid state.

The aeration efficiency of this site has been calculated to be 1.02 kgO_2/kWh, this is lower than might be expected for fine bubble aeration.

The biogas from the digesters is used for sludge heating or is sent to flare. There may be scope to utilize all of the energy from the biogas with the installation of a combined heat and power system. Further investigation into this possibility would be required.

B8 PAPERMILL A WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for Papermill A, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B8 Energy use for Papermill Wastewater Treatment Plant

Duty	Function Description	Typical Running Time Hours/day	On-site energy use kWh/day	% of total On-site energy %
Papermill lift station pump #1	Centrifugal pump	24	715.9	1.6%
Papermill lift station pump #2	Centrifugal pump	24	715.9	1.6%
Papermill lift station pump #3	Centrifugal pump	24	715.9	1.6%
Pulpmill lift station pump #1	Centrifugal pump	24	715.9	1.6%
Pulpmill lift station pump #2	Centrifugal pump	24	715.9	1.6%
Pulpmill lift station pump #3	Centrifugal pump	24	715.9	1.6%
Well water cooling pump	Vertical turbine pump	11	124.9	0.3%
Aeration blower #1	Air compressor	24	4541.3	9.9%
Aeration blower #2	Air compressor	24	5528.5	12.0%
Aeration blower #3	Air compressor	24	5133.6	11.1%
Aeration blower #4	Air compressor	24	5232.4	11.4%
Aeration blower #5	Air compressor	24	3850.2	8.4%
S1 jet pump S2 jet pump	Centrifugal pump Centrifugal pump	24 24	524.9 487.4	1.1% 1.1%
S3 jet pump	Centrifugal pump	24	529.0	1.1%
S4 jet pump	Centrifugal pump	24	556.3	1.2%
S5 jet pump	Centrifugal pump	24	476.5	1.0%
S6 jet pump	Centrifugal pump	24	482.7	1.0%
S7 jet pump	Centrifugal pump	24	417.2	0.9%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
S8 jet pump	Centrifugal pump	24	702.9	1.5%
N1 jet pump	Centrifugal pump	24	1383.9	3.0%
N2 jet pump	Centrifugal pump	24	994.7	2.2%
N3 jet pump	Centrifugal pump	24	1056.1	2.3%
N4 jet pump	Centrifugal pump	24	969.3	2.1%
Phosphoric acid pump	Centrifugal pump	4	2.0	0.004%
North ammonia pump	Centrifugal pump	4	2.9	0.006%
South ammonia pump	Centrifugal pump	4	5.0	0.01%
South clarifier drive	Bridge drive	24	30.1	0.1%
South plant RAS pump S1	Centrifugal pump	24	467.7	1.0%
South plant RAS pump S2	Centrifugal pump	24	600.8	1.3%
South plant WAS pump	Centrifugal pump	24	199.3	0.4%
North RAS pump N1	Centrifugal pump	24	584.0	1.3%
North RAS pump N2	Centrifugal pump	24	756.1	1.6%
North WAS pump N1	Centrifugal pump	24	117.0	0.3%
North WAS pump N2	Centrifugal pump	24	103.8	0.2%
De-foam circulation pump	Centrifugal pump	4	0.7	0.001%
De-foam pump	Centrifugal pump	4	7.8	0.02%
Effluent sample pump	Centrifugal pump	4	117.0	0.3%
Belt thickener	Drive unit	24	62.8	0.14%
Belt thickener	Hydraulic power pack	24	27.5	0.06%
Belt thickener polymer pump	Centrifugal pump	4	4.4	0.009%
Liquid polymer feed pump	Centrifugal pump	4	1.5	0.003%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
Thickener agitator	Drive unit	24	134.2	0.3%
Sludge feed pump #3	Centrifugal pump	20.5	281.8	0.6%
Zimpro sludge feed pump	Centrifugal pump	20.5	165.7	0.4%
North press pump (zimpro)	Hydraulic oil gear pump	20.5	449.0	1.0%
South press pump (zimpro)	Hydraulic oil gear pump	20.5	471.7	1.0%
Center press pump (zimpro)	Hydraulic oil gear pump	20.5	458.9	1.0%
Primary zimpro air compressor	Air compressor	20.5	950.3	2.1%
Primary zimpro air compressor cooling pump	Centrifugal pump	20.5	100.2	0.2%
Booster air compressor	Air compressor	20.5	742.9	1.6%
Zimpro oil filter pump	Centrifugal pump	24	52.0	0.1%
Decant tank overflow pump	Centrifugal pump	24	74.0	0.2%
Zimpro vapor blower	Air blower	24	553.7	1.2%
Belt press feed pump	Piston pump	24	72.3	0.2%
Belt filter press	Drive unit	24	12.4	0.03%
Sludge conveyor	Conveyor drive	24	35.5	0.1%
No 1 sludge conveyor	Conveyor drive	24	35.1	0.1%
No 2 sludge conveyor	Conveyor drive	24	37.3	0.1%
No 3 sludge conveyor	Conveyor drive	24	32.1	0.1%
Belt press polymer pump	Centrifugal pump	24	7.8	0.02%
Combined filtration pump	Centrifugal pump	24	162.2	0.4%
North general service water pump	Centrifugal pump	24	251.1	0.5%
South seal water booster pump	Centrifugal pump	24	134.2	0.3%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
North seal water booster pump	Centrifugal pump	24	73.4	0.2%
Plant air compressor	Air compressor	24	378.0	0.8%
South plant basement sump pump	Submersible pump	15	111.9	0.2%
Pickett building sump pump	Submersible pump	15	55.9	0.1%
Calculated total for the plant			**46096.6**	**100.0%**
Measured total for the plant			**47295.7**	
%age difference			**-2.54%**	

KPI Description	**KPI Value**	**Comment**
Energy use per population equivalent Energy cost per population equivalent	34 kWh per pe per annum $ 1.02 per pe per annum	Low Lowest in Wisconsin
Aeration efficiency	0.89 kgO_2/kWh	Average for Wisconsin

The estimated energy use is a good fit to the measured use, being within 3%.

Aeration amounts to 71.3% of total onsite energy use. This is very high compared with other sites, but it must be noted that this plant treats high strength industrial waste and there is no primary treatment to remove solids prior to activated sludge treatment.

Influent pumping amounts to 9.6% of total onsite energy.

The Zimpro sludge treatment process amounts to 8.6% of total onsite energy. This is not a large proportion of total energy but may be reduced by the use of anaerobic digestion.

B9 CITY OF PORTAGE WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for Portage, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B9 Energy use for Portage Wastewater Treatment Plant

Duty	**Function Description**	**Typical Running Time** Hours/day	**On-site energy use** kWh/day	**% of total On-site energy** %
Raw Wastewater pump # 1	Screw pump	24	434	11.94%
Raw Wastewater pump # 2	Screw pump	0	0	0%
Raw Wastewater pump # 3	Screw pump	24	529	14.6%
Raw Wastewater pump # 4	Screw pump	0	0	0%
Fine screen	Screen drive unit	4.8	5	0.14%
Grit blower	Air blower	24	76.8	2.1%
Primary clarifier # 1	Bridge drive	24	25.3	0.70%
Primary clarifier # 2	Bridge drive	24	41.3	1.14%
Waste sludge pump	Diaphragm pump	4	10.1	0.28%
Sludge pump compressor	Air supply compressor	4	17.2	0.47%
RBC # 1	Drive shaft	24	76.0	2.1%
RBC # 2	Drive shaft	24	72.7	2.0%
RBC # 3	Drive shaft	24	75.5	2.1%
RBC # 4	Drive shaft	24	86.3	2.4%
RBC # 5	Drive shaft	24	82.9	2.3%
RBC # 6	Drive shaft	24	77.2	2.1%
RBC # 7	Drive shaft	24	78.1	2.2%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
RBC # 8	Drive shaft	24	76.7	2.1%
RBC # 9	Drive shaft	24	76.8	2.1%
RBC # 10	Drive shaft	24	75.5	2.1%
RBC # 11	Drive shaft	24	60.2	1.7%
RBC # 12	Drive shaft	24	73.8	2.0%
RBC # 13	Drive shaft	24	80.7	2.2%
RBC # 14	Drive shaft	24	80.7	2.2%
RBC # 15	Drive shaft	24	82.9	2.3%
RBC # 16	Drive shaft	24	77.2	2.1%
RBC supplementary air blower	Air blower	24	471.8	13.0%
Secondary Clarifier # 1	Bridge drive	24	5.7	0.2%
Secondary Clarifier # 2	Bridge drive	24	6.2	0.2%
WAS pump	Rotary lobe pump	1	10.0	0.3%
RAS pump # 1	3hp Centrifugal pump	12	26.8	0.7%
RAS pump # 2	3hp Centrifugal pump	12	26.8	0.7%
Chlorine/ Dechlor injector pump # 1	Centrifugal pump (Disinfection only May 1 to Sept 30)	10	22.4	0.62%
Chlorine/ Dechlor injector pump # 2	Centrifugal pump (Disinfection only May 1 to Sept 30)	10	22.4	0.62%
Digester heat exchanger		24	11.4	0.3%
Digester mixing compressor	Air compressor	24	143.4	4.0%
Digester sludge recirculation pump # 1	3hp Centrifugal pump	24	42.7	1.2%
Digester sludge recirculation pump # 2	3hp Centrifugal pump	24	43.8	1.2%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
De-watering feed pumps	15hp Centrifugal pumps	1.71	19.1	0.5%
Belt filter press wash pump # 1	5hp Centrifugal pump	0.07	0.3	0.01%
Belt filter press wash pump # 2	5hp Centrifugal pump	0.07	0.3	0.01%
Belt thickener	4hp Belt drive	0.07	5.1	0.14%
Filtrate and septage tank pump	5hp submersible pump	1	3.7	0.1%
Effluent sample pump	2hp Centrifugal pump	2.4	3.6	0.1%
Plant effluent reuse pump # 1	10hp Centrifugal pump	1.86	13.9	0.38%
Plant effluent reuse pump # 2	10hp Centrifugal pump	1.86	13.9	0.38%
Plant air compressor		1.2	5.9	0.2%
AHU Exhaust fan		24	350.1	9.6%
Calculated total for the plant			**3633.6**	**100.0%**
Measured total for the plant			**3513.8**	
%age difference			**3.41 %**	

KPI Description	KPI Value	Comment
Energy use per population equivalent	33 kWh per pe per annum	Low
Energy cost per population equivalent	$1.66 per pe per annum	Low

The estimated energy usage is a good fit to the measured use, being within 3.5%.

The raw wastewater pumps use a total of 26.5% of the on-site energy. This is the largest user of energy on site. In this case the site requires the influent to be pumped up to the head of the works so this energy consumption can not be avoided.

The RBC supplementary aeration amounts to 13.0% of the total on-site energy. When it is considered that this air is supplied to sixteen RBCs then the total energy use per unit is less than 1%.

The AHU exhaust fan uses 9.6% of the on site energy. This fan is for ventilation of the RBC building to allow safe entry to site staff. This energy could be reduced if the RBCs were covered individually.

The RBC drives are each using approximately 2% of the on site energy.

Although it reliably produces a high quality of effluent, this plant is not a high-energy consumer. It would be much higher if the plant was an activated sludge plant.

There is no mention in the literature provided as to whether the biogas from the digesters is used to heat the digester sludge. There is possible scope for using the biogas energy to heat the incoming digester sludge, further investigations in to this possibility are recommended.

B10 CITY OF RHINELANDER WASTEWATER TREATMENT FACILITY

The following table compares the average daily energy use for Rhinelander, taken from energy bills for one year with an estimation of energy used by the plant, broken down into each item of equipment.

Table B10 Energy use for Rhinelander Wastewater Treatment Plant

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
		Hours/day	kWh/day	%
West side lift station pump # 1	10 hp Submersible pump	10.45	73.5	3.1%
West side lift station pump # 2	5 hp Submersible pump	10.45	28.1	1.2%
West side lift station macerator	Macerator	24	30.1	1.3%
Pista grit trap	Grit drive	24	45.2	1.9%
Grit pump	Self Priming pump	2.3	10.5	0.5%
Influent sampler pump # 1	Self Priming pump	24	30.6	1.3%
Influent sampler pump # 2	Self Priming pump	24	34.3	1.5%
3 muffin monsters	Macerators	24	108	4.6%
Raw sewage pump # 1	Centrifugal pump	8.9	157.1	6.7%

Duty	Function Description	Typical Running Time	On-site energy use	% of total On-site energy
Raw sewage pump # 2	Centrifugal pump	8.9	175.5	7.5%
Raw sewage pump # 3	Centrifugal pump	8.9	184.8	7.9%
Primary screen pressure washer		2	7.5	0.3%
Primary screen screw conveyor	Screw Conveyor	2	2.2	0.1%
Biotower recycle pump # 1	Self Priming pump	17.1	243.7	10.4%
Biotower recycle pump # 2	Self Priming pump	17.1	247.0	10.6%
Biotower recycle pump # 3	Self Priming pump	17.1	219.8	9.4%
Biotower ventilation fan # 1	Air supply fan	24	35.9	1.5%
Biotower ventilation fan # 2	Air supply fan	24	35.9	1.5%
Biotower ventilation fan # 3	Air supply fan	24	35.9	1.5%
Biotower ventilation fan # 4	Air supply fan	24	35.9	1.5%
South secondary clarifier	Bridge drive	24	14.5	0.6%
North secondary clarifier	Bridge drive	24	14.5	0.6%
Sludge pump air compressor	Air supply compressor	10	218.5	9.3%
Digester feed pump	Centrifugal pump	0.63	1.0	0.04%
Digester recirculation pump # 1	Centrifugal pump	7.3	22.0	0.9%
Gas mixing compressor	Compressor	24	102.6	4.4%
Digested sludge transfer	Centrifugal pump	0.36	0.6	0.03%

Duty	**Function Description**	**Typical Running Time**	**On-site energy use**	**% of total On-site energy**
pump				
Liquid storage mix / loadout pumps	Centrifugal chopper pumps	12	223.7	9.6%
Scum and drain pump	Submersible pump	0.01	0.02	0.001%
Calculated total for the plant			**2339.0**	**100.0%**
Measured total for the plant			**2068.0**	
% age difference			**13.11 %**	

Key performance indicator	Result	Comment
Energy use per population equivalent	60 kWh/pe	Average
Energy cost per population equivalent	$2.53/pe	Above average

The estimated energy usage is a fairly good fit to the measured use, being within 13.11%.

The biotower recirculation pumps use a total of 30.4% of the on-site energy. This is the largest user of energy on site. There may be scope for reducing the recycle flow, reducing the energy used by the pumps, if the performance of the filters was not affected.

The raw sewage pumps use a total of 22.1% of the on-site energy. In this case the site requires the influent to be pumped up to the head of the works so this energy consumption cannot be avoided.

The liquid storage loadout pumps that mix and pump liquid sludge uses 9.6% of the on-site energy.

The air supply compressor that provides air to the air-diaphragm sludge pumps for the secondary clarifiers uses 9.3% of the on-site energy. Replacing the pumps with units that are more energy efficient could reduce this high use of energy.

This plant is not a high-energy consumer; it would be much higher if the plant was an activated sludge plant.

This plant is using natural gas to heat the digester sludge; there is scope for utilizing the biogas produced in the digesters instead of venting the gases to the atmosphere. Further investigation into the use of biogas is required, but could prove to save on the cost of natural gas.

APPENDIX C – PROCESS-RELATED STUDIES FOR EACH PLANT

C1 **CITY OF ASHLAND WASTEWATER TREATMENT FACILITY**

C2 **CITY OF BURLINGTON WASTEWATER TREATMENT FACILITY**

C3 **CITY OF EAU CLAIRE WATER UTILITY**

C4 **GRASSLAND DAIRY PRODUCTS**

C5 **GREEN BAY METROPOLITAN SEWERAGE DISTRICT WASTEWATER TREATMENT FACILITY**

C6 **CITY OF KENOSHA WATER TREATMENT FACILITY**

C7 **CITY OF LA CROSSE WASTEWATER TREATMENT FACILITY**

C8 **PAPERMILL A WASTEWATER TREATMENT FACILITY**

C9 **CITY OF PORTAGE WASTEWATER TREATMENT FACILITY**

C10 **CITY OF RHINELANDER WASTEWATER TREATMENT FACILITY**

GENERAL

In the following process-related study it was found that for the wastewater treatment sites that utilize an activated sludge treatment process the aeration efficiency was less than might be expected for a particular installation. (For derivation of aeration efficiency, see General Section of Appendix B). Possible reasons for this are:

? The size of the aeration tank or ditch is inappropriate for the hydraulic loading;

? Oversized aeration system, for the duty;

? Over-aeration due to ineffective D.O. control;

? The tank or ditch geometry is not optimal;

? The biological process is ineffective;

? A chemical in the incoming sewage is causing a low alpha factor, leading to inefficient oxygen uptake;

? A faulty aerator, e.g. worn brushes or incorrect level of immersion;

? Inadequate mixing, leading to settlement of the mixed liquor at points within the tank;

? Incorrect metering of power or applied flow and load. (i.e. the aeration efficiency is actually higher than the information indicates).

In some cases it has been possible to identify some reasons why this should be the case for a particular plant, and this has been reported on a plant-by-plant basis below. Without a more detailed study it is not possible to identify all the reasons for any particular plant. However it appears for the majority of plants that the low aeration efficiency is due in some part to the fact that the installation is oversized for the duty.

C1 CITY OF ASHLAND WASTEWATER TREATMENT FACILITY

Available Data

There are two circular oxidation ditches, each aerated by 4 jet mixers. Each jet mixer is rated at 15 hp. There is a blower, rated at 150 hp, which provides air to the jet mixers. The total aeration power is therefore 270 hp (200 kW). The blower delivers 2,800 cfm.

The records for the crude sewage and final effluent are given in the following table.

	Influent			Effluent			
Month	**Flow**	**BOD5**	**TSS**	**BOD5**	**TSS**	**TP**	**NH3**
April 2001	3.606	74	59	10	22	0.86	0.58
May	2.064	184	199	7	12	0.42	0.05

June	1.620	221	158	5	7	0.49	0.06
July	1.440	292	193	5	8	0.61	0.06
August	1.533	252	143	4	4	0.50	0.03
September	1.366	283	167	3	4	0.49	0.06
October	1.432	279	168	4	4	0.60	0.00
November	1.515	272	168	4	6	0.44	0.00
December	1.954	192	119	3	6	0.50	0.04
January 2002	1.203	284	183	4	7	0.64	0.00
February	1.279	295	191	6	9	0.62	0.00
March	1.842	223	154	6	8	0.71	0.12

Flow in MGD. All other units mg/l

Ammonia is a single daily composite

Phosphorus is 4-5 daily composites

Letter from EDI, dated May 29, 2002

This letter relates to a proposed upgrade to the aeration system, and recommends replacing the aeration system with membrane diffusers, and operating a single ditch. For the modeling work this data has been assumed to be correct.

? Alpha factor stated as 0.6
? Beta factor stated as 0.95
? Site elevation 675 ft
? Minimum DO 2 mg/l
? Winter 5 ?C
? Summer 20 ?C[1]
? Estimated oxygen requirement: 157 lb O_2/h

We assumed that the temperature would be a minimum (5 C) in February, with the maximum of 20 C 6 months later in August.

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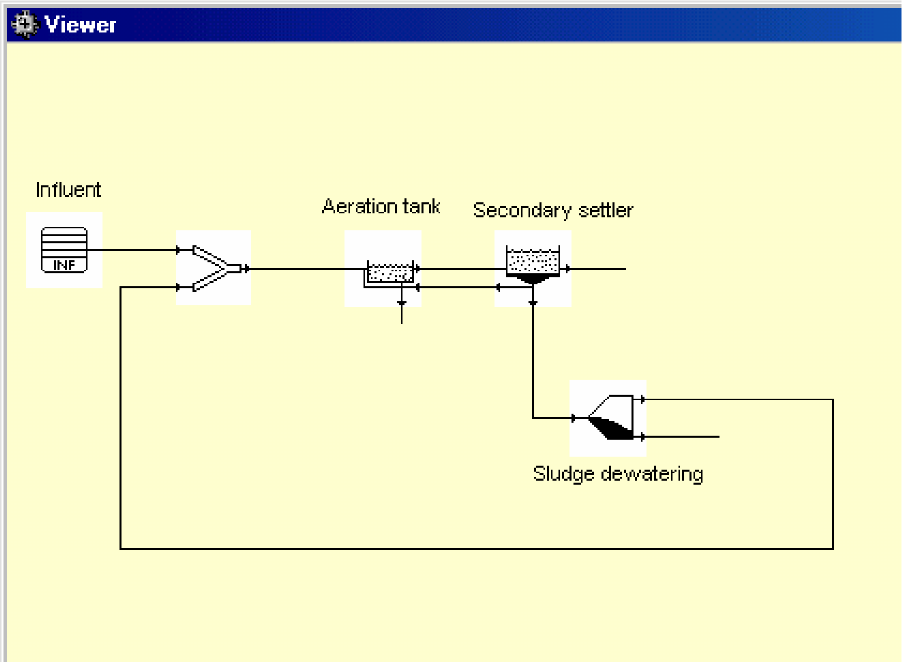
[1] The EDI letter used centigrade units

Period	Month	Sin	Temperature
0	May	0.00	12.50
1	Jun	0.50	16.25
2	Jul	0.87	19.00
3	Aug	1.00	20.00
4	Sep	0.87	19.00
5	Oct	0.50	16.25
6	Nov	0.00	12.50
7	Dec	-0.50	8.75
8	Jan	-0.87	6.01
9	Feb	-1.00	5.00
10	Mar	-0.87	6.00
11	Apr	-0.50	8.75

Assumptions

A model of the site was constructed using Plan-It STOAT software.



No data were available on the influent nitrogen or phosphorus. The BOD was interpreted as a BOD_5, and a standard assumption made that 40% of the BOD was soluble, 60% particulate. Because the site uses chemical phosphorus removal the COD-based IWA ASM2d model was used for the activated sludge tank. The BOD was converted into COD by assuming that 1g biodegradable COD exerts a BOD of 0.68g.

Aeration efficiency was calculated for the Energy study at 0.89 kgO_2/kWh. This value has been assumed for the Plan-it Stoat modeling.

No data was available on the dose used of aluminium salts for phosphorus removal. The dose used was therefore chosen to get an approximate match to the measured effluent phosphorus. ***Without more information about the influent phosphorus content, and the dose of aluminium salts used, it is not possible to estimate if the site could consume less aluminium salt.***

Modeling

The following Plan-It STOAT simulations were run:

? Operation at a constant aeration intensity, reflecting the jet mixers and blower operating at continuous maximum output.

? Operation with the DO profile chosen so as to meet the current effluent requirement.

? Operation with only one ditch in use.

Aeration efficiency 0.89 kg O_2/kWh (we assume that a jet aerator will behave like a surface aerator and have an alpha value close to 1.0).

The UV disinfection system was not modeled.

PLAN-IT STOAT OUTPUT

No DO control

Without DO control we assumed that the aeration system was running at full capacity. The predictions for this scenario are given in the following tables, for selected months. Phosphorus values are simply to show that the model can be tuned to predict large removals of phosphorus – the specific values require more information about the influent phosphorus concentrations, and the aluminium dosing strategy, than is available.

The model predicts that during winter, with a sewage temperature of 5 C (taken from the EDI letter) then Ashland should not nitrify. The laboratory data records values of 0.0 mg/l or 'ND' during winter, which would be unusual, considering that there is an ammonia residual during the hot summer months. The sludge wastage rate used for February is 0.022 MGD, which according to the supplied documentation is as low as the wastage rate goes.

The influent values are taken from the site records, as are the measured effluent values. The columns in the table for MLSS, RAS and effluent are the model predictions.

May 2001

Parameter	Stream	Influent	MLSS	RAS	effluent	Measured
Flow	MGD	2.06	3.5	1.4	2.06	2
BOD	Mg/l	180	1010	2460	3.5	7
TSS	Mg/l	200	4510	11000	14.8	12
NH3	Mg/l	35	0.07	0.07	0.07	0.05
Nitrate	Mg/l	0	23	23	23	
PO4	Mg/l	7	1.51	1.51	1.51	
TP	Mg/l	7	658	1570		0.42

February 2002

Parameter	Stream	Influent	MLSS	RAS	effluent	Measured
Flow	MGD	1.28	2.3	1	1.28	1.28
BOD	Mg/l	280	1530	3430	5.1	6
TSS	Mg/l	170	3520	7920	10.9	9
NH3	Mg/l	40	47.4	47.4	47.4	0.00
Nitrate	Mg/l	0	0	0	0	
PO4	Mg/l	5	0.01	0.01	0.01	
TP	Mg/l	7	658	1570	0.07	0.62

DO control

The DO control simulations were set up so that the DO was 6.0 mg/l in the aerated sections, with a DO fall-off downstream. The DO setpoint was chosen to get the May 2001 data to roughly match the measured effluent quality, especially on the ammonia values. As can be seen the DO control case (below) is comparable to the constant aeration case (above) – but there will be an energy saving.

The constant power case uses an aeration power of 210 hp. The DO control is estimated to require 110 hp (assuming an aeration efficiency of 0.89 kg O_2/kWh) – a 47% saving. In practice turn-down issues and mixing, rather than aeration, requirements will reduce the scope for saving – but there is clearly much scope for energy saving.

May 2001

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	2	3.43	1.4	2	2
BOD	mg/l	180	948	2260	3.3	7
TSS	mg/l	200	4530	10800	14.7	12
NH3	mg/l	30	1.24	1.24	0.08	0.05
Nitrate	mg/l	0	20.3	20.3	20.3	
PO4	mg/l	5	0.01	0.01	0.01	
TP	mg/l	7	658	1570	0.07	0.42

February 2002

Parameter	Stream	Influent	MLSS	RAS	effluent	Measured
Flow	MGD	1.28	2.71	1.4	1.28	2
BOD	mg/l	280	1410	2670	4.8	7
TSS	mg/l	170	3060	5780	9.6	12
NH3	mg/l	40	46.6	46.6	46.6	0.05
Nitrate	mg/l	0	0	0	0	
PO4	mg/l	7	0.01	0.01	0.01	
TP	mg/l	9	1390	2620	4.38	0.42

One ditch, DO control

This is an illustrative run, to see what will happen to nitrification during the test case of May. (The winter month of February will not nitrify, since the model predicts that even with two ditches nitrification will not take place.) Full nitrification is retained, with ammonia reduced from 45 to 0.08 mg/l.

May 2001

Parameter	Stream	Influent	MLSS	RAS	Effluent
Flow	MGD	2.06	3.5	1.4	2.06
BOD	mg/l	180	524	1280	2
TSS	mg/l	200	4120	10000	13.7
NH3	mg/l	30	0.08	0.08	0.08
Nitrate	mg/l	0	22.8	22.8	22.8
PO4	mg/l	5	0.1	0.1	0.1
TP	mg/l	7	658	1570	0.07

CONCLUSIONS

The Plan-It STOAT modeling indicates the following:

? The DO system implemented in June 2002 has the potential to approximately halve the energy consumption in the oxidation ditch.

? Without knowledge of the influent phosphorus concentration no estimate of the efficiency of usage of the aluminium dosing system can be made. Since no records of the aluminium dose have been supplied such a calculation could not, in any case, have been made. But monitoring these two – the dose and the influent phosphorus concentration – would allow an estimate of the necessary consumption to be made.

? The site should not nitrify during winter, given the data about wastage rates and sewage temperature. There is no data on the influent ammonia and it may be that during winter the high BOD is caused by de-icing chemicals, low in nitrogen; otherwise, we would expect the nitrogen load to also increase, so that the site records on ammonia removal would be suspect.

? There is scope, as indicated by EDI, to operate with only one oxidation ditch. However, there would be no real reduction in the energy requirements, other than through a reduction in the mixing energy.

? We calculate the aeration efficiency to be 0.89kg O_2/kWh, this is lower than would be expected for a jet air system and shows the plant is running inefficiently.

C2 CITY OF BURLINGTON WASTEWATER TREATMENT FACILITY

Available Data

The high strength industrial waste treated at Burlington is mixed with the domestic sewage prior to treatment. The settled sewage is firstly treated by biological filters and intermediate clarifiers prior to treatment in the activated sludge plant. The activated sludge plant performs biological nitrification, and phosphorus is removed by chemical treatment. Effluent receives UV disinfection before discharge, this disinfection is carried out from May to September.

The activated sludge process uses six basins in six tanks. Each uses a diffused aeration system. Three blowers provide air to the plant, two of which are running at all times. Each blower delivers 1600 cfm.

The records for the crude sewage and final effluent are given in the following table.

	Influent					**Effluent**			
Month	**Flow**	**BOD 5**	**TSS**	**NH3-N**	**PO4**	**BOD 5**	**TSS**	**NH3-N**	**PO4**
January 2001	2.86	512	292	10.7	5.5	5	3	0.08	0.8
February	3.41	427	303	13.1	6.1	6	5	0.2	0.8
March	3.23	371	216	14.1	4.4	7	3	1.17	0.7
April	3.83	434	265	14.8	5.0	9	3	2.26	0.7
May	3.45	475	265	11.4	4.9	9	6	4.86	0.5
June	3.93	411	378	10.7	5.2	13	8	1.47	0.4
July	3.18	449	246	13.3	5.6	6	3	0.49	0.6
August	3.22	394	230	17.9	5.9	4	3	0.3	0.6
September	3.31	296	144	14.4	5.0	3	3	2.031	0.4
October	3.09	301	169	11.1	4.1	5	5	0.58	0.6
November	2.93	248	78	22.6	5.1	6	7	0.04	0.6
December	2.66	543	311	22.8	6.2	5	9	0.07	0.9
January 2002	2.54	504	323	17.9	11.3	6	11	0.04	0.7
February	2.61	405	252	35	6.6	4	4	0.05	0.4
March	2.70	404	243	37.6	4.9	5	5	0.04	0.4
April	3.39	347	256	63.8	4.5	5	5	0.33	0.4
May	3.46	392	342	29.4	5.7	4	3	0.16	0.4
June	3.71	351	352	37.6	4.8	4	4	0.17	0.4
July	3.27	448	333	38.8	6.4	3	2	0.08	0.42

Flow in MGD. All other units mg/l
All are averages for the month

The records for intermediate sewage are given below. It is understood that these results are sampled from a point after the intermediate clarifiers and before the activated sludge plant.

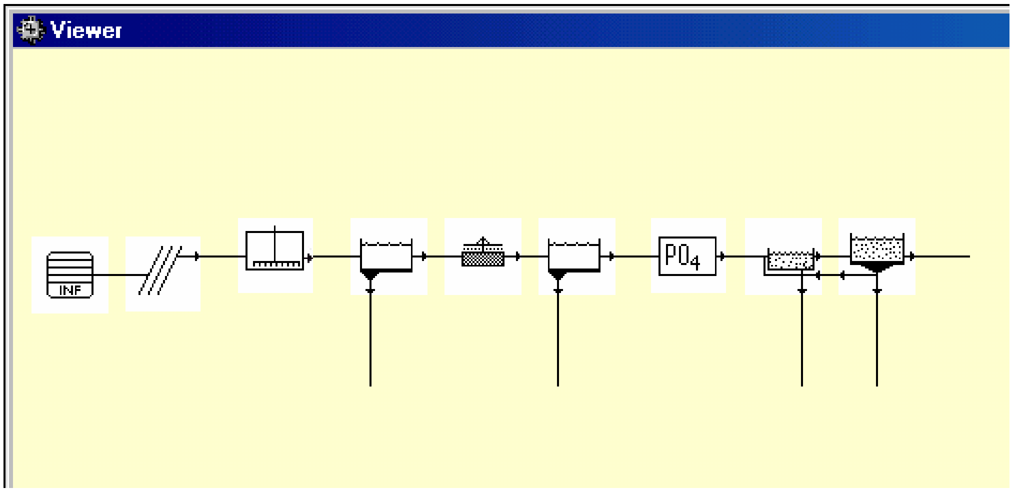
	Intermediate	
Month	**BOD5**	**TSS**
January 2002	115	110
February	72	66.5
March	68.5	66
April	65	49.5
May	22.4	18.8
June	45	118
July	76	70

All units mg/l

All are averages for the month

Assumptions

A model of the site was constructed in Plan-It STOAT as below.



The BOD was interpreted as a BOD_5, and an assumption made that 60% of the BOD was soluble, 40% particulate. The soluble BOD was assumed higher than the standard 40% for domestic sewage because of the high strength industrial waste. For modeling purposes, the BOD was converted into COD by assuming that 1 g biodegradable COD exerts a BOD of 0.68 g, this is the standard value in Plan-In STOAT.

Aeration efficiency was calculated for the Energy study at 0.48 kgO_2/kWh. This value has been assumed for the Plan-it Stoat modeling.

No data was available on the temperature changes throughout the year so the average data was used for all models at a temperature of 68F.

No data was available on the dose used of ferric salts for phosphorus removal. The dose used was therefore chosen to get an approximate match to the measured effluent phosphorus. ***Without more information about the dose of ferric salts used, it is not possible to estimate if the site could consume less ferric salt.***

Modeling

The following Plan-It STOAT simulations were run:

? Operation at a constant aeration intensity, reflecting the blower operating at continuous maximum output.

? Operation with the DO profile chosen so as to meet the current effluent requirement.

The UV disinfection system was not modeled.

PLAN-IT STOAT OUTPUT

No DO control

Without DO control it was assumed that the aeration system was operating at full output. The predictions for this scenario are given in the following tables.

The influent values are taken from the site records, as are the measured effluent values. The columns in the table for MLSS, RAS and effluent are the model predictions.

Average data

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	3.2	5.31	2.16	3.14	-
BOD	mg/l	406	570	1388	3.9	5.74
TSS	mg/l	263	3012	7342	13.9	4.84
NH3	mg/l	23	0.09	0.09	0.09	0.79
Nitrate	mg/l	0	20.9	20.9	20.9	-
PO4	mg/l	5.6	1.22	1.22	1.22	0.56

DO control

The DO control simulations were set up so that the DO was 2.0 mg/l. The DO setpoint was chosen to get the average data to roughly match the measured effluent quality, As can be seen the DO control case (below) is comparable to the constant aeration case (above) – but there will be an energy saving.

The oxygen utilization rate from BOD load/Aeration energy is 0.29 KgO_2/kWh. This is about 22% of what may be reasonable for this particular air delivery system and suggests either a considerable over supply of air, or inefficient air distribution. DO control would be expected to reduce the oversupply of air and therefore reduce energy costs.

The no DO control case uses an aeration power of 160 hp. The DO control is estimated to require 80 hp (assuming an aeration efficiency of 0.48kg O_2/kWh) – a 50% saving. In practice turn-down issues and mixing, rather than aeration, requirements will reduce the scope for saving – but there is clearly much scope for energy saving.

Average data

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	3.2	5.314	2.16	3.14	-
BOD	mg/l	406	573.4	1396	3.9	5.74
TSS	mg/l	263	3005	7326	13.9	4.84
NH3	mg/l	23	0.1	0.1	0.1	0.79
Nitrate	mg/l	0	19.7	19.7	19.7	-
PO4	mg/l	5.6	1.22	1.22	1.22	0.56

CONCLUSIONS

The Plan-It STOAT modeling indicates the following:

- If the aeration lanes were run with DO system control set at 2mg/l there is the potential to save approximately half the energy consumption of the aeration plant, providing adequate mixing can be maintained. Effluent quality is maintained and there is a reduction in energy use.
- No record of the ferric dose has been supplied, monitoring the dose would allow an estimate to be made of the necessary consumption. It is possible that a reduction in chemical may be made.
- The aeration efficiency was calculated to be 0.48kg O_2/kWh, which is much lower than would be expected for a diffused air system. This is because the biofilters installed upstream of the activated sludge plant remove much of the organic load. The aeration lanes are therefore lightly biologically loaded, but still require the aeration for mixing purposes.

C3 CITY OF EAU CLAIRE WATER TREATMENT FACILITY

Eau Claire Water treatment works treats an average flow of 20mgd, the water being abstracted from wells. The main treatment processes on site are VOC removal and iron and manganese removal. The VOCs are removed in a stripping tower. Iron and manganese are removed in the sedimentation basins and gravity filters, the majority of manganese is removed in the filters. The water is dosed with sodium hypochlorite, anhydrous ammonia and hydrofluosilicic acid prior to being pumped to a service reservoir.

ANALYSIS

Air stripping column

The air-stripping column is provided for the removal of volatile organic contaminants (VOCs).

The dimensions and operating conditions of an air-stripping tower are dependent on the water throughput, the volatility of the contaminants in the raw water and the inlet and (target) outlet concentrations of these contaminants. The energy consumption for the tower is a combination of pumping (raising the water the height of the tower, plus friction losses in the pipework) and compression (the air blowers). In order to estimate energy consumption, assumptions have been made of key dimensions and operating conditions of the stripping process.

Tower heights are typically 7m to 8m. A height of 7m has been assumed as the photographs of the site indicate a height of this order. An allowance of 2 m has been made for additional friction losses. Together, these should provide a reasonable estimate of the pumping energy consumption associated with the tower.

For the compression energy consumption, the principal factors to be taken into account are the air/water ratio and the air-side pressure gradient. The assumed values, based on typical designs, are:

? Air/water ratio: 10:1

? Air-side pressure gradient: 200 N/m ^{2}/m

? Operating pressure 3” wg for air blowers

Although these are typical, there is in practice considerable variation in both factors. The air/water ratio can range from 5 to >50, the higher ratios being required for contaminants of lower volatility. Air-side pressure gradient can be between 100 and 400 N/m^2/m. Overall therefore, the actual energy consumption for compression *could* range from 0.25 to 10 times the estimate.

Calculations

? Average flow 20mgd = 0.876 m^3/s,
? Inlet pressure = 1atm = 1.01325 bar absolute,
? Outlet pressure = 1.02725 bar absolute,
? Only wells 10,11,15,16,17 and 19 are aerated so flow = 8.8mgd = 1388 m^3/h,
? With air to water ration 10:1 air capacity = 13880 m^3/h,
? Absolute work of air blowers = 9.2 kW,
? Energy consumption of air blowers = 221.1 kWh/d.
? Energy consumption of pumping associated with stripping tower = 1100kWh/d

The calculated energy consumption of the blowers (221.1 kWh/d) is comparable to the measured energy consumed by the blowers (253 kWh/d), indicating that the air stripping system is utilizing energy effectively.

Filters

The filters are provided for the removal of iron and manganese. The filters are backwashed using water from the backwash feed tank, filtered water being pumped to the tank by two fill pumps. These pumps appear to be oversized, as they only operate on average for 1.5 hours a day with a total energy use for the pumps of 186 kWh/d. In sizing the pumps, a balance must be struck between capital cost of the machine (i.e. the smaller the cheaper) and the need to limit the time that the tank is not sufficiently full to carry out a backwash. Energy estimates for the pumps are as follows, using estimated values where data are not available.

- There are four filters, each of 129.5m^2,
- Each filter has 1' Anthracite size 0.4 to 0.8mm and 3' Sand size 0.425mm,
- This gives a total bed depth of 1.22m,
- The average backwashing frequency is 42.5 hours = 0.6 d^{-1},
- The head above media during backwash is 30" = 0.762m,
- The capacity of the filters is 20mgd,
- Filtration rate = 6.1 m/h.

Backwash energy

- Assume media characteristics:
- Anthracite: voidage = 0.55, density = 1600 kg/m^3
- Sand: voidage = 0.45, density = 2560 kg/m^3
- Mean: voidage = 0.475, density = 2354 kg/m^3
- Assume backwash rate = 20m/h
- Assume backwash duration = 10 minutes
- Assume 1m of extraneous headloss and 0.5m headloss over filter floor
- Backwash water rate = 0.72m^3/s
- Estimated efficiency of motor = 85%, of pump = 65%
- Energy consumption per backwash = 14.5 kWh/day

Given that each of the four filters is backwashed on average 0.6 times a day this gives a total daily backwash energy use of 34.8kWh/d. When comparing this with the actual energy use of 186 kWh/d, it seems that value would be gained from a study of the backwash system performance to check if improvements in energy usage be made.

Conclusions

The analysis of the plant performance data indicates the following:

- The VOC stripping filters appear to be working efficiently with power usage comparable to the calculated value.

- There appears to be potential for reducing the energy used to pump water to the backwash feed tank.

- In common with most water treatment plants the majority of on-site energy is used in the influent and high-lift pumping of the water. At Eau Claire the treatment processes use only a small percentage of the total on-site energy. In seeking energy savings, It would make sense to concentrate on maximizing the efficiency of the pumping systems in preference to investigating ways to save energy in the treatment processes.

C4 GRASSLAND DAIRY PRODUCTS

Available Data

The Grassland Treatment Plant treats wastewater from Grassland Dairy. Wastewater is pumped from the dairy to two equalization basins. Influent is then mixed with RAS in three anaerobic tanks prior to treatment in two oxidation ditches. Three rectangular clarifiers clarify MLSS from the oxidation ditches. All the flow from the clarifiers and WAS are sent to the DAF clarifier due to the poor settling characteristics of the MLSS. Between May and September, effluent receives UV disinfection before discharge.

The two oxidation ditches are each aerated by a surface aerator.

The records for the crude sewage and final effluent are given in the following table.

	Influent		**.1 Effluent**			
Month	**Flow**	**BOD5**	**BOD5**	**TSS**	**NH3-N**	**PO4**
July 2001	0.0528	2473	5.45	18.58	1.00	1.14
August	0.0501	2615	7.19	15.06	1.10	1.08
September	0.0661	1893	9.83	22.06	2.60	1.09
October	0.0755	1958	14.09	20.67	2.60	0.76
November	0.0673	2360	13.4	16.16	0.30	0.63
December	0.0674	2339	16.25	16.29	1.30	0.64
January 2002	0.0695	2593	16.0	20.0	1.00	0.45
February	0.0757	2929	16.0	17.0	1.70	0.79
March	0.0985	2253	20.0	34.0	1.20	1.30
April	0.0938	2284	16.0	15.0	1.60	0.74
May	0.0943	2245	16.0	25.0	0.10	0.81

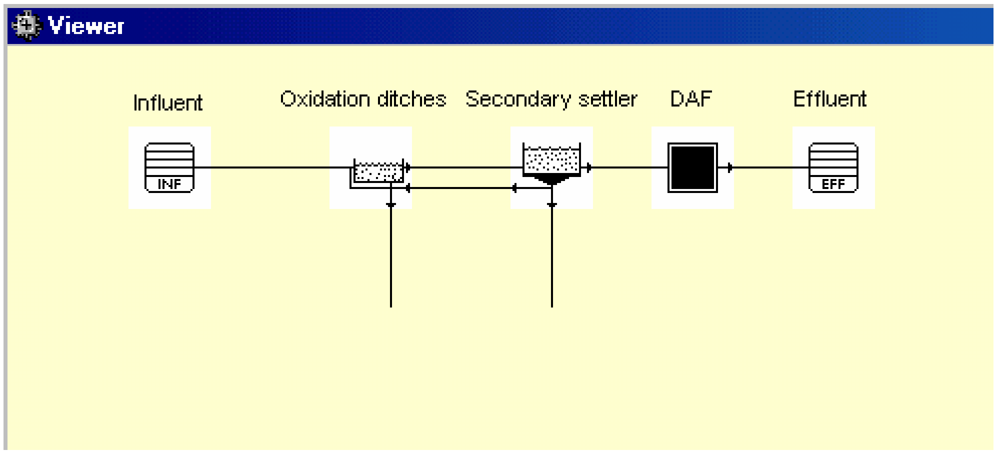
June	0.1039	2796	15.81	27.88	-	1.45
July	0.1085	3777	11.0	12.81	-	0.72

Flow in MGD. All other units mg/l

All are averages for the month

8. ASSUMPTIONS

A model of the site was constructed in Plan-It STOAT as below.



The BOD was interpreted as a BOD_5, and a standard assumption made that 60% of the BOD was soluble, 40% particulate. Because the site uses biological phosphorus removal the COD based IWA ASM2 model was used for the activated sludge tanks. The BOD was converted into COD by assuming that 1g biodegradable COD exerts a BOD of 0.68g, this is the standard conversion in Plan-It Stoat.

The influent TSS, NH3-N and TP were not available on the Discharge monitoring log report so the following average values obtained from the site were used:

Parameter	Mg/l
TSS	1200
NH3	117
PT	50

The summer and winter temperature of mixed liquor suspended solids (MLSS) were reported as 86°F and 65°F respectively.

No data were available for the Alpha or Beta factors so these were left to the default values of 1.

Aeration efficiency was calculated for the energy study at 0.56 kgO_2/kWh. This value has been assumed for the Plan-it Stoat modeling.

8.1 Modeling

The following Plan-It STOAT simulations were run:

? Operations with the DO profile chosen so as to match the plant setpoint and current effluent requirement.
? Operation with only one anaerobic tank and one oxidation ditch.

8.1.1 Plan-It STOAT Output

8.2 DO control

The DO control simulations were set up so that the concentration at the DO probe was 0.5 mg/l. The DO set point was chosen to match this and to roughly match the measured effluent quality.

Using the test case of January the effluent quality calculated by the model is better than measured for BOD and suspended solids, this is due to the difficulty in modeling the DAF plant as a model does not exist within Plan-It. A 'black box' model was used to simulate the DAF plant.

The measured influent and effluent values are taken from the site records. The columns in the table for MLSS, RAS and effluent are the model predictions.

Jan 2002 data

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	0.0695	0.16	0.09	0.06	0.084
BOD	mg/l	2593	1170	1870	1.6	16.0
TSS	mg/l	1200	4390	7030	4.8	20.0
NH3	mg/l	117	1.36	1.36	1.36	1.00
Nitrate	mg/l	-	0.2	0.2	0.2	-
TP	mg/l	50	195	312	0.42	0.45

8.3 One anaerobic tank and one ditch, DO control

This is an illustrative run, to investigate what would happen to effluent quality if only one of the oxidation ditches was in use.

Effluent quality is retained with all flow treated in one anaerobic tank and one oxidation ditch. There is therefore scope to operate the plant with only one ditch in service, providing that the aerator can provide enough oxygen to maintain the required dissolved oxygen level.

Jan 2002 data

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	0.0695	0.17	0.1	0.06	0.084
BOD	mg/l	2593	1990	3080	2.4	16.0
TSS	mg/l	1200	5310	8200	5.4	20.0
NH3	mg/l	117	1.4	1.4	1.4	1.00
Nitrate	mg/l	-	0.22	0.22	0.22	-
TP	mg/l	50	200	308	0.3	0.45

8.3.2 Conclusions

The Plan-It STOAT modeling indicates the following:

? The aeration efficiency is estimated to be 0.56kg O_2/kWh, which is lower than would be expected for an oxidation ditch.
? There is scope to run only one of the anaerobic tanks and one of the oxidation ditches. Further investigation would be required, but if this were possible then energy savings would be realized by shutting down one stream.
? The mixing of clarified secondary effluent and waste activated sludge for treatment in the DAF plant is not ideal. A process investigation into the cause of the poor settleability of the MLSS could lead to a more energy-efficient solution.

C5 GREEN BAY METROPOLITAN SEWERAGE DISTRICT WASTEWATER TREATMENT FACILITY

Available Data

Green Bay treats sewage using the activated sludge process. There are two plants, the older North plant and the newer South plant. Each plant comprises an anoxic zone and aerated zones. The site processes are designed to remove organic content, phosphorus, ammonia and nitrate. From May to September, effluent receives UV disinfection before discharge.

The activated sludge plant is aerated by fine bubble diffusion. Of the five blowers installed, typically only one blower is required to provide sufficient air. The South plant has ceramic diffusers and the North plant has membrane diffusers.

The records for the crude sewage and final effluent are given in the following table.

	Influent				**.1 Effluent**			
Month	**Flow**	**BOD5**	**TSS**	**NH3-N**	**BOD5**	**TSS**	**NH3-N**	**TP**
January 2001	25.913	290	246	19.55	2.7	4.4	0.10	0.21
February	26.993	251	205	17.84	3.3	5.1	0.13	0.23
March	30.849	218	232	15.94	2.8	4.6	0.07	0.19
April	37.520	160	167	10.91	3.2	5.3	0.13	0.16
May	32.697	188	192	12.78	2.8	5.1	0.09	0.17
June	36.217	188	190	12.10	2.7	5.2	0.11	0.21
July	29.554	243	209	13.87	2.1	4.0	0.17	0.18
August	-	-	-	-	-	-	-	-
September	-	-	-	-	-	-	-	-
October	26.979	261	215	16.02	1.1	3.9	0.14	0.27
November	27.035	219	223	15.61	1.0	3.3	0.08	0.29
December	27.408	198	204	17.74	2.4	3.9	0.02	0.22

Flow in MGD. All other units mg/l

All are averages for the month

The records for settled sewage are given below.

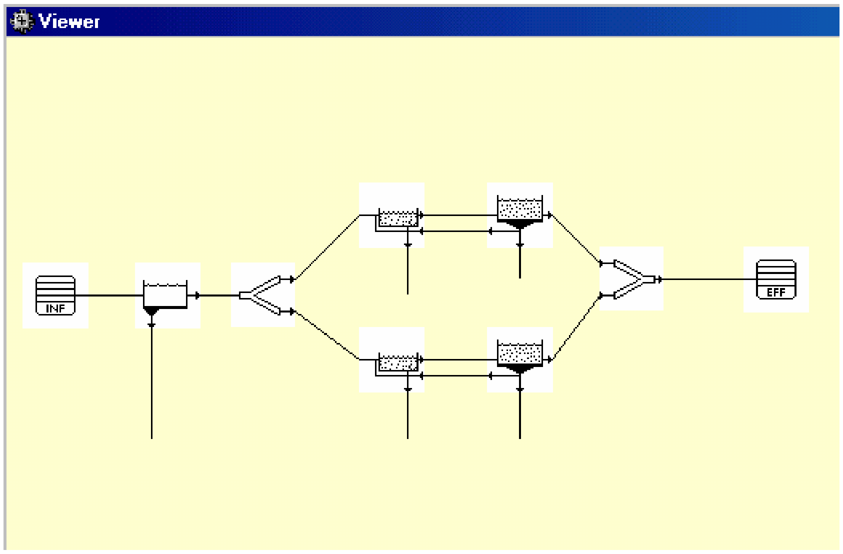
	Settled sewage		
Month	**BOD5**	**TSS**	**TKN**
January 2001	167	105	27.4
February	146	103	24.6
March	136	103	20.9
April	111	108	19.1
May	120	152	19.2
June	119	114	18.8
July	160	110	22.3
August	148	123	22.3
September	164	112	23.9
October	164	79	22.8
November	126	71	22.9
December	133	96	24.4

All units mg/l

All are averages for the month

Assumptions

A model of the site was constructed in Plan-It STOAT as below.



No data was available on the influent phosphorus. The BOD was interpreted as a BOD_5, and a standard assumption made that 40% of the BOD was soluble, 60% particulate. Because the site uses biological phosphorus removal the COD based IWA ASM2 model was used for the activated sludge tanks. The BOD was converted into COD by assuming that 1 g biodegradable COD exerts a BOD of 0.68 g, this is the standard conversion in Plan-It Stoat.

The summer temperature of Mixed liquor suspended solids (MLSS) was provided as 85F and the winter temperature of MLSS was provided as 65 °F.

No data was available for the Alpha or Beta factors so these were left to the default values of 1

Aeration efficiency was calculated for the Energy study at 1.14 kgO_2/kWh. This value has been assumed for the Plan-it Stoat modeling.

8.4 Modeling

The following Plan-It STOAT simulations were run:

- Operation with the DO profile chosen so as to meet the current effluent requirement.
- Operation with all four lanes in the North running and the South plant shut down.

The UV disinfection system was not modeled.

9. PLAN-IT STOAT OUTPUT

9.1.1 Operation as at present

The DO control simulations were set up so that the DO was 2.5 mg/l in the aerated sections. The DO set point was chosen to match the site set point and to get the June 2001 data to roughly match the measured effluent quality.

In creating the model there were problems with matching the observed level of phosphorus in the effluent. These problems may have been caused by one or more of the following:

- The presence of iron or aluminium salts in the incoming wastewater. Some chemicals are added in the pulp factory, but the nature of these chemicals is unknown. By using a dissolved concentration of around 100 mg/l it was possible to predict that there would be high levels of phosphorus removal. No chemicals are deliberately added at the site. There are signs at the site that biological phosphorus removal is taking place, since the anoxic zone is recorded as having elevated phosphorus concentrations that are removed in the aerobic zone. This would suggest that chemical phosphorus removal is not a dominant mechanism.
- Inadequate mixing, leading to larger anaerobic zones. When the modeled anaerobic zone was tripled in size then again it was possible to match the measured phosphorus levels.
- Phosphorus-accumulating organisms (PAOs) with a higher growth rate than the default used in the computer models. This was not investigated with Plan-It STOAT.

The fact that site is removing phosphorus could be worthy of further investigation. If there is a strain of PAO that grows faster than normal then its cultivation and use elsewhere could be beneficial. However it is more likely that the behavior is a consequence of unknown anaerobic zones, but even here better identifying these zones may lead to their deliberate creation at other sizes.

The influent values are taken from site records, as are the measured effluent values. The columns in the table MLSS, RAS and effluent are the model predictions.

9.1.2 June 2001

Parameter	Stream	Influent	MLSS		RAS		Effluent	Measured
			N	S	N	S		
Flow	MGD	36.271	43.9	18.4	25	11.5	25.5	-
BOD	mg/l	188	518	267	903	421	1.0	2.7
TSS	mg/l	190	1920	1260	3350	1980	3.0	5.2
NH3	mg/l	12.1	0.1	0.13	0.1	0.13	0.11	0.11
Nitrate	mg/l	-	6.39	6.32	6.39	6.32	6.37	-
TP	mg/l	-	54.4	31.5	92.6	47.9	3.08	0.21

9.1.3 Jan 2001

Parameter	Stream	Influent	MLSS		RAS		Effluent	Measured
			N	S	N	S		
Flow	MGD	25.913	42.4	20	25	11.5	25.5	-
BOD	mg/l	290	1270	856	2140	1460	2.7	2.7
TSS	mg/l	246	3020	2150	5090	3690	4.4	4.4
NH3	mg/l	19.55	0.1	0.12	0.1	0.12	0.11	0.10
Nitrate	mg/l	-	9.42	11	9.42	11	9.93	-
TP	mg/l	-	141	83.5	236	141	2.27	0.21

9.1.4 Operation with North plant in full operation and South plant shut down

This is an illustrative run only to see the effect on effluent quality in the North plant is run to full capacity and the South plant is shut down. This has been modeled because all effluent from the South plant requires pumping, the energy required for this pumping could be saved if only the North plant was used.

Effluent quality is maintained when all lanes of the North plant are run.

9.1.5

9.1.6 June 2001

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	36.271	50.8	25	25.6	-
BOD	mg/l	188	364	734	0.8	2.7
TSS	mg/l	190	1950	3930	3.2	5.2
NH3	mg/l	12.1	0.1	0.1	0.1	0.11
Nitrate	mg/l	-	7.49	7.49	7.49	-
TP	mg/l	-	44	85.4	3.34	0.21

9.1.7 Jan 2001

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	25.913	42.4	25	17.2	-
BOD	mg/l	290	1240	2090	1.7	2.7
TSS	mg/l	246	2720	4580	3.2	4.4
NH3	mg/l	19.55	0.11	0.11	0.11	0.10
Nitrate	mg/l	-	9.13	9.13	9.13	-
TP	mg/l	-	114	191	2.62	0.21

10. CONCLUSIONS

The Plan-It STOAT modeling indicates the following:

- There is scope to run all four lanes on the North plant and shut down the South plant without losing effluent quality. This would save on the cost pumping effluent from the South plant to the outlet.
- The aeration efficiency was calculated to be 1.14kg O_2/kWh, this is lower than would be expected for a fine bubble aeration system.
- The provision of aeration blowers is oversized, with typically one of the five blowers in operation at any time.

In both the modeled winter and summer cases it was not possible to achieve the same phosphorus concentration as the measured value. There are several possible explanations as to why the site is behaving in this way and the why the model cannot mirror the same behavior.

The presence of volatile fatty acids or iron or aluminium salts in the incoming wastewater. Volatile fatty acids are used by phosphorus-accumulating organisms and are a key component in the cycle of biological phosphorus removal. No chemicals are deliberately added at the site, but it is possible that chemicals added at the paper mills are present in the incoming wastewater. These metal salts would chemically aid the removal of phosphorus. Inadequate mixing, leading to larger anaerobic zones increasing the biological removal of phosphorus. Phosphorus-accumulating organisms (PAOs) with a higher growth rate than is normally observed. The site is removing phosphorus, and could be worth further investigation. If there is a strain of PAO that grows faster than normal then its cultivation and use elsewhere could be beneficial. More likely is that the behavior is a consequence of unknown anaerobic zones, but even here better identifying these zones may lead to their deliberate creation at other sizes.

C6 CITY OF KENOSHA WATER TREATMENT FACILITY

C7 CITY OF LA CROSSE WASTEWATER TREATMENT FACILITY

10.1.1 Available Data

La Crosse treats sewage using the activated sludge process. The secondary treatment process comprises an anaerobic zone, an anoxic zone and an aerated zone. As well as removing organic content, this process is designed for the biological removal of phosphorus. From May to September effluent receives UV disinfection before discharge.

In the activated sludge plant the mixed liquor is aerated using fine bubble diffusion, the air being supplied by up to five blowers. Typically only one of the blowers is running at a time.

The records for the crude sewage and final effluent are given in the following table.

	Influent				**Effluent**				
Month	**Flow**	**BOD 5**	**TSS**	**NH3-N**	**BOD5**	**TSS**	**NH3-N**	**NO3**	**TP**
January 2001	8.24	241	170	20.3	5	7	21.4	3.4	0.48
February	8.44	253	170	22.7	9	19	21.6	2.2	1.38
March	8.21	282	185	17.9	9	22	20.1	3.1	0.62
April	15.9	155	126	17.0	3	6	21.1	4.0	0.56
May	18.3	118	106	11.1	3	5	10.0	4.3	0.43
June	12.8	158	142	13.5	3	3	8.8	4.1	0.27
July	11.1	180	150	16.1	3	3	1.7	5.1	0.32
August	9.99	211	163	17.1	2	3	1.2	6.0	1.23
September	9.06	213	163	21.4	2	2	1.7	6.5	0.21
October	8.89	219	164	19.8	2	3	7.7	5.2	0.98
November	8.74	259	234	29.5	3	5	2.8	5.4	0.53
December	8.83	274	285	24.9	4	5	8.8	3.6	0.39

Flow in MGD. All other units mg/l

All are averages for the month

The records for settled sewage are given below.

	Settled sewage		
Month	**BOD5**	**TSS**	**NH3-N**
January 2001	157	81	26.5
February	170	106	29.0
March	204	87	28.0
April	107	88	22.7
May	78	54	15.5
June	104	57	17.4
July	121	56	15.6
August	131	58	23.4
September	134	55	29.2
October	143	63	35.2
November	153	70	27.7
December	140	70	24.3

All units mg/l

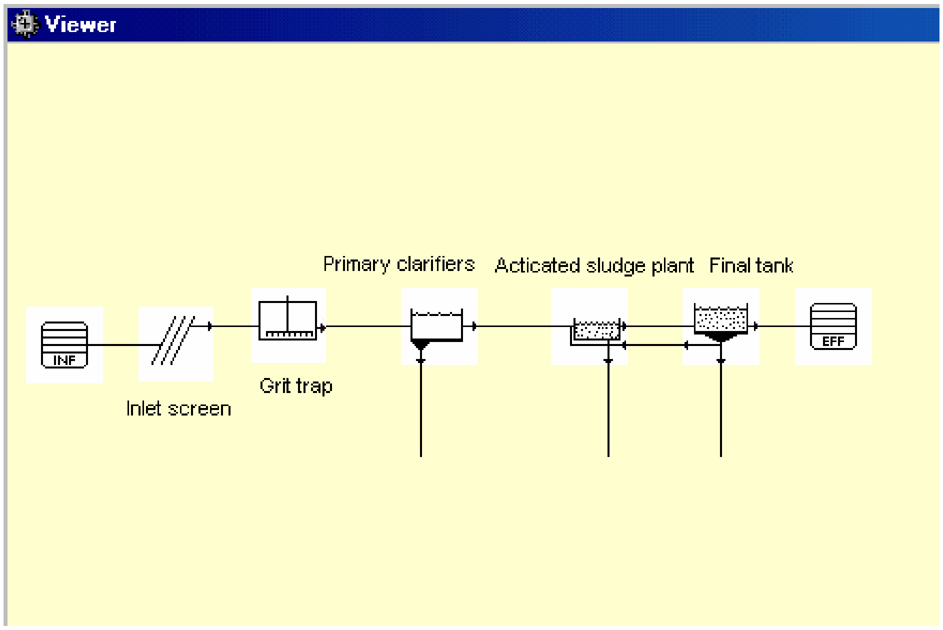
All are averages for the month

The records for mixed liquor suspended solids are given below.

Month	**Concentration** **Mg/l**	**Temperature** **?C**
January 2001	1055	13
February	1133	13
March	2236	14
April	2198	14
May	1599	17
June	1343	20
July	1027	22
August	1055	24
September	1091	22
October	988	21
November	935	19
December	981	17

ASSUMPTIONS

A model of the site was constructed in Plan-It STOAT as below.



No data was available on the influent phosphorus. The BOD was interpreted as a BOD_5, and a standard assumption made that 40% of the BOD was soluble, 60% particulate. Because the site uses biological phosphorus removal the COD based IWA ASM2 model was used for the activated sludge tanks. The BOD was converted into COD by assuming that 1 g biodegradable COD exerts a BOD of 0.68 g.

No data was available for the Alpha or Beta factors so these were left to the default values of 1.

Aeration efficiency was estimated in the Energy study at 1.04 kgO_2/kWh. This value has been assumed for the Plan-it Stoat modeling..

10.2Modeling

The following Plan-It STOAT simulations were run:

? Operation with the DO profile chosen so as to meet the current effluent requirement.
? Operation with only one lane in use.

The UV disinfection system was not modeled.

PLAN-IT STOAT OUTPUT

10.3DO control

The DO control simulations were set up so that the DO was 6.0 mg/l in the aerated sections. The DO set point was chosen to get the July 2001 data to roughly match the measured effluent quality.

The model predicts as expected that during winter, with a MLSS temperature of 13 ?C, the plant does not nitrify. The sludge wastage rate for both models had to be increased from the 0.08 mgd to give MLSS concentration matching the supplied information.

10.3.1 July 2001

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	11.1	18.6	7.5	10.68	-
BOD	mg/l	180	477	1120	1.5	3
TSS	mg/l	150	1033	2425	2.8	3
NH3	mg/l	16.1	1.87	1.87	1.87	1.7
Nitrate	mg/l	-	5.82	5.82	5.82	5.1
PO4	mg/l	5	0.29	0.29	0.29	-
TP	mg/l	10	85.34	200	0.52	0.32

10.3.2 Feb 2001

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	8.44	15.9	7.5	7.96	-
BOD	mg/l	253	663	1317	11.2	9
TSS	mg/l	170	1085	2153	17.5	19
NH3	mg/l	22.7	22.57	22.57	22.57	21.6
Nitrate	mg/l	0	0.17	0.17	0.17	2.2
PO4	mg/l	5	0.01	0.01	0.01	
TP	mg/l	10	72.5	143.9	1.18	1.38

10.4One ditch, DO control

This is an illustrative run, to see what will happen to plant performance during the test case of July. Partial nitrification is retained if the recycle rate from the aeration basin to the anoxic zone is increased to 100mgd. The results for this run are shown below.

July 2001

Parameter	Stream	Influent	MLSS	RAS	Effluent	Measured
Flow	MGD	11.1	18.6	7.5	10.8	-
BOD	mg/l	180	175.3	1701	2	3
TSS	mg/l	150	1393	3314	3.3	3
NH3	mg/l	16.1	4.75	4.75	4.75	1.7
Nitrate	mg/l	-	6.27	6.27	6.72	5.1
PO4	mg/l	5	1.2	1.2	1.2	-
TP	mg/l	10	97.0	229.1	1.43	0.32

Conclusions

The Plan-It STOAT modeling indicates the following:

? If the aeration lanes are run with DO control, the plant should achieve all effluent limits, assuming that the limits allow for a higher level of Ammonia in the effluent in the colder winter months.

? The current wastage rates are much lower than Plan-It Stoat predicts for MLSS concentrations provided.

? The model indicates that there is scope to operate with only one train. However this would result in no real reduction in the energy requirements since much energy would still be required to sustain the necessary recycle rate within the train.

? Aeration efficiency was estimated to be 1.04 kgO_2/kWh. This is lower than would be expected for fine bubble aeration.

C8 PAPERMILL A WASTEWATER TREATMENT FACILITY

Available Data

Papermill A wastewater treatment facility treats high strength industrial effluent from the papermill. The effluent is pumped to two activated sludge plants where it is dosed with ammonia and phosphorus, as it is nutrient deficient, and mixed with RAS. Three circular clarifiers clarify MLSS from the activated sludge plants. Effluent from the clarifiers is then discharged from site.

The activated sludge plants are aerated by jet pumps. There are five blowers that provide air for the jet pumps. Each blower delivers 5000 cfm.

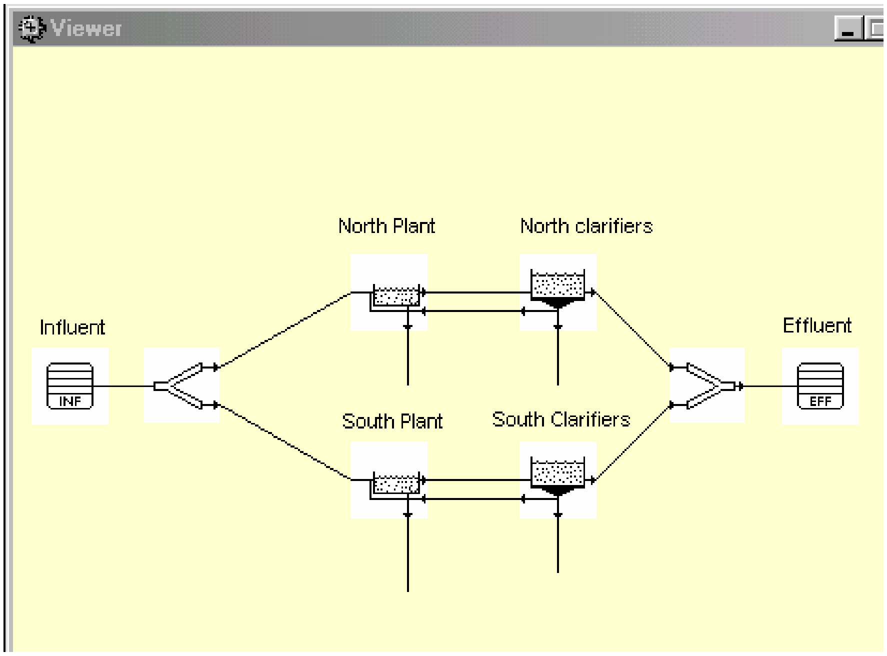
The records for the papermill effluent and final effluent are given in the following table:

	Influent				Effluent		
Month	**Flow**	**BOD5**	**COD**	**TSS**	**BOD5**	**COD**	**TSS**
January 2002	6.369	1405	3086	666	11	643	15
February	6.074	1295	3287	632	19	682	36
March	6.424	1334	3065	663	18	878	27
April	6.468	1318	3052	680	14	659	22
May	7.050	1174	2829	638	14	652	35
June	7.847	1193	2856	845	17	621	34
July	6.934	1054	2548	704	14	526	20
August	7.517	935	2683	704	12	550	16
September	7.002	1243	3054	787	12	579	16
October	6.731	1419	3359	832	13	698	20
Average	6.84	1237	2982	715.1	14.4	648.8	24.1

Flow in MGD. All other units mg/l

Assumptions

A model of the site was constructed in Plan-It STOAT as below.



The BOD was interpreted as a BOD_5, and an assumption was made that 50% of the BOD was soluble and 50% particulate. Because there was no nitrification or phosphorus removal the COD based ASM1 model was used for the activated sludge plants. The BOD was converted into COD assuming that 1g biodegradable COD exerts a BOD of 0.62g. This conversion was calculated to match the influent data.

Information regarding the dosing of ammonia and phosphorus was not available, as a result these parameters were not included in the model.

Temperature of the MLSS was provided with year-round temperatures above 80?F.

No data were available for the Alpha or Beta factors so these were left to the default values of 1.

Aeration efficiency was calculated for the energy study at 0.96 kgO_2/kWh. This value has been assumed for the Plan-it Stoat modeling.

Modeling

The following Plan-It STOAT simulations were run:

? Operations with the DO profile chosen so as to match the plant setpoint and current effluent requirement.

? Operation with a lower DO setpoint.

Plan-It STOAT output

DO Setpoint as Site

The DO control simulations were set up so that the concentration at the DO probe was 2.5mg/l in the North plant and 1.4mg/l in the South plant. These DO setpoints were advised by site.

Using the test case of October the effluent quality calculated by the model is very similar to the measured effluent quality.

The measured influent and effluent values are taken from the site records. The columns in the table for MLSS, RAS and effluent are the model predictions.

Oct 2002 data

Parameter	Stream	Influent	MLSS		RAS		Effluent	Measured
			North	South	North	South		
Flow	MGD	6.731	9.062	6.559	5.29	3.60	6.009	-
BOD	mg/l	1419	724	565	1160	923	10.9	13
COD	mg/l	3359	3530	2828	5306	4273	608.1	698
TSS	mg/l	832	2057	1587	3300	2598	21.1	20

Lower DO setpoint

This is an illustrative run, to see what happens to plant performance during the test case of October. The set point on both North and South plants was changed to 1.0 mg/l.

The results for this run show that with the decreased set point the effluent is still very similar to the measured effluent quality.

Oct 2002 data

Parameter	Stream	Influent	MLSS		RAS		Effluent	Measured
			North	South	North	South		
Flow	MGD	6.731	9.062	6.559	5.29	3.60	6.009	-
BOD	mg/l	1419	736	570	1180	930	11.4	13
COD	mg/l	3359	3558	2850	5305	4300	610	698
TSS	mg/l	832	2076	1600	3330	2620	21.3	20

Conclusions

The Plan-It STOAT model indicates the following:

- If the aeration lanes are run with a lower DO setpoint the plant should still achieve all effluent limits.
- The current MLSS have higher suspended solids concentration than Plant-It STOAT predicts. This is possibly due to the composition of the trade effluent being vastly different to domestic sewage.
- The model indicates that there is no scope for diverting all of the flow to either of the plants, these scenarios caused failure of effluent quality.
- Aeration efficiency was estimated to be 0.96 kgO_2/kWh. This is lower than would be expected for a jet aeration system.

C9 PORTAGE

Available Data

The records for the crude sewage and final effluent are given in the following table:

	Influent			Effluent		
Month	**BOD5**	**TSS**	**Flow**	**BOD5**	**TSS**	**TP**
July 2001	337	263	1.620	8	14	0.88
August	352	265	1.511	7	12	0.93
September	377	276	1.212	4	8	0.44
October	403	332	1.353	7	13	0.92
November	374	297	1.314	8	13	0.66
December	333	269	1.353	7	9	0.56
January 2002	358	296	1.358	6	9	0.42
February	415	288	1.353	6	10	0.59
March	366	258	1.394	6	10	0.73
April	352	264	1.658	7	11	0.90
May	363	271	1.681	8	12	0.89
June	358	277	1.806	5	10	0.83
Average	365.7	279.7	1.577	6.58	10.91	0.73

Flow in MGD. All other units mg/l

Analysis

Applied Loading Rate

The major design parameter for RBC plant is organic loading per unit surface area of the rotating medium, usually expressed as g BOD/m^2.day. The German professional body ATV (Sewage Engineering Association 1983) indicates that for production of effluent meeting a quality of 30 mg/l BOD and 30 mg/l SS, the maximum design loading rate should not exceed 10 g BOD/m^2.d. This assumes no additional aeration or return sludge from the clarifier – features that are present at Portage. By adding these features to the design it is claimed that the loading rate can be doubled for the same effluent quality.

If there was no additional aeration or return sludge from the clarifier, the following average organic loading per unit surface area would be estimated for the 16 RBC units at Portage Wastewater Treatment Facility:

? Average flow: 1.577 mgd x 3.785 / 1000 x 10^6 = 5969 m^3/d,

? Average crude sewage BOD: 366 mg/l,

? Average crude sewage BOD load: 366 x 5969 / 1000 = 2185 kg/d,

? Assuming 30% BOD removal across the primary tanks, settled sewage BOD load: 1530 kg/d,

? Number of RBC units: 16,

? Surface area / RBC unit: 100,000 ft^2 = 9295 m^2,

? Total surface area: 16 x 9295 = 148,700 m^2,

? Surface area loading rate: 1530 x 1000 / 148,700 = 10 gBOD/m^2.d

Hence the existing 16 units operate close to the maximum surface loading recommended for RBC plant proving carbonaceous removal **if there was no additional aeration or return sludge from the clarifier**.

The available historical data (DMRs) indicates that the modified operating regime with additional aeration and returned sludge enables the plant to produce an effluent quality significantly better than 30:30. The return sludge will contact the solids sloughing off from the RBC and will assist in removing fine suspended solids, thus improving effluent quality. Under this operating regime the plant has spare biological treatment capacity.

Aeration

The surface loading applied to the first stage RBC should be less than 40 g BOD/m^2.d to avoid blocking the channels within the media with excessive biological growth and generating malodors. The existing RBC units are arranged in 4 rows with 4 units in each row. The first unit in each row has a surface loading of about 40 gBOD/m^2.d close to the maximum. The current operating practice of recirculating humus sludge liquor to the first unit in each row limits the applied BOD load and reduces the risk of blockages developing in the rotating medium with only a low power requirement. Hence it is beneficial. Continuous aeration will remove solids that accumulate in the first unit in each row. Intermittent aeration of the first unit in each row would scour any solids that accumulate in the channels within the rotating medium and hence would be more cost-effective. The downstream units in each row will have less biofilm accumulation that the first unit and hence would require less or no aeration.

Chemical treatment with iron salts is used to remove phosphorus from effluent prior to discharge to the receiving waters. The plant configuration allows iron salts to be dosed into either sewage entering the primary sedimentation tank, settled sewage entering the RBC or effluent from RBC flowing into the final settling tank. Maximizing the use of iron salt required for P removal at the inlet of the primary sedimentation tanks maximizes the organic load removed by the primary sedimentation tanks, minimizes the load applied to the RBC and hence reduces the risk of excessive biological growth blocking the rotating medium. It is beneficial in reducing the air required to scour solids from the RBC units.

Dewatering

The belt press dewaters the digested sludge forming a cake containing 18% DS. A belt press would be expected to dewater digested sludge to produce a cake containing about 25% DS. The recycling of sludge through the RBC units will trap fine suspended solids. It may also generate a sludge similar to that from a 'high rate' process, which has poor dewatering properties. This may explain the low solids concentration of sludge cake from the belt press.

Currently the belt press is operated for two days per week over a period of about 6 hours on each day. It may be worth carrying out a short trial to test the effect on the cake solids concentration of reducing the sludge feed rate (unless the disposal route requires wet cake). Producing cake with a higher DS and less volume would reduce the cost of transport and disposal of sludge cake from site.

CONCLUSIONS

The analysis of the plant performance data indicates the following:

- The RBC units produce a satisfactory effluent quality.
- The downstream RBC units in each row do not need to be aerated.
- Maximizing the use of iron salt required for P removal at the inlet of the primary sedimentation would be beneficial in reducing the load applied to the RBC minimizing the need to run the air blower.
- The recirculation pump is beneficial in distributing the organic load through all the RBC units in each row and is cost-effective.
- The DS of the cake produced by the belt press is low (18%). Consideration should be given to a short trial to test the effect on the cake solids concentration of reducing the sludge feed rate. This will have the effect of reducing the cost of cake transport and disposal from site.

10.5Reference

Sewage Engineering Association (ATV) in collaboration with Federation of Communal Municipal Cleansing Undertakings (VKS). (1983) Fundamental Principles for the Dimensioning of Single-Stage Trickling Filters and Submerged Disk Contact Aerators with Connection Values of more than 500 Inhabitant Equivalents. Society for the Promotion of Sewage Engineering e. V. (GFA), Markt 71, D

C10 CITY OF RHINELANDER WASTEWATER TREATMENT FACILITY

Available Data

There are two trickling filters served by four primary fine screens. 30% of effluent from the filters is recirculated through the filters. Effluent then flows to the secondary clarifiers. Effluent from the secondary clarifiers is chlorinated before discharge from the works.

The two trickling filters are each served by a pair of fans. Each fan is rated at 2 hp, the total forced air ventilation power is therefore 8 hp. Each fan delivers 2300cfm, this is equivalent to 850 kgO_2/d for all four fans. The fans run continuously for 10 months of the year. The fans are switched off for the remaining two months to avoid freezing caused by the low air temperature.

A summary of average monthly values for the crude sewage and final effluent are given in the following table.

	Influent		**Effluent**		
Month	**BOD5**	**TSS**	**Flow**	**BOD5**	**TSS**
May 2001	179	168	1.217	17	19
June	165	145	1.143	20	29
July	202	175	1.102	21	21
August	192	191	1.041	23	25
September	165	157	1.086	16	14
October	194	216	0.976	17	18
November	169	197	0.990	16	20
December	180	134	1.085	16	18
January 2002	195	161	0.954	19	22
February	190	140	0.914	16	13
March	191	154	0.942	15	16
April	132	122	1.88	15	14

Flow in MGD. All other units mg/l

Assumptions

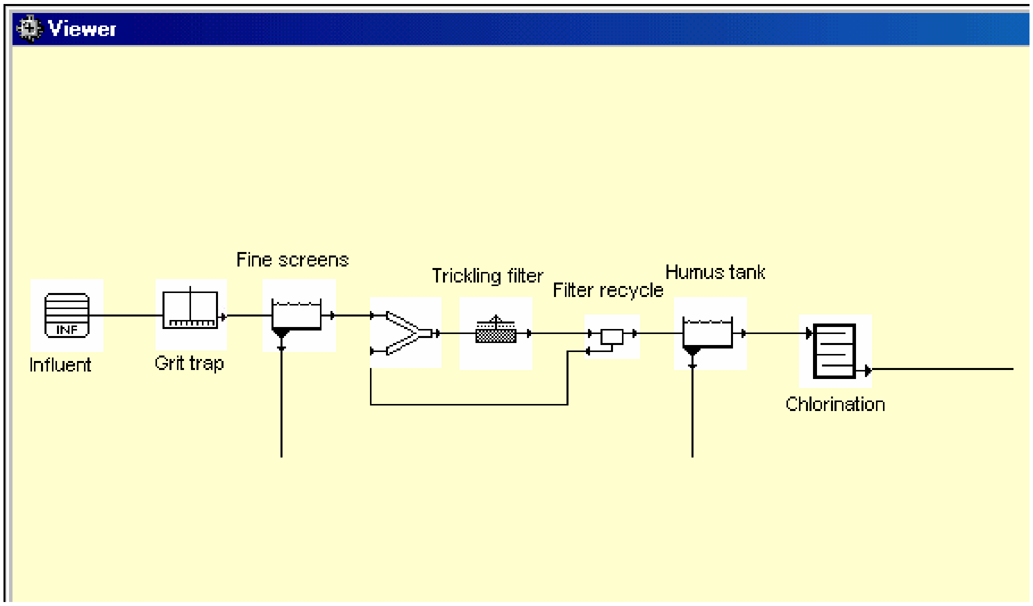
A model of the site was constructed in Plan-It STOAT.

No data was available on the influent or effluent nitrogen or phosphorus, an influent Ammonia-N concentration of 25 mg/l was assumed. For BOD a standard assumption made that 40% of the BOD was soluble, 60% particulate.

Due to lack of data it was assumed that the sludge from both the primary screens and the secondary clarifiers was of the same concentration.

It was assumed that the primary screens remove 13% of the TSS. The fine screens used at the works have a spacing of 1.5mm. Data was not available on the mass of solids removed by the screens, but the volume of screenings was available. Coarse screens (5mm) may remove 2-5% of total suspended solids; fine mesh screens (0.1mm) may remove 30% of total suspended solids. Therefore it was assumed that removal would be in the region of 10%. The value of 13% was inferred during calibration of the Plan-It STOAT model to achieve the same volume flow as reported at the assumed concentration of 2.3%. To achieve the solids removal in the screens the percentage removal primary sedimentation tank model was used.

Plan-It STOAT process flow



Plan-It STOAT Output

The influent values are taken from the site records, as are the measured effluent values. In the table, the column for effluent depicts the model predictions.

Average

Parameter	Stream	Influent	Effluent	Measured
Flow	MGD	-	1.10	1.11
BOD	mg/l	180	13.7	17.6
TSS	mg/l	160	16.5	19.0
NH3-N	mg/l	25	19.8	-

CONCLUSIONS

? There appears to be no difference in the effluent quality when the trickling filters are not supplied with forced ventilation in the two months of the year when the fans are not running. The saving from not using the forced air ventilation and presuming that natural ventilation was sufficient would be $2600 per annum assuming a cost of 0.05$/kWh.

? No information was available on diurnal variations that could result in extreme loadings on the filters that might require enhanced levels of ventilation.

? The efficiency of the forced air ventilation fans was estimated to be 3.2 kg BOD removed/kWh. This figure is double the efficiency of a good aeration basin. This is based on the filters removing an average of 468 kgBOD/day.

? The forced air ventilation fans provide the filters with 852 kgO_2/day.

? The trickling filter process is more energy efficient than the activated sludge process. However filters are more sensitive to loading variation and may take longer to become operational. The filters at this works require less long-term maintenance than low-rate stone-filled filters and require less plan area

? If it was thought to be beneficial, there is scope for reducing the recycle rate of the trickling filters and therefore the pumping energy required.

? The desludging pumps for the secondary clarifiers are driven by air motors that are fed from a compressor. A saving in energy may be realized by replacing this arrangement with modern electric-motor driven pumps.

APPENDIX D – PLANT DESCRIPTIONS

D1 CITY OF ASHLAND WASTEWATER TREATMENT FACILITY

The City of Ashland wastewater treatment facility has the following design treatment capacities:

? Average Design Flow:	1.92 mgd
? Peak Design Flow through treatment:	3.84 mgd
? Design BOD Loading:	3,500 lbs/day
? Design TSS Loading:	2,900 lbs/day
? Design NH3 Loading:	600 lbs/day

Ashland wastewater treatment facility receives raw domestic sewage from two off site pump stations. The pollutants in the wastewater are removed by the treatment process before the effluent is discharged into Lake Superior.

The main goal of the treatment facility is to remove organic content, suspended solids, ammonia and phosphorus.

The majority of raw sewage is pumped by the main lift station, which consists of six pumps. One of these pumps is running continuously and the others are only used during periods of high flow. Approximately 15% of the raw sewage is pumped to site by the Knight Road Lift Station, which has four pumps, two 60 hp pumps and two 25 hp pumps. Normally only one of the 25 hp pumps is used, while the other pumps are used during periods of high flow.

During periods of heavy rainfall or snow-melt an 8.0 million gallon retention basin is used to store flow in excess of the 3.84 mgd maximum process capacity. Excess flow stored in the basin is aerated by five floating aerators and pumped back to the headworks by three pumps as the influent flow subsides.

Raw sewage is screened by a step screen. The collected solids are dewatered before disposal to landfill.

Grit is removed from the screened sewage through an aerated grit trap. Flow enters the trap and spirals through the tank depositing grit into a hopper. The collected grit is washed and dewatered by a grit cyclone and deposited into a dumpster for landfill disposal.

The screened sewage then enters two oxidation ditches to remove organic content and ammonia. As the sewage enters the oxidation ditches it is dosed with aluminium sulfate to aid the removal of phosphorus. The sewage is mixed with return activated sludge to create mixed liquor suspended solids. Each oxidation ditch is aerated by four jet mixers that run continuously. Air is supplied to the jet mixers by up to three centrifugal blower and two positive displacement blowers. Typically one of the centrifugal blowers runs continuously to provide air to the jet mixers. These five blowers also provide air to the liquid sludge storage tank jet mixer.

Mixed liquor suspended solids are clarified by two circular final clarifiers. The clarified effluent flows to the final treatment stage and the settled sludge is split into returned activated sludge (RAS) and waste activated sludge (WAS). RAS is continuously pumped by two of five pumps back to the head of the oxidation ditches. WAS is pumped by two pumps, both of which run for an average of 45 min/day, to the aerated sludge holding tank..

Prior to discharge to Lake Superior, the effluent is disinfected through a low pressure, low output UV disinfection system. The disinfection system consists of two banks of 96 UV lamps. Typically only one bank is used unless the flow exceeds 1 mgd, in which case both banks are used.

The solids handling portion of the plant consists of a liquid sludge storage tank, a 2.0 meter belt press and a cake storage building. WAS is pumped to the liquid holding tank which is aerated by a jet mixer. The tank is decanted prior to dewatering. Sludge from this tank can either be spread on agricultural land or thickened in belt filter press. The press dewaters and dries the sludge, forming a cake which can be spread on agricultural land or stored for future application. Filtrate from the press and clear liquid from the tank is pumped back to the head of the works by two site drainage pumps.

Ashland has a 750 kW diesel powered standby generator. Ashland has an agreement with the power utility to run the generator during periods of peak power demand. During these periods, the utility will call Ashland and request they run the generator, which typically lasts for periods of eight to twelve hours per event.

D2 CITY OF BURLINGTON WATER POLLUTION CONTROL

The City of Burlington wastewater treatment plant has the following design treatment capacities:

- Average Design Flow: 3.50 mgd
- Peak Day Design Flow: 7.70 mgd
- Average Design BOD Loading: 7,500 lbs/day
- Peak Day BOD Loading: 16,500 lbs/day
- Average Design TSS Loading: 4,000 lbs/day
- Peak Day TSS Loading: 8,800 lbs/day
- Average Day NH_3 Loading: 376 lbs/day
- Peak Day NH_3 Loading: 827 lbs/day

The facility receives raw domestic sewage from an off-site pumping station. Septage and high strength industrial waste are received separately into a pair of receiving tanks at the treatment plant. The two tanks are aerated and mixed through a coarse bubble aeration system. The high strength industrial waste, septage and raw domestic sewage are blended prior to entering the treatment process.

The main goal of the treatment facility is to remove organic content, suspended solids, ammonia and phosphorus from the wastewater. The pollutants are reduced to acceptable levels by the treatment process before the effluent is discharged into the Fox River.

Raw domestic sewage is screened by a step screen at the off-site pumping station prior to pumping to the works. The off-site pumping station consists of three pumps, one of which is running 24 hrs/day. The other two pumps are only used during periods of high flow.

Grit is removed from the raw sewage pumped to the facility through a vortex grit removal system. Collected grit is washed and dewatered by a grit cyclone and deposited into a dumpster for landfill disposal.

A pair of circular primary clarifiers removes readily settleable solids and floating material from the wastewater to reduce the suspended solids content. Sludge is regularly removed from the tank by two pumps and scum is removed from the surface by two scum pumps twice a month.

Three centrifugal pumps transfer the primary clarified wastewater to a pair of biofilters. Typically, only one pump is required to pump the wastewater to the two biofilters. The biofilters contain rigid PVC media. Wastewater trickles down through the media of the biofilters, thus reducing the organic loading to the following suspended growth activated sludge system.

A pair of intermediate clarifiers removes further settleable solids and "slough" from the towers from the wastewater before it flows to the activated sludge process. Sludge is removed from the tank by three plunger pumps.

Effluent from the intermediate clarifiers is dosed with ferric chloride to aid the removal of phosphorus.

Dosed effluent is then treated in six aeration tanks to further reduce the organic content and provide nitrification. The effluent enters the tank and is mixed with return activated sludge to created mixed liquor suspended solids. The tanks are aerated by fine bubble diffused air provided by three blowers, two of which run 24 hrs/day.

Mixed liquor flows from the aeration tanks and is settled in two final clarifiers. The clarified effluent flows to the final treatment stage and the settled sludge is split into return activated sludge (RAS) and waste activated sludge (WAS). RAS is pumped by three pumps, two of which run continuously, back to the head of the aeration lanes. WAS is pumped by three pumps, two of which run for 15 mins/day, to the solids handling plant.

Between May 1st and September 30th of each year, treated wastewater is disinfected through ultraviolet disinfection prior to discharge to the Fox River. The UV system consists of two banks of 125 low pressure, low output UV lamps.

The solids handling portion of the plant consists of raw and digested sludge thickening, anaerobic digestion, and liquid sludge storage. 180-days of sludge storage is provided by a 1.27 MG sludge storage tank. Primary and intermediate clarifier sludge is pumped directly to the anaerobic digester. WAS is thickened through a 2.0 meter gravity belt thickener to approximately 4.0% solids prior to being loaded to the digester. The anaerobic digestion process consists of one mesophilic anaerobic digester followed by a secondary digester that is not heated or mixed. The primary digester is heated through a combination boiler/heat exchanger and is mixed through a large bubble gas mixing system.

Biosolids from the secondary digester are thickened with the same 2.0 meter gravity belt thickener prior to being transferred to the liquid storage tank. The liquid storage tank is mixed during periods of loadout with three submersible mixers.

The wastewater plant has a 100 kW co-generation plant that can operate on digester gas. The use of the co-generation unit was discontinued due to fouling problems associated with the digester gas.

Burlington has a 300kW standby diesel generator. The City of Burlington has an agreement with the power utility to operate the generator during peak power demands, at the utility's request

D3 CITY OF EAU CLAIRE WATER UTILITY

The Eau Claire Water Treatment Plant receives groundwater from a well field around the facility. The extracted water is treated and provided as potable water to the local community. The summer peak throughput for 2001 was 18 million gallons per day (mgd), whereas the annual average throughput is 8.35 mgd.

The main goals of the water plant are iron and manganese removal and corrosion control.

The well field consists of 15 wells. Wells 10, 11, 15,16,17,19 pump to a pair of stripping towers both of which operate 24 hrs/day, 365 days a year for the purpose of removal of volatile organic contaminants. A side benefit of the stripping towers is that the pH of the raw water through the towers is raised by 1.0.

The stripping towers contain packed media. The water trickles from the top to the tower to the bottom through the media. A pair of fans force air against the flow of water through each tower. Sodium hypochlorite is added at the headworks and the stripping tower for biofilm control.

A pair of tower effluent pumps discharge to the main water treatment processes. The pumps have a variable frequency drive which adjusts the speed of the pumps based on the level in the stripping tower effluent basin.

A booster pump is also provided at the stripping tower facility to increase the capacity of well pumps 11, 15, 16, 17, and 19. The booster pump is rarely used.

Hydrated lime is added to the raw water at the splitter box of the sediment basins to raise the pH from 7.0 to 9.0.

After pH adjustment and permanganate addition, the water passes through a pair of sedimentation basins before filtration in one of four dual media filters.

The filtered water passes through a clearwell before pumping to distribution using high service pumps. The pumps are turned on and off manually by the operators to match the demand in the system.

Water from the clearwell is pumped to a backwash tower for use in filter backwashing. The filters are backwashed with water only. The backwash sequence is manually initiated, usually due to increasing turbidity.

The majority of solids are removed in the filters. Sludge from the sedimentation basins is only removed once a year. The floc is very light and does not readily settle in the basins.

The filter backwash and overflow from the sedimentation basins flows to an infiltration basin. The water infiltrates to the groundwater and the solids accumulate in the basin, which has never needed to be cleaned out in 31 years of operation.

Eau Claire has a trailer mounted generator that is only used during power outages.

The generator is only capable of powering a 200 hp high lift pump, 2 wells and ancillary equipment. On standby power, the plant can only deliver 4 million gallons per day.

High Lift Pumps 1, 2, 3 were equipped with new premium efficiency motors 3 years ago. In addition, reduced voltage starters were installed for the three pumps.

D4 GRASSLAND DAIRY PRODUCTS

Grassland treats an average flow of 0.07 mgd, whereas peak flow can be up to 0.13 mgd. Grassland wastewater treatment works treats dairy effluent from Grassland Dairy Products. Pollutants in the effluent are removed by the treatment process prior to discharge of the effluent to the Black River.

The main goal of the treatment facility is to remove organic content, suspended solids, and phosphorus from the wastewater.

Effluent from the dairy is pumped to two equalization basins. Each basin is mixed by a submersible mixer, which runs continuously.

Effluent is pumped from the equalization basins to three anaerobic mixing tanks by a pair of submersible pumps, one for each basin. Return activated sludge is also pumped to the three covered anaerobic mixing tanks to create mixed liquor suspended solids. The anaerobic zones help create an environment conducive to biological phosphorus removal. Typically only two of the three anaerobic tanks are used. Each anaerobic tank has a three horsepower mixer, which operates 24 hrs/day.

Mixed liquor then flows to two oxidation ditches for the removal of organic content. Air is provided to each oxidation ditch through a low-speed, mechanical surface aerator that runs 24 hrs/day. One of the aerators is operated through a VFD based on a D.O. setpoint. The second aerator has a two-speed motor (100hp/50hp) that will be converted to VFD control in the future.

Mixed liquor from the oxidation ditch is clarified in three final clarifiers. Two of the clarifiers operate in parallel. The effluent from the first two clarifiers flow to the third clarifier. The third clarifier acts as a final “polishing” clarifier. The influent to the third clarifier is dosed with ferric chloride, to aid the removal of phosphorus. The settled sludge is split into return activated sludge (RAS) and waste activated sludge (WAS). RAS is pumped back to the anaerobic tanks by three pumps, which run continuously. WAS is pumped to the DAF clarifier by one pump, which is also run continuously. Originally the DAF plant was installed for waste sludge thickening only. The mixed liquor suspended solids has very poor settling characteristics so both the clarified effluent and the WAS are sent concurrently to the DAF.

The DAF clarifier separates the effluent and the sludge. Separation is achieved by introducing fine bubbles of air into the liquid, the bubbles attach to the light particles of sludge and rise to the surface. The heavy particles of sludge settle under gravity to the bottom of the DAF clarifier. Air is supplied by a compressor, which has an average running time of 3 hrs/day. Clarified effluent flows to the final treatment stage. Sludge is pumped to a liquid sludge holding tank by a pump, which runs an average of 4 hrs/day.

The final stage of treatment for the effluent is seasonal ultraviolet disinfection. Seasonal disinfection runs from May 1st to September 30th of each year. The UV system consists of 8 low pressure, low output lamps. All 8 lamps operate during the disinfection season.

Final effluent is pumped through a 2-mile forcemain to the Black River by two submersible pumps. The pumps are VFD driven, although they are strictly operated as on/off based on the wetwell level.

Sludge storage is provided by a 1.2 MG liquid storage tank. The sludge is land applied at a total solids concentration of 3%.

Grassland has a 350kW standby diesel generator. Grassland Dairy has an agreement with the power utility to operate the generator during peak utility power demands

D5 GREEN BAY METROPOLITAN SEWERAGE DISTRICT

The Green Bay Metropolitan Sewerage District Wastewater Treatment Facility has the following design capacities:

- Average Design Flow: 35.3 mgd
- Peak Day Design Flow: 103.2 mgd
- Average Day BOD Loading: 95,210 lbs/day
- Max Day BOD Loading: 234,110 lbs/day
- Average Day TSS Loading: 72,490 lbs/day
- Max Day TSS Loading: 220,090 lbs/day
- Average Day NH3 Loading: 5,820 lbs/day
- Max Day NH3 Loading: 12,970 lbs/day

The Green Bay Met. Wastewater Treatment Plant receives wastewater from two interceptors. One interceptor serves two papermills within the District. The other interceptor serves the remainder of the District (municipal wastewater). The pollutants are removed by the treatment process prior to discharge to the Fox River.

The main goal of the treatment facility is to remove organic content, suspended solids, ammonia, and phosphorus.

Raw sewage from the industrial interceptor and municipal interceptor are received in separate wetwells. The municipal wastewater is pumped by three 900-hp, variable speed centrifugal pumps and one 900-hp constant speed centrifugal pump. The variable speed pumps consist of a 900 hp AC motor with an eddy-current clutch. Typically, only one of the variable speed pumps is required to handle the municipal wastewater.

The industrial wastewater is pumped by two 150-hp variable speed centrifugal pumps and one 100-hp constant speed centrifugal pump. The variable speed system consists of a 150-hp AC motor with an eddy-current clutch. Typically only one variable speed pump is required to handle the industrial wastewater

The industrial and municipal wastewaters are combined prior to screening. The wastewater is screened through a pair of mechanically cleaned coarse barscreens and four ¼-inch mechanical fine screens. The screenings from the fine screens are washed and dewatered prior to being disposed of in a dumpster.

The combined screened sewage flows to four 120-foot diameter primary clarifiers. The clarifiers remove readily settleable solids and floating material from the waster. Each pair of clarifiers shares three torque-flow centrifugal pumps. One pump is designated for each clarifier along with a shared standby pump. A pump for each clarifier is run continuously to remove collected sludge. The primary sludge is pumped to four “teacup” grit removal systems. The degritted primary sludge flows to a wetwell that also collects primary scum. The combined sludge and scum are transferred to four gravity thickeners by a total of 8 torque-flow centrifugal pumps. Typically only 4 to 5 of the pumps operate at a time.

The plant consists of two activated sludge plants, the old plant called North plant and the newer plant called South plant. In both plants settled sewage and return activated sludge are mixed to create mixed liquor suspended solids. The North plant has four trains, each train has one anoxic zone and three aeration zones. At present only two of the North plants trains are used. The South plant has two trains, each train has one anoxic zone and four aeration zones. This treatment process removes organic content, ammonia, and phosphorus. Fine bubble aeration is used to provide oxygen to the aerobic zone by up to four blowers, typically one blower runs continuously.

Mixed liquor suspended solids are clarified in ten secondary clarifiers. The North plant has eight clarifiers and the South plant has two clarifiers. The clarified effluent flows to the final treatment stage and the settled sludge is split into return activated sludge (RAS) and waste activated sludge (WAS).

A variable speed return pump for each clarifier pumps the RAS to the anoxic zones of each plant. The RAS pumps for the north plant utilize a constant speed 60-hp motor and an eddy current clutch driven drive. The RAS pumps for the newer south plant utilize an inverter duty 75-hp motor that is driven by variable frequency drive (VFD).

Sludge is wasted (WAS) in the north plant by throttling a valve on the RAS line. Sludge is wasted in the south plant by four 15-hp VFD driven pumps. Typically, two run 24 hours per day. Scum from the secondary clarifiers is pumped to the four gravity thickeners.

The final stage of treatment for the effluent is disinfection by dosing with chlorine. Chlorine is then reduced to a residual level by dosing with sulfur dioxide. Disinfection is only carried out on a seasonal basis. Effluent is then discharged from the site to the Fox River.

The solids handling portion of the plant consists of four gravity thickeners, four gravity-belt thickeners (gbt), four belt presses, and a pair of incinerators.

Primary sludge and all the scum collected at the facility is pumped to four gravity thickeners. In addition plant effluent is pumped to the thickeners to maintain a set total flow to the thickeners. The additional flow is added to prevent the thickeners from becoming septic.

Waste Activated Sludge (WAS) is pumped to an aerated holding tank. The WAS is thickened through three gbt's. Typically, only one gbt is operated 24-hours per day.

Thickened primary sludge and thickened WAS are pumped to a blend well in the dewatering area. The sludge is dewatered through four 2.0 meter belt presses. Typically 2 presses operate 24-hours per day

Dewatered sludge is sent to one of two, seven-hearth incinerators. The first couple of hearths dry the sludge, then it enters the burn stage in the middle hearths. The sludge exists the incinerators as ash, which is transported to a landfill. The heat generated by the incinerators is captured and used to heat the process buildings in the winter. The main loads on the incinerators include a 200-Hp fan for each incinerator and a third 200-Hp fan for the heat recovery system. Scum from the gravity thickeners is pumped to a concentrator in the incinerator area. The concentrated scum is sent directly into the incinerators.

D6 CITY OF KENOSHA WATER TREATMENT FACILITY

The City of Kenosha Water Treatment Plant draws water from Lake Michigan. The raw water is treated and provided as potable water to the City of Kenosha and surrounding areas. The summer peak throughput for 2001 was 25 million gallons per day (mgd), whereas the annual average throughput is 13.78 mgd.

Kenosha runs two separate treatment plants in parallel. The first plant is a conventional plant utilizing flocculation basins, sedimentation basins and rapid gravity filters. The second plant is a microfiltration membrane plant. The treated water from the plants is blended prior to distribution. Currently the majority of water is treated in the membrane plant due to the superior water quality achieved.

The main goals of the water plants are to remove solids and disinfect the water.

There are three water intakes from the Lake. Low lift pumps serve both treatment processes: two pumps for the conventional plant, two pumps for the microfiltration plant and one pump which can back up either plant.

10.5.2 Microfiltration plant

Raw water is strained prior to entering the microfiltration plant. There are 25 microfiltration skids, which remove suspended solids in the form of particles, colloids, algae, bacteria, yeast, protozoa and cysts. Treated water is then blended with water from the conventional plant. Each microfiltration skid is backwashed approximately once ever half-hour.

Backwashing of skids is carried out using both air and water. During a backwash sequence air is used to dislodge trapped particles from the hollow fibers, which are then washed away using raw water.

10.5.3 Conventional plant

The conventional filtration plant has two flocculation basins. Raw water is pre-chlorinated prior to entering the flocculation basins. Aluminium sulfate is added to aid coagulation. Potassium permanganate can also be dosed upstream of the flocculation basins to aid the removal of odor from the water, although this practice is rarely carried out. Water is mixed in the flocculation basins by two horizontal shaft paddles. The water is then clarified in two sedimentation basins to remove settleable solids.

Four rapid gravity mono-media filters then receive the clarified water and remove any residual solids remaining following the sedimentation process. Filtered water is blended with treated water from the microfiltration plant. The filters are backwashed using pumped water to remove the build up of solids. The backwash cycle is initiated by excessive headloss across the filter.

Dirty backwash water from both plants is stored in the wastewater equalization basin prior to being pumped to the sewer for disposal.

The blended treated water is dosed with chlorine for disinfection purposes. Hydrofluosilic acid is dosed to leave a residual level of fluoride for improved dental health and polyphosphate is dosed as a corrosion inhibitor. Water then flows to the chlorine contact tank prior to entering the clearwell.

The treated water passes through the clearwell before being pumped to distribution by six high lift pumps.

The plant has two 1000 kVA diesel powered generators, the combined power of these generators can run the entire plant. The generators can be used both in the event of a power outage or if the electricity utility request a reduction in power demand.

D7 CITY OF LA CROSSE WASTEWATER UTILITY

The City of La Crosse wastewater treatment facility has the following a design average flow capacity of 20 mgd and a design average BOD loading of 29,500 lbs/day. The pollutants in the wastewater are removed by the treatment process prior to the effluent discharge to the Mississippi River.

The main goal of the treatment facility is to remove organic content, suspended solids and phosphorus.

Raw sewage entering the facility is screened through a ¼-inch step screen. The collected solids are washed and dewatered prior to landfill disposal.

Grit removal is provided by two vortex grit removal systems. Collected grit is washed and dewatered through a pair of coanda grit washers. The washed grit is deposited into dumpster for landfill disposal.

The screened and de-gritted sewage is pumped to the primary clarifiers by five raw sewage pumps. Three of the pumps have variable frequency drives. Typically only one VFD-driven pump is required to handle the raw sewage flow.

The plant has two different sets of primary clarifiers, the old plant which has two rectangular clarifiers and one circular clarifier; and the new plant which has two circular clarifiers. The clarifiers remove readily settleable solids and floating material from the wastewater to reduce the suspended solids content. Each of the plants has one centrifugal pump to pump the sludge to the gravity thickeners. The scum is also pumped by two primary scum pumps from each of the plants to the anaerobic digesters.

Settled sewage is pumped by four VFD-driven centrifugal pumps to the activated sludge plant. Typically one pump is required to handle the primary effluent flow.

The activated sludge plant consists of two parallel trains which are designed for biological phosphorus removal. Wastewater from the primary clarifiers and return activated sludge are mixed to create mixed liquor suspended solids. Each train has an anaerobic, an anoxic and an aerobic zone. This treatment process removes organic content and phosphorus. Each train has seven mixers; six of them are used for mixing and one for the recycle of sludge from the aerobic zone to the anoxic zone. Fine bubble aeration is provided to the aerobic zone by four blowers, typically only one blower is required to meet the aeration demand.

Mixed liquor suspended solids are clarified in four secondary clarifiers. The clarified effluent flows to the final treatment stage and the settled sludge flows to a sludge well. The settled sludge is either returned to the process as return activated sludge (RAS) or is wasted as waste activated sludge (WAS). RAS is pumped to the anaerobic zone by three VFD-driven pumps, two of which run continuously. WAS is pumped to the gravity thickeners by a pair of vertical turbines pumps. Typically only one pump operating an average of 18-hrs per day is required for wasting. Any scum from the secondary clarifiers is pumped by the same scum pump for the new primary clarifiers directly to the anaerobic digesters.

The final stage of treatment for the effluent, which only runs from May 1st to September 30th each year, is UV disinfection. The UV disinfection system consists of a total of 12 banks, each with 128 low pressure, low output UV lamps. Normally 8 of the 12 banks operate during disinfection season.

The solids handling portion of the plant consists of gravity thickening, anaerobic digestion, digested sludge thickening, liquid and cake storage, and dewatering. Primary and secondary sludge is thickened by two gravity thickeners prior to anaerobic digestion. The anaerobic digestion system consists of four mesophilic primary digesters. The digesters are heated through a single heat exchanger. One pump on a rotating basis is used to recirculate sludge from the digesters through the heat exchanger. Hot water is provided to the heat exchanger by a boiler utilizing digester gas. No further mixing is provided in the digesters.

Anaerobically digested sludge is thickened by a 2.0 meter gravity belt thickener prior to being transferred to a liquid sludge storage tank. Approximately 65% of the sludge is dewatered and land applied as a cake. The sludge is dewatered out of the liquid storage tank by a belt press and two older centrifuges. The centrifuges discharge to a truck loadout utilizing a pair of progressive cavity cake pumps. Filtrate and centrate from dewatering and thickening is dosed with ferric chloride to aid phosphorus removal and struvite control prior to being returned to the head of the works.

La Crosse has four back-up power generators. One for the headworks and digestion, a 400 kW generator for Plant 1, a 400 kW generator for Plant 2 and a portable generator for the UV plant. The generators can either be used in the event of a power outage or if the electricity utility requests a reduction to power demand.

D8 PAPERMILL A WASTER WATER TREATMENT FACILITY

Papermill A wastewater treatment plant treats effluent from the papermill's pulp and paper processes. The treatment process removes pollutants in the effluent before the effluent is discharged to the local watercourse. Papermill A treats an average flow of 6.84 mgd, whereas peak flow can be up to 7.85 mgd.

The main goal of the treatment facility is to remove organic content and suspended solids from the wastewater.

Wastewater from the mill is pumped to the treatment plant by the papermill and pulpmill lift stations. The wastewater is screened at the pump stations prior to entering the wetwell.

The pulp and papermill wastewater is split between two activated sludge plants: the North plant and the South plant, which receive 56% and 44% of the flow respectively. The aeration basins remove organic content from the effluent. Return activated sludge is pumped to both aeration basins to maintain mixed liquor suspended solids.

Both activated sludge plants are mixed and aerated by jet aeration systems. The wastewater is nutrient deficient and as a result both aeration plants are dosed with phosphoric acid and ammonia.

Mixed liquor flows from the aeration tanks to the final clarifiers. The South aeration plant has one final settling tank located in the center of the aeration plant. The North plant has two final settling tanks. These are 'Eimco Clarathickeners', which include a conventional clarifier and a thickener in the center of the clarifier. The thickener drive of the clarifier is not used.

Clarified effluent is discharged to the local watercourse. The settled sludge is split between return activated sludge (RAS) and waste activated sludge (WAS). RAS is pumped to its respective activated sludge plant, the North plant utilizing three pumps and the South plant utilizing two pumps. WAS is pumped to the solids handling plant by four pumps, three for the North plant and one for the South plant.

The papermill solids handling plant treats the WAS. The WAS is first thickened by a gravity belt thickener and is then pumped by three pumps in series to the Zimpro low-pressure oxidation system (LPO). The LPO process heats the sludge to a required temperature to rupture the cell walls of the biosolids, releasing the water within. The sludge from the LPO is decanted and then dewatered further by two belt thickeners, typically only one of which is used. Sludge is currently disposed of to landfill. Filtrates and decant from the thickening processes are returned to the head of the plant.

D9 CITY OF PORTAGE WASTEWATER TREATMENT FACILITY

The City of Portage wastewater treatment facility has the following design capacities:

- Average Design Flow: 2.0 mgd
- Maximum Day Flow: 3.5 mgd
- Average Design BOD Loading: 5,000 lbs/day
- Maximum Day BOD Loading: 20,000 lbs/day
- Average TSS Loading: 4,000 lbs/day
- Maximum Day TSS Loading: 22,000 lbs/day
- Average Day NH3 Loading: 290 lbs/day
- Maximum Day NH3 Loading: 1,160 lbs/day
- Average Day P Loading: 125 lbs/day
- Maximum Day P Loading: 600 lbs/day

The treatment plant receives raw sewage by gravity through a 27-inch sewer. The pollutants in the wastewater are removed by the treatment process prior to the effluent discharge to the Wisconsin River.

The main goal of the treatment facility is to remove organic content, suspended solids and phosphorus.

The influent wastewater is pumped to the headworks by four screw pumps. The pumps consist of two parallel trains of screw pumps. Each train consists of two screw pumps operating in series. Normally, only one train (2 pumps) operating continuously is required to handle the incoming wastewater.

The raw sewage is screened by a rotamat style fine screen. Following screening, grit removal is provided by an aerated grit trap. Grit removed from the aerated grit trap is transported by a screw conveyor to a grit washer.

A pair of circular primary clarifiers removes readily settleable solids and floating material from the wastewater to reduce the suspended solids content. Primary sludge and scum are pumped to an anaerobic digester by a pair of air diaphragm pumps.

Primary clarified sewage flows to a pair of basins with a total of sixteen Rotating biological contactors (RBC) to remove organic content. A series of closely spaced circular disks are partially immersed in the sewage and rotated slowly through it. Biomass grows on the surface of the disks. The plant has been modified to increase organic capacity. Sludge from the secondary settlement tanks is returned to the head of the RBCs to create a mixed liquor. Aeration is provided by coarse bubble diffusion to maintain the suspension of solids in the mixed liquor.

Mixed liquor and solids from the RBC's are clarified in two final clarifiers to remove settleable solids. The clarified effluent flows to the final treatment stage and the settled sludge is either returned to the head of the RBCs by a pair of "RAS" pumps or is wasted to the primary clarifiers for co-thickening. Returned sludge is pumped to the head of the RBCs by two centrifugal pumps, which run for an average of 12 hrs/day. WAS is pumped to the primary clarifiers by a rotary lobe pump, which runs an average of 10 mins/hr.

Ferric sulfate is added to the influent of the final clarifiers to aid the removal of phosphorus. This can be dosed to the raw influent, or the primary clarifier effluent or the RBC effluent.

The final stage of treatment for effluent is disinfection, which is only carried out on a seasonal basis, by dosing with chlorine. The concentration of chlorine is then reduced to a residual level by dosing with sulfur dioxide. Effluent is then discharged from the site to The Wisconsin River.

The solids handling portion of the plant consists of anaerobic digestion and dewatering. Co-settled primary and secondary sludge are transferred to a primary mesophilic digester. The plant has two digesters that operate in series. Both are heated and mixed. The digesters are mixed by gas mixing systems.

Digested sludge is dewatered 2-3 times per week through a 2.0 meter belt press. The dewatered sludge is transported to a sludge storage building by a screw conveyer. The stored cake is land applied in the spring and fall. Filtrate from the belt press is returned to the head of the works.

Portage has a 250 kW standby generator that is used in the event of a power outage.

D10 CITY OF RHINELANDER WASTEWATER UTILITY

The City of Rhinelander wastewater treatment facility has the following design capacities:

- Average Design Flow: 1.86 mgd
- Peak Flow: 4.37mgd
- Average Design BOD Loading: 4,171 lbs/day
- Average Design TSS Loading: 3,242 lbs/day

The treatment plant receives raw sewage by gravity and from the West Side pump station. The pollutants in the wastewater are removed by the treatment process prior to the effluent discharge to the Wisconsin River.

The main goal of the treatment facility is to remove organic content and suspended solids.

The headworks of the facility consists of three sewage grinders which operate continuously. Following communition, the sewage flows through a vortex grit removal system. The removed grit is pumped from the bottom of the vortex unit to a grit classifier.

Following communition and grit removal, the sewage is pumped to four hydroscreens by three 20 hp, variable speed pumps. Normally only one pump is required to handle the influent flow. A second pump will operate an average of 3 hours per day. Variable speed capabilities is provided through an eddy-current drive clutch system

The four hydroscreens have a spacing of 0.06-inches. Solids removed from the screens are deposited into a sludge hopper by a screw conveyor. The effluent flows to the recycle wet well

Wastewater is pumped from the recycle wet well to two trickling filters by three trickling filter re-circulation pumps. The trickling filters contain plastic media. Wastewater trickles from the top of the filters to the bottom through the media, thus removing organic matter from the wastewater. Forced air ventilation is provided to the trickling filter by four fans, which run continuously for ten months of the year. The fans are not used during the other two months of the year due to freezing concerns. Approximately 30% of the flow from the trickling filter is recirculated through the filter by returning to the recycle wet well.

The effluent from the trickling filters flows to a pair of final clarifiers. Sludge is pumped from the clarifiers by two air-driven diaphragm sludge pumps to the sludge hopper where it combines with the screenings from the hydroscreen.

The final stage of treatment for effluent is disinfection by dosing with chlorine. Chlorine is then reduced to a residual level by dosing with sulfur dioxide. Effluent is then discharged from the site to The Wisconsin River.

The solids handling portion of the plant consists of anaerobic digestion and sludge storage. The screenings and sludge from the final clarifiers flows to a mesophilic anaerobic digester. The plant has two digesters, although one is out of service. The digester is heated through a external heat exchanger and is mixed through a gas mixing system. The heating circuit receives hot water from a boiler in the Service Building that utilizes natural gas. Digester gas is not utilized at the facility.

Sludge is transferred to a 1.04 MG liquid sludge storage tank.. The liquid sludge is land applied on agricultural land when available at a total suspended solids concentration of less than 2%.

Rhinelander has a 260 kW emergency diesel generator that is used during power outages.

APPENDIX E – BENCHMARKING

E1 Purpose of Section

In this section key performance indicators (KPIs) related to energy use for the Wisconsin treatment plants are compared with each other and also with a selection of similar sized treatment plants from England and elsewhere in Europe. The European plants are identified by the letters ‘A’ to ‘O’ throughout this section. Comments are made on factors that may explain differences between plants, and recommendations are made for further action or investigation.

E2 KPIs

The KPIs used are these:

- Energy costs ($ per annum);
- Energy costs, normalized using the population equivalent served ($ per pe per annum);
- Energy used (kWh per annum);
- Energy used, normalized using the population equivalent served (kWh per pe per annum);
- Aeration efficiency, expressed as kg oxygen demand removed per kWh used;
- Aeration energy costs and aeration energy used ($ per annum and kWh per annum)
- Energy used for each process kWh per day and kWh per pe per day);
- Average sewage flow, m^3 per pe per day and as a proportion of the flow to full treatment;

Population equivalents

In many instances the key performance indicators are expressed in terms of the population equivalent served by the treatment works. The population equivalent is therefore a fundamental piece of information, and was checked against influent loads using 60g BOD and 6g ammonia per PE per day as rules of thumb.

Table E1 Population equivalents

Works identification	**Data used in KPIs**
	Pe
	000s
Ashland	26.1
Burlington	82.0
Grassland	9.8
Green Bay	421.1
La Crosse	138.5
Papermill A	506.0
Portage	36.9
Rhinelander	12.6
A	56.0
B	77.0
C	42.8
D	61.6
E	64.3
F	13.8
G	82.0
H	733.3
I	17.3
J	406.4
K	61.0
L	9.0
M	33.0
N	68.0
O	275.0

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E3 Treatment Processes

A comparison of the sewage and sludge treatment processes is shown in Table E

Table E2 Comparison of treatment processes

Treatment works	PE	Sewage treatment processes						Sludge treatment processes			
	000s	**Preliminary**	**Primary**	**Activated sludge**	**P removal**	**NH3-N removal**	**Tertiary**	**Thickening**	**Digestion**	**De-watering**	**Other**
Ashland	26.1	1		1	Chemical		UV			1	
Burlington	82.0	1	1	Biofilters first	Chemical	1	UV	1	1		
Grassland	9.8			1	Biological and chemical	1	DAF & UV				DAF
Green Bay	421.1	1	1	1	Biological	1	Cl_2	1		1	Incineration
La Crosse	138.5	1	1	1	Biological		UV	1	1	1	
Papermill A	506.0			1						1	Zimpro
Portage	36.9	1	1	RBC	Chemical		Cl_2		1	1	
Rhinelander	12.6	1	1	Biofilters			Cl_2		1		
A	56.0	1	1	1				1			
B	77.0	1	1	1			Filter	1	1	1	
C	42.8	1	1	1				1			
D	61.6	1	1	1							Co-settling
E	64.3	1	1	1				1			
F	13.8	1	1	1	Chemical						
G	82.0	1	1	1							
H	733.3	1	1	1						1	
I	17.3	1	1	1					1		Lime dosing
J	406.4	1	1	1	Chemical	1		1	1	1	
K	61.0	1	1	1	Biological and chemical	1		1	1	1	
L	9.0	1	1	1	Chemical	1		1	1		
M	33.0	1	1	1	Chemical			1	1		
N	68.0	1	1	1	Chemical			1		1	
O	275.0	1	1	1				1	1		

Sewage treatment

All of the European plants and most of the Wisconsin plants have some form of activated sludge process. There is also one Wisconsin site with high rate biological filters and one site with aerated RBCs. Activated sludge plants have the benefit that they reliably produce effluent of a high quality from a plant with low capital cost. A major disadvantage is that activated sludge plants are energy-intensive and therefore suffer from a high operating cost.

Six of the eight Wisconsin wastewater treatment plants studied have phosphorus removal, three chemically, two biologically and one with a combination of both. Only half of the European plants were obliged to remove phosphorus, and most of these adopt a chemical removal process.

Sludge treatment

Sludge treatment ranges from none (at some European plants) or just thickening to digestion and dewatering. Also there is one site which has sludge incineration.

At plants where no sludge treatment is carried out on site, the plant is close to a large sludge treatment facility, either at another wastewater treatment plant or at a sludge-only treatment facility. Sludge may be piped or transported by road or sea tankers to the sludge treatment site.

Four of the Wisconsin wastewater treatment plants studied are equipped with sludge digestion plant, whereas seven of the fifteen European plants have digesters.

Digester gas as a fuel

Biogas is a beneficial by-product from sludge digestion. There is significant scope for large energy recovery benefits to be obtained from the sludge treatment and biogas processes.

It is universal practice in Europe to utilize gas generated in the digesters (biogas) to fuel boilers to heat the digesters. Of the four Wisconsin plants with digestion facilities, two use biogas and the other two rely on natural gas. There are perhaps sound reasons for ignoring the fuel value of the biogas in these two plants, but it appears to be a significant waste of fossil-fuel energy.

Also in Europe it is universal practice to burn any excess biogas at a flare stack. Whereas that appears to be a common method of destruction of this gas at Wisconsin plants, one plant simply vents all the biogas to atmosphere through the digester roof. This is not an environmentally sound disposal method, containing as it does methane (a greenhouse gas, heating up the earth’s atmosphere) and hydrogen sulfide (responsible for ‘acid rain’).

Of all the plants studied in Wisconsin and Europe, none operates combined heat and power (CHP) units. The City of Burlington has an abandoned system.

The energy value of biogas

Biogas is a beneficial by-product from sludge stabilization. There is significant scope for large energy recovery benefits to be obtained from the sludge treatment and biogas processes.

The biogas production rate can be checked against the amount expected from complete digestion of a primary sludge. Gas production is typically about $1m^3$/kg volatile solids destruction. For a primary sludge, it would be common to find a gas production in the region of $300m^3$/tonne dry weight of biosolids.

Burlington works produces $41.8m^3$ of sludge per day, at a concentration of 2.5% to 3% TSS, of which 60% is Volatile Suspended solids (VSS). This equates to a daily mass of VSS of up to 752kg VS per day.

Primary digestion reduces the VS concentration to 48% of the TS concentration, in the region of 1.2% VS, or about 12 kg/m^3 x $41.8m^3/d$ = 502kg VS per day. This is a reduction in VS concentration of 250kg / day or about 33% of the influent VS.

E4 Energy Costs

This section deals with the comparison of costs of electrical energy.

Factors that explain differences in unit costs (per pe) include:

? Population equivalent served. Economies of scale mean that lower unit cost would be expected at larger works.

? Sewage treatment processes. At some works phosphorus and/or nitrogen removal is carried out. Phosphorus removal would be expected to add to energy costs.

? Sludge treatment processes. Sludge thickening, digestion and dewatering would be expected to add to energy costs. The site with incineration would be expected to have an increased energy cost even though the natural gas used for incineration is not considered.

Table E3 shows the on-site energy use and cost per pe.

Table E3 Comparison of energy use and cost

Works code	**Population equivalent**	**Total energy use**		**Total energy cost**	
	000s	**000kWh/yr**	**kWh/pe**	**$000/yr**	**$/pe**
Ashland	26.1	1911	73	82	3.14
Burlington	82.0	2654	32	118	1.44
Grassland	9.8	803	82	35	3.56
Green Bay	421.1	35241	84	1171	2.78
La Crosse	138.5	5535	40	242	1.75
Papermill A	506.0	17253	34	518	1.02
Portage	36.9	1223	33	61	1.66
Rhinelander	12.6	757	60	32	2.53
A	56.0	1613	29	81	1.45
B	77.0	3059	40	164	2.13
C	42.8	468	11	28	0.65
D	61.6	1628	26	81	1.33
E	64.3	1306	20	77	1.19
F	13.8	-	-	41	2.94
G	82.0	2067	25	103	1.26
H	733.3	22132	30	1096	1.50
I	17.3	-	-	189	10.9
J	406.4	15030	37	1024	2.52
K	61.0	2003	33	136	2.24

Works code	**Population equivalent**	**Total energy use**		**Total energy cost**	
	000s	**000kWh/yr**	**kWh/pe**	**$000/yr**	**$/pe**
L	9.0	322	36	22	2.43
M	33.0	633	19	59	1.78
N	68.0	2000	29	155	2.28
O	275.0	12000	44	743	2.70

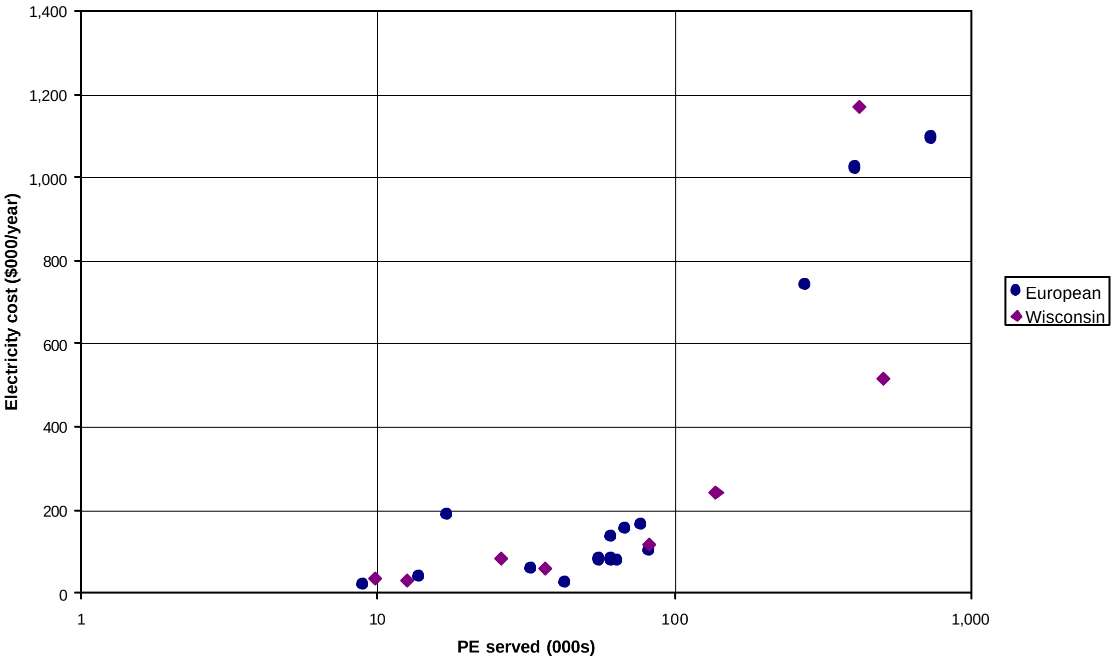

Figure E.1 Total annual cost of electricity and population equivalent

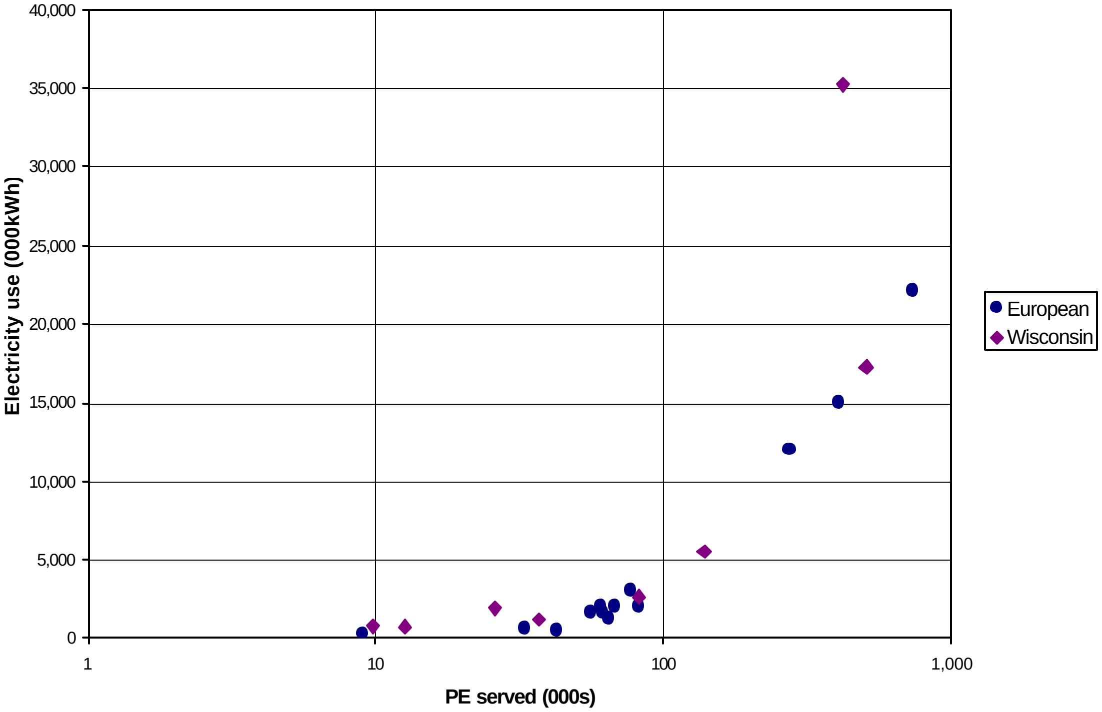

Figure E.2 Annual use of electricity and population equivalent

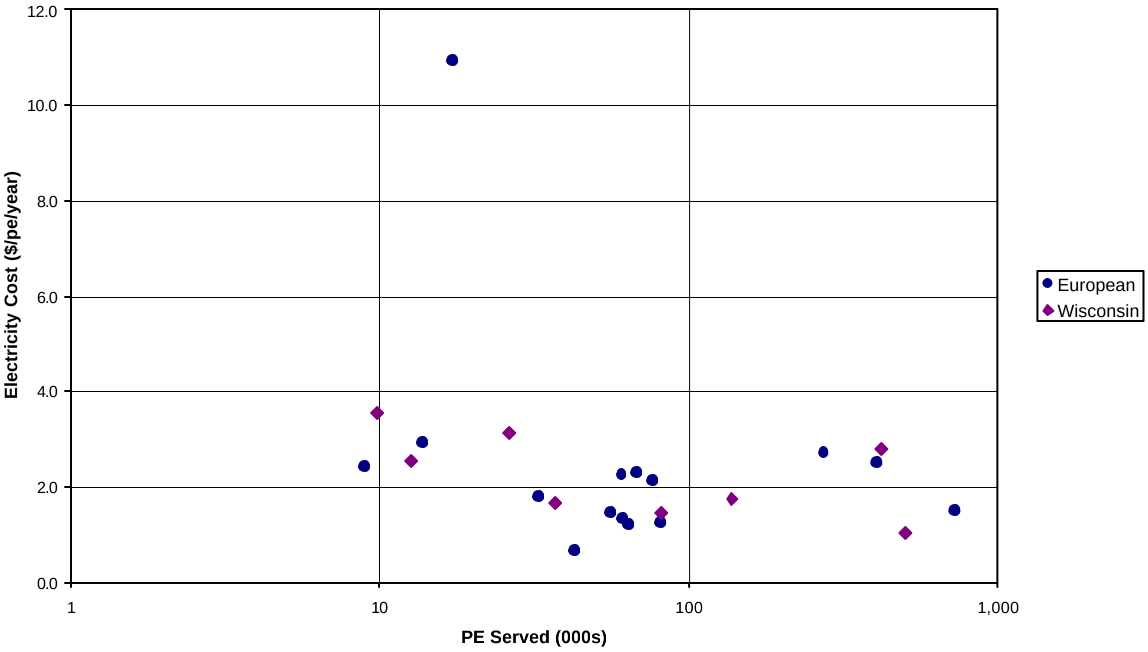

Figure E.3 Annual cost of electricity/pe and population equivalent

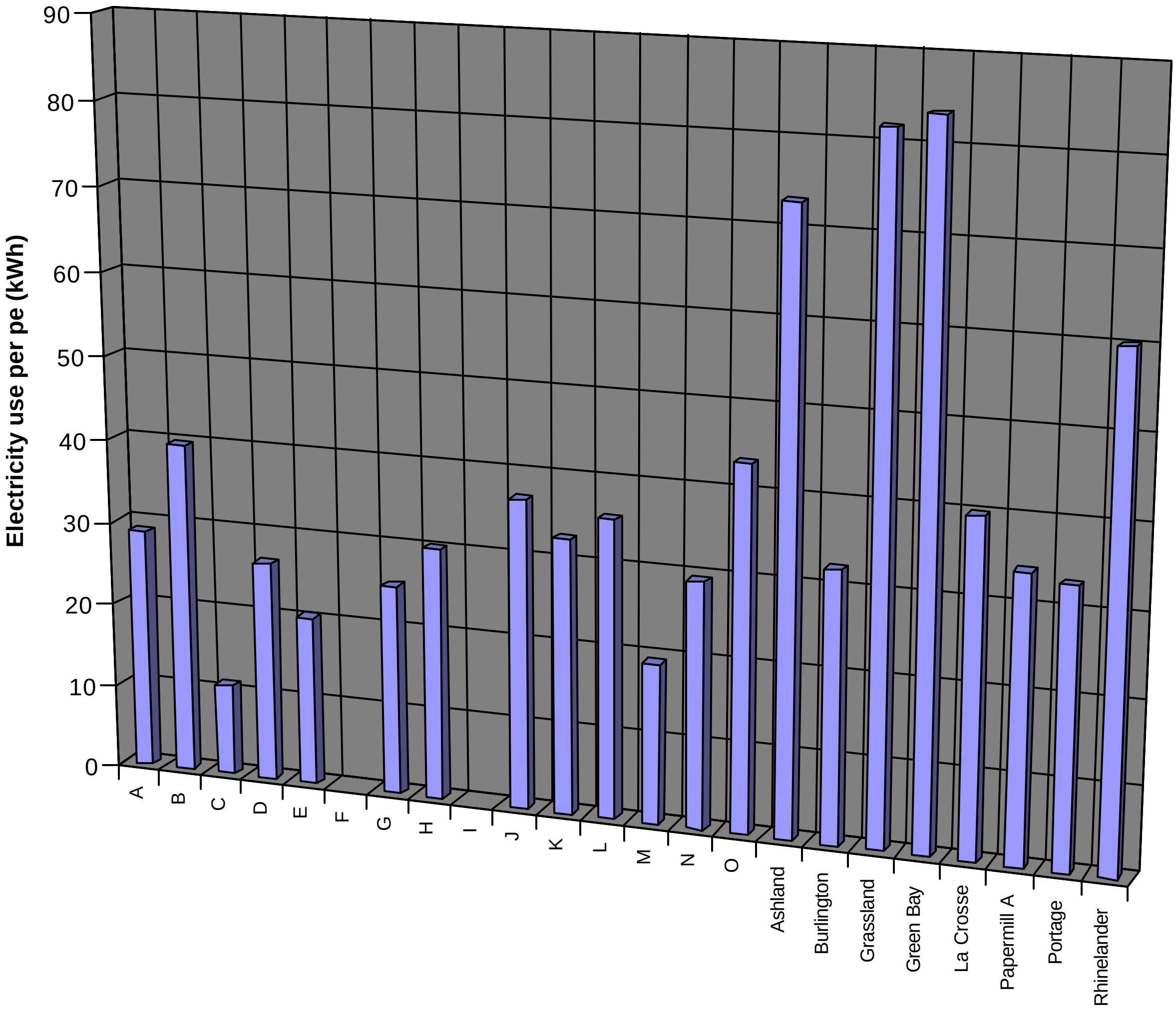

Figure E.4 Annual use of electricity/pe

It is important to note when comparing the energy costs of Wisconsin sites with European sites that the average unit cost in Wisconsin is $0.041 per kWh whereas in Europe it is $0.062 per kWh.

Figures E1 and E2, show as expected, that the total cost and use of electricity increases as the size of the works increases. Figure E2 shows that in terms of energy used, the Wisconsin sites tend to use more energy than European sites of a similar size. A small proportion of this higher use can be explained by the biological nutrient removal in the Wisconsin sites. A further factor in the difference is that, although European plants tend to be slightly over-sized, Wisconsin plants are over designed to a greater degree as can be seen in the comparison of sewage flows appendix E7. Figure E3 expresses the same information in a slightly different way.

Figure E4 compares the energy use per pe for each plant. This figure shows that Ashland, Grassland, Green Bay and Rhinelander are using substantially more electricity per population equivalent than all other sites, and that usage at the Wisconsin plants generally tend to be high compared to the European plants. In the case of Green Bay this is due to the complexity of the site and the sludge incineration plant. Ashland and Grassland both have low aeration efficiencies, aeration being the greatest energy use in the plants. Rhinelander is a biological filter site, but does use are large percentage of energy for pumping which may explain why it is higher.

When studying Figure E3, it can be seen that the average value of specific energy cost appears to be approximately $2 per pe per year. Four of the Wisconsin sites (50%) fall below $2 per pe per year, which compares well with seven of the European sites (47%).

Papermill A has the lowest energy cost per population equivalent among the Wisconsin plants, this is possible because the high BOD in the raw influent makes the population equivalent very high. Burlington has the second lowest energy cost per population equivalent, this being due to the beneficial use of biofilters upstream of the aeration lanes. Portage is also in the lower range, which would be expected for an RBC site as they are low energy users. Although the secondary treatment process has been upgraded to include sludge recycle and supplementary aeration, Portage remains relatively energy-efficient. La Crosse is the other site in the lower range of electricity cost per population equivalent. This is due to the fairly efficient aeration plant and the fact that 35% of the site sludge is not dewatered.

Rhinelander is in the higher range of electricity cost per population equivalent. Although this would not normally be expected from a biological filter treatment plant with no sludge dewatering on site, the large use of on-site energy for influent pumping has a dramatic effect on the specific energy cost. Green Bay is also in the higher range of specific energy cost, and is fairly close to European sites of a similar size. Ashland is slightly higher than the other sites in the range of electricity cost per population equivalent. This can be explained by the high degree of aeration on site, not only of the aeration lanes but also the aerated grit chamber, the liquid sludge holding tank and the retention basins in times of high flow.

Grassland has the highest specific energy cost of all Wisconsin sites, and is second only to one of the European sites. The high value can be explained by the fact that the influent treated at the site is a lot stronger than municipal waste or a mixture of municipal and industrial waste, having a BOD an order of magnitude greater than the average site.

E5 Aeration efficiency

Aeration efficiency (kg oxygen demand removed per kWh) of an activated sludge plant is an important guide to the effective use of energy in the aeration process. A value of 1.5 kg oxygen per kWh indicates an efficient use of energy. A value below 1.0 kg oxygen per kWh for a plant indicates that there may be scope for improvement in performance and therefore a saving in energy costs. However some factors, for example depth of aeration basin, may affect the practicality of improvement.

Typical aeration efficiencies for both submerged and surface aeration can be seen in Table E4 below.

Table E4 Typical ranges of aeration efficiency

Aeration system	**Aeration efficiency kgO_2/kWh**
Submerged	
Fine bubble diffused air	1.2 –1.8
Coarse bubble diffused air	0.7 – 1.2
Jet aeration	1.2 –1.8
Surface	
Low speed	0.7 – 1.5
High speed	0.7 – 1.2
Horizontal rotor	0.5 – 1.1

For most works the largest energy user on site is the aeration of the activated sludge plant. This is not the case for Portage or Rhinelander as they are not activated sludge plants and have been omitted from this comparison.

Aeration efficiency was calculated as described in Appendix B. The results can be seen in Table E5 and Figure E5 below.

Table E5 Comparison of Aeration Efficiencies and Aeration Energy Costs

Works code	**Oxygen demand**	**Energy used by blowers & aerators**	**Aeration efficiency**	**Aeration energy cost**	
	kg/day	**KWh/day**	**KgO_2/kWh**	**$000/yr**	**$/pe**
Ashland	3626	4059	0.89	64	2.44
Burlington	2603	5369	0.48	87	1.06
Grassland	801	1432	0.56	23	2.32
Green Bay	36445	31991	1.14	388	0.92
La Crosse	6650	6540	1.02	105	0.75
Papermill A	31509	32867	0.96	360	0.71
A	2287	3315	0.69	-	-
B	8035	5028	1.60	-	-
C	1504	962	1.56	-	-
D	1931	3344	0.58	-	-
E	2783	2398	1.16	-	-
G	3639	4247	0.86	-	-
H	58763	40626	1.45	-	-
I	2211	6998	0.32	-	-
J	28831	22771	1.27	522	1.28
K	3337	3485	0.96	85	1.38
L	733	494	1.48	12	1.30
M	2052	1317	1.56	-	-
N	4930	4112	1.20	-	-
O	26563	19411	1.37	-	-

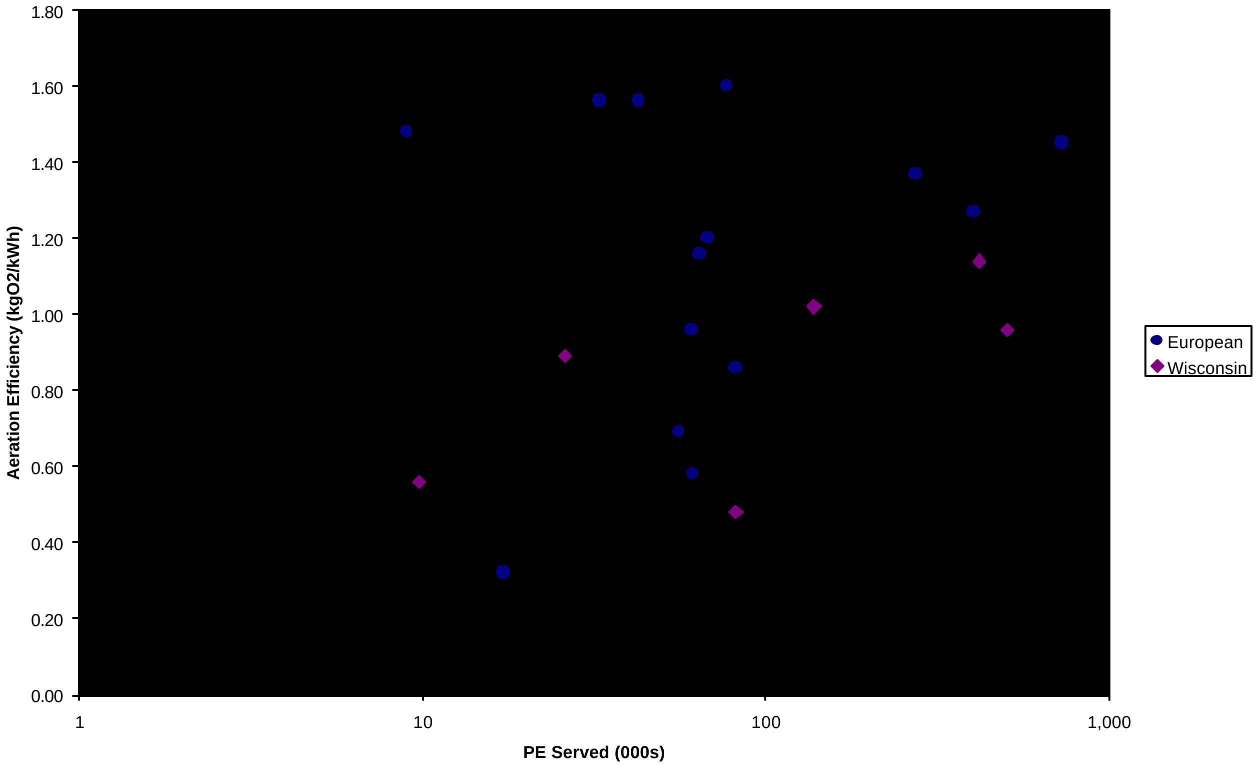

Figure E.5 Aeration efficiency and population equivalent

As can be seen from the graph of aeration efficiencies above, there is a wide range of values for both the Wisconsin and the European sites. This range is due to the different aeration methods and the design of the aeration tanks. Overall the European sites appear to be running more efficiently than the Wisconsin sites, with 65% of sites running over 1 kgO_2/kWh compared to only 33% for Wisconsin sites. However the figure shows that there are many European plants operating at a low efficiency.

Works 'I' has the lowest aeration efficiency of any of the plants studied. The inefficiency of the aeration system is due to two reasons; first there is no control of dissolved oxygen, and second, the aeration system is of an unusual design that is not commonly installed, and it is possible that it might be an inherently inefficient design.

Burlington has the lowest aeration efficiency (0.48 kgO_2/kWh) of the Wisconsin plants. Because this site has fine bubble aeration, one would expect the aeration efficiency to be over 1 kgO_2/kWh. In this case the efficiency is low because the influent on site is first treated by biofilters, which remove the vast amount of the organic content. The blowers still have to provide the aeration for mixing purposes even though the oxygen is not used for organic content removal.

Grassland has an aeration efficiency of 0.52 kgO_2/kWh. This is low for a plant with DO control and there appears to be room for improvement. As this is a surface aerator site, the aeration efficiency would be expected to be between 0.7 and 1.5 kgO_2/kWh. The surface aerators provide mixing to the oxidation ditches so turning the aerators down might have an adverse effect on plant performance.

Ashland has an aeration efficiency of 0.89 kgO_2/kWh, which again would appear low. It must be borne in mind however that the blowers at Ashland are providing aeration for grit removal, the retention basins and the sludge holding tank There is room for improvement here and if one of the aeration lanes was shut down as is suggested in the process related study then this efficiency would improve to a more expected level.

Papermill A has an aeration efficiency of 0.96 kgO_2/kWh. This is slightly low for a jet aeration system and may be explained by the several factors. Jet aeration uses more power than diffused or surface aeration because both the blowers and jet pumps are used. In this case the type of waste being treated may be having an effect on the aeration efficiency because papermill waste is inherently difficult to degrade, it therefore requires more oxygen for biological treatment. There is also the possibility that the solids in the mixed liquor are over time causing blockages within the jet pump system and are therefore decreasing efficiency.

La Crosse has an aeration efficiency of 1.02 kgO_2/kWh. This is one of the better Wisconsin aeration efficiencies. It is still lower than would be expected for a fine bubble system. The plant being oversized may explain low efficiency.

Green Bay has the best aeration efficiency of the Wisconsin sites at 1.14 kgO_2/kWh. This site has dissolved oxygen control and only runs four of the six aeration lanes on site in normal operation. Here again the low efficiency may be explained by the plant being oversized.

E6 Energy uses by treatment method

Electricity use can be broken down further into the different treatment methods used on site. This performance indicator can be used to explain why a particular site is using more electricity than expected.

This comparison is only possible with a few European sites due to the lack of raw data.

Table E6 Categorization for detailed energy breakdown

Category	**Included**
Influent pumping	? Pumping of influent
Mechanical treatment	? Sewage screening ? Grit removal ? Primary clarifiers ? Primary desludging pumps ? Intermediate pumping ? Secondary clarifiers ? Secondary desludging pumps
Biological treatment	? Aeration ? RAS pumping ? WAS pumping ? Biofilter influent pumping ? Biofilter recirculation pumping ? RBCs
Tertiary treatment	? UV treatment ? Chlorine treatment ? DAF plant
Sludge digestion	? Feed pumps ? Recirculation pumping ? Gas compressors
Sludge dewatering	? Feed pumps ? Belt thickener ? Belt presses ? Centrifuges ? Thickened sludge pumps ? Zimpro sludge treatment
Other	? Heating ? Lighting ? Wash water pumping ? Sludge incineration ? Service compressors

A uniform case has also been added for comparison based on the distribution of energy of an activated sludge plant taken from ERPI[2] 1994. The distribution has been applied to

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[2] ERPI (1994) Energy Audit Manual for Water and Wastewater Facilities, Electrical Power Research Institute, St Louis, MO.

a uniform case where an average flow of 7 MGD and a population equivalent of 110,000 have been assumed. This is the average for all the Wisconsin sites.

The energy use has then been calculated per thousand-population equivalent so as to allow a better comparison.

Table E7 Detailed energy breakdown

		Sewage treatment processes				**Sludge treatment processes**		**All site**
Works code	**Population equivalent**	**Influent pumping**	**Mechanical treatment**	**Biological treatment**	**Tertiary treatment**	**Sludge digestion**	**Sludge dewatering**	**Other**
	000s	**kWh/day**	**kWh/day**	**kWh/day**	**kWh/day**	**kWh/day**	**kWh/day**	**KWh/day**
Ashland	26	0	77	4435	236	0	133	339
Burlington	82	153	147	5574	224	518	150	277
Grassland	10	275	156	1648	112	0	0	46
Green Bay	421	18902	2809	45086	0	0	5891	18304
La Crosse	139	1451	219	10097	838	954	1596	1630
Papermill A	506	4295	0	35744	0	0	1339	4240
Portage	37	963	188	1761	45	241	24	387
Rhinelander	13	649	486	435	0	149	0	225
J	406	3294	1112	22771	0	1647	6135	6218
K	61	570	704	3485	0	811	423	51
L	9	0	238	494	0	106	0	35

		Sewage treatment processes				**Sludge treatment processes**		**All site**
Works code	**Population equivalent**	**Influent pumping**	**Mechanical treatment**	**Biological treatment**	**Tertiary treatment**	**Sludge digestion**	**Sludge dewatering**	**Other**
	000s	**kWh/day**	**kWh/day**	**kWh/day**	**kWh/day**	**kWh/day**	**kWh/day**	**KWh/day**
Uniform case	110	583	1386	7679	518	0	1114	1671

Table E8 Detailed energy breakdown per thousand population equivalent

		Sewage treatment processes				Sludge treatment processes		All site
Works code	Population equivalent	Influent pumping	Mechanical treatment	Biological treatment	Tertiary treatment	Sludge digestion	Sludge dewatering	Other
	000s	kWh/000 pe/day	kWh/000 pe/day	kWh/000 pe/day	kWh/000 pe/day	kWh/000 pe/day	kWh/000 pe/day	KWh/000 Pe/day
Ashland	26	0	3	170	9	0	5	13
Burlington	82	2	2	68	3	6	2	3
Grassland	10	28	16	168	11	0	0	5
Green Bay	421	45	7	107	0	0	14	43
La Crosse	139	10	2	73	6	7	12	12
Papermill A	506	31	0	258	0	0	10	31
Portage	37	26	5	48	1	7	1	10

Rhinelander	13	52	39	35	0	12	0	18
J	406	8	3	56	0	4	15	15
K	61	9	12	57	0	13	7	1
L	9	0	26	55	0	12	0	4
Uniform case	110	5	13	70	5	0	10	15

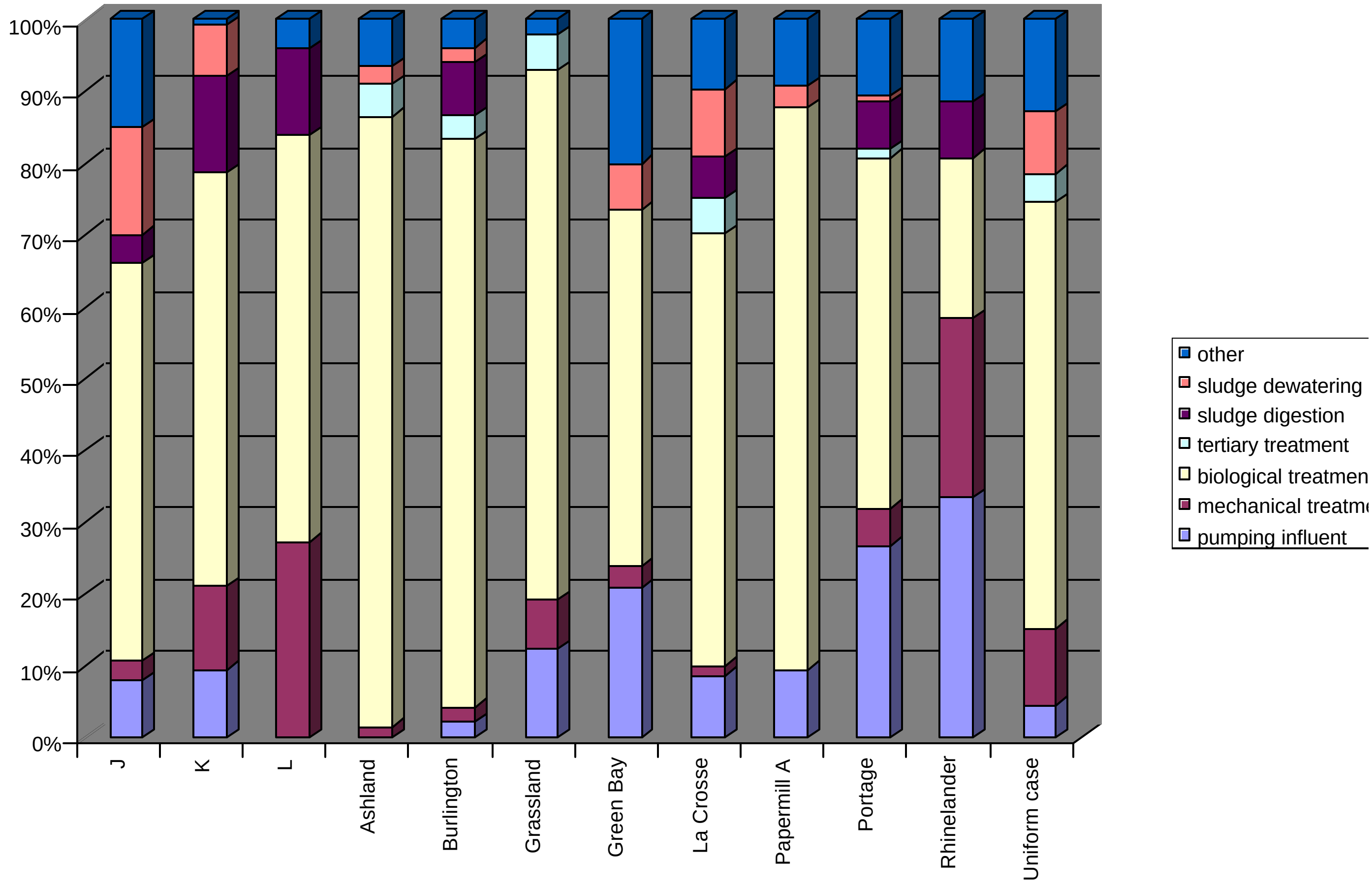

Figure E.6 **Process energy use distribution**

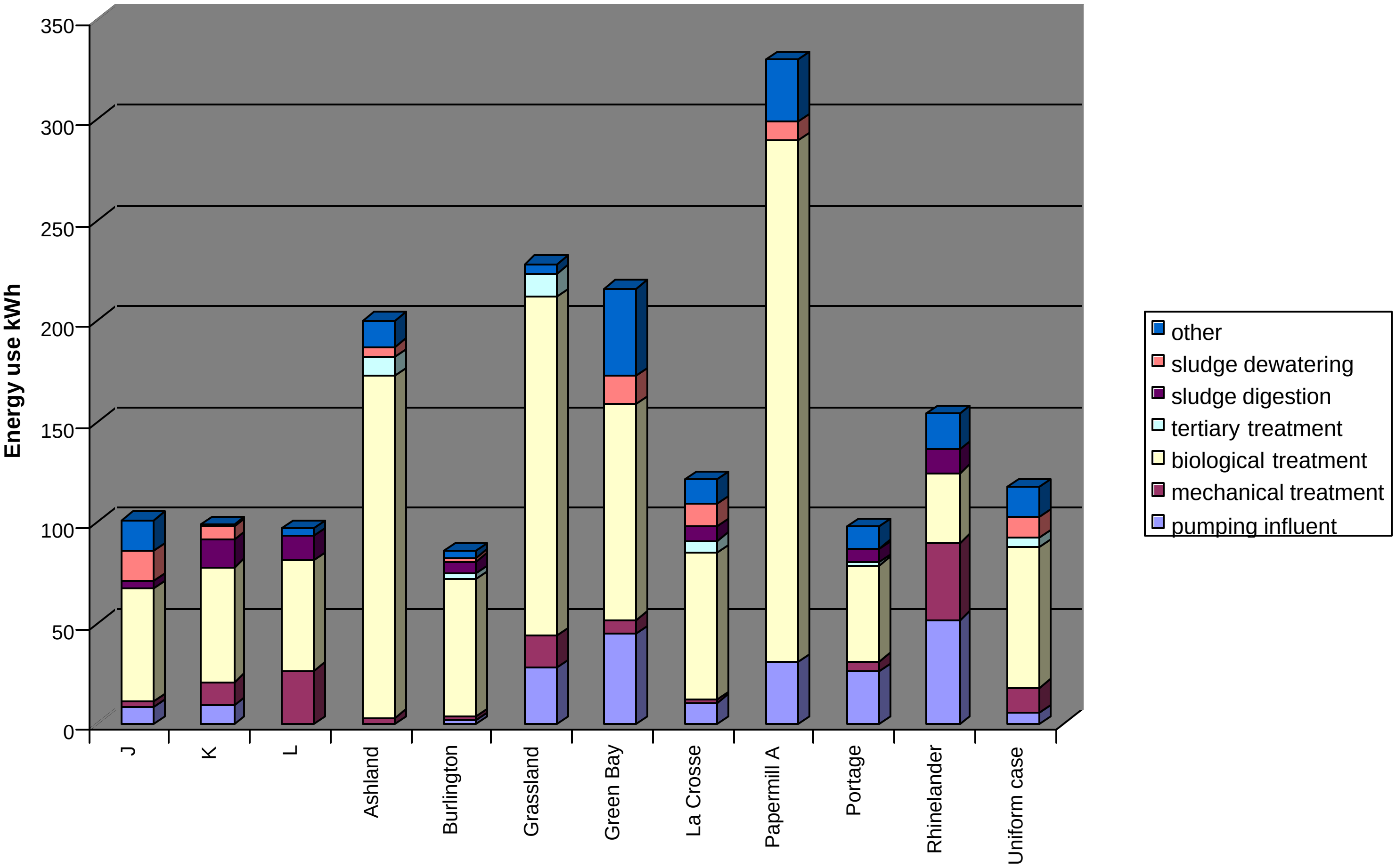

Figure E.7 Process energy use (kWh) per 1000-population equivalent

The process energy use distribution chart, Figure E6 shows that the majority of Wisconsin sites use a higher percentage of energy for biological treatment than the European sites.

The Wisconsin sites use a higher percentage of energy for influent pumping than both the European sites and the uniform case.

The digestion energy percentage used by the Wisconsin sites is lower on average compared to the European sites.

The process energy use per 1000 population equivalent chart, Figure E7, shows that there is a large variation in the energy used for individual processes across the Wisconsin sites.

Ashland is using over double the biological treatment energy of Burlington. This can be partially explained by the strength of the influent at the two sites. At Burlington secondary treatment is by biological filters as well as activated sludge treatment. These filters remove a large amount of the organic content of the effluent with a lower energy use than activated sludge. Burlington uses a similar amount of energy for biological treatment as the uniform case, which is affected by the fact that the biological filters remove large amounts of the organic content of the influent. If this site were an activated sludge plant only then it would be vastly different from the uniform case because of the high strength of the influent.

Grassland uses more energy for biological treatment than any other site. This is greatly influenced by the dairy waste that the plant is treating. It also has a fairly high influent pumping cost.

Green Bay has a high influent pumping cost. This cost cannot be compared to others as it is site specific. The biological treatment cost is not much greater than the uniform case. The costs associated with sludge incineration, not present on any other site, affect the picture for Green Bay.

La Crosse is almost identical to the uniform case, and the energy used for biological treatment is almost a match to the uniform case. Both cases are for similar sized plants with an activated sludge process treating average strength sewage.

Papermill A uses nearly double the amount of energy for biological treatment compared to Ashland, this is because of the type of waste being treated. Papermill waste is inherently difficult to degrade and therefore requires more oxygen for biological treatment. The influent pumping energy is similar to that of Grassland another industrial treatment facility.

Portage as an RBC site can be compared to the others as it is using less energy for biological treatment than the activated sludge plants. RBCs are expected to be low energy users, and although the energy use at this site is increased by sludge recycling and supplementary aeration, it is not expected to be on a par with activated sludge plants.

As would be expected for a biofilter site, Rhinelander has low biological treatment costs. The influent pumping costs are however high as are the mechanical treatment costs. The energy used for influent pumping is site specific, and the mechanical treatment is high because of the maceration of incoming sewage and the high-energy use of the secondary clarifier pumped air diaphragm desludging pumps.

E7 Sewage volumes

The volume of crude sewage entering a treatment works is one indicator of the level of infiltration. Results below suggest a big range of volume per pe, this is needless to say dependent on the strength of influent.

The dry weather flow for the Wisconsin sites was taken from the DMRs as were the average flows. The consented flow to full treatment was defined as 3 times the DWF, this was so that the data could be compared with the European sites.

An indicator of the works ability to treat storm flow is the ratio of consented flow to full treatment to average flow. The consented flow to full treatment is normally set by the environmental authority, as the minimum flow that the work should be able to treat fully. Above this flow the sewage may be partially treated.

A low value of the ratio indicates the possibility of frequent partial treatment discharges. A very high value of this ratio indicates that the works is over sized for the average flow.

Table E8 Comparison of sewage flows

Works	Total pe	DWF		Average flow		Consented flow to full treatment (3DWF)	
	000s	m^3/day	l/pe/day	m^3/day	l/pe/day	m^3/day	Multiple of average flow
Ashland	26.1	4550	174	6587	252	13661	2.1
Burlington	82.0	10850	132	12113	148	32513	2.7
Grassland	9.8	255	26	265	27	764	2.9
Green Bay	421.1	98100	233	114020	271	294273	2.6
La Crosse	138.5	31200	225	40540	293	93600	2.3
Papermill A	506	22993	45	24529	49	68979	2.8
Portage	36.9	5150	139	6057	164	15422	2.5
Rhinelander	12.6	3600	287	4202	333	10834	2.6
A	56.0	10500	188	15625	279	29290	1.9
B	77.0	15000	195	12900	168	40000	3.1
C	42.8	12200	285	15250	356	32400	2.1

D	61.6	15874	258	15800	256	47621	3.0
E	64.3	8000	124	8746	136	32832	3.8
F	13.8	7430	540	4406	320	14860	3.4
G	82.0	20000	244	25736	314	75000	2.9
H	733.3	273024	372	400000	545	655766	1.6
I	17.3	9000	519	11000	634	15500	1.4
J	406.4	-	-	165888	408	259200	1.6
K	61.0	7670	126	11315	185	-	-
L	9.0	2645	294	4045	449	15600	3.9
M	33.0	8653	262	10400	315	26000	2.5
N	68.0	12500	184	17000	250	34560	2.0
O	275.0	129600	471	159155	579	316244	2.0

The Wisconsin sites are all designed in such a way that they can treat storm flows without affecting the effluent quality. This is to be expected as the Wisconsin sites are designed with a larger capacity than is required for the current treatment flows.

E8 Replacing motors for Premium Efficiency

When a motor reaches the end of its life it requires replacement. This is a study into the value of replacing a motor with a more expensive Premium efficiency motor. For this study eight different motor sizes were selected between 1hp and 500hp, they were chosen on the basis of the most frequently used sizes of motors in the Wisconsin sites that were studied.

For each size of motor the payback period was calculated based on an operating time of 6, 12, 18 and 24 hours running time per day. The capital cost and the Net Present Cost running cost were calculated for both the Premium efficiency motor and a general-purpose motor for a five-year period. The net present cost (NPC) is the overall cost including capital and discounted operating cost for a given period of time. For the calculation of NPC the number of running hours per day and the efficiency of the motor were taken into account.

Assumptions

? Electricity set at a constant price of $0.03 per kWh

? Discounting factor for Net Present Cost set at 5%

The following observations were made and can be seen in the tables below for each running time.

In the UK water industry it is current practice to expect a pay back period of one year for any cost-saving activity. In Wisconsin the required payback time is longer and so for this study we have assumed that a five-year payback period is acceptable.

Conclusions are:

? Medium size 15hp to 100hp pumps payback within the five year period no matter what the running hours.

? Small motors below 10hp have a longer payback period as the motor size decreases

? Larger 200hp motors take longer than medium size motors to payback

? The largest 500hp motors will never payback unless they are run 24 hours a day

For motors running for 6 hours a day it can be seen that it is only worth replacing 15, 60 and 100 hp motors to get pay back within the first five years.

For motors running twelve hours a day only very small motors, 1hp and 5hp, and the largest 500hp do not payback within the five-year period.

All motors except the 500hp motor payback within five years when running for 18 and 24 hours per day.

It is not worth replacing a 500hp motor with a more efficient motor because the payback period when running 24 hours a day is 29 years, which is longer than the life of the motor.

This selection table may be used as a guideline when selecting whether to replace an end of life motor with a premium efficiency motor.

Table E9 Guide to selecting efficiency of replacement motor

Hours run time	Premium efficiency motor	General purpose motor
6	? 15hp up to 100hp	<15hp, >100hp
12	? 5hp up to 200hp	<5hp, >200hp
18	1hp up to 200hp	500hp

24	1hp up to 200hp	500hp

Ref. Marathon Electric, Three phase, Drip proof, Rigid Base motors.

Table E10 Motor cost comparisons - Six hours running time per day

Size of motor	Premium efficiency motor					General purpose motor			
	Capital cost	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**	**Pay back time**	**Capital cost**	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**
Hp	**$**	**$**	**$**	**%**	**Years**	**$**	**$**	**$**	**%**
1	325	248	573	85.5%	20	277	265	542	80.0%
5	389	1185	1574	89.5%	16	323	1212	1535	87.5%
10	683	2313	2996	91.7%	11	577	2370	2947	89.5%
15	908	3421	4329	93.0%	3	864	3496	4360	91.0%
60	2625	13467	16092	94.5%	4	2532	13597	16129	93.6%
100	4130	22234	26364	95.4%	4	3933	22541	26474	94.1%
200	9022	44282	53304	95.8%	6	8592	44655	53247	95.0%
500	28551	109903	138454	96.5%	Never	17375	110706	128081	95.8%

Table E11 Motor cost comparisons - Twelve hours running time per day

Size of motor	**Premium efficiency motor**					**General purpose motor**			
	Capital cost	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**	**Pay back time**	**Capital cost**	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**
Hp	**$**	**$**	**$**	**%**	**Years**	**$**	**$**	**$**	**%**
1	325	496	821	85.5%	8	277	530	807	80.0%
5	389	2370	2759	89.5%	7	323	2424	2747	87.5%
10	683	4626	5309	91.7%	5	577	4740	5317	89.5%
15	908	6842	7750	93.0%	2	864	6993	7857	91.0%
60	2625	26935	29560	94.5%	2	2532	27194	29726	93.6%
100	4130	44468	48598	95.4%	2	3933	45082	49015	94.1%
200	9022	88564	97586	95.8%	3	8592	89310	97902	95.0%
500	28551	219805	248356	96.5%	Never	17375	221411	238786	95.8%

Table E12 Motor cost comparisons - Eighteen hours running time per day

Size of motor	**Premium efficiency motor**					**General purpose motor**			
	Capital cost	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**	**Pay back time**	**Capital cost**	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**
Hp	**$**	**$**	**$**	**%**	**Years**	**$**	**$**	**$**	**%**
1	325	744	1069	85.5%	5	277	795	1072	80.0%
5	389	3555	3944	89.5%	4	323	3636	3959	87.5%
10	683	6939	7622	91.7%	3	577	7110	7687	89.5%
15	908	10263	11171	93.0%	1	864	10489	11353	91.0%
60	2625	40402	43027	94.5%	2	2532	40791	43323	93.6%
100	4130	66702	70832	95.4%	1	3933	67623	71556	94.1%
200	9022	132847	141869	95.8%	2	8592	133965	142557	95.0%
500	28551	329708	358259	96.5%	Never	17375	332117	349492	95.8%

Table E13 Motor cost comparisons - Twenty Four hours running time per day

Size of motor	**Premium efficiency motor**					**General purpose motor**			
	Capital cost	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**	**Pay back time**	**Capital cost**	**NPC operating cost for 5 years**	**Total cost for 5 years**	**Efficiency**
Hp	**$**	**$**	**$**	**%**	**Years**	**$**	**$**	**$**	**%**
1	325	992	1317	85.5%	4	277	1061	1338	80.0%
5	389	4740	5129	89.5%	3	323	4848	5171	87.5%
10	683	9252	9935	91.7%	3	577	9480	10057	89.5%
15	908	13685	14593	93.0%	1	864	13985	14849	91.0%
60	2625	53870	56495	94.5%	1	2532	54388	56920	93.6%
100	4130	88936	93066	95.4%	1	3933	90164	94097	94.1%
200	9022	177129	186151	95.8%	2	8592	178620	187212	95.0%
500	28551	439610	468161	96.5%	29	17375	442822	460197	95.8%

E9 Water Treatment Energy Use and Costs

Table E14 contains benchmark figures of actual operating costs of water treatment plants in the UK. The columns are for one of two types of Works as follows:

- Works Type 2 - Single stage complex physical or chemical treatment (e.g. super chlorination, flocculation or biofiltration)
- Works Type 3 - More than one stage of complex treatment

Table E14 Actual operating costs of UK water treatment works

Flow (Ml/d)	**2.5 - 4.9**	**5.0 - 9.9**	**10 - 24.9**	**25 - 49.9**	**50 - 99.9**	**100 - 174.9**	**>175**
Flow (mgd)	**0.66 - 1.29**	**1.32 - 2.62**	**2.64 - 6.58**	**6.61 – 13.18**	**13.2 - 26.3**	**26.4 - 46.2**	**46.2**
Works type	**2**	**2**	**3**	**3**	**3**	**3**	**3**
Abstraction energy costs $ p.a.	9249	18499	43163	92493	184986	339142	493297
water treatment energy costs $ p.a.	10947	13748	27824	45656	69587	102231	178324
sludge treatment energy costs $ p.a.	136	181	543	3621	14710	27363	54614
total per works	20332	32427	71530	141770	269283	468736	726235

The City of Eau Claire water treatment works is a Type 3 plant in the size range 6.61 - 13.18 mgd. Table E15 compares Eau Claire operating costs with those of a similar type and size of UK plant.

Table E15 Comparison of Eau Claire with UK works

Plant description	**UK plant**	**Eau Claire**
Flow MGD	**6.61 - 13.18**	**8**
Abstraction energy costs $ p.a.	92493	70493
water treatment energy costs $ p.a.	45656	130482
sludge treatment energy costs $ p.a.	3621	10
total per works $ p.a.	141770	200985

The City of Kenosha water treatment works is a Type 3 plant in the size range 13.2 – 26.3 mgd. Table E16 compares Kenosha operating costs with those of a similar type and size of UK plant.

Table E16 Comparison of Kenosha with UK works

Plant description	**UK plant**	**Eau Claire**
Flow MGD	**6.61 - 13.18**	**8**
Abstraction energy costs $ p.a.	184986	96630
water treatment energy costs $ p.a.	69587	247838
sludge treatment energy costs $ p.a.	14710	468
Total per works $ p.a.	269283	344936

APPENDIX F – GLOSSARY

Aeration efficiency	The ratio of the mass of oxygen required to treat the wastewater compared with the energy required by the aeration equipment.
Aerobic treatment	Wastewater treatment depending on oxygen for bacterial breakdown of waste.
Anaerobic treatment	Wastewater treatment in which bacteria breakdown waste without using oxygen.
Activated sludge process	A biological treatment process in which a mixture of sewage and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated sewage by settlement and may be re-used.
Alpha factor	A correction factor used to estimate actual oxygen mass transfer coefficient in a system.
Autotrophic	A term applied to organisms which produce their own organic constituents from inorganic compounds utilizing energy from sunlight or oxidation processes.
Beta factor	A correction factor used to correct the test system oxygen transfer rate for differences in oxygen solubility due to constituents in water such as salts, particulates and surface-active substances.
BOD	The amount of dissolved oxygen consumed by micro-biological action when a sample is incubated, usually for 5 days at 20 deg. C. (in the UK expressed as BOD5). In some countries the BOD test is carried out over differing periods such as 7 days (BOD7), and 10 days (BOD10).
COD	The amount of oxygen used in the chemical oxidation of the matter present in a sample by a specified oxidizing agent under standard conditions.
Denitrification	The chemical reduction of nitrate and nitrite to gaseous forms: nitric oxide, nitrous oxide and dinitrogen: NO_3^- ? $NO_2^{-?}$ NO ? N_2O ? N_2.
Disinfection	The removal or inactivation of pathogenic organisms.
Dissolved oxygen	A measure of the amount of oxygen dissolved in water, expressed as either: (i) mg/1 – which is the absolute amount of oxygen dissolved in the water mass; (ii) as percentage saturation of the water with O_2 (% sat).
Dry weather flow (DWF)	The combination of wastewater and dry weather infiltration flowing in a sanitary sewer during times of low precipitation.
Effluent	The outflow from a sewage treatment plant.
Energy	The capacity to do work. Measured in kW.

Equalization basin	A holding tank within which variations in sewage inflow rate and liquid nutrient concentrations are averaged.
Flocculation	The water treatment process in which particle collisions are induced in order to encourage the growth of larger particles.
Food/micro-organism ration (F/M)	A measure of the organic loading rate of a wastewater treatment system, i.e. the ratio between the daily BOD load and the quantity of activated sludge in the system (microbes).
Heterotrophic	A term applied to organisms which need ready-made food materials from which to produce their own constituents and to obtain all their energy.
Key performance indicator (KPI)	A performance indicator used to compare different sizes of plants on an equal basis.
Kla	Oxygen mass transfer coefficient when considering the uptake of oxygen by micro-organisms.
Microfiltration	Filtration of a liquid to retain particles within a range of about 0,1 µm upwards.
Mixed liquor suspended solids (MLSS)	Solids suspended in the mixed liquor of the aeration tank of a wastewater treatment plant.
NH_3	The concentration of ammonia in the wastewater or effluent.
Nitrification	The conversion of the ammonium ion, NH_4^+, into the nitrite ion, NO_3^+. It occurs in two steps: (i) $2NH_4^+ + 3O_2 = 2NO_2^- + 2H_2O + 4H^+$ by the bacteria genus *Nitrosomonas;* (ii) $2NO_2 + O_2 = 2NO_3^-$ by the bacteria genus *Nitrobacter..*
Population equivalent (pe)	The equivalent number of people calculated for a particular flowrate and BOD and ammonia load.
Power	The rate of doing work. Measured in kW.
Return activated sludge	Settled activated sludge from the clarifier which is returned to the aeration tank to ensure an active population of microbes will be mixed with the incoming wastewater.
Rotating biological contactor	A form of biological treatment in which fixed media is grown on circular discs mounted on a horizontal axle. These discs are partially submerged in wastewater while the axle rotates, allowing bio-oxidation of the wastewater, using oxygen from the air.
Sludge	Biosolids remaining after primary, secondary or tertiary treatment.
Sludge volume index (SVI)	A measure of the ability of sludge to settle, coalesce and compact on settlement.
Trickling filter	A biological reactor in which micro-organisms, growing as a slime on the surface of fixed media, oxidize the colloidal and dissolved

	organic matter in wastewater using atmospheric oxygen which diffuses into the thin film of liquid as the wastewater is trickled over the slimed surfaces at regular intervals.
TKN	The Total Kjeldahl Nitrogen is the sum of the ammonia nitrogen and the organic bounded nitrogen. Nitrates and nitrites are not included.
TSS	The total suspended solids is the amount of suspended material (mg/l) that is present in the wastewater.
TP	Total phosphorus (mg/l) present in the wastewater.
Volatile fatty acid (VFA)	A fatty acid with, at most, six carbon atoms which are water soluble.