Storm and Wastewater

Wastewater Treatment Plant Optimization

This document is the fifth in a series of best practices that deal with buried linear infrastructure as well as end of pipe treatment and management issues. For titles of other best practices in this and other series, please refer to *www.infraguide.ca.*

National Guide to Sustainable Municipal Infrastructure

NRC · CNRC Federation of Canadian Municipalities Canada

Wastewater Treatment Plant Optimization

Issue No. 1.0

Publication Date: November 2003

ISBN 1–897094–32–9

InfraGuide – Innovations and Best Practices

Why Canada Needs InfraGuide

Canadian municipalities spend $12 to $15 billion annually on infrastructure but it never seems to be enough. Existing infrastructure is ageing while demand grows for more and better roads, and improved water and sewer systems responding both to higher standards of safety, health and environmental protection as well as population growth. The solution is to change the way we plan, design and manage infrastructure. Only by doing so can municipalities meet new demands within a fiscally responsible and environmentally sustainable framework, while preserving our quality of life.

This is what the National Guide to Sustainable Municipal Infrastructure (InfraGuide) seeks to accomplish.

In 2001, the federal government, through its Infrastructure Canada Program (IC) and the National Research Council (NRC), joined forces with the Federation of Canadian Municipalities (FCM) to create the National Guide to Sustainable Municipal Infrastructure (InfraGuide). InfraGuide is both a new, national network of people and a growing collection of published best practice documents for use by decision makers and technical personnel in the public and private sectors. Based on Canadian experience and research, the reports set out the best practices to support sustainable municipal infrastructure decisions and actions in six key areas: municipal roads and sidewalks, potable water, storm and wastewater, decision making and investment planning, environmental protocols, and transit. The best practices are available on-line and in hard copy.

A Knowledge Network of Excellence

InfraGuide´s creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers and other experts, and a host of volunteers throughout the country. By gathering and synthesizing the best Canadian experience and knowledge, InfraGuide helps municipalities get the maximum return on every dollar they spend on infrastructure—while being mindful of the social and environmental implications of their decisions.

Volunteer technical committees and working groups—with the assistance of consultants and other stakeholders—are responsible for the research and publication of the best practices. This is a system of shared knowledge, shared responsibility and shared benefits. We urge you to become a part of the InfraGuide Network of Excellence. Whether you are a municipal plant operator, a planner or a municipal councillor, your input is critical to the quality of our work.

Please join us.

Contact InfraGuide toll-free at 1-866-330-3350 or visit our Web site at ***www.infraguide.ca*** for more information. We look forward to working with you.

The InfraGuide Best Practices Focus

Storm and Wastewater

Ageing buried infrastructure, diminishing financial resources, stricter legislation for effluents, increasing public awareness of environmental impacts due to wastewater and contaminated stormwater are challenges that municipalities have to deal with. Events such as water contamination in Walkerton and North Battleford, as well as the recent CEPA classification of ammonia, road salt and chlorinated organics as toxic substances, have raised the bar for municipalities. Storm and wastewater best practices deal with buried linear infrastructure as well as end of pipe treatment and management issues. Examples include ways to control and reduce inflow and infiltration; how to secure relevant and consistent data sets; how to inspect and assess condition and performance of collections systems; treatment plant optimization; and management of biosolids.

Decision Making and Investment Planning

Elected officials and senior municipal administrators need a framework for articulating the value of infrastructure planning and maintenance, while balancing social, environmental and economic factors. Decision-making and investment planning best practices transform complex and technical material into non-technical principles and guidelines for decision making, and facilitate the realization of adequate funding over the life cycle of the infrastructure. Examples include protocols for determining costs and benefits associated with desired levels of service; and strategic benchmarks, indicators or reference points for investment policy and planning decisions.

Environmental Protocols

Environmental protocols focus on the interaction of natural systems and their effects on human quality of life in relation to municipal infrastructure delivery. Environmental elements and systems include land (including flora), water, air (including noise and light) and soil. Example practices include how to factor in environmental considerations in establishing the desired level of municipal infrastructure service; and definition of local environmental conditions, challenges and opportunities with respect to municipal infrastructure.

Potable Water

Potable water best practices address various approaches to enhance a municipality's or water utility's ability to manage drinking water delivery in a way that ensures public health and safety at best value and on a sustainable basis. Issues such as water accountability, water use and loss, deterioration and inspection of distribution systems, renewal planning and technologies for rehabilitation of potable water systems and water quality in the distribution systems are examined.

Transit

Urbanization places pressure on an eroding, ageing infrastructure, and raises concerns about declining air and water quality. Transit systems contribute to reducing traffic gridlock and improving road safety. Transit best practices address the need to improve supply, influence demand and make operational improvements with the least environmental impact, while meeting social and business needs.

Municipal Roads and Sidewalks

Sound decision making and preventive maintenance are essential to managing municipal pavement infrastructure cost effectively. Municipal roads and sidewalks best practices address two priorities: front-end planning and decision making to identify and manage pavement infrastructures as a component of the infrastructure system; and a preventive approach to slow the deterioration of existing roadways. Example topics include timely preventative maintenance of municipal roads; construction and rehabilitation of utility boxes; and progressive improvement of asphalt and concrete pavement repair practices.

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The dedication of individuals who volunteered their time and expertise in the interest of the *National Guide to Sustainable Municipal Infrastructure (InfraGuide)* is acknowledged and much appreciated.

This umbrella best practice for wastewater treatment plant optimization was developed by stakeholders from Canadian municipalities and specialists from across Canada based on information from a scan of municipal practices and an extensive literature review. The following members of InfraGuide's Storm and Wastewater Technical Committee provided guidance and direction in the development of this document. They were assisted by the Guide Directorate staff and by XCG Consultants Ltd.

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In addition, the Storm and Wastewater Technical Committee would like to thank the following individuals and institution for their participation in working groups, peer reviews, and support.

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Great Lakes Sustainability Fund,
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Acknowledgements

This and other best practices could not have been developed without the leadership and guidance of the Project Steering Committee and the Technical Steering Committee of the *National Guide to Sustainable Municipal Infrastructure (InfraGuide)*, whose memberships are as follows:

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EXECUTIVE SUMMARY

Wastewater treatment plants (WWTPs) are typically designed to conservative design guidelines and are operated based on historic practices. Generally, experience has shown that such facilities often have considerable additional capacity that can be realized through optimization. Improvements in effluent quality and reductions in operating costs can also be realized. This best practice provides an overview of the approach that should be taken to optimize an existing WWTP. It also describes a set of tools that can be used to achieve the specific objectives of an optimization program. By applying this best practice, the capacity of the existing infrastructure can be maximized, the performance of the works enhanced, and the operating and maintenance costs reduced.

WWTP optimization should become an operating philosophy for the municipality that is championed by management, supported by council and staff at all levels, and has the overall objective of continuous improvement. The best practice for WWTP optimization includes the following elements.

- Establish the objectives of optimization.
- Evaluate the WWTP to establish or benchmark conditions, prioritize opportunities for optimization, and determine performance or capacity limiting factors.
- Identify and implement operational or process changes to address performance or capacity limiting factors.
- Conduct follow-up monitoring to document the benefits.

A WWTP optimization program is iterative, and clear objectives should be established before each iteration. Depending on the objectives established, the outcome of WWTP optimization may include any or all of the following:

- an increase in the capacity of the existing works without the major capital costs associated with a plant expansion;
- an improvement in process without the major capital costs associated with a plant upgrade; and
- a reduction in operating costs through more efficient use of power, chemicals, or labour.

This best practice provides WWTP owners and operators with a description of some of the state-of-the-art tools available to evaluate and optimize their WWTP and the individual unit processes that comprise it, such as:

- oxygen transfer testing;
- hydraulic modelling;
- clarifier hydraulic testing;
- stress testing; and
- process modelling and simulation.

Available tools to optimize through improved operations and maintenance practices; instrumentation, control, and automation; and process modifications are described in the document, along with opportunities to achieve resource cost savings.

A key element of the WWTP optimization best practice that is often ignored is the follow-up monitoring needed to document the level of success achieved. Communication of the benefits of the optimization program is essential to build support for future initiatives. This support is the key to ensuring the iterative process of optimization is sustained and an environment conducive to optimization is fostered within the municipality.

As a guide to conducting WWTP optimization, a step-wise approach is illustrated that suggests the type of testing that could be done to meet various optimization objectives.

1. General

1.1 Introduction

Wastewater treatment plants (WWTPs) have traditionally been designed to conservative design guidelines and standards that were developed based on historic design practices. Procedures are often passed from operator to operator without consideration for new approaches that might improve performance or reduce costs. Generally, experience has shown that WWTPs often have considerable additional capacity beyond the rated capacity that was assigned at design. Furthermore, improvements in performance and reductions in operating costs can often be achieved through optimization approaches.

This best practice provides an overview of an iterative approach to optimization of an existing WWTP that will allow the owner/operator to maximize the capacity of the existing infrastructure, enhance the performance of the facility, and reduce the operational costs.

1.2 Scope

This best practice has been developed by the *National Guide to Sustainable Municipal Infrastructure: Innovation and Best Practices*. It is one of more than 50 aspects identified by the Guide's Storm and Wastewater Technical Committee relating to linear infrastructure, wastewater treatment, customer interaction, and receiving water issues.

This best practice applies to the optimization of municipal wastewater treatment plants. WWTP optimization is considered to be a step-wise process that results in the maximum use of the existing infrastructure at a competitive operating cost consistent with principles of sustainability. Depending on the objectives of the optimization program, the outcomes may include any or all of the following:

- increasing the capacity of the existing works without the major capital costs associated with a plant expansion;
- improving process performance without the major capital costs associated with a plant upgrade; and
- reducing operating costs through more efficient use of power, chemicals, or labour.

This best practice covers the processing of the most common liquid and sludge treatment processes that typically comprise a WWTP. The liquid treatment processes include preliminary, primary, secondary, and tertiary treatment, and the disinfection of the treated effluent. The sludge treatment processes include thickening, dewatering and digestion (aerobic and anaerobic). Management of the biosolids stream produced by the WWTP is not addressed in this best practice. A best practice for biosolids management has been developed by the *National Guide to Sustainable Municipal Infrastructure: Innovation and Best Practices.* The reader is referred to that best practice for information specific to biosolids management.

1.3 Health and Safety

Some of the test procedures described in this best practice involve using hazardous chemicals or working in hazardous areas of a WWTP around electrical and mechanical equipment. Appropriate safety measures should be taken before undertaking any of the testing described, including reference to manufacturer's safety data sheets (MSDSs) on chemicals that might be used during testing and adherence to occupational health and safety standards.

1.4 Glossary

Biochemical oxygen demand (BOD) — The quantity of oxygen consumed, usually expressed in mg/L, during the biochemical oxidation of organic matter over a specified time period (i.e., five day BOD or BOD_5) at a temperature of 20ºC.

Biological nutrient removal (BNR) — Processes that remove nitrogen and/or phosphorus by biological rather than chemical or physical means.

Chemical oxygen demand (COD) — The quantity of oxygen required in the chemical oxidation of organic matter under standard laboratory procedures, expressed in mg/L.

Dissolved oxygen (DO) — The concentration of oxygen dissolved in water usually expressed in mg/L. Dissolved oxygen is important for aerobic ("with air") biological treatment. An adequate DO concentration in a wastewater effluent is important for the aquatic life in the receiving stream or river.

Endogenous Oxygen Demand — Oxygen demand for the basic respiration of the micro-organisms, independent from the current wastewater loading.

Food-to-micro-organism ratio (F/M) — The ratio of the influent mass loading (usually expressed in kg/d) of BOD or COD to the mass of volatile suspended solids concentration in a wastewater treatment aeration tank. The units of F/M are typically d^{-1}.

Hydraulic retention time (HRT) — A measure of the length of time a volume of liquid is retained in a tank or vessel, calculated by dividing the tank or vessel volume (L) by the liquid flowrate (L/d) and is presented in either days or hours.

Inflow and infiltration (I/I) — Inflow is water entering the sanitary sewer during wet weather events from such sources as roof leaders, foundation drains, manhole covers or storm sewer interconnections. Infiltration is water entering the sanitary sewer system from the ground through defective pipes, pipe joints, connections, or manhole walls.

Mixed liquor suspended solids (MLSS) — The concentration of dry solids in mg/L of mixed liquor biomass in the aeration tank of a suspended growth (activated sludge or extended aeration) WWTP.

Oxidation-reduction potential (ORP) — A measure of the net potential of all oxidants and reducing agents in a solution usually expressed in mvolts.

Return activated sludge (RAS) — That portion of the activated sludge separated from the mixed liquor in the secondary settlement tanks, which is returned to the aeration tanks.

Sequencing batch reactors (SBR) — A treatment process characterized by the interruption of flow to the reactor during the sedimentation and decanting phase of treatment.

Sludge loading rate (SLR) — The mass loading rate in kg/d of mixed liquor suspended solids (MLSS) per unit area of the secondary clarifier. It is typically expressed as $kg/m^2{\cdot}d$

Sludge volume index (SVI) — A measure of the settling characteristics of biomass defined as the volume in mL occupied by 1 g of settled sludge after settling for 30 minutes in a settling column, typically a 1 litre graduated cylinder. SVI is usually expressed in mL/g.

Solids retention time (SRT) — A measure of the theoretical length of time the average particle of mixed liquor suspended solids has been retained in the biological reactor section of the treatment plant. It is usually presented in days, and is also referred as mean cell residence time (MCRT) or sludge age.

Specific Oxygen Uptake Rate (SOUR) — Also known as the oxygen consumption or respiration rate, is defined as the milligram of oxygen consumed per gram of volatile suspended solids (VSS) per hour.

Step-feed aeration — A modification of conventional plug-flow process in which the settled wastewater is introduced at several points in the aeration tank to equalize F/M ratio, thus lowering peak oxygen demand.

Stirred Sludge Volume Index (SSVI) — A measure to determine the settling properties of an activated sludge. It is expressed in mL/g.

Supervisory control and data acquisition (SCADA) — A computer-monitored sensing, alarm, response, control, and data acquisition system used in WWTPs to monitor their operations.

Total Kjeldahl nitrogen (TKN) — The sum of the organic and ammonia nitrogen in a water sample usually expressed in mg/L.

Total Phosphorus (TP) — Total amount of phosphorus present in the wastewater (or water) either in soluble or insoluble forms, in organic and inorganic (orthophosphates, metaphosphates or polyphosphate) compounds, expressed in mg/L.

Total suspended solids (TSS) — Solids present in a water sample that are retained on the filter paper after filtering the sample, usually expressed in mg/L.

Volatile Suspended Solids (VSS) — The amount of total suspended solids burned off at 550 ± 50°C expressed normally as mg/L. It indicates the biomass content of the mixed liquor.

Waste activated sludge (WAS) — The excess portion of the activated sludge separated from the biological treatment process.

2. Rationale

2.1 Background

In the 1980s and early 1990s, WWTP optimization first gained recognition as a cost-effective way to achieve improved performance, reduce costs, and maximize the use of existing infrastructure. Early efforts at optimization in the United States were initiated by the recognition that considerable capital dollars had been spent on new facilities, but these facilities were not performing to expectations. The Composite Correction Program (CCP) was developed to identify the major causes of poor performance in these plants (Water Pollution Control Federation, 1985).

Rising energy prices in the 1980s led to a focus on energy conservation in WWTPs through optimization techniques. The process audit was developed based on work undertaken at the Tillsonburg, Ontario WWTP, primarily as a means to reduce process energy use at these facilities (Speirs and Stephenson, 1985). Experience with the tool showed it could also be applied to evaluate plant capacity and identify opportunities to obtain additional capacity in an existing works at lower capital costs.

Case histories showing substantial capital and operating cost savings as a result of optimization of WWTPs began to appear in the technical literature. Guidance manuals were prepared describing the benefits of, and available approaches for, WWTP optimization (WEAO, 1996). By the mid-1990s, WWTP optimization had become a well-established practice. In some jurisdictions, optimization of the existing works became a prerequisite for obtaining grants for plant expansion.

In some jurisdictions, optimization of the existing works became a prerequisite for obtaining grants for plant expansion.

Specific goals of WWTP optimization may include any or all of the following:

- improved plant performance, reliability, flexibility, and efficiency;
- reduced capital costs of expansion or upgrading;
- reduced operating costs associated with energy use, chemical use, and labour; and
- improved operating practices.

2.2 Expected Benefits of WWTP Optimization

2.2.1 Improved Plant Performance, Reliability, Flexibility, and Efficiency

Applying this best practice will result in improved plant performance, and reduce the risk of noncompliance with either effluent quality requirements or biosolids quality regulations.

The Regional Municipality of Halton, owner and operator of the Burlington Skyway WWTP, used the Composite Correction Program (CCP) as an optimization tool, together with other optimization tools, to improve the performance of this facility significantly. This was in response to a need to achieve enhanced effluent quality requirements. The CCP approach is described in Section 3.5 of this best practice. Through a comprehensive performance evaluation (CPE), non-technical or management and human resources related limitations are identified as performance limiting factors. As a result of improvements achieved during the follow-up comprehensive technical assistance (CTA), significant improvements in plant performance were achieved, allowing the plant to attain both phosphorus and ammonia limits not considered achievable without major capital expenditures. At the same time, substantial savings in capital costs for future plant expansion were deferred as a result of the additional capacity realized at the plant. The total savings in capital costs were estimated at about $50 million. A more detailed case history of the Burlington Skyway WWTP optimization project accomplishments is presented in Appendix A (Case History 1).

An enhanced understanding of the fundamentals of sewage treatment processes through operator training and appropriate application of these concepts to process control will improve plant performance and reliability.

2.2.2 Reduced Capital Costs of Expansion/Upgrading

Through WWTP optimization, significant capital cost savings can be realized by maximizing the capability and capacity of the existing infrastructure.

The Regional Municipality of Waterloo, owner and operator of the Ayr WWTP, was able to re-rate this facility from a nominal rated capacity of 1,181 m^3/d to a new rated capacity of 1,500 m^3/d after applying some of the optimization tools described in this best practice. A historic data review and production of a process capacity chart identified additional available capacity in the major unit processes comprising the packaged extended aeration plant. This review also questioned the accuracy of the plant flow metering. Stress testing of the secondary clarifiers, oxygen transfer testing, and biological simulation modelling were used to confirm the findings of the desktop evaluation. As a result, the regulator issued a new certificate of approval for the plant for the increased capacity and with more stringent effluent limits for ammonia and phosphorus, allowing further development in the community. The 27 percent increase in capacity was realized after minor upgrades to the aeration system, the raw sewage pumping station, and the return sludge pumping system. No new aeration or clarification tankage was required to allow the increased capacity. A more detailed case history of the Ayr WWTP project is presented in Appendix A (Case History 2). Another example of optimization leading to reduced capital costs for expansion of the Montréal WWTP is also presented in Appendix A (Case History 4).

2.2.3 Reduced Operating Costs

The operating costs associated with energy use, chemical use, and labour can be reduced through WWTP optimization.

A demonstration of optimized aeration mode operation was conducted at the Tillsonburg WWTP to determine the impact of on-off aeration on energy costs. The plant configuration allowed for a direct comparison of parallel activated sludge aeration basins (also known as bioreactors) operated in the on-off mode and in the conventional continuous aeration mode. Aeration energy savings of between 16 and 26 percent were achieved at the plant depending on whether one of the two aeration cells or both aeration cells were cycled. Operation in the on-off mode also resulted in denitrification at the plant, reducing the total nitrogen concentration in the plant effluent. A more detailed case history of the on-off aeration demonstration is presented in Appendix A (Case History 3). Another example of optimization resulting in reduced chemical costs at the Montréal WWTP is also included in Appendix A (Case History 4).

2.2.4 Improved Operating Practices

Improved operating practices will result in benefits in all the areas outlined above.

An enhanced understanding of the fundamentals of sewage treatment processes through operator training and appropriate application of these concepts to process control will improve plant performance and reliability, and allow operating staff to recognize opportunities to reduce costs. Through the use of techniques like comprehensive technical assistance (CTA), it is possible to transfer the knowledge and skills that will lead to sustained WWTP optimization and continuous improvement, as illustrated by the optimization work undertaken at the Burlington Skyway WWTP.

3. Work Description

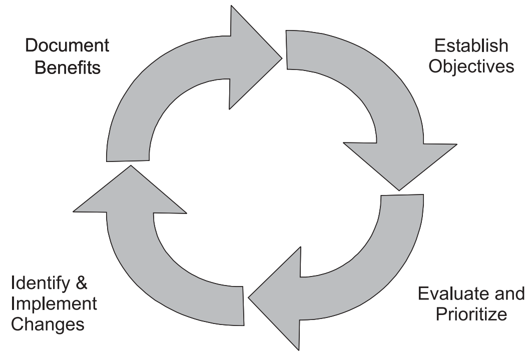
3.1 Elements of a WWTP Optimization Program

WWTP optimization is not a "one shot" project conducted by a contractor on behalf of the WWTP owner. Rather, it is an operating philosophy that is sustained with the overall objective of continuous improvement. Some of the tools used to optimize the WWTP described in this best practice can be undertaken by a contractor on behalf of the municipality, but the overall optimization program must be championed by the municipality and supported by staff at all levels of the organization. The elements of the best practice for WWTP optimization apply to any size or type of treatment plant; however, the tools used may vary. Those applied at a small WWTP may be different than those applied at a larger WWTP, because the costs and the potential return from some approaches may not be justified at smaller facilities.

The best practice for WWTP optimization includes the following elements.

- Establish the objectives of optimization.
- Evaluate the WWTP to establish the baseline or benchmark conditions, prioritize opportunities for optimization, and determine performance or capacity limiting factors.
- Identify and implement operational or process changes to address performance or capacity limiting factors.
- Conduct follow-up monitoring to document the benefits.

Figure 3–1: Elements of WWTP optimization



The level of improvement achieved and the benefits realized from implementing this best practice will depend on the starting point. Initial corrective measures may be needed to bring operating staff to a basic level of knowledge and plant performance to an acceptable level. Subsequently, further enhancement to the performance of the facility can be targeted. Thus, the process is iterative, and clear objectives should be established before each iteration.

The Composite Correction Program (CCP) was developed by the U.S. Environmental Protection Agency (EPA, 1985) to identify factors that prevent a WWTP from achieving compliance with its effluent requirements and to mitigate operational problems at such facilities. Through the CCP, the problems causing poor plant performance can be resolved with minimal capital expenditure. The approach has been modified for application at Canadian WWTPs (MOEE, 1996).

WWTP is an operating philosophy that is sustained with the overall objective of continuous improvement.

3. **Work Description**

3.1 Elements of a WWTP Optimization Program

Table 3–1
Performance Limiting Factors at a WWTP

The CCP is a two-step process that follows a fairly rigorous format. The first stage, the Comprehensive Performance Evaluation (CPE), is conducted to evaluate the potential of the WWTP to achieve the desired performance levels. The evaluation focuses on four major areas: plant design, operation, maintenance, and administration. During the evaluation, performance limiting factors, typically five to fifteen, are identified and prioritized. Some of the factors that can limit performance or capacity are identified in Table 3–1.

The methodology of conducting a CPE can be summarized as follows.

- Identify performance limiting factors.
- Prioritize performance limiting factors.
- Assess the approach to improve performance.
- Produce a CPE report.

Based on the results from the evaluation, the WWTP is classified as capable (Type 1), marginal (Type 2), or not capable (Type 3), in terms of its ability to achieve compliance at its current flow. The causes of the problems are identified and grouped into three priority categories.

- Priority A factors have a major effect on plant performance on a continuous basis.
- Priority B factors have a major effect on plant performance on a periodic basis, or a minor effect on a continuous bases.
- Priority C factors have a minor effect on plant performance.

Table 3–1: Performance Limiting Factors at a WWTP

Category	Factors	
Operation	■ Process monitoring ■ Sludge wasting and disposal ■ Knowledge of operating staff	■ Manual and technical support ■ Availability of equipmentProper chemical selection and use
Design	■ Hydraulic load ■ Organic load ■ Oxygen transfer ■ Inflow and infiltration (I/I) ■ Instrumentation and control (I&C) ■ Industrial load ■ Lack of flexibility	■ Sludge treatment capacity ■ Sludge storage capacity ■ Sludge disposal capacity ■ Process equipment ■ Non-modular design ■ Configuration of process tankage
Maintenance	■ Scheduling and recording ■ Equipment malfunction ■ Availability of equipment ■ Skilled manpower ■ Age of equipment ■ Knowledge/training of staff	
Administration	■ Level of staffing ■ Support from administrative bodies ■ Financial ■ Policies ■ Record keeping ■ Operator training	

To achieve long-term performance improvements, all the factors contributing to poor performance at a facility must be addressed in the next stage of optimization.

The second stage of the CCP, termed Comprehensive Technical Assistance (CTA), is normally undertaken at a Type 1 or Type 2 WWTP and involves systematically addressing the performance limiting factors identified in the CPE that do not involve capital works. A major component of the CTA is hands-on operator training and support to implement process control techniques and standard operating procedures (SOPs) to improve process performance. In addition, empowerment of operating staff in priority setting and problem-solving skills is accomplished with the result that performance is improved. WEAO has published guidance manuals comprising an instructor's manual and a student workbook ("Training Operators on Problem Solving Skills"). The manuals can be obtained by contacting WEAO at *www.weao@weao.org.*

Within the context of this best practice, the CPE phase of the CCP would be considered to be a plant evaluation tool (refer to Section 3.3) and generally involves such components as a historical data review (Section 3.3.2) and unit process capacity charts (Section 3.3.3). However, the CPE also includes a broader evaluation of administrative factors that can limit plant performance.

The CTA phase of the Composite Correction Program is the actual optimization phase and is discussed in this best practice in Section 3.5.1.

3.2 Establish Objectives

The tools used for WWTP optimization will depend on whether the objectives are:

- reduced energy costs;
- reduced chemical costs;
- improved reliability by eliminating operational problems and upsets;
- improved effluent quality;
- improved biosolids quality;
- increased treatment plant capacity;
- reduced labour costs;
- reduced sludge production or biosolids management costs;
- reduced capital costs for plant upgrading or expansion; or
- reduced odour production.

Clear objectives should be established and documented before WWTP optimization is initiated. The objectives may be qualitative (i.e., fewer upsets, fewer effluent exceedances) or quantitative (15 percent reduction in energy costs, 25 percent increase in plant capacity). This will allow the success of the measures taken to be compared to the objectives.

3.3 Plant Evaluation Tools

During the WWTP evaluation stage, performance is evaluated, capacity limiting factors are identified and prioritized, and the approach to optimizing the WWTP is developed. In doing this evaluation, various tools can be used.

Table 3–2
Examples of historical data review impacts on subsequent optimization tasks

3.3.1 Self-Assessment Report

A self-assessment report, prepared by a qualified operational staff, allows the WWTP to evaluate its performance, and identify and prioritize areas for optimization by collecting information on the condition, quality, and capacity of the treatment system.

The report should be done annually and represents a report card on the facility for municipal managers and councillors. The report is used to evaluate the status of:

- effluent compliance and plant performance;
- plant capacity (current and five-year projections);
- combined sewer overflows and plant bypasses;
- biosolids handling, storage, and disposal;
- effluent sampling and analysis;
- equipment maintenance;
- operator training and certification; and
- budgets for current operation and maintenance, as well as for future facility replacement and growth.

A sample self-assessment report has been developed by the Ontario Ministry of the Environment (MOE) based on the model which has been successfully used for many years by the Wisconsin State's Department of Natural Resources. The report can be obtained from the MOE Web site *<http://www.ene.gov.on.ca/>.*

3.3.2 Historical Data Review

A historical data review is an essential component of the evaluation stage of a WWTP optimization program. The review defines the current loadings on the facility, the performance of each unit process, and the key process operating parameters. It also identifies data gaps that need to be filled through additional monitoring and can be used to determine the representativeness of the historical data.

The detailed historical data review can also be used to redefine the project. Table 3–2 provides examples of possible impacts of the historical data review on subsequent optimization tasks.

Table 3–2: Examples of historical data review impacts on subsequent optimization tasks

Historical Data Review Finding	Impact on Optimization Tasks
Mass balance cannot be completed	Obtain required information
Mass balance does not close within 15 percent	Complete flow meter assessment and/or review of off-line sampling accuracy
Effluent BOD_5 and/or nitrogenous compounds concentrations exceed criteria	Conduct aeration capacity analysis
Return stream flows/concentrations not available	Include sampling of recycle streams in off-line monitoring program
Effluent SS higher than design values	Conduct stress tests and hydraulic analysis (dye tests) to determine capacity and performance limits

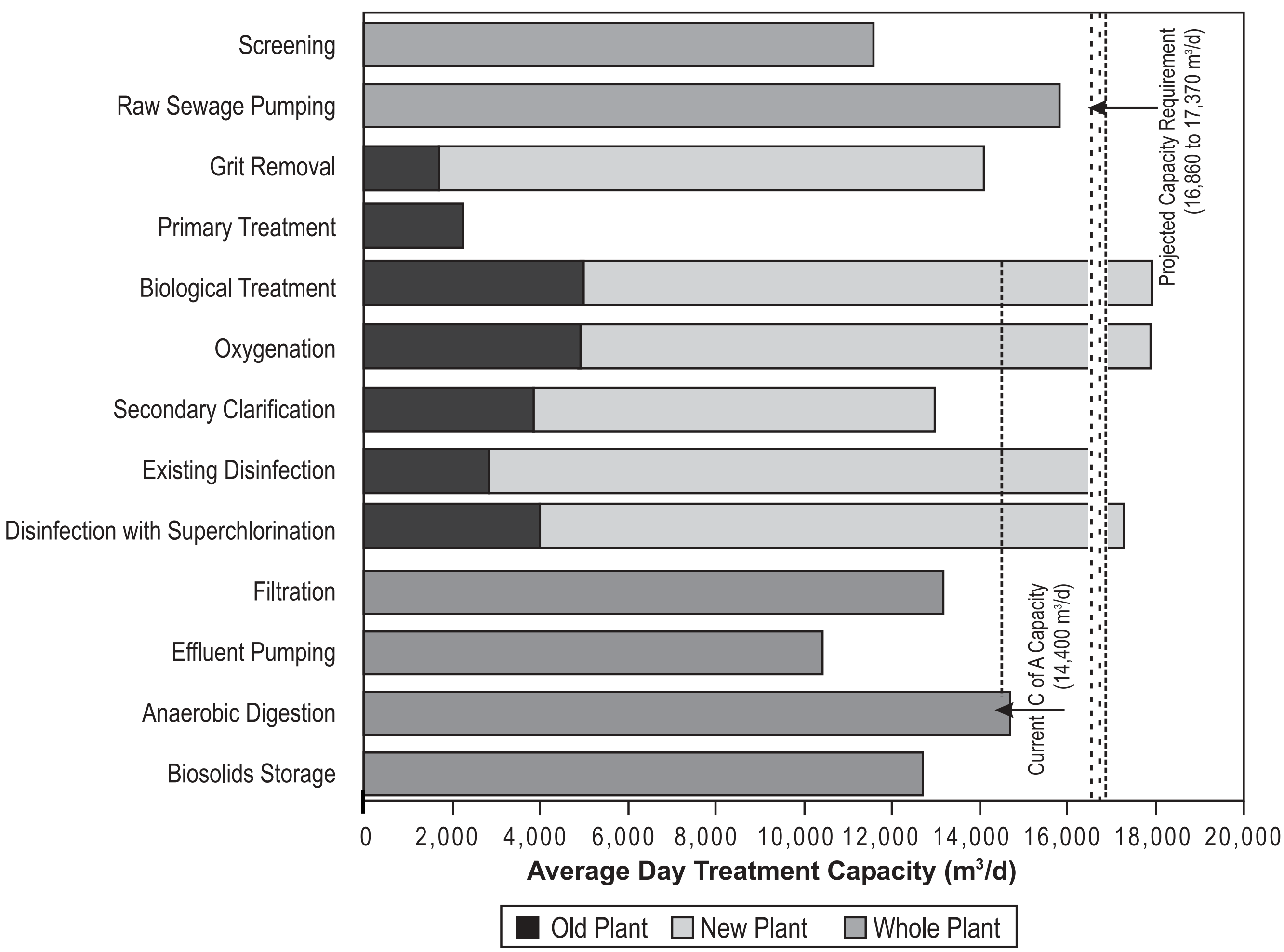
Source: Adapted from WEAO (1996).

3.3.3 Unit Process Capacity Chart

One outcome of a historical data review is a process capacity chart based on the results of a process capacity assessment of the key unit treatment processes at the WWTP. The process capacity chart is used to identify bottlenecks that need to be addressed to increase the capacity of the facility. The unit process capacity chart should cover both the liquid and sludge treatment processes as either could be the limiting factor in maximizing overall WWTP capacity. Figure 3–2 provides an example of a process capacity chart. Full-scale stress testing is often performed following a process capacity assessment to confirm the capacity suggested by this analysis, especially for borderline cases. It should be noted that the chart is based on typical design guidelines or standards which are often conservative.

Figure 3–2
Examples of a process capacity chart

Figure 3–2: Example of a process capacity chart



Source: XCG Consultants Ltd. (2002).

As a first step in any evaluation, a physical inspection should be done to confirm that the flow meters are installed according to sound engineering practices.

3.3.4 Sludge Accountability Analysis

An output of the historic data review is a sludge accountability analysis. This is basically a solids mass balance across unit processes (e.g., clarifiers) or the overall plant to account for solids within the treatment process. In general, mass balances will not close exactly. A discrepancy from about 10 to 15 percent is considered acceptable; however, a discrepancy of more than 15 percent indicates the need for further assessment to resolve the cause of the inconsistency. The common sources of discrepancies in solids mass balance analysis include:

- non-representative samples (analytical accuracy, sampling techniques);
- inaccurate flow monitoring;
- the impact of periodic recycle streams (the boundaries of the balance must be clearly defined and all inputs/outputs must be accounted for in the mass balance); and
- assumptions made concerning accumulations.

A sludge accountability analysis should be performed on a routine basis by plant operating staff to verify the accuracy of flow measurements and analytical data.

3.3.5 Benchmarking Operating Costs and Staffing

If an objective of the optimization program is to reduce operating costs, the historical operating and maintenance costs for the facility should be compared to those of other similar plants of similar size. This will identify the magnitude of the cost reduction opportunity for energy, chemicals, sludge disposal, and labour that represent the largest components of the operating costs. Benchmarking information for resource costs (energy, chemicals, water) is available in the *Guide to Resource Conservation and Cost Savings Opportunities in the Water and Wastewater Sector* (MOEE, 1997). More detailed benchmarking data are available in *Benchmarking Wastewater Operations: Collection, Treatment and Biosolids Management* (WERF, 1997).

3.3.6 Flow Meter Assessment

Field evaluation and calibration of plant flow meters are important since evaluation of historical data and unit process capacity is based on the assumption that recorded flows are representative of the historical plant operation. As a first step in any evaluation, a physical inspection should be done to confirm that the flow meters are installed according to sound engineering practices. Any questions regarding flow meter installation and flow data should be verified before proceeding further with other investigations. Sludge accountability imbalance can be an indicator of inaccurate flow meters.

A number of different methods can be used in flow metering assessment and calibration, including:

- recording run times on pumps and estimating flow based on the pump capacity or pump curve;
- injecting a tracer material into the flow stream at a constant and known rate upstream of the flow meter and determining the concentration of the tracer in samples collected downstream;
- drawing down the liquid level in a basin or tank and filling it back up while recording the meter reading;
- flow measurement from a redundant meter to calibrate a suspected meter over a range of flow; and
- hydraulic modelling to develop the head versus flow relationship for non-standard flume and weir installations.

3.3.7 Continuous Monitoring

Typical data collection at a WWTP involves a combination of grab and composite sampling. This type of sampling will not identify dynamic conditions occurring in the plant. On-line continuous monitoring involves the use of temporarily or permanently installed instrumentation to measure the process loading and performance parameters, and a data acquisition system to collect real-time process data. The real-time process data allow for the identification of various dynamic relationships in the plant, such as:

- the impact of hydraulic surges on process performance;
- floc shear caused by extreme variation in process air flow;
- effluent quality deterioration caused by diurnal loadings;
- return activated sludge concentration variations and;
- process upsets or instabilities caused by return streams from sidestream solids processes such as digester supernatant or biosolids dewatering.

On-line monitoring data have also been used to identify potential energy and chemical savings at WWTPs. Primary clarifier sludge, return activated sludge (RAS) and waste activated sludge (WAS) flows are useful on-line process variables, and are important for solids accountability. Measurement of the flows of internal recycle streams such as digester supernatant, dewatering filtrate or centrate, and thickener overflow is also beneficial. Table 3–3 identifies some process variables typically measured with on-line instrumentation (WEAO, 1996).

Figure 3–3

On-Line process variables

Measurement of the flows of internal recycle streams such as digester supernatant, dewatering filtrate or centrate, and thickener overflow is also beneficial.

Table 3–3: On-Line process variables

Category	Measurements
Process flow rates	■ Influent/effluent wastewater ■ Primary clarifier sludge ■ RAS ■ WAS ■ Biosolids flow ■ Process air flow ■ Chemical metering rates
Process variables	■ MLSS concentration ■ RAS/WAS suspended solids concentration ■ Dissolved oxygen concentration ■ Effluent suspended solids concentration ■ Sludge blanket height ■ pH ■ Ammonia-nitrogen ■ Nitrite/nitrate-nitrogen ■ Orthophosphate ■ Conductivity ■ UV transmissivity

Aeration is one of the most fundamental and costly processes in aerobic biological wastewater treatment, representing as much as 75 percent of total plant energy use.

Wherever possible, on-line monitoring is encouraged, because of the benefit real time data provide to operating staff; however, it is recognized that on-line monitoring may not be feasible for some WWTPs, depending on size and available resources. These plants are still encouraged to monitor their operation by conducting sampling and analysis on a regular basis. A sampling and analysis schedule should be developed, including a list of the parameters to be analyzed daily or weekly. For example, mixed liquor and effluent suspended solids concentrations can be analyzed by obtaining daily grab or composite samples. For parameters that do not change rapidly, such as sludge quality data (e.g., solids concentrations in digested sludge), sampling can be performed on a daily or weekly basis. Grab samples can also be obtained to monitor variations in process parameters throughout the day. It is good practice to conduct on-line monitoring of those parameters with more rapid fluctuations such as dissolved oxygen concentrations in aeration basins (also referred to as bioreactors), or process flows.

3.3.8 Off-Line Monitoring

Off-line monitoring is conducted to supplement plant historical data, or to obtain data not historically collected at the plant but important for plant evaluation purposes. These may include analytical parameters or internal streams within the plant not routinely monitored by plant staff.

Microscopic examination of the biological mass can be performed to determine the general state of the system, and to identify potential problems such as bulking sludge due to filamentous organisms. Jar testing is generally performed to evaluate and optimize coagulant or chemical addition to wastewater for improved settleability or precipitation of some element in the wastewater (e.g., phosphorus removal). Additional laboratory/field tests can be performed to assess the performance of a particular unit process such as settling column tests, dissolved oxygen monitoring and profiling, oxygen uptake rate, sludge volume index (SVI), and sludge blanket monitoring.

3.4 Process Analysis Tools

Various tests can be used to optimize a WWTP. These process analysis tools are used to identify cost-effective ways to increase plant capacity and meet more stringent effluent limits or improve biosolids quality, without major capital works. They can also be applied at those facilities identified by a CPE to be incapable of meeting compliance limits at the current flow due to design deficiencies.

This toolbox of tests is often referred to as a “process audit.” When applied at a WWTP, the audit can lead to an optimized facility in terms of capacity, operating cost, and performance. The Water Environment Association of Ontario (WEAO) has published the *Guidance Manual for Sewage Treatment Plant Liquid Train Process Audits* (WEAO, 1996), an invaluable resource for any WWTP owner/operator embarking on a WWTP optimization program. Unfortunately, no similar guidance manual has been developed as yet that is specific to sludge treatment unit processes.

3.4.1 Aeration System Capacity and Efficiency Analysis

Aeration is one of the most fundamental and costly processes in aerobic biological wastewater treatment, representing as much as 75 percent of total plant energy use. Inadequate oxygen transfer may result in the deterioration of effluent quality due to insufficient oxygen to meet the biological oxygen demand and the endogenous oxygen demand of the biological mass. Aeration system capacity analysis is conducted to evaluate the aeration system capacity, and to identify opportunities for energy savings.

The two most common techniques for testing in-situ oxygen transfer efficiency (OTE) are the off-gas analysis and hydrogen peroxide tests. The results of these tests are used to compare the existing aeration capacity with current and future (or potential) oxygen demands. This comparison is then used to evaluate the capacity of an aeration system for increased loadings and further treatment capabilities (e.g., nitrification), and to evaluate the energy saving potential for a plant. For more information on oxygen transfer testing and test protocols, readers are referred to American Society of Civil Engineers *Standard Guidelines for In-Process Oxygen Transfer Testing* (ASCE, 1997).

3.4.2 Hydraulic Modelling

Hydraulic modelling involves developing the head loss versus discharge relationships for the hydraulic control sections and performing backwater calculations for the open channel sections between control sections. The calibrated hydraulic model can be used to:

- determine the hydraulic capacity of an existing facility;
- identify hydraulic bottlenecks and investigate alternative strategies for reducing the hydraulic limitations identified;
- determine flow imbalances and investigate methods of improving the flow distribution between parallel unit processes; and
- determine velocity gradients and identify optimum locations for chemical addition.

3.4.3 Analysis of Recycle Streams

Sludge treatment recycle streams are often responsible for problems in the liquid train of a WWTP. These streams can increase the organic loading by five to fifty percent, depending on the type and number of solids treatment processes used. The following are possible solutions to minimize or eliminate the impact of sludge handling recycle streams on the liquid train.

- Modify the solids handling processes to improve the quality of the recycle streams.
- Change the timing, return rate or return point of the recycle streams to minimize the impact.
- Modify the liquid train to handle the recycle streams.
- Provide separate treatment for the solids recycle streams.

Analysis of recycle streams from sludge processing (digester supernatant, dewatering centrate, or filtrate) can also provide an indication that these processes would benefit from optimization.

3.4.4 Stress Testing

Stress testing is conducted to identify the loading rate at which the process performance approaches the design value. Diurnal and/or wet weather flow increases may be used to stress unit processes that are affected by hydraulics, such as clarifiers. Hydraulic, organic and solids loading rates to the unit processes can be increased by varying the number of units in service, biasing the flow to the test unit.

Stress testing is generally not conducted until process failure occurs due to the potential implications on compliance. Prior to undertaking stress testing, a plan should be developed that identifies the possible impacts of stressing a specific unit process, the monitoring that will be done to evaluate the performance of the process, and the steps that will be taken if it appears that process failure is imminent. The need to inform the pertinent regulatory agency about the test must also be considered.

Table 3–4
Summary of typical unit process design parameters and evaluation critieria

Table 3–4 summarizes typical unit process design parameters and evaluation criteria that would be applied during a stress test.

Stress testing is seldom conducted on sludge digestion processes due to the long response time to changing conditions and the long recovery time if stress testing results in a process upset.

Table 3–4: Summary of typical unit process design parameters and evaluation criteria

Unit Process	Design Parameter	Evaluation Criteria
Primary clarifier	■ Surface overflow rate	■ Removal efficiencies ■ Sludge blanket depth ■ Real detention time
Secondary clarifier	■ Surface overflow rate ■ Solids loading rate	■ Effluent quality criteria ■ Sludge blanket depth
Activated sludge (Including aeration)	■ HRT/SRT ■ Organic/nitrogenous loading rate ■ F/M ratio ■ Recycle ratio	■ Effluent quality ■ Dissolved oxygen concentration ■ SVI/SSVI ■ SOUR
Effluent filter	■ Hydraulic and solids loading rate	■ Effluent quality ■ Head loss ■ Backwash solids concentration
Disinfection (chlorination/UV)	■ Cl_2 dosage ■ Retention time ■ Effluent solids ■ UV dosage/transmissivity	■ Residual Cl_2 ■ Bacterial concentrations (total/fecal coliform, E. coli)
Sludge Thickening and Dewatering	■ Hydraulic and solids loading rate ■ Chemical dosage (if applicable)	■ Sludge concentration ■ Recycle stream quality
Sludge Digestion (Aerobic or Anaerobic)	■ Hydraulic retention time ■ Solids retention time	■ Gas production (anaerobic digestion) ■ Volatile solids destruction ■ Pathogen destruction ■ Supernatant quality ■ Biosolids concentration

Source: Adapted from WEAO (1996).

3.4.5 Clarifier Hydraulic Tests

Clarifier hydraulic tests are conducted to evaluate the hydraulic characteristics within a clarifier and to determine possible methods to increase the hydraulic capacity of the clarifier. The clarifier dye test, also called the Crosby Dye Test, is a qualitative test that uses dye to test the hydraulic flow pattern of clarifiers (Crosby, 1987). The test has two components: the dispersion test and the flow pattern/solids distribution test.

The dispersion test involves an instantaneous injection of tracer upstream of the clarifier and sampling the effluent over a period of time. The test is used to determine the actual hydraulic residence time, estimate the degree of hydraulic short circuiting, and determine sampling times for the flow pattern test.

The flow pattern/solids distribution test involves injecting dye continuously at a constant rate into the flow entering the clarifier. Samples are then collected at multiple depths and locations in the body of the clarifier to provide "snapshots" of the movement of dye. TSS concentrations are monitored at each position and depth. Flow pattern tests are used to evaluate the spatial distribution of flow through the clarifier including the location of dead zones, density currents, and the possible effect of baffle arrangements.

Sophisticated hydrodynamic models can also be used to simulate the hydraulic patterns in clarifiers, and to assess the effect of various physical modifications to the clarifier (inlet baffles, weir baffles, etc.) on clarifier perfomance or to predict the impact of high flows, high solids loading rates or poor settleability. Two-dimensional and complex three-dimensional models have been successfully used to improve clarifier performance (Ekama *et al.*, 1994).

3.4.6 Other Clarifier Diagnostics Tests

While SVI and SSVI are the most common tools used to determine the settleability of biological sludges, other diagnostic tools such as State Point Analysis (Keinath, 1985) and Dispersed Suspended Solids (DSS)/ Flocculated Suspended Solids (FSS) testing (Wahlberg *et al*, 1995) can provide insight into the causes of poor secondary clarifier performance. State Point Analysis (SPA) will provide information on whether a clarifier is operating in an overloaded condition and direction on operational steps that can be taken to eliminate the problem. DSS/FSS testing will indicate whether poor secondary clarifier performance is related to poor solids flocculation or poor clarifier hydraulics.

3.4.7 Mixing Tests

Mixing tests are conducted to evaluate the hydraulic characteristics of unit process tanks when mixing problems are suspected, and are also used to evaluate mixing equipment, equipment layout, and geometry. The results of the mixing test can be used to:

- identify hydraulic short circuiting;
- define mixing characteristics;
- identify dead zones within the fluid volume;
- evaluate the effectiveness of baffling arrangements; and
- determine the predominant flow patterns within the unit process.

Mixing tests are particularly valuable in digestion tanks because scum, grit, and other materials can accumulate causing a loss of active reactor volume and short-circuiting. Improving mixing can often result in increased volatile solids destruction and improved biosolids quality.

While fluorescent dyes can be used effectively in mixing tests in clarifiers or chlorine contact chambers, lithium chloride is the preferred tracer in digesters. Test procedures and data analysis methods are outlined in Monteith and Stephenson, 1984.

3.4.8 Process Modelling and Simulation

Process models are efficient tools to determine optimum operating conditions. This can include hydraulic retention time (HRT) and solids retention time (SRT), and the capacity of the system to meet specified performance criteria. Process models are available for many of the common biological processes, such as activated sludge, extended aeration, sequencing batch reactors (SBRs), rotating biological contactors (RBCs), and trickling filters.

Process modelling and dynamic process simulation can be used for:

- process capacity estimation;
- bottleneck identification;
- hydraulic load change analysis;
- optimization of aeration system operation;
- optimization of sludge recycle and wastage;
- optimization of the operational sequence of SBR systems;
- bypass impact reduction;
- evaluation of alternate design strategies;
- management of wet-weather flow;
- sludge production estimation; and
- design of reactor configurations for biological nutrient removal (BNR).

A dynamic model simulates variations throughout the diurnal and seasonal cycles and tracks the effects of these variations on process performance. Process simulation modelling is also employed to establish the capacity of biological components of the wastewater treatment plant and model the effects of process changes on plant capacity or performance. Recent work has focused on linking dynamic models with supervisory control and data acquisition (SCADA) and laboratory information management systems (LIMSs) to further improve the accuracy and value of their predictions (Irrinki et al., 2002).

3.5 Optimization Approaches

3.5.1 Improved Operations and Maintenance

Improved process control procedures tailored for the particular WWTP can both improve process performance and save money. A process control testing schedule to monitor control parameters, including but not limited to sludge settling, sludge mass, sludge wasting, sludge return concentration and flow, volatile solids destruction in digesters, dewatering performance, and aeration basin dissolved oxygen should be established as a first step in WWTP optimization. On-the-job training should also be provided for the operators in specific process control sampling and testing requirements, as well as process control calculations.

Formalizing record keeping will generally improve maintenance practices. The following four-step procedure is suggested for developing a maintenance record keeping system:

- Inventory all equipment.
- Gather manufacturers' maintenance information and schedules on all equipment.
- Complete equipment information summary sheets for all equipment.
- Develop a time-based preventive maintenance schedule.

The list of equipment should be updated when equipment is added or removed from the facility. The maintenance schedule should include daily, weekly, monthly, quarterly, semi-annual, and annual checklists of required maintenance tasks.

For larger facilities, a computerized maintenance management system (CMMS) can cost effectively optimize the maintenance function. Through information technology (IT), process control information, SCADA, CMMS, laboratory data and other information can be linked so all key information is available to staff on-line and in real time.

A staffing plan (Daigger and Buttz, 1992) should be developed to determine if a facility is properly staffed. Benchmarking information is available from various sources to assess staffing needs (WERF, 1997).

Staff training can help improve plant performance (as it relates to poor operational practices), address safety issues, and improve staff morale. Staff training should recognize that on-site training is the most effective way to develop an operator's capability to apply wastewater treatment concepts properly to process control. Operating personnel should also be encouraged to improve sewage treatment understanding through budget support for off-site training and certification. Comprehensive technical assistance (CTA) is a systematic approach to eliminate those factors that inhibit performance in existing WWTPs. CTA facilitators work with plant operators and managers to develop process control activities and to transfer skills and knowledge.

3.5.2 Instrumentation, Control, And Automation

Opportunities to reduce costs and improve operational performance and reliability are potentially available through the on-line instrumentation and/or automation of wastewater treatment operations. By adding process measurements, the operator also has more information on which to base judgments and implement control decisions. Efficient operation can be maintained using automated controls. Optimization of processes through the use of on-line measurement and feedback control can significantly reduce the amount of chemical, energy, and water use as well as reduce the production of waste residuals requiring treatment and disposal (WEF, 1997). Higher savings potential occurs in facilities with high variability in wastewater quality and flow. Examples of best practice automation applications are summarized in Table 3–5.

Instrumentation and Control (I&C) at a WWTP can provide information to the operator on the status of equipment, provide real time measurements of process parameters, allow for automatic control of equipment (e.g., turning equipment on and off), and signal alarm conditions. Various parts of the I&C systems can be upgraded. For example, primary elements can be upgraded by adding process measurements, and control hardware and software can be upgraded by adding alarms that automatically switch to a backup when equipment fails. The overall process control system can be improved for WWTPs with outdated I&C systems. In emergencies, automatic controllers can switch to a backup. All critical control functions should have a manual control backup. Proper staffing support to calibrate and maintain instrumentation is critical to attain the benefits provided by automation.

Automated process control strategies for specific unit processes are discussed in detail in the WEF special publication *Automated Process Control Strategies* (WEF, 1997) and in the recent WERF report *Sensing and Control Systems: A Review of Municipal and Industrial Experiences* (WERF, 2002).

Operating personnel should also be encouraged to improve sewage treatment understanding through budget support for off-site training and certification.

Table 3–5
Automation applications at WWTPs

Table 3–5: Automation applications at WWTPs

Process/Unit	Application
Preliminary treatment	■ Automatic screen cleaning based on head loss, total flow treated and/or timers
Primary and chemically enhanced primary treatment	■ Flow proportional chemical dosage control ■ On-line effluent suspended solids/turbidity monitoring ■ Automated sludge density control of sludge pumping ■ Automated sludge blanket height control of sludge pumping
Biological treatment	■ On-line respirometry ■ On-line measurement of BOD load ■ Automated sludge age (SRT) control ■ Automated biological sludge wasting control ■ Automated ORP control in the control of biological nutrient removal processes ■ On-line measurement of MLSS concentration ■ On-line dissolved oxygen monitoring and control ■ On-line measurements of NH_3-N, NO_x-N and PO_4-P concentrations
Secondary clarifiers	■ On-line effluent TSS or turbidity analysis
Tertiary filters	■ On-line monitoring of turbidity and/or phosphorus concentration ■ On-line monitoring of head loss
Aeration system	■ Automated blower control based on on-line dissolved oxygen sensors ■ On-off aeration control ■ Variable speed control of mechanical aerators
Disinfection (i) Chlorination/ dechlorination (ii) UV irradiation	■ Flow proportional chemical dosage ■ Automated chlorine residual control ■ Automated ORP control ■ UV intensity monitoring and control ■ Flow pacing of UV lamps ■ Initiation of automatic self-cleaning
Sludge thickening/dewatering	■ Automatic flow pacing of chemical addition ■ Automatic mass dosage control of chemical addition ■ Automatic monitoring of solids content of liquid stream ■ Automatic chemical dosage control based on flocculation properties
Digestion	■ Automated control of sludge distribution between multiple reactors based on flow or solids mass load ■ On-line monitoring of supernatant quality

Source: WERF (2002).

3.5.3 Treatment Process Modifications

A variety of modifications are possible depending on the unit process under consideration and the specific performance limiting factor identified during the plant evaluation stage. Table 3–6 summarizes, on a unit process by unit process basis, some of the optimization opportunities that could be considered to increase capacity, improve efficiency, or reduce the costs associated with chemical or energy use.

More detailed discussions of how these and other optimization opportunities might be implemented in each specific unit process are provided in Appendix B. Readers should refer to Appendix B for a discussion of potential approaches to optimize the particular unit processes that make up their WWTP, or for those unit processes that have been identified during the plant evaluation stage to limit performance or reduce overall plant capacity.

Table 3–6
Potential treatment process optimization approaches

Table 3–6: Potential treatment process optimization approaches

Process	Optimization Approach	
Plant hydraulics	■ Eliminate surges due to pump station operation ■ I/I control ■ System storage and real-time control	
Preliminary treatment	■ Upgrade screens and improve control ■ Improve hydraulics in grit tanks ■ Improve grit removal and handling	
Primary treatment	■ Optimize chemical use ■ Improve hydraulics	■ Improve scum/sludge removal ■ Eliminate co-settling of waste activated sludge
Biological treatment	■ Improve process flexibility ■ Optimize BOD_5 removal ■ Optimize nitrification ■ Implement BNR	■ Optimize oxygen transfer ■ Implement step feed ■ Implement foam/scum control measures
Secondary clarifiers	■ Improve flow splitting ■ Eliminate hydraulic surges ■ Improve hydraulic patterns	■ Control sludge bulking ■ Improve RAS/WAS flexibility
Tertiary filtration	■ Optimize chemical use ■ Optimize backwash	
Disinfection	■ Improve mixing ■ Implement automatic control	
Sludge Thickening/ Dewatering	■ Optimize chemical dosage or chemical type ■ Manage primary sludge and WAS separately	
Aerobic Digestion	■ Optimize oxygen transfer ■ Optimize settling to increase sludge thickness or improve supernatant quality	■ Improve mixing ■ Increase raw sludge concentration
Anaerobic Digestion	■ Improve mixing ■ Increase temperature to improve volatile solids destruction	■ Improve load distribution between multiple tanks ■ Increase raw sludge concentration ■ Use biogas for energy value

Note: More detailed discussion of these optimization approaches is provided in Appendix B

The most attractive lifecycle payback occurs when existing motors need replacement, and high-efficiency motors or variable speed drives are appropriate for that application.

3.5.4 Achieving Resource Cost Savings

Energy usage in wastewater treatment can be a major portion of the annual operating costs. Much of the information presented in this sub-section is adapted from the *Guide to Resource Conservation and Cost Savings Opportunities in the Water and Wastewater Sector* (MOEE, 1997). Readers are referred to this document for more detail on opportunities for resource cost savings in WWTPs.

High Efficiency Motors/Variable Speed Drives

Many facilities operate using inefficient pumps and motors designed and installed years ago when system constraints and requirements were very different than today. Motor efficiencies are now much higher than what was available even 10 years ago. As a result, significant energy savings can be realized by replacing old motors in existing equipment. Using variable speed drives, facilities can optimize pump operation by matching energy requirements with pumping requirements.

The most attractive lifecycle payback occurs when existing motors need replacement, and high-efficiency motors or variable speed drives are appropriate for that application. It must also be noted that relative cost of maintenance and replacement of variable speed drives (variable frequency drives (VFDs) in most cases) needs to be considered in the evaluation of payback expected from such devices. Higher energy savings will also occur in facilities with high peak demand ratios that are pumping outside of the efficient range of the existing pumps. The plant operator should ensure that pumps operate at the most efficient point on their operating curve.

Off-Peak Operation

During peak demand periods, energy demand and consumption charges may be higher than during off-peak demand periods. Where possible, moving the operation of existing processes to off-peak periods can significantly reduce energy costs. Shifting demands to off-peak periods requires operational changes only (i.e., no capital investment) and, as a result, payback can be immediate. Although the energy cost is reduced, the amount of energy used during off-peak operation is not always reduced. Energy use reductions will only be achieved if the operating ranges of the process equipment are better suited for lower intensity/longer duration operations implemented by transferring operation to off-peak periods.

This technique is applicable throughout a facility. The potential benefit varies with the type of process, available storage and the design of the specific facility under review. It should be noted that small plants do not necessarily have hydro demand meters or off-peak rates available. Therefore, this technique will not offer any savings in energy use or cost in these instances.

Flow Measurement

Accurate flow metering equipment for wastewater flows, sludge flows, effluent and backwash water, and chemical dosing rates ensures optimized resource usage with significant effects on chemical usage, filter runs, backwashes, and sludge production rates. For example, if flow measurement is inaccurate in a flow-paced disinfection process, then unnecessary wastage of energy and chemical use can occur by overpumping and overchlorinating.

Biological Treatment System

When nitrification is not required, controlling solids retention time and/or reducing dissolved oxygen levels will reduce oxygen requirements significantly, which can reduce run time for mechanical aerators or blowers, resulting in reduced energy use, preventing unnecessary nitrification. The addition of coagulant during primary treatment improves the removal of particulate matter before aeration. This reduces aeration energy consumption. Although energy use is reduced, chemical use and primary sludge production are increased during primary treatment, and trade-offs must be investigated.

By switching to an on/off aeration mode, blowers or mechanical aerators can be operated for short periods (e.g., 30 minutes) and then shut down for equal or smaller periods. This reduces energy usage significantly. This approach should not be used for aeration systems that would foul if the air supply is shut off (i.e., ceramic, fine pore, or some coarse bubble diffusers). Aeration devices will need to be retrofitted with some form of ramp starting equipment to protect them from the wear associated with an increased number of start-ups. Soft start devices can be used to reduce the peak demand.

By optimizing the solids retention time (SRT), biomass production can be reduced resulting in a reduction in energy use required for handling and disposal. There may be an energy increase for aeration at a higher SRT.

Fine pore aeration systems produce smaller air bubbles, which provide better oxygen transfer efficiency compared to coarse bubble systems. Improved oxygen transfer reduces the amount of air blowers must supply and, therefore, reduces energy consumption by blowers. Energy savings potentials ranging from nine to forty percent can be achieved with fine pore systems (EPRI, 1996). Additional cleaning is sometimes required with fine pore systems to eliminate problems with clogging; however, the associated costs are minimal.

Anoxic reactors will recover bound oxygen from nitrate, reducing the oxygen input requirement for blowers in downstream aeration basins. Although additional pumping to recirculate flow will be required, the significant reduction in blower use can provide for net energy savings.

Excessive power use by blowers or aerators can be eliminated by monitoring dissolved oxygen within the aeration basins, and manually or automatically controlling the number of blowers and air flow rates.

By providing anaerobic/aerobic environments to increase the biological uptake of phosphorus, significant reductions in chemical use can be achieved. In some cases, the need for chemical input may be eliminated, however, the need for increased process control and operator knowledge will increase.

Backup Generators

Most treatment facilities have backup generators to provide power during emergencies. They are not normally used except for testing and as part of routine maintenance procedures. By operating these generators during peak periods, electrical energy use reductions and significant electrical energy cost savings can be achieved. Air quality requirements and the costs of fuel for backup generators may limit this application in some facilities. This scenario will only provide worthwhile savings for facilities with low generator operating costs and high peak demand ratios and rate structures.

Effluent Water Use

In wastewater treatment facilities, potable water may be used in a number of processes for backwashing, rinsing, chemical makeup, foam control, and odour control. By replacing the use of potable water with treated effluent water, significant savings in water costs can be achieved. Effluent water use depends on the level of treatment, and is generally limited to usage as process water. The effluent water should be disinfected with chlorine to protect operator health.

Biogas Utilization

The methane contained in the biogas produced by anaerobic digestion can be used to replace natural gas for digester or space heating. In large facilities, generation of electrical power using biogas can have a favourable payback time.

Energy savings potentials ranging from nine to forty percent can be achieved with fine pore systems (EPRI, 1996).

Resource Costs

There are a number of opportunities to reduce the costs of resources, although the specific resource use is not reduced.

- Negotiate utility bills to reduce electrical energy and gas costs. For example, improving a plant's time to come off-line during peak periods or in emergencies can assist in negotiating lower energy charge rates.
- Combine/separate utility bills between plants and pumping stations to reduce energy and gas costs. For example, combining plant energy costs with zone pumping station energy costs can reduce energy charge rates.
- Combine chemical purchasing with other plants or industries to increase shipment sizes and reduce unit costs.

3.6 Document Benefits

Following completion of a WWTP optimization program, it is important to ensure that an evaluation of the benefits of optimization is completed and the benefits are documented. This assessment should compare the objectives established for the project (e.g., capacity gain of 30 percent) to the actual outcome of the optimization program and the return on investment (i.e., savings realized compared to program costs).

Communication of the benefits of the optimization program to the decision makers in the municipality and plant operators is essential to maintain benefits gained by the optimization initiative and to build support for future initiatives. This support is key to ensure the iterative process of optimization is sustained and an environment conducive to optimization is fostered.

3.7 Optimization Task Flow Sheet

Figure 3–3 illustrates a WWTP optimization task flow sheet as a guide to the approach that might be used to achieve various objectives. It is important to note that many optimization programs have multiple objectives, and different approaches can be used to achieve the same objectives. For example, during the CTA phase of a CCP, any of the process analysis tools described in this best practice could be used to evaluate a particular unit process that appears to limit the performance of a facility. Similarly, operator training can be undertaken in a manner similar to that done in a CTA even if the CCP approach to optimization has not been formally applied. Any of the process analysis tools, such as oxygen transfer testing or simulation modelling, can identify opportunities for operating cost reduction.

It is essential to recognize the importance of the plant evaluation stage to the success of the optimization program. This stage will establish the validity of the historic data that are the basis for determining the performance capabilities and capacity of the facility. This stage will also establish the benchmarks against which the benefits of subsequent optimization steps can be measured. If the data are suspect due to poor sludge accountability or poor flow meter installation, additional monitoring at this stage is important to ensure subsequent work is based on sound knowledge of the plant's capabilities and limitations.

The plant evaluation stage will also establish the approach and work plan that will subsequently be implemented to optimize the plant and meet the optimization objectives previously established. The task flow sheet (Figure 3–3) suggests the type of tests or optimization tools that might be used to achieve specific objectives. Again, it is emphasized that this is merely a guide. The approaches used must be tailored to meet the overall objectives and will vary depending on the size and type of plant being optimized, the resources available, and the capabilities of the plant staff to conduct the specific tests.

4. Applications and Limitations

4.1 Applications

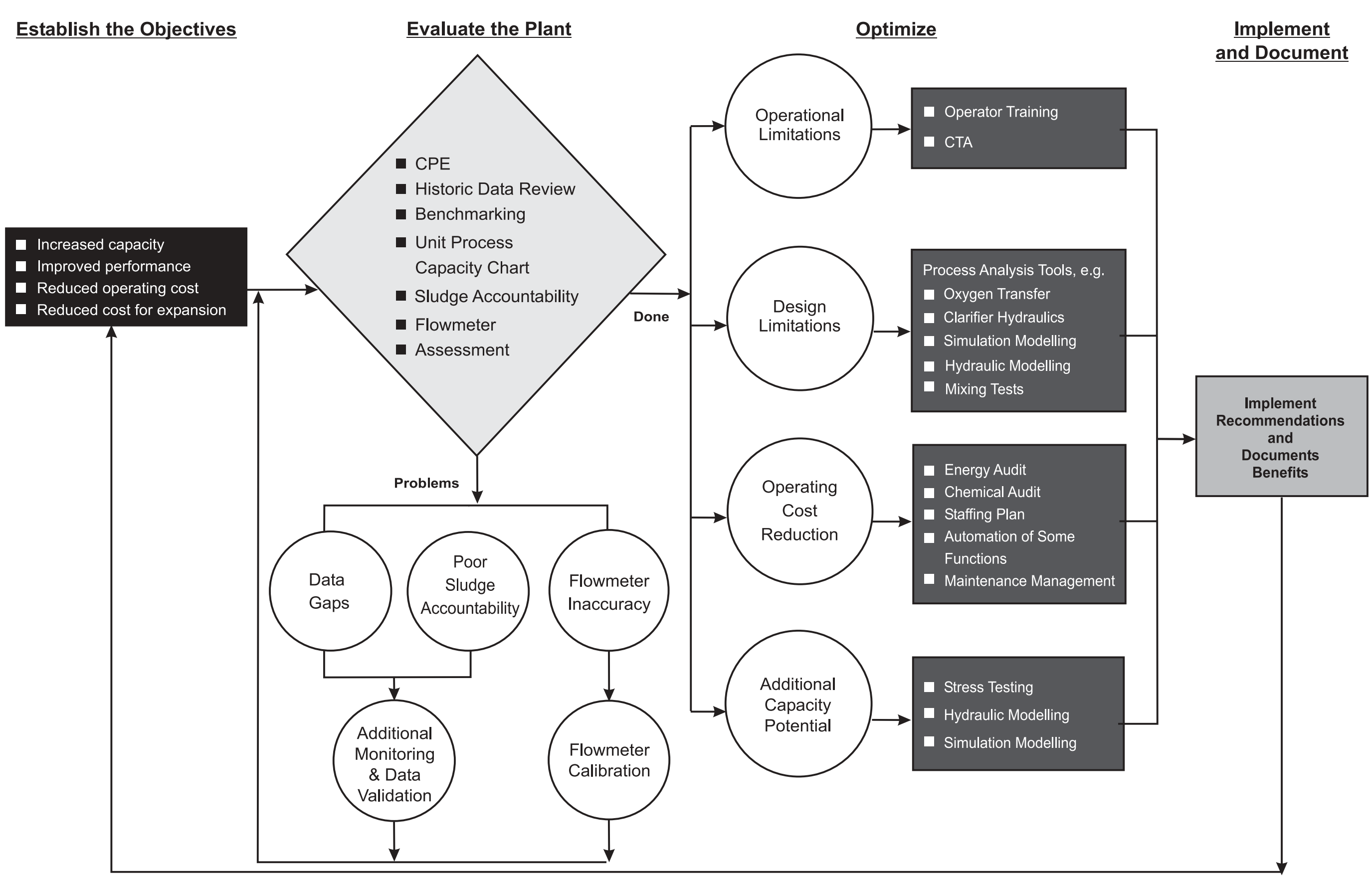
The elements of the best practice for WWTP optimization apply to any size or type of treatment plant. The tools that might be applied at a small WWTP may be different than those that would be applied at a larger WWTP, because the costs and the potential return from some approaches may not be justified at smaller facilities.

4.2 Limitations

This best practice covers most common liquid and sludge treatment processes, including such processes as preliminary, primary, secondary, and tertiary treatment, and the disinfection of the treated effluent and thickening, dewatering, and digestion (aerobic and anaerobic) of sludge. Optimization of more sophisticated and complex sludge treatment processes, such as incinerators, dryers, and pelletizers is not included in this best practice. Management of biosolids produced at the WWTP is also not addressed in this best practice. A best practice for biosolids management has also been developed by the *National Guide to Sustainable Municipal Infrastructure: Innovation and Best Practices.* The reader is referred to that best practice for information on biosolids management.

This best practice focuses primarily on optimization of mechanical WWTPs rather than lagoon-based systems, although aspects of the best practice that relate to operator training are equally applicable to all types and sizes of WWTPs. A best practice for operation and maintenance of lagoons will be developed by the *National Guide to Municipal Infrastructure: Innovation and Best Practices.* The reader is referred to that best practice for information on optimization of lagoon-based systems.

Figure 3–3: Representation of optimization task flow sheet



Appendix A:
Selected Case Histories

A.1 Case History 1 – Burlington Skyway WWTP (Wheeler and Hegg, 1999)

The Burlington Skyway WWTP is the largest treatment facility in the Regional Municipality of Halton. Treated effluent from the plant is discharged to Hamilton Harbour. Hamilton Harbour has been designated as one of seven Canadian areas of concern in the Great Lakes by the International Joint Commission. Stringent effluent limits (TP = 0.3 mg/L, ammonia = 5.6 mg/L, and TSS = 10 mg/L) have been initially targeted for discharge from the Burlington Skyway facility to alleviate eutrophication and toxicity in Hamilton Harbour. To meet stringent effluent limits, the Regional Municipality of Halton implemented a formal optimization program in 1995. The goals were to maximize the hydraulic capability of the existing infrastructure while meeting performance requirements, and to empower staff with skills and initiative to implement activities to maintain the targeted performance levels economically.

The Burlington Skyway plant is a conventional activated sludge facility with a nominal design capacity of 93,000 m^3/day, and serves both industrial and residential dischargers. The main components of the liquid train treatment processes include preliminary treatment, primary settling, conventional activated sludge secondary treatment, and disinfection. The dual point addition of ferric chloride (to primary clarifier influent and to secondary clarifier influent) is employed for phosphorus control. The solids treatment train includes dissolved air flotation (DAF) waste activated sludge thickening and mesophilic anaerobic digestion. The primary digesters are equipped with gas mixing. The off-gas is used in gas-fired boilers, and excess gas is stored on-site. Digested sludge is hauled to the regional biosolids handling facility before land application.

The optimization tool used at the Burlington Skyway WWTP was the Composite Correction Program (CCP). The CPE identified non-technical or management and human resource-related limitations to be major performance limiting factors, including inadequate communication between operators and managers, a lack of understanding of facility needs, inadequate application of operational concepts, and inadequate plant coverage to respond to high flow events. The approach to resolving non-technical issues was to address these in conjunction with addressing technical limitation, based on the realization that any improvements in effluent quality may not be sustained if these non-technical issues are not resolved. Enhanced communication and properly applying priority setting and problem-solving skills were emphasized during the CTA phase of the CCP.

Other optimization efforts undertaken at the facility during the CTA included:

- evaluation of the optimum polymer dosage and dosage control (December 1996 to February 1997);
- pilot scale evaluation of spiral blade mechanism to enhance clarifier sludge removal efficiency for improved nitrification (September 1997 to March 1998);
- retrofitting the remaining clarifiers with spiral blade mechanism (summer of 1998);
- optimizing the removal mechanism (rake tip speed of 305 cm (10 feet/min) (summer of 1999); and
- reactivation of the existing Dissolved Air Floatation (DAF) unit (March 1999).

The approach to resolving non-technical issues was to address these in conjunction with addressing technical limitation, based on the realization that any improvements in effluent quality may not be sustained if these non-technical issues are not resolved.

A. Selected Case Histories

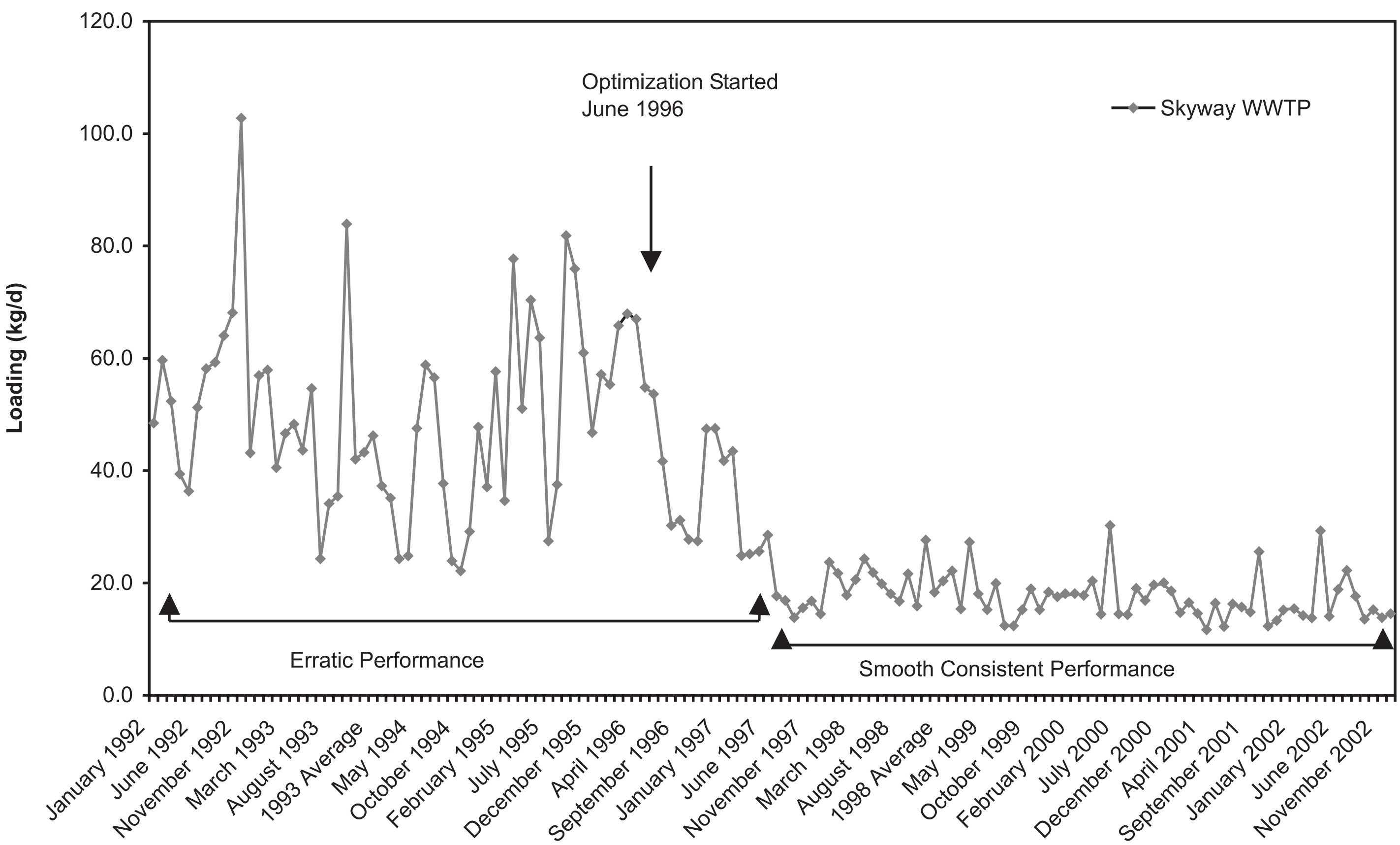
A.1 Case History 1 – Burlington Skyway WWTP (Wheeler and Hegg, 1999)

Figure A–1
Total phosphorus average loading – Burlington Skyway WWTP effluent

In terms of operational control, improved operator application of process control techniques at all the major unit processes was emphasized, with priority given to the secondary unit process. Improved solids inventory control consisted of daily sampling and testing to monitor sludge mass in aeration basins (also known as bioreactors) and secondary clarifiers, return activated sludge (RAS) underflow lines, as well as in the primary clarifiers to maintain stable removal.

The ongoing optimization efforts at the Burlington Skyway WWTP resulted in a substantial improvement in the plant performance in terms of phosphorus removal. The reduction in the phosphorus loading to Hamilton Harbour achieved as a result of the optimization efforts is illustrated in Figure A–1. In addition, the plant was able to achieve nitrification without major capital expenditure, meeting the targets established for Hamilton Harbour.

Figure A–1: Total phosphorus average loading – Burlington Skyway WWTP effluent



Source: WEFTEC (1999)

Maximizing the operational skills through the CTA, in conjunction with the other optimization work done at the plant, resulted in a level of performance not considered achievable before optimization. It had been estimated that $33 million in capital upgrades would be needed to achieve nitrification at the plant.

In addition, additional capacity was found at the plant to defer $17 million in plant expansion costs. Based on the success achieved, the Region has expanded its optimization program to include all its wastewater and water treatment facilities.

A.2 Case History 2 – Ayr WWTP (XCG, 2000b)

The Ayr WWTP serves the Town of Ayr in the Regional Municipality of Waterloo. It is a circular, package extended aeration plant constructed in 1978 with a design capacity of 1,181 m^3/d. The treatment processes at the plant include coarse screening, grit channels, aeration using fine pore membrane diffusers that had been installed as a retrofit for energy savings, secondary clarification, ferric chloride addition for phosphorus removal, and chlorine disinfection. Excess sludge is aerobically digested and hauled either directly to land for utilization or to a regional sludge storage facility for interim storage.

By 2000, the plant was operating at about 89 percent of its design capacity and further growth in the community was restricted due to servicing constraints. To determine if additional capacity was available in the existing facility, an optimization and re-rating study was commissioned to define the maximum capacity of the plant, identify any processes that would need to be upgraded, and collect adequate data to support an application to increase the rated capacity of the facility.

A detailed historic review and process capacity analysis indicated there was potential to increase the rated capacity of the plant from 1,181 m^3/d to 1,500 m^3/d. At the same time, the regulatory agency imposed more stringent phosphorus removal limits on the plant and included a requirement to nitrify year-round and produce a non-toxic effluent after disinfection.

Process testing at the plant to confirm the results of the plant evaluation phase included oxygen transfer testing to determine the ability of the existing aeration hardware to achieve nitrification, clarifier stress testing, and biological process simulation modelling. In addition, the evaluation phase suggested the plant flow meter accuracy was questionable. Therefore, flow meter calibration testing was also undertaken to confirm the validity of the historic flow and loading data.

The process testing demonstrated that upgrades to the RAS pumping system, which used air lift pumps that lacked controllability and operated at a high return rate, would be needed to ensure adequate clarification capacity was available. Increased oxygen transfer capacity would also be required to sustain the nitrification needed to meet the new effluent limits for ammonia. Upgrades to the raw sewage pump station and a new flow metering station were also included. To meet the non-toxic effluent requirement imposed on the plant, UV disinfection was installed to eliminate the toxic chlorine residuals associated with the original chlorine disinfection.

The estimated cost to achieve a 27 percent increase in capacity from 1,181 m^3/d to 1,500 m^3/d was $450,000. Of this total, more than half was associated with the installation of UV disinfection that was a requirement of the new certificate of approval and not specifically required to achieve additional capacity. The cost estimates to upgrade the plant are summarized in Table A–1. To achieve the higher capacity, no new tankage construction was needed except for the UV disinfection system. The equivalent cost of achieving the additional capacity was less than $700 per m^3/d of capacity, exclusive of the cost of the UV disinfection installation. Equally important to the low upgrade cost, additional development in the community was allowed without extensive delays normally associated with major treatment plant construction.

Table A–1: Summary of Upgrades and Costs to Re-Rate the Ayr WWTP to 1,500 m^3/d

Process	Description	Estimated Capital Cost ($)
Raw wastewater pumping	■ Two raw lift pumps, each with 4,000 m^3/d capacity ■ Pumps could either be two-speed or installed with one variable frequency drive with switch gear to allow it to be used for either raw lift pump	80,000
RAS pumping	■ Self-priming centrifugal pumps ■ Firm capacity for 1,500 m^3/d	55,000
Oxygenation capacity	■ Add two new 900 m^3/h positive displacement blowers ■ Provide additional aeration basin diffusers	75,000
Disinfection	■ Upgrade to UV disinfection ■ Separate contact chamber with approximately 40 low pressure lamps ■ New flow metering station consisting of rectangular weir and ultrasonic sensor	240,000
Total	■ Upgrades to provide 1,500 m^3/d capacity	450,000

These upgrades have now been implemented and a new Certificate of Approval issued with a re-rated capacity of 1,500 m^3/d

A.3 Case History 3 – Tillsonburg WWTP (Phagoo et al., 1996)

Nitrification in an activated sludge plant can result in a significant increase in energy costs to provide the additional oxygen required by the nitrifying bacteria to oxidize ammonia to nitrate. Denitrification, the reduction of nitrate to nitrogen gas under anoxic conditions, can recover some of the bound oxygen present in the nitrate. Typically, denitrification occurs in a separate mixed reactor that is maintained at dissolved oxygen concentrations approaching zero to allow the process to occur. Thus, implementing denitrification can require a significant capital investment.

In an optimized approach, aerators can be cycled on and off within the same tank to provide the oxygen supply needed to achieve nitrification and to then recover the bound oxygen under non-aerated (anoxic) conditions. This optimized approach can reduce the overall energy costs while at the same time producing an effluent lower in total nitrogen concentrations.

A demonstration of on-off aeration was conducted at the Tillsonburg, Ontario WWTP to determine the possible energy savings and the impact on plant performance. The Tillsonburg WWTP is a conventional activated sludge plant with a design capacity of 8,200 m^3/d. It was ideally suited for the demonstration since it contains two parallel, identical treatment trains (primary clarifiers, aeration basins and secondary clarifiers). Aeration and mixing in the biological reactors are provided by coarse bubble diffusers, and air is supplied by fixed and variable speed positive displacement blowers. Aeration DO concentrations are monitored and automatically controlled.

One of the two parallel trains was retrofitted to allow on-off aeration. Each train consisted of two aeration basins in series and the retrofit allowed either one or both basins to be operated in the on-off mode. The control system allowed the on and off cycle times to be varied and included air bursts during the off cycle of varying frequency and duration to provide mixing in the reactor. The two trains were then operated under comparative loading conditions in summer and winter to establish the energy savings achieved and the impact, if any, on effluent quality.

The plant operated in the on-off aeration mode achieved poorer nitrification than the plant operated with continuous aeration; however, the test plant (on-off aeration) had lower total nitrogen concentrations than the control plant (continuous aeration). The improvement in total nitrogen removal was 39 percent when one of the two aeration basins was cycled and 67 percent when both basins were cycled. The aeration savings were 16 percent when air supply to one of the two tanks was cycled and 26 percent when the air supply to both tanks was cycled. With one tank cycled, about nine percent of the savings was due to the recovery of bound oxygen during denitrification while the remaining seven percent resulted from improved oxygen transfer efficiency due to the lower dissolved oxygen present in the tank when the air on cycle was initiated. Similarly, when both tanks were cycled, about 20 percent of the 26 percent aeration savings resulted from the recovered of bound oxygen during denitrification.

A.4 Case History 4 – Montréal WWTP (Forest, 2003)

The Wastewater Treatment Plant (WWTP) of Montréal is the largest treatment plant in the Province of Quebec, treating all wastewater from the Island of Montréal with its 1.8 million inhabitants since 1995. It is an enhanced primary (physical chemical) treatment plant with a maximum capacity of 88 m^3/s (7,600 MLD) and a dry weather flow capacity of 25 m^3/s (2,160 MLD). There are two interceptors, one on each shore of the island, which intercept all the wastewater outfalls and direct the flow by gravity to the WWTP. Treatment at the WWTP comprises addition of a metal salt (ferric chloride or alum) plus an anionic polymer prior to clarification.

The north interceptor was the first to be put into operation, in 1984. At that time, there were 14 rectangular primary clarifiers, 91 m long x 30 m wide x 4.6 m deep. When the south interceptor was connected, it was anticipated that the flow would double, necessitating construction of an additional 14 clarifiers. Prior to the expansion, studies were undertaken by the Lasalle Hydraulic Laboratory in Quebec to simulate the hydraulic patterns in a modelled clarifier and identify ways to modify it to increase its capacity. Based on the modelling, two existing clarifiers were modified to allow testing at full scale. Modifications included the addition of a special vertical screen across the full width at the clarifier entrance to avoid flow short-circuiting, changing effluent horizontal collectors at the clarifier exit from 60 cm to 76 cm diameter pipes with the addition of a vent to increase flow capacity, and installation of exit holes on these collectors at the bottom to avoid scum suction. Full scale tests were done in 1991 using two types of coagulant for phosphorus removal, ferric chloride and alum, and results proved conclusive. The hydraulic capacity with the modified clarifiers increased from 3.5 to 5.0 m^3/s.

A.4 Case History 4 – Montréal WWTP (Forest, 2003)

All existing clarifiers were then retrofitted with these modifications at a total cost of $1 million. As a result of the optimization work, it was necessary to construct only 7 additional clarifiers instead of 14 as originally planned. The construction cost was $37 million. The savings resulting from the optimization of the clarifier capacity was estimated at approximately $36 million.

Subsequently, optimization work at the Montréal WWTP focussed on reducing chemical costs. In 1994, the metallic salt (ferric chloride or alum) was added at the entrance of each of the 14 grit chambers. Based on laboratory jar testing, the coagulant dosage was increased during the time period when loads to the WWTP were higher and reduced when loads had declined. In 1994, coagulant costs represented $4 million per year on an operating budget of $38 million.

In order to reduce costs, a process optimization study was conducted in 1994. As an initial step, the coagulant dosing point was moved from the entrance to each of 14 grit tanks to a point at the front of the bar screens and air injection was added to improve mixing at the dosage point. This change eliminated problems with unequal chemical dosages to individual grit chambers and remedied dosage control problems.

Secondly, analysis of venturi scrubber water collecting particles (fly ash) in combustion gas in the incinerator air treatment system was found to contain significant concentrations of phosphorus (about 0.2 mg/L). This scrubber water recycle stream was discharged into the WWTP effluent at a flow rate of about 160 L/s, raising phosphorus concentrations in the plant effluent. In order to achieve the objective of 0.5 mg/L total phosphorus in the plant effluent, it was necessary to operate at higher chemical dosages. A modification was made in the piping to return this venturi scrubber water back to the front of the plant so that it would be treated along with the raw wastewater for phosphorus removal.

After these modifications were complete, an automated chemical dosage control system was installed as part of the implementation of a plant-wide SCADA system. On-line turbidity and phosphorus analyzers were installed in the plant to measure the characteristics of raw wastewater in the North and South interceptors, the effluent from a settling column that simulates in five minutes the performance of the full scale clarifiers, and the effluent water at the WWTP discharge. The SCADA system sets initially the chemical dosage based on the raw wastewater flow rate and characteristics as measured by the on-line analyzers. The dosage is then adjusted based on the output of the on-line analyzers monitoring the simulated effluent from the settling column, and later fine-tuned based on the on-line analyzers monitoring the treated effluent from the plant.

With all these modifications, an estimated chemical dosing reduction of about 40 percent was realized. At 2002 chemical coagulant costs, this represent an annual saving of about $3 million per year on a total 2002 plant operating budget of $46 million.

Appendix B:
Optimization Opportunities Through Process Modifications

B.1 Plant Hydraulics

Rapid changes in hydraulic load are caused by such things as intermittent pumped flows, the dormitory nature of the community, or combined sewage systems. Excessive variations in flow and load can affect the performance of the whole plant. These issues can be addressed by operational modifications such as:

- using a recycle system for variable flow control;
- using multiple smaller constant speed pumps;
- replacing the constant speed pumps with variable speed pumps or screw pumps;
- operation of the constant speed pumps in an influent pump station at a lower flow rate over a longer period of time;
- use of step feed and contact stabilization modes to alleviate the impact of excessive inflow and infiltration (I/I) on suspended growth treatment plants;
- returning digester supernatant or other concentrated streams during low flow periods;
- pump speed controllers and wet well level controllers set to minimize the number of pump starts and stops; and
- providing system storage and real-time control.

Inflow and infiltration (I/I) can be major sources of flow in wastewater systems. This impacts on system performance due to increased flow through the system and higher demand requirements from pumping stations. By implementing I/I reduction programs, wastewater flows requiring treatment can be significantly reduced resulting in lower treatment requirements and consequent resource (chemical and energy) savings. A best practice for I/I control/reduction has been developed by the *National Guide to Sustainable Municipal Infrastructure: Innovation and Best Practices.*

B.2 Preliminary Treatment

B.2.1 Screening

Inadequate screening can limit plant performance and capacity, and greatly increase O&M requirements. Although many small WWTPs still use manually cleaned screens, all plants should consider upgrading to automatically cleaned screens. Screen cleaning should be automated based on head loss and operating time. Adding bypass lines around screens for maintenance can also increase process flexibility.

B.2.2 Grit Removal

The installation of longitudinal or transverse baffles or modifying air flow in aerated grit tanks can improve performance. If grit problems are occurring in a plant and the grit chamber appears to be adequately designed, the problem may be with the grit removal system. Components such as pumps, chain and flight conveyors, screw conveyors, or bucket elevators may be inadequately designed, installed, or maintained.

B.3 Primary Treatment

The following modifications should be considered to improve the process efficiency of primary treatment.

- Add coagulants to an undersized primary clarifier, or clarifier with high surface overflow rates (in excess of 40 to 60 $m^3/m^2.d$).
- Relocate internal recycle or WAS flows.
- Improve flow splitting and control.
- Improve scum and sludge removal through automation.

B.3.1 Reduce Chemical Usage

By improving the feed rate control and mixing of chemicals at the point of addition, reduced chemical use will be achieved. There are many techniques and products available to improve chemical addition and mixing. Among others, they include in-line flash mixers or high velocity mixing systems. Jar tests should be performed on a routine basis to determine the optimum chemical dosage and dosing procedure.

High velocity mixing systems (HVMS) can be used to replace the injector, injector pump, diffuser, mechanical mixer, filter, and strainer of traditional induction systems. The HVMS operate with a propeller that injects the chemicals into the process stream at high velocities for better mixing. As a result of the better mixing achieved with HVMS, significant chemical use reduction can be achieved.

B.3.2 Reduce Pre-Precipitation Chemicals for Phosphorus Removal

Chemicals can be added for phosphorus removal at either the primary or secondary level of treatment. Generally, chemicals are more efficient for phosphorus removal when added to secondary treatment, and chemical use savings can be achieved. Chemicals may still be used in primary treatment to enhance biological nutrient removal (BOD5) removal in some facilities, reducing energy use in the biological system and secondary sludge production. Multi-point chemical addition results in the lowest chemical usage and sludge production when low effluent phosphorus concentrations must be achieved.

B.4 Biological Treatment

B.4.1 Inadequate Process Flexibility

If inadequate process flexibility is limiting the biological treatment process performance or capacity, piping and valving can be installed so aeration basins can be operated in the complete mix mode, the plug flow mode, the step feed mode, or the contact stabilization mode depending on flows, loads, and other critical conditions.

Process equipment can be installed to increase process flexibility. This includes:

- the piping necessary to isolate individual tanks or processes;
- variable speed aerators or blowers in the aeration basin(s);
- variable speed sludge pumps for return and waste sludge flow; and
- chemical feed systems to improve settling characteristics.

B.4.2 Nitrification

Ammonia, chloramines, and chlorinated municipal effluents are considered to be toxic substances under the *Canadian Environmental Protection Act* (CEPA). Many new permits now include ammonia limits. Nitrification is the biological conversion of ammonia into nitrate. Alkalinity control is important in activated sludge systems designed for nitrification.
If insufficient alkalinity is present during the conversion of ammonia to nitrate, the pH of the system drops, and nitrification may become inhibited. An adequate alkalinity adjustment system must be in place to provide a residual alkalinity of 50 mg/L for aeration and 150 mg/L for high-purity oxygen systems (EPA, 1982).

B.4.3 Biological Nutrient Removal Processes

BNR processes improve the nutrient removal capability of the WWTP and may also result in other benefits, such as improved sludge settlement, reduced sludge production, reduced process alkalinity consumption, and reduced process oxygen requirements. The potential reduction in plant capacity from implementing BNR needs to be considered.

A wide variety of BNR process configurations are available. The process configuration selected must consider the effluent limits to be achieved and the current configuration of the bioreactors. It is also possible to create the required anaerobic and/or anoxic zones by installing baffles in the existing tankage if sufficient reactor volume and hydraulic gradient are available. Installation of mixing equipment and reconfiguration of aeration system and recycle pumping capabilities may be required depending on the BNR process selected.

B.4.4 Oxygen Transfer System

If a WWTP is experiencing inadequate oxygen transfer or if energy costs associated with the aeration system are to be minimized, methods of reducing the organic loading should be investigated before major modifications are made. Operational steps, such as cleaning diffusers or removing rag accumulation on surface mechanical aerators should also be pursued. If these measures do not improve the oxygen transfer capacity of the system, the following modifications can be considered.

- Install additional blowers to address an oxygen deficiency in a diffused aeration system if higher flow per diffuser is acceptable.
- Upgrade the diffused air system by replacing a mechanical system with a diffused air system, or replacing a low efficiency diffused aeration system with a higher efficiency system.
- Upgrade the mechanical aerator by refurbishing the old aerator cones, modifying aerator submergence, and operating all aerators at a higher rotational speed.
- Rearrange the aerator or diffuser spacing to remove dead zones and improve mixing.
- Increase the horsepower of existing blowers or mechanical aerators.
- Install baffles or mechanical mixing devices to improve basin mixing.
- Install/check air filters on the intake side of blowers.
- Supplement aeration systems with additional diffusers, or by alternative means.
- Inspect/maintain/repair the diffusers and delivery piping.

If the existing system must be upgraded or replaced as part of the plant upgrade, the following list outlines the best practice to upgrade an existing oxygen transfer system.

- Examine the condition of the existing oxygen transfer system.
- Determine the efficiency of the existing system through oxygen transfer testing.
- Calculate an estimate of existing system capacity, based on the efficiency of the existing system.
- Estimate the efficiency of alternative oxygen transfer systems.
- Determine whether evaluation of upgrade alternatives is necessary and desirable.
- Evaluate alternatives and select the most desirable alternative.
- Evaluate options for implementing the selected alternative.
- Implement oxygen transfer system improvements.
- Install an automatic dissolved oxygen system to vary air input according to the basin dissolved oxygen level to reduce energy consumption.

B.4.5 Cold Climate Operation

Cold wastewater temperatures result in decreased microbial activity and lower treatment efficiencies. To prevent freezing problems and minimize the effect of cold temperatures on biological treatment efficiency, covers can be placed over open tanks, and an earthen berm can be constructed to insulate above-ground tanks. The principles discussed for optimization in this best practice are applicable to WWTPs in any climatic condition.

B.5 Secondary Clarifiers

B.5.1 Clarifier Modifications

Modifications that have proven effective in improving the performance and capacity of clarifiers at existing wastewater treatment plants include the following (Daigger and Buttz, 1992).

- Influent flow splitting can be implemented when the full capacity of existing clarification units is not used due to an unequal and uncontrolled flow split. Several techniques are available, including flow splitting using multiple weirs, or orifices with a flow meter and flow control valve on the influent to each treatment unit. Hydraulic analysis is required to verify that adequate head is available and to design an effective system.
- Rapid flow variations are generated when a constant speed pump either turns on or turns off. Variable speed pumping can be implemented to smooth out and control flow variations. One method of variable speed pumping is to provide adjustable speed pumps with the number of pumps and their speed determined by fluid level in an upstream wet well. Constant speed pumps can also be coupled with recycle of pumped flow in excess of the influent flow back to the pump wet well. It is noted that implementation of a variable speed pumping system can increase the mechanical complexity of the plant and result in increased O&M costs.
- An appropriately sized flocwell can be included in the clarifier to minimize the occurrence of dispersed suspended solids in the effluent.
- Inlet baffles can be used to dissipate energy contained in the influent flow, and to distribute flow for uniform entry into the clarifier. For circular clarifiers, a ring baffle supported off the sludge collection mechanisms has also proven useful in dissipating inlet energy and disrupting the density current. Outlet baffles are useful to direct high solids streams away from the clarifier effluent withdrawal point. Two types of effluent baffles are commonly used: McKinney baffle, which is horizontal in orientation and located just below the effluent weir, and the Stamford baffle, which is oriented at a 45 degree angle and is generally placed lower on the clarifier sidewall.
- Tube or plate settlers act as shallow clarifiers and improve the performance of existing clarifiers by increasing the effective area for clarification. The hydraulic flow pattern within the clarifier can also be partially modified to improve performance. Tube settlers are not effective for sludge thickening.
- Separate WAS and RAS pumps with flow meters provide the flexibility to optimize each function.
- Polymer can be added to enhance settling characteristics of sludge.
- Implementation of rapid sludge withdrawal systems can reduce sludge blanket levels in clarifiers, preventing blanket washout at high flows.
- If the ability of sludge to settle is a cause of reduced clarifier capacity, the implementation of a selector zone to enhance settlement should be considered.

Before adding clarifiers at high capital cost, these optimization measures should be thoroughly investigated.

Wahlberg (1998) has developed a protocol that can be used to optimize clarifiers.

B.5.2 Excessive Clarifier Hydraulic Currents

Dye testing can be used to identify excessive hydraulic currents. Modifications used to correct hydraulic current problems include inlet modifications to achieve both horizontal and vertical distribution of the incoming flow across the entire cross-sectional area, while minimizing short circuiting and turbulence by the addition of inlet or outlet baffles, or weir relocation/addition and blanking off corner weirs. If short circuiting or a sludge density current is observed, baffling should be provided to prevent short circuiting and poor solids removal. Baffles and flow deflectors can also provide equal flow distribution across the width of the clarifier.

B.5.3 Sludge Bulking Control

A common misconception associated with the performance of clarifiers in a suspended growth system is that solids loss is the result of a clarifier failure, when, in fact, it is often due to poor sludge settling characteristics. The presence of excessive quantities of filamentous micro-organisms can cause a poorly settled biomass. By improving the settling characteristics of the sludge, the mixed liquor suspended solids (MLSS) concentration that can be maintained in the system is increased, which allows an increase in the organic loading on the system, resulting in the opportunity to increase plant capacity without increasing the basin volume. For a nitrifying system, an increased MLSS concentration allows nitrification to be accomplished at shorter HRTs. Alternatively, higher hydraulic loadings can be applied to the secondary clarifiers. Several sludge bulking control measures are available including:

- chlorinating the return activated sludge or mixed liquor in the reactor;
- modification of the environmental conditions (e.g., addition of nutrients, including nitrogen, phosphorus, and dissolved oxygen);
- introduction of an organic loading gradient through addition of a selector to the suspended growth system;
- implement selective wasting to remove foam/scum-causing microorganisms from the system;
- remove impediments to the free passage of foam/scum through the bioreactor/ secondary clarifier system to a point where the foam/scum can be eliminated from the system; and
- discontinue the practice of co-settling of waste activated sludge in the primary treatment system.

Microscopic examinations should be performed routinely to monitor biomass for sludge bulking due to filamentous organisms. The methods are described in *Manual on the Causes and Control of Activated Sludge Bulking, Foaming, and Other Solids Separations Problems* (Lewis Publishers, 2003) and in *Dynamic Corporation* (USEPA,1987), along with options to control sludge bulking.

B.5.4 Inadequate Return Sludge and Waste Sludge Flexibility

According to *Assessment of Factors Affecting the Performance of Ontario Sewage Treatment Facilities* (XCG, 1992), the lack of instrumentation to measure return sludge and waste sludge flow rates was the most serious limitation at small WWTPs with air lift sludge return systems. Without the knowledge of these flow rates, it is difficult to adjust for changes in flow or settling characteristics, or to control solids inventory in the plant.

A variety of factors affect the filter performance, including the size and nature of the particles to be removed, filtration rate, media size and type, and bed depth.

Return sludge flow is used to control the distribution of sludge between the aeration basin (also referred as bioreactor) and the clarifier. Return sludge flexibility is important to address adverse process conditions on a timely basis. If insufficient or inflexible sludge return pumping capacity is limiting the plant performance, auxiliary sludge pumping and piping can be added or, alternatively, the impeller and/or motor size of the existing sludge pumps can be increased. Possible modification to improve RAS flexibility include:

- recycling flow around a constant speed pump;
- using pumps with adjustable speed drives;
- installing time clocks to control valve operations (airlift pumps);
- using multiple pumps for RAS pumping; and
- providing continuous flow measurement capability.

By adjusting return sludge rates, a facility can maintain optimal sludge blanket levels in the secondary clarifier. This reduces RAS pumping rates and energy use.

To increase sludge wasting flexibility, separate waste and return sludge pumps can be provided to optimize each function. In small to medium-sized plants, positive displacement pumps are typically the most appropriate. Variable speed drives, timers, or a combination of both can provide the needed flexibility.

The waste sludge removed is typically directed to a sludge treatment facility, such as thickening, digestion, and dewatering, before final disposal. The operation of the biological process should not have to be modified, because of limitations of the sludge wasting, treatment, and disposal facilities.

B.6 Tertiary Filtration

Granular media filtration has been used to control suspended solids and phosphorus discharges from WWTPs. A variety of factors affect the filter performance, including the size and nature of the particles to be removed, filtration rate, media size and type, and bed depth. The effluent quality is a function of the upstream biological treatment process, the use of chemical pre-treatment prior to filtration, and the filter itself. Enhanced removal of TP and TSS can be achieved through polymer addition and/or dual point coagulant application (i.e., application of coagulant prior to settling and to the secondary effluent prior to tertiary filtration).

By performing backwashing during off-peak hours, energy costs associated with operating pumps will be reduced due to lower unit charge rates; however, there will be no reduction in energy or water use. The ability to perform off-peak filter cleaning is influenced by the available storage and effluent concentrations. Alternately, elevated backwashing storage can be used to store during low demand periods for use during peak periods.

B.7 Disinfection

A number of processes can be used for disinfection. The most common one is chlorination. As chloramines and chlorinated municipal effluents are considered to be toxic substances under the *Canadian Environmental Protection Act* (CEPA) (CWWA, 2003), when chlorine is used, it is frequently necessary to remove excess chlorine through the use of a dechlorinating agent once acceptable levels of pathogen reduction have been achieved. Disinfection by ultraviolet irradiation has become popular in recent years, because of low operating costs to achieve a non-toxic effluent.

B.7.1 Chlorination/Dechlorination

Flow proportional and/or residual chlorine control of the chemical addition to meet requirements will prevent excessive chemical use. This will reduce chemical use during periods of the day when flows are lower or chemical requirements are not high. By improving mixing, the effectiveness of the chemical addition is maintained with reduced chemical input.

Other factors that can impact the effectiveness of the disinfection include short circuiting, the applied chlorine dosage, and length of contact time. A dye tracer study can be used to identify the extent of short circuiting and the ratio of actual to theoretical contact time. Baffling can be installed to facilitate plug flow. Initial mixing should be very rapid and thorough. Diffusers can be relocated to a location with more turbulence. Some options for improving mixing include supplemental mixers or high velocity mixing systems. The required dosage will vary depending on water quality, mixing conditions, temperature, pH, contact time, and the level of disinfection required. The amount of dechlorination agent depends on the applied chlorine dosage.

Flexibility in chlorination/dechlorination processes can be enhanced by providing multiple contact chambers and a chemical addition system, as well as piping and valving necessary to isolate a contact chamber and/or chemical feed systems (e.g., chlorinator) for maintenance purposes.

B.7.2 Ultraviolet Irradiation

Inadequate maintenance and cleaning can reduce UV system performance. Ultraviolet tubes and lamps must be cleaned frequently and lamps replaced on a regular basis to maintain a high level of radiation intensity transferred to the wastewater. The use of iron salts in the process for phosphorus removal can increase the frequency of lamp cleaning in manually cleaned systems since the residual iron in the effluent can deposit on the lamp sleeve. If this is problematic, alum could be used instead of iron salts. Weirs and baffles can be used in the UV reactors to distribute the flow evenly through UV reactors and lamp spacing can be adjusted.

B.8 Sludge Thickening and Dewatering

The optimization goal for sludge thickening and dewatering processes, whether by gravity or mechanical means (dissolved air flotation, gravity belt, rotary drums, centrifuges, belt filters or filter presses) is to obtain maximum sludge concentrations at maximum hydraulic loadings while achieving satisfactory solids capture and minimizing chemical dosage. Regardless of the unit process applied, jar testing is essential to ensure that the proper chemical is used at the optimum dosage. The frequency of jar testing depends on the variability of the sludge being processed.

Chemical dosage control based on solids mass loading to the thickening unit is also important. Thickening processes handling WAS that can vary significantly and quickly in strength require more frequent adjustment of chemical dosages than dewatering processes handling digested sludges from a well mixed, long retention time digester. Automation of chemical feed systems in sludge thickening and dewatering has been shown to be beneficial in terms of reducing chemical dosages, improving capture, and producing more consistent cake and centrate/filtrate quality (WERF, 2001); however, maintaining the instrumentation required to automate these processes is time-consuming.

Sludge thickening and dewatering processes are very sensitive to variations in flow and mass loading. Providing equalization facilities upstream of thickening and dewatering processes to minimize variations in feed strength and flow will result in improved performance.

B.9 Sludge Digestion

Anaerobic digesters commonly are poorly mixed (Monteith and Stephenson, 1981) due to the accumulation of scum, grit and other material and relatively low energy inputs. Improving the mixing in the digesters through retrofitting mechanical mixers for gas mixing or cleaning the digester to remove the accumulated material will often significantly improve digester performance. Although aerobic digesters are more intensively mixed in order to ensure that adequate oxygen is available to the micro-organisms, heavy grit and scum can also accumulate in these reactors, reducing available reactor volume. Tracer tests should be done to evaluate the mixing characteristics in both anaerobic and aerobic digestion tanks and to assess the benefits of upgraded mixing.

Poor flow or mass loading distribution among multiple digestion tanks can overload or underload some reactors. Automation of feed cycles and on-line monitoring of raw sludge concentrations from settling tanks or thickeners will prevent hydraulic overloading associated with pumping thin sludge.

The methane-forming bacteria in anaerobic digesters are very temperature sensitive. Temperature variations of more than 0.5 to 1.0°C should be avoided and automated temperature control is preferred. Frequent pumping of raw sludge into the digester in small volumes prevents the temperature changes associated with the addition of large volumes of cold sludge.

The rate of bacterial activity in aerobic digestion processes slows significantly at low temperatures and almost stops at temperatures below 10°C (WEF, 1990). At lower temperatures, it is important to provide longer solids retention times in the process to achieve adequate volatile solids destruction and sludge stabilization.

Operation of both aerobic and anaerobic digesters at thermophilic temperatures (50 to 60°C) results in greater volatile solids destruction and increased pathogen reduction at shorter retention times. However, operating existing mesophilic reactors at thermophilic temperatures requires significant upgrades to existing works and is not considered to be within the scope of optimization. Similarly, there are a number of new, innovative sludge treatment processes (WERF, 1998) that produce a better quality biosolids stream and should be considered in the design of new or expanded facilities, but are outside the scope of optimization of existing works.

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